Resource Demand and Structure of the Agricultural Industry

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Preface

RETURNS TO CAPITAL and human resources in agriculture have been low relative to resource returns in nonfarm sectors a greater part of the time since 1920. On the surface, these income problems appear to be caused by large output and by low commodity supply and demand elasticities. Major farm policies have been initiated accordingly with attempts to support prices and restrain output. More fundamentally, however, the commercial farm problem rests on resources. The magnitude of farm output, and hence of commodity prices, is determined by the quantity and productivity of resources employed in agriculture. The elasticity of agricultural output in both the short run and long run similarly has its foundation in resource demand and supply elasticities. Hence, if the basic cause of large output and low commodity prices and resource returns is to be explained, it must be tackled at the level of resource use.

The organization of agriculture, i.e. the number and size of farms, employment and farm population and use of capital inputs rests importantly on the factor demand functions. The size of the nonfarm sector in rural communities depends on the number of farmers and their purchases. As farms become larger, fewer farm families are available to purchase consumer goods. Substitution of capital for labor also changes the mix of inputs supplied to farmers by local merchants. Obviously, then, the structure of resource demand in agriculture has wide ramifications for both farm and nonfarm sectors.

The operating techniques in agriculture are a reflection of the resource structure. Evidently cultivators in less advanced countries use labor methods and less productive techniques because of the prices of capital items, or because of inadequate knowledge of the productivity coefficients of capital resources. Economic development which changes the relative supply price of various resources and gives rise to greater knowledge of productivity coefficients evidently leads to a capital intensive industry resting on larger and more specialized units. A major goal in development evidently is to change production functions and factor supply elasticities in order that the resource demand structure of agriculture will change. In countries at the level of development in the United States, the problem is to lower the commitment and increase flexibility of resources in agriculture, causing commodity supply to be lower and more elastic. In other countries, the goal is to shift capital supply and demand to the right, thus substituting capital for labor in order that farming will depend less on human effort; thus workers can be made more productive and will be freed for nonfarm employment. In still other countries, extension of the use of agricultural capital items representing improvements in technology is vital to lessen the drag of food supply on population and economic growth.

A number of the terms used in this study have no generally accepted meaning. Hence, at this point it seems desirable to clarify the meanings of some of the terms most commonly used in subsequent sections. The *structure* of agriculture is defined as the demand, supply and production functions which reflect more basic concepts such as technology, goals, values, laws, etc. The *parameters* such as demand and supply elasticities in the structural relationships determine the *organization* of agriculture, i.e. farm size and numbers, prices, quantities, cost and returns. A *change* in *structure* is a shift in the magnitude and/or number of parameters in the structure. *Demand* or *supply* in general refer to the simple schedule (curve) of prices and quantities. A demand *function* includes not only the price-quantity relationship, but also includes influences which shift the demand schedule.

Because of the relevance of the resource structure to the U.S. farm problem, the over-all research project reported in this volume was initiated in 1955. Its emphasis was on resource demand functions, since these relationships are extremely important in determining the quantities of resources employed in the industry and the magnitude of farm output. The nature of resource supply functions is equally important in determining the quantities of resources employed, the magnitude of farm output and the level of factor returns. Part of the analysis has been devoted to input-supply relationships but major emphasis has been on single demand functions for resources in farming. An interdependent system will focus on resource supply functions and their interrelationships with demand functions in explaining the prices and quantities in agriculture.

Several other studies relating to resource demand were initiated at approximately the time of this study. These studies, by Cromarty, Griliches and Shuh, are discussed in the text. However, since the models and specifications employed are not identical, the results of this current study which parallel those of other studies (and which were generally in process at the same time) are reported in some detail in the text. Some estimates from early phases of the study are brought up to date, but for others the "cut off" date is the time of their completion. Emphasis in the study, however, is in a fairly comprehensive analysis of demand for major input aggregates and revolves around a more or less central model. Some other aspects of resource demand also are included since they have previously had little analysis and do provide some insight, even if remote, to conditions surrounding resource demand. In this vein, a chapter which includes static demand and supply functions based on experimental data is presented. We are, of course, aware of the fact that these data do not particularly provide a representative sample for U.S. agriculture, and do not necessarily reflect the setting for farmer decisions. Yet we look upon them as being useful in providing some information on the technological foundation of an ultra short-run resource demand and product supply framework. Similarly, Chapter 5 is designed to illustrate the possible magnitudes of resource substitutions underlying change in the structure of agriculture. While the data are meager, they begin to provide more basic knowledge than has previously existed.

The early chapters provide a descriptive summary of the major changes taking place in the resource structure and organization of agriculture. The descriptive chapters provide insights sometimes unavailable from econometric techniques. That is, the econometric analysis of later chapters essentially identifies and measures the parameters in the resource structure in recent years. Although time variables and other techniques are used to accommodate a dynamic structure, rigidities of econometric models restrict the analysis and often only allow single-valued estimates of parameters. The early descriptive sections provide useful insight into the structure itself by indicating (a) forces which have generated the resource structure (e.g. education, research, etc.) and (b) the "product" of the resource structure, i.e., the organization of agriculture. The various approaches used in the study supplement each other, and we attempt to provide, within the limitations of the data and methods, the basis for a broad understanding of forces underlying the structure and organization of agriculture. We hope that the analysis also can be useful for persons other than those interested in formal and technical quantitative tools.

As an aid to reviewers, we add that the study does not provide "the final answers" in resource structure. It has limitations in the models, specifications, aggregations and quantitative techniques employed. It rests largely on conventional least squares single equation estimates when simultaneous equations in some instances would seem more logical. Perhaps too little is attempted with simultaneous models in the sense that more small interdependent models might be attempted for subsystems of the over-all structure analyzed; or too much is attempted in assuming a higher degree of interdependence than necessary within the over-all system. Too much perhaps is aggregated under time variables. The degree of intercorrelation between this and other variables is great enough that some bias occurs in estimating the parameters relating to resource and product prices and other economic or explanatory variables. The independent variables are not all measured without error, with estimational biases arising accordingly. The study may be too heterogeneous in the sense that it includes analysis ranging from normative and static demand for a single resource to a predictive demand for extremely broad aggregates. In another sense, it may be too homogeneous in the sense that a general model is formulated and applied repeatedly to various categories of input aggregates. Some of the criticisms are those which apply to all studies based on time series data and devoted to economic structure. In most cases, of course, these are the only types of data available. We believe that we do provide useful predictions and analysis subject to the restrictions of data availability. On the other hand, we consider this study to be only one step in a more complete and continued analysis of the phenomena considered.

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Luther G. Tweeten

Contents

1.

Economic Development, Agricultural Structure and Farm Problems

THE WORLD has two problems relating to the kinds and quantities of resources used in agriculture. The first is found in underdeveloped nations where the techniques and resources used by cultivators give rise to a low food supply and subsequent malnutrition, disease and consequent social and political discontent. The second problem is found in "advanced" countries where the kinds and quantities of resources used result in overcapacity and relatively low returns.

Basic aspects of the structure of U.S. agriculture relate to these world problems. The growth in output and productivity of resources in U.S. agriculture provide a pattern of accomplishments that developing nations would like to attain. Dramatic evidence of the "success" aspect of U.S. agricultural development is apparent from the following statistics: From 1940 to 1960 total agricultural output in the United States increased 55 percent although total inputs increased only 5 percent. Output per unit of labor increased 210 percent in the same period. One farm worker supplied 10.7 persons in 1940 and 26.2 persons in 1960. During the same period farm output per man-hour increased 210 percent. Increased farm labor productivity permitted many farmers to migrate to urban areas and to increase the real income of society through employment in other sectors. This migration was made possible through substitution of the many forms of capital resources for labor.

Evidence of the second world problem, overcapacity and low relative returns on resources, is apparent from the following statistics for U.S. agriculture: Despite the 129 percent increase in farm labor productivity, real income per farm worker was 17 percent lower in 1960 than in 1946. Moreover, average farm income per worker as a percent of average income per factory worker declined from 66 in the first decade of the 1900's to 47 in the 1951-60 decade. The epochal structural revolution in U.S. agriculture has brought vast benefits to society but all economic sectors have not benefited equally.

The problem of overcapacity and low incomes in agriculture has been one of the major problems in U.S. society over the three decades of 1933-62. Other domestic and international problems have been more intense at times in this period, but few have been more persistent. The problems of agriculture have been superficially reflected in a large supply of crop and livestock products, and low level of commodity prices and farm income. These quantities must, of course, be gauged in relative terms. They are high or low depending on comparisons with similar quantities and variables in the nonfarm sector, and in comparison with the return on and quantity of resources employed in agriculture. However, the definition of the U.S. farm problem has been so long one of large commodity supply, that particular public policies have persisted accordingly. The nation invested billions of dollars in programs to reduce commodity supply, support or increase prices and improve farm income during the period 1933-62. Even then, the problems of agriculture remained basically unchanged after 30 years. Commodity supply in aggregate was still great relative to consumers' preference and the rate at which society through the price system was willing to award resources employed in agriculture.

While the problems of agriculture are directly those of commodity supply and price, basically they are problems of resource demand and supply. Even more fundamentally, the farm problems stem from technical and economic development where "development" is reflected in the shifting supply prices and productivity of resources.

The two world problems of agriculture, undercapacity and overcapacity, have some features in common: (a) both are associated with low returns on labor resources, the former absolute, the latter relative; (b) both have become the focus of concern by policy makers; (c) both have roots in the resource structure of agriculture; and (d) both are partly characterized by the status of agricultural technology as it is reflected in types of resources used. The resource structure is defined as the over-all framework of institution, behavioral and technological relationships which determine resource employment and hence output, efficiency and income in agriculture. This framework may be systematized into a set of demand, supply and production functions. The parameters (coefficients or elasticities) in these functions may be identified and measured in certain instances, and one objective of this study is to derive quantitative estimates of the parameters in the resource structure of U.S. agriculture.

Although the study is oriented to U.S. agriculture, the resource demand and supply relationships derived for it embody universal relationships which exist in other agricultures. That is, the structure and organization of any agriculture at a given time is largely a function of the values of farmers and the general public, the stage of economic development, the natural resource base and technology. These forces underlying the structure are highly interrelated and it is impossible to analyze one apart from the other. For example, the technology of agriculture is itself a reflection of resource demand and supply. The resource structure, including the supply price of factors, causes the cultivator in India to use bullock power rather than the crawler tractors used by the Kansas wheat farmer. The structure of resource demand reflects the Japanese farmer's use of amounts of chemical fertilizer and seed varieties which produce a larger yield than techniques used by the Philippine cultivator. Or in synonymous terms, the stage of technology and development of agriculture in any country is a reflection of the resource demand structure, as well as of factor prices.

If we are to know how the level of technological and economic development of agriculture in any country can be modified, we must understand how resource demand can be altered. The kinds of seed, the amount of mechanization and the general practices of agriculture are a reflection of the nature of resource demand and supply for those who make decisions in agriculture. In turn, the structure of resource demand and supply is determined largely by the stage and rate of national economic growth.

RESOURCE DEMAND AND ECONOMIC DEVELOPMENT

The process of economic development may be characterized by changes in relative size and interaction of the farm and nonfarm sectors. A nonfarm sector arises in a primitive agrarian society when transportation, governmental and other services are necessary. In the early stages, the fortunes of the new sector largely are tied to the agrarian economy. The few capital inputs and services supplied by the nonfarm sector in the beginning stage of development may permit surplus production (above subsistence), freeing farm labor for additional production and capital accumulation in other sectors. The process of capital growth and rising productivity of land and labor allows society to devote some resources to improvements in skills and technologies and to production of nonfood and luxury consumer items. Expenditures for food represent an increasingly smaller portion of the national budget, and the relative size of agriculture declines. Hence, the organization of agriculture becomes more a function variable in the nonfarm economy.

The accumulation of capital in the national economy increases labor returns (real income) and productivity. The capital/labor price ratio perhaps is more an effect than a cause of national growth, but for agriculture the situation appears different. For the farming industry, which becomes more capital intensive, prices of capital tend to be a function of variables in other sectors. Furthermore, the effective labor return or opportunity cost for agricultural labor becomes tied more closely with nonfarm wages which are unaffected by farm variables. Consequently, the effective capital/labor ratio and resulting pressures to substitute capital for farm labor tend to become exogenous to agriculture. How these and other interactions between sectors in a growing economy affect resource use and farm size in agriculture depends on the economic structure.

Resource demand and the consequent organization of agriculture is specified largely by the relative prices of resources, technological coefficients and by goals and values. For centuries, labor productivity on farms throughout the world remained low despite opportunities for farmers to improve techniques through their own judgment and experience. While opportunities do exist for farmers operating independently to increase productivity, rapid advances in output and productivity did not begin until associations and interactions among institutions and economic sectors increased. The initial conditions for the breakthrough largely arose not on farms as such, but from schools and colleges, nonfarm industry and research organizations. The most basic indirect source of the changing resource demand structure in U.S. agriculture has been the large public and private investment in education. This has resulted in new capital forms which substitute for and increase the productivity of conventional inputs such as land and labor. Investment in education also has provided the engineering and other talents of human resources which have enabled private industry to develop the coal, steel, chemical and other basic resources necessary in providing fertilizer, machinery and other inputs to farmers. These same influences not only have been responsible for introducing new capital forms, but also have helped to make these forms available in quantities and at prices favorable to farmers. As capital inputs supplied by industry become increasingly important in agriculture, the private sector is assuming a more prominent role in education through commercial advertising, field demonstrations, etc., which acquaint farmers with new inputs.

Education also helps provide farmers with a management base and broad perspective necessary for the adoption and efficient utilization of new technologies. Whatever the source, the goals and values of farmers have been an important element in determining the resource structure of agriculture. Materialistic goals (perhaps partially arising from the firm-household complex), the desire to reduce cost and increase profits, to accumulate capital for increasing future income or for retiring and the work ethic all are reflected in empirical coefficients of demand elasticities of later chapters. The relatively high quantitative estimates of demand elasticity, marginal propensity to invest and adjustment coefficients indicate a rapid adoption of technology in the form of new and improved capital forms. These goals and values favor rapid expansion in output and productivity in agriculture, and hence are highly consistent with economic growth and development. But when coupled with other farm values which reduce mobility of conventional resources in agriculture (reflected in the low empirical estimates of labor supply elasticity in Chapters 8 and 9) the result is relatively low labor returns in agriculture.

Goals and values of farmers and other segments of society also are reflected in historic public policies affecting the price of resources and knowledge of factor productivity and substitutability. Both of these developments affect the nature of resource demand and the structure of the farm industry. In the first century as an independent nation, through immigration policy, the U.S. public caused the supply to be elastic and the price of agricultural labor to be low. At the same time it provided an elastic supply and low price for land. With restraint on land supply under near-complete settlement of the public domain, the public increased the supply and lowered the real price of another important production resource, namely knowledge or technique. In so doing it changed the agricultural production function, shifting resource demand through changes in the production coefficients. This was accomplished through public investments in the agricultural colleges and the U.S. Department of Agriculture.

A supply function does exist, both conceptually and effectively, for technical and other knowledge required in agricultural production. Without public subsidy to enlarge its amount and lower its real price, it could still be produced and supplied by the private sector. The rate of advance in the supply of knowledge undoubtedly would have been less, however, without public investment. This would have been especially true at lower stages of economic development when agriculture rested less on capital, and profit incentive for the private sector to produce and communicate technical knowledge (as a complement with the new capital forms it retails) was less or market opportunity was smaller.

Farmers can acquire knowledge at low real price when it is produced and communicated by public agencies. However, it never has zero real cost to farmers since some outlay or opportunity cost is entailed to obtain it. The real cost increases as the supply is smaller or restricted. Relatively, it is much higher in backward as compared to advanced countries. To obtain the amount of technical knowledge available in the county seat to the U.S. farmer, the cultivator of India would have to travel far, and at a much greater sacrifice to his consumption or investment funds. Translation into understandable form for him would add even further to its real cost, as compared to the U.S. farmer who already is literate as a result of greater prior public investment in education. But even in the United States, the supply of technical knowledge is not restricted to that furnished by the agricultural colleges and the USDA. At a price, the farmer can buy newspapers, magazines, radios and television sets; or he can even subscribe to a professional farm management service. All of these provide him a source of technical knowledge at a relatively low real price because the stage of economic development has allowed widespread public education which facilitates reading and the use of these media. They would have small value and a restricted market without farmer literacy.

Further technical knowledge is provided in another form by U.S. private industry, but is a much lacking source in less developed countries. This source often is overlooked by the foreign specialist who visits the nation to determine the secrets of U.S. agricultural development and rapid farm improvement. If only the comparable public facilities for research and education on agricultural improvement were duplicated in backward countries, the upsurge in farm technology and structure would not parallel that of this country. The private sector provides knowledge as a joint product with the agricultural resources and materials it sells. It calls this knowledge to the attention of farmers through salesmen, newspaper and billboard advertising and numerous other media. This knowledge, as a joint product with the materials being retailed, comes at a high or low real cost depending on the price of its "joint material." A decline in the real prices of important biological resources has accompanied their upsurge in use over the United States since 1940. In the "joint sense" above, knowledge itself thus comes at a lower real cost to the farmer.

Even if knowledge had been always complete in respect to technology and the production function, we would expect economic growth and relative change in factor prices to bring a gradual transition in the structure of agriculture. Or, given the same and complete knowledge of the production in all countries regardless of the stage of economic development, we would still expect different structures of agriculture to prevail over the world. In less advanced countries where capital supply is short and labor supply is long, with prices of these resources in opposite position, agriculture would rest more on labor technology than capital even if technical knowledge were complete. Since labor technology does not give rise to marked scale economies or cost advantages, farm units are expected to be small. With transition to larger supply and lower relative price of capital in a more advanced economy, labor supply and price relative moving in the opposite direction, we expect capital to be substituted for labor. However, scale economies or cost advantages with greater volume typically accompany mechanical forms of capital. Hence, not only is the capital/labor ratio of farming expected to grow with economic development and change in relative factor prices, but also farm units are expected to be larger. These developments are expected under economic growth, even if all technical knowledge were known "once and forever."

INPUT SUPPLY AND ECONOMIC DEVELOPMENT

The nature of the resource supply function to agriculture has had an important impact on rapid increase in agricultural labor efficiency and also on the differential rate of labor returns in the farm and nonfarm sectors. Yet shifts in the composition of the national economy as development takes place could proceed without giving rise to problems in resource returns and family income. The real level of commodity prices, resource returns and farm family incomes could rise, both absolutely and relative to the nonfarm economy, under certain resource supply conditions. If supply elasticities of resources were zero or very small, these results would follow expansion of commodity demand under population growth and economic development. Considering technical knowledge also to be a resource of zero or low supply elasticity, new knowledge would not flow readily to agriculture and technical change would be slow or nonexistent (in all economic sectors because of low food supplies). More resources of conventional or known forms, such as heavier fertilization rates, could be used; but new resource forms representing innovations in technology would take place only slowly or not at all. Or, if knowledge per se were of high supply elasticity, but new resource forms such as tractors, new crop varieties and insecticides had very low supply elasticities, the same would hold true: Prices of these resources would be extremely high, and few would be used in agricultural production. Only limited opportunity would exist to increase the use of these inputs in farming; consequently the supply of agriculture products would increase slowly, if at all. Output might increase but only along a given supply curve, with the commodity price necessarily spiraling to meet growth in demand for farm products. Supply elasticity of farm commodities would be extremely low in the long run and a given demand increase would be accompanied by proportionately greater increase in the farm commodity price. With resource supply conditions for nonfarm industries being the opposite of that above, the farm commodity prices would rise relative to prices of nonfarm commodities, and terms of trade for agriculture would be increased.

Income-wise, farming would be a favored industry under these conditions of resource supply. The real income of persons in agriculture would rise relative to incomes of nonfarm persons who own an equal collection of resources. The consumer sector, excluding agriculture, would fare less well. A greater proportion and an increased absolute amount of its budget would be allocated to food, in contrast to economies where supply elasticities of major farm inputs are high and technological change is rapid. Given permanence of this supply condition in agriculture, the fortunes of farm families would not accumulate as favorably over generations. In the long run, the price of resources would parallel their return. With competition, the income gain at one period in time would, with distributed lag, be capitalized into resource values and a given farm investment would return little more than an alternative investment. Yet persons owning farm resources would realize capital gains and their incomes and wealth gradually would move upwards.

The lot of U.S. agriculture has been largely the opposite of this imagined state. Resources such as knowledge and new capital forms such as fertilizer, tractors, improved machinery, higher yielding crop varieties, ration improvements, insecticides and others have had high supply elasticity. Too, the supply of investment funds and credit has been sufficiently elastic to allow additions of these capital innovations in agriculture. Because the capital items have been highly productive, profitable and available, the food supply function has shifted rapidly to the right.

These conditions of high resource supply elasticity and an increase in the farm commodity supply do not themselves predestine agriculture to overcapacity and depressed farm income. Given high supply elasticity for all agricultural resources, food supply would increase and output and commodity prices would fall, but the price system would quickly bring resource adjustments necessary for marginal value productivities and returns of resources to be comparable with those of other industries of similar competitive structure. Still, as we show in Chapter 3, where some resources have high supply elasticity but others have extremely low supply elasticities because they are specialized or value-oriented to agriculture and depreciate slowly, the following occurs: Output will move ahead rapidly in the short run, perhaps more rapidly than demand if supply elasticity is sufficiently high and supply price is sufficiently low relative to marginal value product for the one group of agricultural resources. Given a high level of economic development, with high per capita income and low price elasticities of food demand, aggregate farm income will decline. The marginal value productivities and imputed returns to resources of low elasticity will decline and remain low as long as these redundant resources remain in agriculture.

Under conditions where the elasticity of supply of all resources to agriculture is sufficiently elastic, however, technical change and rapid movement of the supply function to the right need not permanently depress resource returns. With sufficiently high supply elasticity and resource mobility, value productivities and income per resource unit would quickly adjust to levels comparable to other economic sectors lacking monopoly profits — for all resources.

We begin to see, then, that problems of income in agriculture have their more basic origin in resources. But we must look still further. Economic development also is an element of this complex. It is largely through national economic growth that capital increases sufficiently in supply to be furnished agriculture at low real prices and to serve as a large-scale substitute for land and labor. Relative decline in the price of capital places increased economic premium and pressures to substitute it for the conventional resources. Under these economic conditions, technical research also is favored in the private sector, establishing new and higher rates of substitution of capital for labor and land. Together, the development of (a) new production functions and knowledge of increased marginal rates of substitution of capital for labor and land and (b) a lower real price of capital, cause the structure of agriculture to turn in the direction of smaller dependence on land and labor.

Capital accumulation in agriculture gives rise to a larger nonfarm sector to process and supply inputs to farming. The basic science and methodology of these input-furnishing sectors often are more related to technical and scientific developments in nonfarm sectors than to agriculture. The science and technology of developing and producing tractors is more akin to that of the automobile industry than to farming. Technology in fertilizer and insecticide industries is more a branch of the chemical industry than of agriculture. The antibiotics of livestock rations are related more to the drug sector rather than to agriculture. Increasingly the scientific technology even of the production and supplying of new seeds falls outside of the "purely farm sectors." To an extent, this also is true for livestock inputs such as baby chicks and the breeding technology underlying their improvement. Discoveries in these input industries, as they grow under development and further technical knowledge, allows supply prices of inputs to be kept low relative to prices of farm commodities, labor and land. The demand for capital items grows accordingly and agriculture comes to rest more on this resource.

FACTOR SUBSTITUTION AND ECONOMIC DEVELOPMENT

Relationships among economic development, factor supplies and resource prices are illustrated through comparison of agricultures in countries at different stages of economic development. India and the United States fall nearly at extremes in the spectrum of economic growth; Mexico, Japan and France fall at intermediate points within the range of structure and development.

Agriculture of India rests largely on labor technology; labor inputs constitute over 80 percent of all inputs, and capital inputs are small. Paucity of capital inputs not only limits the substitution of mechanization for labor, but also restrains substitution of fertilizer, insecticides and similar biological capital forms for land. Farm units are small (i.e., the agricultural firm has demand for only a small amount of land), as is generally true in economies at low stages of development where the supply price of capital is high relative to that of labor, and farming is based on labor technology.

In contrast is the United States where the price of labor is greater, and the supply of capital, including both knowledge of it and its physical forms, has greater elasticity. While comparable figures are not available for India, Table 1.1 indicates the change in the combinations of resources for U.S. agriculture under national economic growth, changing factor prices and relatively rapid farm technological advance. These figures refer to decades after national economic development and technical development of agriculture had already gained some momentum. A century prior to 1910, dependence of U.S. agriculture on labor was even greater, with nonland capital inputs amounting to as little as 5 percent of aggregate inputs. By 1910, labor still represented 75 percent of total farm inputs. By 1960, labor had dropped to 30 percent of total inputs, with an accelerated rate of decline in proportion of total inputs represented by labor after 1940. Labor may constitute no more than 10 percent of total inputs by 1980, with total capital comprising 90 percent and nonland capital comprising 80 percent. The response of labor to changed conditions of returns and employment alternatives have been somewhat sluggish in the short run. Important substitutions have been made in the long run, however.

Capital is, of course, not an internally homogeneous input category. Items within the category differ physically as much as do the tripartite of land, labor and capital. The capital forms now in use have little resemblance to those of decades past; very few forms remain unchanged as substitution has taken place. A major change taking place

Table 1.1. Percent of Total U.S. Farm Inputs Represented by Capital, Labor and Land, 1910-60*

Year	Labor	Capital	Land	Total
1910	74.6	16.7	8.7	100.0
1915	72.6	19.0	8.4	100.0
1920	70.1	21.6	8.3	100.0
1925	69.3	22.7	8.0	100.0
1930	65.8	25.9	8.3	100.0
1935	66.7	23.7	9.6	100.0
1940	58.6	32.3	9.1	100.0
1945	52.5	38.6	8.9	100.0
1950	41.8	49.3	8.9	100.0
1955	35.0	56.5	8.5	100.0
1960	30.1	61.4	8.5	100.0

*Basic data from Economic Research Service, USDA. For the series represented, see USDA Tech. Bul. 1238, 1961 and USDA Stat. Bul. 233. 1961.

within the capital category, one also stemming from economic development and its impact on the supply price and productivity of resources, has been the substitution of capital inputs produced in the nonfarm sector for those formerly produced on farms. (See Table 2.4, p. 20.)

The basis in resource prices favoring a shift from a labor-oriented agriculture to one resting on capital is further suggested by Table 1.2. The first five rows show the change in real price of selected capital items relative to labor price by decades from 1910 to 1959; the sixth row shows the real price of fertilizer in relation to land price while the seventh shows the real price of fertilizer in relation to all farm

Table 1.2. Index of Price Relatives for Particular Categories of Inputs, Selected Periods, U.S. 1910-19 = 100*

Price Relative	1910-19	1920-29	1930-39	1940-49	1950-59
Short-term interest/labor	100.0	67.0	94.0	32.8	18.9
Machinery/labor	100.0	91.0	133.2	66.7	66.8
Fertilizer/labor	100.0	78.0	87.8	42.9	29.9
Land/labor	100.0	78.8	87.8	58.9	48.9
All capital/labor	100.0	66.4	101.5	61.9	51.5
Fertilizer/land	100.0	98.1	100.1	77.0	61.0
Fertilizer/products	100.0	97.4	116.0	66.1	56.6

*Price of resource in numerator divided by price of resource in denominator in each period, with 1910-19 = 100.

commodity prices. A tremendous change took place in these price relatives and agricultural technology after 1940, and favored a rapid and near-revolutionary change in the resource mix of the industry. Measured against the price of labor, the real or relative price of all capital categories has declined markedly since 1910. Similarly, the price of inputs such as fertilizer have declined relative to land price

RESOURCE STRUCTURE AND QUANTITATIVE ECONOMICS

We have attempted to describe how "failure" elements of low income and "success" elements of high productivity and capital accretion have their origins in the resource structure of agriculture. If resource demand and supply are favorable to rapid adoption of productive capital inputs, opportunities for growth in output and productivity of resources is large. But if opportunities for adjusting redundant labor resources out of agriculture are low because of values, specialized training or other reasons, the returns to farm labor may be low indeed. The above discussion essentially is a set of hypotheses about the parameters in the structure of agriculture. The quantitative estimates of structural parameters in later chapters provide more concrete knowledge about the resource structure. The purpose of this study is to identify, interpret and explain the developing structure and organization of agriculture.

The organization of agriculture is a reflection of parameters in the structure of agriculture. The organization is defined as the numbers and sizes of farms which make up the industry, the size of the labor force and the amount and composition of capital used. To explain why a particular organization has been attained, or to predict the organization which might emerge, it is necessary to know the demand functions for resources by the firms which make up agriculture. The size and number of units is a function of the farm firm demand for land. Similarly, the size of the labor force in agriculture is explained by the demand of each individual farm for this resource, with the aggregate demand for firms being that of the industry. The total amount of capital used also is a function of the variables which effectively enter into the resource demand functions of individual farms and the industry. Hence, the structure of agriculture is a term more or less synonymous with the concept of resource demand in the industry. To understand or predict the quantity and mix of the many resources which are or will be used, it is necessary to have knowledge of resource demand functions in agriculture. The demand function for a particular resource obviously is interrelated, through resource prices, technical coefficients and substitution rates, with the demand function for other resources.

Analysis and prediction of resource demand functions do not, by themselves, fully explain the quantity and mix of particular resources employed in the industry. Resource employment is explained as much by the conditions under which resources are supplied to agriculture as by the conditions which determine the demand for resources. Hence, an analysis of the structure of agriculture must deal with the conditions of factor supply to agriculture, as well as with conditions of resource demand. While in this study major emphasis is given to aggregate resource demand functions for the agricultural industry, some analysis is necessarily and appropriately made of resource supply. For some resources such as hired labor, it is difficult to analyze demand apart from supply. But other important cases of identification also arise. In chapters dealing with refined empirical estimates, regression models are applied accordingly. For resource markets where prediction of supply is not necessary in identifying demand functions, or where complex estimating systems are not possible, single equations, least-squares techniques are used to estimate factor demand functions. In other cases where demand functions for particular resources cannot be identified apart from supply functions, or where demand for one factor cannot be explained apart from other factors, various types of simultaneous equations estimates are used. However, the major emphasis is on estimation of resource demand functions using relatively simple empirical techniques.

This analysis was initiated as more than a mechanical attempt to estimate demand functions of agricultural resources. Interest extends beyond this purely statistical routine to an analysis and interpretation of the conditions surrounding the structure of agriculture, both in respect to trends in the amount of mix of resources used and that in prospect. Hence, analysis also is made of data which are not incorporated into the refined estimates of some later chapters. Too, the form of data available for analysis of agricultural structure, largely time series data, gives rise to limitations in regression analysis and predictions. Accordingly, data in other forms and representing less formal empirical methods are used wherever useful and appropriate.

Predicting and interpreting the structure of agriculture is only an intermediate end in analysis. A more ultimate end is to explain how the supply and demand conditions surrounding agriculture relate to returns on resources and to income of the industry. At this level of ends, in the means-end chain of analysis, fundamental interest also relates to adjustments which must be made in agriculture if its income is to be made more favorable, or if its structure can be brought into more consistent juxtaposition with the developmental stage of the nation.

2.

Changes in the Structure and Organization of Agriculture

THE PROCESS of economic development is characterized by technological change, capital accumulation and improvements in managerial and labor skills.[1] Improved technology introduces new and improved inputs which have high productivity relative to conventional resources. Consequent structural changes in resource demand and production functions increase the supply of products. In industries such as agriculture characterized by a low elasticity of commodity demand, the increasing product supplies depress prices and signal the need to transfer resources from agriculture to other sectors. If resource supply conditions permit rapid introduction of highly profitable and productive capital inputs and prohibit rapid outmovement of less productive resources such as labor, returns to the latter may be chronically depressed. Also, conditions associated with economic development and structural change create pressures for farm consolidation. In this chapter a descriptive summary is presented of the substitution of capital for labor, increased productivity, changes in factor returns and other characteristics of agriculture in a growing economy.

OUTPUT AND PRODUCTIVITY

Physical productivity of agricultural resources has increased rapidly since the mid-1930's. Even in earlier periods, output increased. However, differences exist between earlier and recent periods in two major aspects: (a) the rate of growth in output was much more rapid after 1935 than for the previous 60 years, and (b) a marked increase in the average productivity per unit of resource took place after 1935. Before this, growth in output was accompanied by a growth in total farm inputs, the rate for the latter being only slightly smaller than the rate for the former. Since 1935, however, the increase in aggregate inputs has been slight while the growth in output has been great. The result has been a sharp upturn in average productivity of inputs. These facts are illustrated in Figure 2.1 for the period 1870-1961. Output grew

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[1] See Heady, Earl O. Agricultural Policy Under Economic Development. Iowa State University Press. Ames. 1962. Chap. 2.

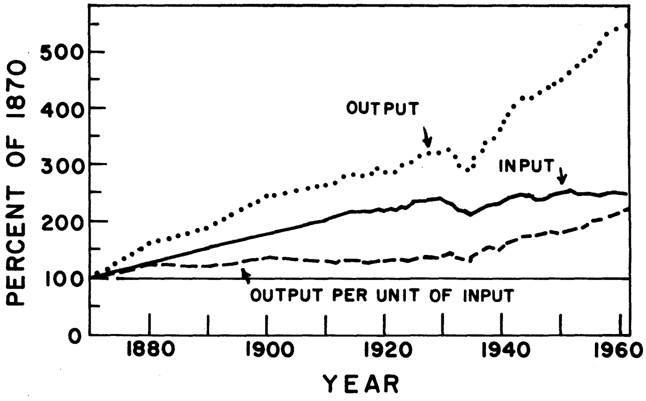

Figure 2.1. Trends in aggregate output, input and resource productivity for U.S. agriculture, 1870-1961. (Source: Based on USDA Tech. Bul. 1238 and USDA Stat. Bul. 233.)

quite rapidly up to 1900. This was a period in which demand conditions favored growth in farm output and slow rates of technological improvement encouraged use of more total resources in agriculture. Labor, land and capital were drawn into agriculture as a means of extending output to match demand growth. The supply of new land furnished agriculture was quite restrained, however, and growth in inputs stemmed largely from the increase in the farm labor force and in capital used.

Labor employment reached its peak around 1920, a time when land had become largely a fixed restraint. Total inputs still increased up to 1930, at somewhat the earlier rate. Capital representing new technology evidently was added in amounts to offset small reductions in the work force. Following 1930, inputs dropped somewhat as the depression caused some labor to flow back into agriculture but new capital investment declined greatly. With recovery and World War II, asset accumulation and relative prices of farm products and resources caused a large growth in nonreal estate capital items and a decline in labor used in agriculture. Since 1940, increase in inputs has been very slight, with the addition of capital inputs representing new technology being almost offset by the decline in labor inputs.

With relative constancy in inputs since 1940 and an accentuated growth in output, productivity per unit of input has grown rapidly. With output growing by 55 percent and input by only 5 percent, output per unit of input increased by nearly 45 percent between 1940 and 1961. Growth in productivity per unit of input was greater in agriculture than for the average of nonfarm sectors over the period 1929-57; productivity nearly doubled for agriculture and increased by 75 percent for the nonfarm economy.[2]

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[2] Cf. Historical Statistics of the United States; Colonial Times to 1957. Bureau of the Census. Washington. 1960. P. 599.

FACTOR LEVELS AND PROPORTIONS

Table 2.1 indicates the tremendous growth in farm capital inputs since 1910. Only two major input categories declined in magnitude. While labor continued to increase up to 1920, input of this resource was more than halved over the next 40 years. While it declined slightly after 1930, cropland input has remained highly stable as compared to other input categories. Decline in cropland would have been even greater in the absence of price support programs, growing public stocks and special foreign disposal programs. It has been estimated that the nation's food needs can be attained in 1980 with a further reduction of 10 percent, 51 million acres, in cropland.[3] Except for buildings, the capital items included in Table 2.1 increased by several hundred percent between 1910 and 1960. Even with an increase in total farm output, farm consolidation lessened building needs and growing farm size allowed better attainment of scale economies associated with this capital resource.

The categories of inputs shown in Table 2.1 are broad aggregates. Changes for individual capital were even more extreme. Capital items such as feed additives, weed-killing chemicals and others had tremendous growth rates even in the last 10 years. Similarly, other forms such as horses and open-pollinated seed corn declined at nearly parallel rates. In mix of agricultural resources, the major change has been

Table 2.1. Index of Major Categories of Inputs for Selected Years, 1910-1960, U.S. (1947-49 = 100)*

Resource Category	1910	1920	1930	1940	1950	1960
Farm labor	135	143	137	122	90	62
Machinery and power	28	44	55	58	118	142
Farm buildings †	99	116	111	98	106	128
Fertilizer and lime	20	28	36	48	118	192
Tractors	‡	9	32	55	119	133
Combines	‡	1	12	37	137	205
Cornpickers	‡	‡	17	36	151	251
Feed, seed and livestock purchased	22	32	37	63	101	149
Miscellaneous capital operating items	71	85	96	93	108	138
Cropland	87	95	103	100	100	92

*USDA Stat. Bul. 233. 1961.

† Index of value of farm buildings is based on census enumerations and includes the farm dwelling.

‡ Less than 1.0.

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[3] Cochrane, W. W. Needs for products of land and water. USDA. Mimeo. 1962.

in growth of the capital/labor ratio. This ratio has increased both because of growth in capital and decline in the farm work force. As indicated in Table 2.2, land input per person employed in agriculture has increased by 150 percent from 1910 to 1960 and by 70 percent from 1940 to 1960. This trend has continued at an accelerated pace as mechanization has allowed each worker to handle more acres and as farms too small for efficient utilization of labor, even under earlier technology, have disappeared.

Table 2.2. Magnitude of the Farm Labor Force, Land, Assets and Related Resource Quantities, 1910-60, U.S.*

Item	1910	1920	1930	1940	1950	1960
Work force (mil.)	13.6	13.4	12.5	11.0	9.9	7.1
Man-hours used (bil.)	22.5	24.0	22.9	20.5	15.1	10.3
Total land in farms (mil. acres)	879	956	989	1060	1159	1158
Value of production assets						
Current dollars (bil. $)	†	†	†	38.7	95.9	156.8
1947-49 dollars (bil. $)	†	†	†	83.3	95.9	107.8
Acres per worker	64.6	71.3	76.5	96.4	117.1	163.1
Value of productive assets per worker ($)						
Current dollars	†	†	†	3413	9625	21235
1947-49 dollars	†	†	†	7347	9625	14599
Capital input per labor input ($)	.87	1.00	1.17	1.41	2.41	3.96

*USDA Agr. Info. Bul. 232. 1961.
†Not available.

The rate of increase in capital per worker has been even more rapid than for land acreage. Physical capital per worker more than doubled between 1940 and 1960 while value of capital per worker increased by nearly seven times. In terms of annual capital input (including real estate) per unit of labor input, the ratio of 1960 was 4.5 times that of 1910 and 2.8 times that of 1940. The annual value of capital inputs began to exceed that of labor inputs by 1920 and the ratio is expected to continue increasing rapidly with further economic development.

The sum effect of alteration in demand by farms for resources, of course, results in a great change in the proportion of total inputs furnished by particular resource categories. Figure 2.2 emphasizes how these proportions have changed for some resource categories in a period of less than 20 years for U.S. farming. The percentage contribution of labor was almost halved in this period while that of items such as machinery, purchased seeds and fertilizer more than doubled. Over a longer period, 1910-60, as illustrated in Table 2.2, the relative value of inputs furnished by the aggregate categories of labor and capital have largely reversed positions, while land has remained almost constant.

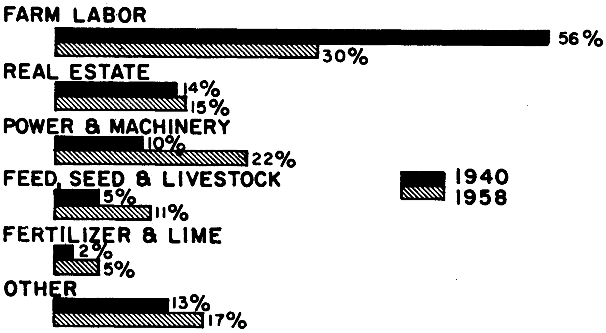

Figure 2.2. Major input groups as a percent of total inputs for the U.S., 1940 and 1958. (Source: USDA.)

These figures again emphasize the extent to which technical and economic development have caused the position of the dominant agricultural resource to shift from labor to capital.

Farm Size and Numbers

With American farming still centered around the farm family, and particularly the labor of the farm operator, the increase in ratio of capital and land per worker has been paralleled by a large increase in farm size. The average acreage of all census farms increased by 70 percent between 1940 and 1960 (Table 2.3). The acreage increased by a similar percentage for all commercial farms. Decline in number of farms has been greatest for units too small to (a) provide an adequate family income and (b) realize scale economies from mechanization. The number of farms less than 100 acres in size nearly halved between 1940 and 1960 while the number of all farms decreased by only a third. Similarly, mortality was greatest for farms operated by nonwhite persons, most of these being share-cropper or similar farms providing low family income. As a result of both (a) inflation and (b) increased physical volume encouraged by income pressure and scale economies, the number of farms with sales of $10,000 and over increased rapidly between 1940 and 1960. The number with sales of less than $10,000 decreased by a similarly rapid rate. The rate of decline in farm numbers also was greatest in the South where units generally have been small and family income has been low.

Further change in farm size has several possible implications in the use of, and demand for, resources in agriculture. Obviously, decline in farm numbers will be accompanied by further reduction in the work force, especially if farms which add acreage are those with an underemployment of labor and a surplus capacity of farm machinery. For example, studies by Heady and Hoffmann indicate that in a commercial farming area such as southwest Iowa, farm consolidation can

Table 2.3. Numbers and Sizes of Farms, 1910-60, U.S., by Indicated Classes*

Item	1910	1920	1930	1940	1950	1960
Number of all farms, U.S. (1000)	6,362	6,448	6,289	6,096	5,382	3,704
With white operators	5,441	5,498	5,373	5,378	4,801	3,422
With nonwhite operators	921	950	916	719	581	282†
In the South	3,097	3,206	3,223	3,007	2,652	1,646
Rest of U.S.	3,265	3,242	2,966	3,089	2,730	2,058
Under 50 acres	2,254	2,300	2,417	2,286	1,863	1,051
Under 100 acres	3,692	3,775	3,792	3,577	2,911	1,708
Under 260 acres	5,369	5,839	5,597	5,373	4,601	2,897
20 acres and over	4,108	4,148	3,872	3,810	3,519	2,646
100 acres and over	2,670	2,673	2,497	2,286	2,222	1,995
260 acres and over	693	619	692	724	781	807
With sales of $10,000 and over	‡	‡	252	312	484	794
With sales less than $10,000	‡	‡	6,037	5,784	3,138	1,582
Acres per farm, U.S.						
All farms	147	137	157	174	215	302
Commercial farms	‡	‡	‡	220	300	371

*U.S. Census, printed in year reported and enumerated in previous year.
† Estimated from number of nonwhite operators in the South.
‡ Not available.

take place with only a slight increment of labor by farms which add land and a complete replacement of the operator labor on farms being consolidated.[4] But other changes in resource demand also are posed. Consolidating farms have relatively "largest demand" for land and its biological capital complements such as seed and fertilizer. The demand of the consolidating farm simply replaces that of the liquidating farm for land and, to an important extent, for items such as seed. Since remaining operators, as compared to those who leave agriculture, often are better blessed with management and capital, they tend to use more fertilizer per acre. However, their investment in machinery need not correspond with their additions of land. The Iowa study shows that after consolidation the total machinery investment is less than for the two sets of farms before consolidation.

During the period 1944-54, U.S. farmers purchased $24 billion in new machinery, power and equipment. The net investment was $7

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[4] See Hoffmann, R. A., and Heady, Earl O. Production, income and resource changes from farm consolidation. Iowa Agr. Exp. Sta. Bul. 502. Ames. Feb. 1962.

billion, since depreciation charges on old equipment were $17 billion. In 1954, however, the depreciation on machinery began to exceed addition through purchases, suggesting not a net increment but a slight decline in machinery, power and equipment investment.[5] An important reason why individual farms have added acreage since 1940 has been that of using existing machinery, equipment and labor more effectively. Thus as some farms are absorbed by others, output tends to increase with the use of more inputs such as fertilizer, but with smaller inputs of machinery and labor on the combined unit. Consequently, in aggregate effect, resources such as the former are substituted for categories such as the latter. Also, substitutions may take place within categories such as machinery and equipment. The Iowa consolidation study showed a net addition expected in feed handling equipment but a decline in power and machinery for crop operations.

Purchased Inputs

In a somewhat similar vein of substitution, economic development encourages specialization which, in turn, causes inputs produced off the farm to be substituted for those produced on the farm. Classical examples are tractors for horses, tractor fuel for horse feed, chemical fertilizers for manure and legume rotations, purchased seeds for farm-produced seeds, etc. These substitutions take place because the price declines and the productivity increases for inputs supplied from outside of agriculture, relative to their counterpart supplied from within the industry. Since favorable factor prices lead to mechanization and consequent scale economies, farming also moves in the direction of specialization. For techniques oriented towards labor, large enterprises have relatively small scale or cost advantages relative to small ones. Under high mechanization and its greater fixed costs, however, the scale of output over which per unit costs decline rapidly is extended, as compared to labor technology. Hence, within typical capital limitations, the commercial farmer is drawn to fewer enterprises and activities as a means of lowering unit costs, because of the higher fixed costs of mechanization. This development occurs only if the supply price of materials furnished to agriculture by outside sectors is favorable relative to the productivities of these same resources. Within the complex of economic development and factor prices which bring greater capital inputs to agriculture, a broader market results in scale economies for firms which process inputs. These nonfarm industries then

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[5] All of the above estimates are from Nikolitch Radoje, Farm Economies Research Service, USDA. The net extent to which farm consolidation changed the demand for machines (power and machinery reduction versus the addition of handling equipment) is yet to be established with certainty. Brewster and Wunderlich (Adjustments in Agriculture - a National Basebook. Iowa State University Press. Ames. 1961) show that net investment (purchases in excess of depreciation) reached a peak in 1954, then remained lower until 1960. These figures parallel our own calculations in later chapters.

can supply capital items such as chemicals, baby chicks and feed additives at lower real cost.

These developments lead to a greater commercialization of agriculture. Fewer inputs are represented by resources furnished directly by the farm and household and a greater proportion represent factors for which a market price is paid. At early stages in economic development, inputs are largely those represented by labor and land owned by the farm family, and by power, seed, feed and other items produced on the farm where used and which do not pass through the market. Under advanced stages of development, and under the conditions of resource pricing and supply discussed previously, the greatest proportion of inputs become those of capital. These are, under a capital-intensive structure, best produced at low cost in specialized firms outside of agriculture. Their volume then is sufficient to allow a more complete realization of inherent scale economies in producing a farm resource of particular quality and productivity.

Under these conditions of direct cash payment for inputs, farmers are expected to be more price responsive than under circumstances where most resources are family furnished and have only an indirect or implicit price. Even as late as 1910 (see Table 2.4) around two-thirds of all inputs used in agriculture were unpaid. By 1960, however, the percentage of unpaid or nonpurchased inputs had fallen to about a third of total inputs.

Increased demand for inputs furnished outside the farm and household is expected to continue as structural change in agriculture progresses further. An important element in decline of the proportion of nonpurchased inputs is the diminution in farm numbers and the agricultural labor force. Small farms depend relatively more on labor and less on capital than do large farms. Since the major reduction in farm numbers is among farms with small volume and inadequate income, the

Table 2.4. Percentage of Paid and Unpaid Inputs Used in American Farm Production, 1910-60*

Year	Percentage of Total Inputs From:		
	Unpaid inputs	Paid inputs	All inputs
1910	60	40	100.0
1920	56	44	100.0
1930	53	47	100.0
1940	45	55	100.0
1950	35	65	100.0
1960	29	71	100.0

*USDA Stat. Bul. No. 233. 1961, for basic input data. These figures are based on 1935-39 price weights. If 1947-49 price weights are used, the percent of unpaid inputs is estimated at 72, 67, 64, 54, 43 and 33 respectively for the years above.

amount of unpaid or low paid labor inputs will decline further. Labor released from small units combined with other undersized units, or even with more adequate ones, largely is replaced by machinery and other purchased mechanical inputs. While less apparent, labor also is replaced by biological capital such as fertilizer, improved seeds and livestock, pesticides, ration additives and others which increase output per acre or animal against a relatively fixed labor input per producing unit. Consequently, a given amount of food can be produced with less labor as more of these biological capital items are used. These capital items come largely from purchased sources and have an explicit price. Continued technical improvement through these capital materials also causes the proportion of unpaid inputs to decline.

The same shift and substitution also takes place between these biological capital materials and land. The new technologies increase yield per acre, so that a given output can be obtained from fewer acres. If consumer demand grows at a slower rate than the increase in farm productivity encouraged by these inputs, fewer acres of land are needed for crop production. With surplus land shifted to less intensive uses, as it would do more readily under agricultural policies differing from those of the 1940's and 1950's, the capital innovations mentioned above substitute for it. The proportion of total inputs from purchased sources increases accordingly.

INCOME CLASS OF FARMS

The extent to which farms can still increase in size, as a method of reducing inadequate units, is suggested by the data of Table 2.5. These classifications, excluding part-time, residential and abnormal farms, indicate that in 1954 only 44 percent of U.S. farms produced over 90 percent of total sales. If only farms with sales exceeding $5000 are included, less than 30 percent of all farms produced nearly 80 percent of

Table 2.5. Number and Percentage of Commercial Farms by Income Class (1000 Farms), 1954 and 1959*

Class in Dollar Sales per Farm	1954 Number of farms	1954 Percent of farms†	1954 Percent of industry sales†	1959 Number of farms	1959 Percent of farms†
$10,000 and over	583	12.2	58.2	795	21.4
5,000 - 9,999	707	14.8	20.5	654	17.7
2,500 - 4,999	812	17.0	12.1	618	16.7
2,500 and less	1,225	25.7	7.1	348	9.4
Total	3,327	69.7	97.9	2,415	64.5

*U.S. Census.

†Percent of all farms, including the noncommercial classes of part-time, residential and abnormal farms.

the nation's farm product sales. It has been estimated that in 1959 the 21.4 percent of all farms with sales over $10,000 made more than 70 percent of the industry sales.[6] Farm numbers obviously could be cut by half or more, without material effect on the output of U.S. agriculture.

If reduction came from farms with less than $5,000 in sales, total value of output could, starting from the 1954 distribution, be maintained with only an 8 percent increase in sales per farm. This slack and more exists over the total of farms with sales equal to $5,000 or more. In fact, as pointed out previously, if land were relinquished by the one group and added by the other, it is likely that total output would be increased from total inputs of equal or smaller magnitude than formerly. But on a gross value of sales, even $5,000 is too little to provide an adequate net income, or one consistent with the current stage of economic development and per capita income in the United States. With production expenses subtracted, sales of this magnitude leave a family income much smaller than the labor return from employment in other industries. With further time, knowledge and vocational guidance of farm children, few commercial farms with gross income of $6,000 or less are likely to be maintained. Accordingly, farms will be even fewer and larger and will depend more on capital and purchased inputs. By 1960 (Table 2.6) a large proportion of farmland purchases was for consolidation purposes, and the percentage for these purposes was increasing.

These changes in farm size, associated with changes in the resource structure of farming, help relieve the low income and productivity problem which arises because of the small ratio of land and capital per unit of labor on many farms of the nation. Other than a few specialized fruit and vegetable farms, those which use an input mix

Table 2.6. Percent of Farm Land Transfers for Farm Enlargement, 1950-55 and 1960, by Regions and Type*

Region and Type	1950-55 Average	1960
Northeast dairy	14	21
Lake states	16	31
Eastern cotton	26	37
Western cotton	30	46
General	19	29
Range livestock	31	47
Corn Belt	28	53
Wheat	48	69

*USDA Outlook Charts, 1961.

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[6] Estimate from Brewster, John. Changing organization of American farming. USDA Econ. Res. Serv. Mimeo. Oct. 1961.

Table 2.7. Distribution of Farm Families by Net Income Class, U.S., 1958*

Net Family Income	Number Farm Families (1000)	Percent Farm Families	Percent Nonfarm Families	Farm Families as Percent of Nation
Under $2,000	1,777	25	6	33
$2,000 - 2,999	834	18	6	26
$3,000 - 4,999	1,242	26	24	12
$5,000 - 9,999	1,160	24	47	6
$10,000 and over	336	7	17	5
Total	4,749	100	100	--

*U.S. Dept. of Commerce.

based mainly on labor generally have low income. Farming possesses a disproportionate number of the nation's low-income families. Most of these low-income farm families are on undercapitalized and small units. As the data of Table 2.7 indicate, a fourth of farm families had incomes under $2,000 in 1958 while 43 percent had incomes of less than $3,000. Of total U.S. families with income less than $2,000, a third were in agriculture.

These changes in farm size and composition do not threaten the U.S. structure of family farming, however. Hired labor has been declining at a slightly more rapid rate than family labor, leaving agriculture based more on the latter as machine capital substitutes for the former. Defining a family farm as one using less than 1.5 man-years of hired labor and "larger than family farms" as one using 1.5 man-years or more of labor, Brewster has arranged the figures in Table 2.8.[7]

Table 2.8. Classification of Commercial Farms by Family and "Larger Than Family" Units for Specified Years (1000)*

Class of Commercial Farms	Number 1949	Number 1954	Number 1959	Percent Change 1949-59
Family size				
Adequate	334	440	680	104
Inadequate	3,138	2,698	1,582	-50
Total	3,472	3,138	2,262	-35
Larger than family				
$10,000 or more sales	150	142	114	-24
Less than $10,000 sales	84	47	36	-57
Total	234	189	150	-36
All commercial farms	3,706	3,327	2,412	-35

*See footnote 7 for source.

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[7] Brewster, ibid.

Adequate family farms are those with over $10,000 sales per year. Under this classification (except that adjustment still needs to be made for declining value of the dollar), the number of adequate family farms almost doubled between 1949 and 1959. Extending this criterion further, only 30 percent of family farms had increased to an "adequate stage" by 1959. In contrast, the number of "larger than family farms" decreased between both census periods.

CHANGES IN COMPOSITION AND LOCATION OF INPUTS

As previous data indicate, change in land inputs over the past several decades has not paralleled change in demand and use of labor and capital. The aggregate supply elasticity of land is, of course, much lower than for capital. Mobility of farm labor to other sectors is slower than for other nonfarm intersector transfers of this resource. Farm labor does, however, have long-run opportunity to migrate, not only to other economic sectors but also to other geographic sections of the country. Extended disparity of farm returns, as compared to other employment opportunities, has caused large-scale migration from farms since 1940. Similarly, capital items for agriculture also have high supply elasticity as compared to land in general. Capital fabricated at one location can be moved to other locations where demand is greater in agriculture. While some capital already in agriculture is "fixed" in the short run, it eventually becomes depreciated or obsolete and is supplied continuously to agriculture only if producer demand is sufficiently high. In contrast, land in aggregate has very low supply elasticity or opportunity for increasing its quantity.

Table 2.9 illustrates the differential adjustment which has taken place in land inputs for crop production by census regions. A large amount of land has moved out of production into less intensive and nonfood crops such as forestry and into pasture in the Northeast, Appalachian, Delta, Southeast and Southern Plains regions. Land also has gone into urban and industrial uses, especially in the East. These changes have decreased land in farms by more than half in Massachusetts and Connecticut. Others of the states in Table 2.10 also had large losses of land to urban uses since 1900. Land for farming decreased by more than half for all of New England and by nearly half for the Middle Atlantic States.

Farm output and fertilizer inputs increased in all ten regions of Table 2.9. Labor used also decreased universally. Land in crops decreased in only five regions. Fertilizer and other capital inputs obviously serve as a substitute for both labor and land in all regions. The 1939 level of output could have been produced by using less land, as well as less labor, in all regions. Substitution of capital for land is not expressed directly and explicitly in any regions. In aggregate over the nation, however, use of more capital representing new technology increases output in some areas while marginal land goes out of crops or

Table 2.9. Percent Changes in Output and Major Input Categories by Regions, 1939 to 1960*

Region	Total Output	Cropland Used for Crops	Plant Nutrients	Man-Hours of Labor
Northeast	42	-21	106	-49
Lake States	52	-3	1,379	-46
Corn Belt	59	8	1,146	-48
Appalachian	33	8	179	-49
Southeast	58	-34	164	-57
Delta	35	-25	339	-61
Southern Plains	60	-17	1,500	-55
Northern Plains	136	6	6,780	-46
Mountain	79	38	1,642	-39
Pacific	75	11	747	-56
U.S.	61	-6	314	-50

*USDA Stat. Bul. No. 233, 1961. Figures are 1939-60 for all items but plant nutrients which are for 1939-59. Output data for Northern and Southern Plains in 1960 are slightly above trend line.

farming in other areas. The substitution takes place in fact for the nation, even if by round-about methods.

Regionally, the greatest change in farming structure has occurred and will continue in locations with the largest proportion of small, low-income farms and underemployed labor. The number of farms could be reduced by two-thirds in the Delta, Appalachian and Southeast regions,

Table 2.10. Land in Farms in Specified States and Regions (1000 Acres)*

State or Region	1900	1920	1940	1960†
Massachusetts	3,147	2,494	1,938	1,142
Connecticut	2,312	1,899	1,512	884
New York	22,648	20,633	17,170	13,490
Pennsylvania	19,371	17,658	14,594	11,862
Virginia	19,908	18,561	16,445	13,126
West Virginia	10,655	9,570	8,909	6,063
North Carolina	22,749	20,022	18,845	15,886
Tennessee	20,342	19,511	18,493	16,081
New England	20,549	16,991	13,371	9,315
Middle Atlantic	44,860	40,573	33,639	26,731
South Atlantic	104,298	97,775	92,555	83,408

*Statistical Abstract of the U.S. Volumes 44, 63, 71 and 82.
† Preliminary 1959 U.S. Census estimates.

without placing great pressure on national commodity supply. The problem of adjustments in this direction are, of course, those resting on resource supplies. On the one hand, many farm families continue to "supply" their labor to agriculture because they lack knowledge or skills for alternative employment, are reluctant to move to new locations and industrial experiences or lack funds for transfer. The supply of knowledge and funds is too high in price or is too low in elasticity to allow them to compete effectively for nonfarm employment and to reduce sufficiently the supply quantity of labor in agriculture. Accordingly, they stay in agriculture and maintain inadequate farm units which might otherwise be made available to their neighbors.

But many who will or should remain in farming find the supply price for credit and capital to be too high. Consequently, they cannot "effectively express demand" for additional land and other resources for

Table 2.11. Comparison of Inputs, 1937-41 and 1960, for Specified Types of Farms in the United States*

Type of Farm and Location	Land (acres)		Labor (days)		Nonreal Estate Capital (dollars)		Power and Machinery (index, 1947-49=100)	
	1937-41	1960	1937-41	1960	1937-41	1960	1937-41	1960
Cotton								
So. Piedmont	158	214	526	440	1,010	3,550	54	140
Black Prairie, Tex.	140	190	475	284	1,580	5,840	61	111
High Plains, Tex.	258	426	431	316	2,530	8,450	78	115
Delta (small)	53†	58	375†	320	1,540†	3,690	100†	201
Peanut-cotton								
So. Coastal Plains	122†	177	404†	395	1,820†	4,500	100†	326
Poultry								
New Jersey	10†	10	590†	570	8,840†	8,880	100†	167
Corn Belt								
Hog-dairy	155	178	507	442	4,690	17,440	69	123
Hog-beef cow	181	249	328	350	3,540	15,900	70	145
Hog-steer	178	216	425	415	6,280	27,430	71	110
Cash grain	209	248	380	323	4,910	11,950	69	101
Dairy farms								
Central northeast	176	226	533	440	4,100	19,400	75	159
Eastern Wisconsin	115	146	578	415	3,720	17,150	42	117
Southern Minnesota	135	163	482	399	3,460	16,530	56	121
Tobacco								
Coastal Plain (large)	170†	170	1,084†	898	6,630†	8,310	100†	103
Coastal Plain (small)	50†	50	381†	335	1,900†	2,250	100†	102
Wheat								
Northern plains (stock)	497	715	340	281	3,420	16,720	51	123
Northern plains (corn)	427	515	374	354	3,220	19,000	44	106
Southern plains	586	773	272	304	2,860	17,610	57	117
Washington (pea)	416	576	389	347	6,600	21,280	73	120
Ranches								
Northern plains (cattle)	3,322	4,380	412	406	9,090	32,960	65	106
Intermountain (cattle)	1,573	1,735	487	521	14,050	53,060	84	128
Southwest (cattle)	8,316†	11,150	395†	371	26,460†	36,720	100†	149
Northern plains (sheep)	4,721	6,638	657	882	10,500	36,540	58	114

*Farm costs and returns, USDA Agr. Info. Bul. 176. Washington. Revised, 1959; and USDA Agr. Info. Bul. 230. Washington. Revised, 1961.

†1947-49 average; estimates unavailable for 1937-41.

increasing productivity of these resources and for extending operations to attain greater scale economies and income. If these forces which condition resource supply and demand in low-income farming regions are lifted sufficiently, these same areas likely will have a proportionately greater change in farm organization during the period of 1960-80 than will those such as the Corn Belt, Lake States and Western regions.

Changes for typical farms scattered over the above regions are indicated in Table 2.11. Since these are farms which "remained in production," their changes are less extreme than the changes for entire regions where many small farms, not classified by type, shifted out of existence.

Important differences prevail between the adjustments of agriculture in aggregate and for individual farms. The data of Tables 2.9 and 2.11 cause the adjustment to appear much greater for the farm than for the regional sectors since the former includes all farms regardless of type, while the latter includes only "staying-in" farms. There are some changes which are much greater for the average of farms than for the industry — capital investment is an example. Aside from changes in land price, disappearance of one farm which is added to another may not cause acreage or investment to increase for the industry, but it does for the individual remaining farm. As an example of this difference, value of all farm assets (in constant 1947-49 dollars) used in production for the whole of U.S. agriculture increased by 29 percent or from 83.3 to 107.6 billion dollars in the period 1940-61. The per farm average for the nation increased by 85 percent or from $13,118 to $24,185 in the same period.

REGIONAL CHANGES IN PRODUCTIVITY

Changes in productivity and resource use have taken place in all farming regions of the nation. As Tables 2.9, 2.10 and 2.11 suggest, adjustments in resource mixes have been by somewhat different proportions and directions. In all regions greater absolute amounts of capital are being used while smaller amounts of labor are employed. In all regions too, the ratio of capital to both land and labor is increasing. The capital/labor ratio is increasing faster than the capital/land ratio, because either (a) labor is decreasing rapidly while land is constant or increasing only slowly in some regions, or (b) labor is decreasing more rapidly than land in regions such as the Northeast, the Plains and the Southeast.

The substitution of capital for labor and land increases the average and marginal physical productivity of land and labor in all regions. While comparison between two discrete years gives rise to problems of trend deviation due to weather abnormalities, the comparison of productivity change between 1939 and 1960 in Table 2.12 suggests the gross magnitude of changes in land and labor productivity by regions as

Table 2.12. Percent Increases in Crop Production per Acre and in Labor Productivity, U.S. by Regions, 1939 to 1960*

Region	Crop Production per Acre	Labor Productivity
Northeast	47	178
Lake States	45	185
Corn Belt	43	206
Northern Plains	134	331
Appalachian	47	164
Southeast	70	276
Southern Plains	90	259
Mountain	39	189
Pacific	48	191
U.S.	52	225

*Based on USDA Stat. Bul. 233. Revised July 1961.

altered by the resource mix. Yields in the Plains and Southern regions were abnormally high in 1960 due to favorable weather. In these very regions, however, labor productivity has increased rapidly due to the rapid (a) exodus of workers and (b) creation of farms with higher capital/labor ratios. No region lacked rapid growth in gross productivity of land and labor. As illustrated in Figure 2.3, average labor productivity for the United States has grown rapidly. Real estate productivity, including both land and improvements, has grown less rapidly because decline in land input has been relatively minute for the nation

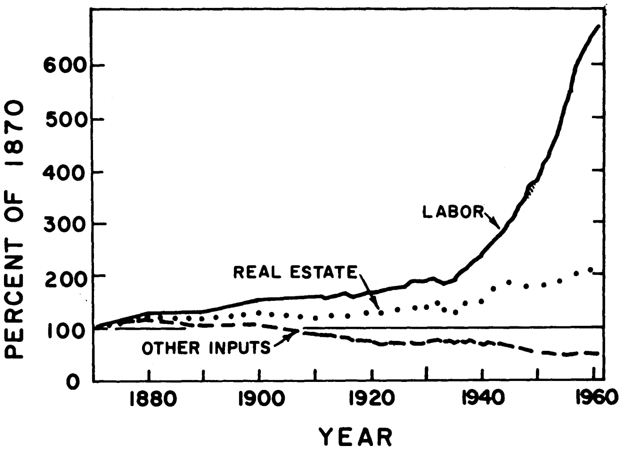

Figure 2.3. Average productivity of three farm resource categories, U.S., 1870-1961. (Source: Based on USDA Tech. Bul. 1238 and USDA Stat. Bul. 233.)

(improvements increasing slightly). Productivity of other inputs or capital items evidently has declined since 1900 as their use has been stepped up. For conventional types of inputs, such as capital, marginal and average productivity is expected to decline as their use is extended alone a scale line or as they are substituted for other resources due to change in price relatives. On the other hand, highly productive capital investments representing innovations might be expected to increase the productivity of conventional capital items which remain in use. Evidently, however, declining productivity of capital due to its greater use may have dominated.

For two classical resource categories such as capital and labor (or land), Figure 2.4 can be used to illustrate a major source of the growth in gross productivity of labor. Lines q_1, q_2 and q_3 are isoquants representing equal increments in output from the capital and labor production function. If only one resource is increased, its marginal and average productivity will decline. For example, if capital is increased by quantities denoted along the line c_2e, its incremental productivity decreases among the isoquants since $\Delta q/be < \Delta q/ab$ where Δq is the constant increment in output. Increasing capital input, with labor input held constant at oc_2, raises average productivity of labor from q_1/oc_2 to q_2/oc_2 and then to q_3/oc_2. Its marginal productivity will increase accordingly, depending on the algebraic nature of the production function. A change of this nature, with labor constant, is hardly expected, however. More typical is a change in both factors due to a change in

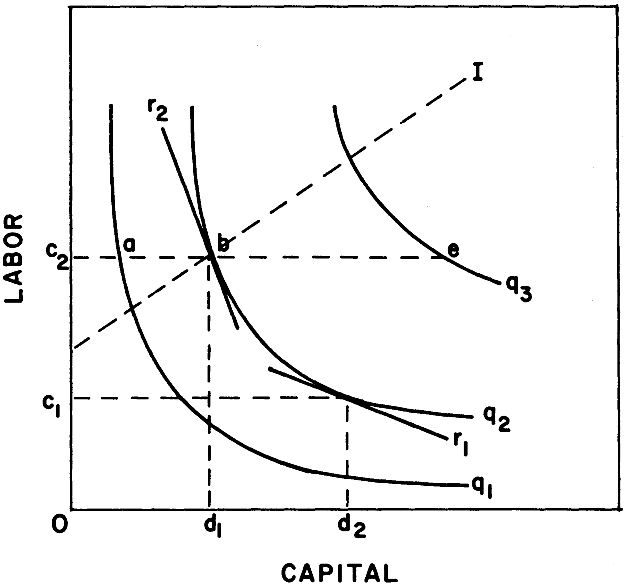

Figure 2.4. Effect of factor substitution on resource productivity.

the factor/factor price ratio, or in the factor/product price ratio. With a change in the factor price ratio to favor capital use, as represented by the slope of the isocost line r_1 as compared to r_2, the resource combination theoretically would shift for an output of q_2 level, from oc_2 of labor and od_1 of capital, to oc_1 of the former and od_2 of the latter. Average productivity then will decline from q_2/od_1 to q_2/od_2 for capital and increase from q_2/oc_2 to q_2/oc_1 for labor. (Generally, however, we might expect some "expansion effect" so that output would increase above q_2 and capital input would extend beyond od_2, and labor might not fall to oc_1.) If only the product/factor price ratio increases, more of both factors would be used and physical productivity of both would decline. The substitution effect evidently has dominated the expansion effect, in causing labor and land productivity to increase and capital (aggregate) productivity to decrease.[8]

SOURCES OF OUTPUT GROWTH

Growth in farm productivity can come from increased quantities or productivities of resources. The greater productivity arises under the realm of aggregate capital as one specific form of capital is substituted for another, or under the realm of aggregate labor where one specific skill of labor is substituted for another. Both sources of productivity change have occurred in U.S. agriculture. While approximate methods, rather than imputational procedures based on marginal productivities and elasticities, are used by Loomis and Barton (Table 2.13) they estimate that nearly the entire growth in farm output of recent years has come from increased productivity of general resource categories; the aggregate input having increased very little.[9] In contrast, most of the output increments of earlier decades is ascribed to greater inputs, with the productivity of inputs declining from 1910-20. Prior to 1870 an even greater proportion of output growth was attributable to input increase since, at this time, the land area of the nation was being increased and large increments in the farm labor force were bringing it into production. Evidently, even over the period 1911-20, the main increase in output was from use of more capital and labor, without major changes in the agricultural production function to boost input productivity. But after 1920, when a greater tempo in farm research and communication was attained in both the public and private sectors, the production function changed sufficiently to allow (a) given output with a smaller value-aggregated input, and (b) increased output to match population and

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[8] Figure 2.4 refers to a "fixed production function." The production function also has changed with time, causing the slope of the isoquants to change in the direction of increased marginal rates of substitution of capital for labor. Changes in proportions of capital and labor, as the factor/product price ratio declines, will depend on the exact nature of the isoclines.

[9] Loomis, R. A., and Barton, G. T. Productivity of agriculture, United States, 1870-1958. USDA Tech. Bul. 1238. 1961.

Table 2.13. Sources and Percentage Rates of Change in U.S. Farm Output for Selection Periods*

Period	Change in Output Imputed to:		Average Annual Rate of Change in:		
	Input quantity	Input productivity	Output	Input	Input productivity
1870-1911	72	28	2.45	1.77	.67
1911-20	129	-29	.70	.89	-.19
1920-39	16	84	1.08	.17	.91
1939-45	34	66	3.05	1.04	1.99
1945-50	49	51	.81	.40	.41
1950-56	-9	109	1.89	-.17	2.06
1939-56	22	78	1.98	.42	1.55
1911-56	31	69	1.34	.41	.93
1870-56	56	44	1.86	1.05	.80

*Loomis and Barton, ibid. (See footnote 9.)

demand growth requiring only a modest increase, and perhaps even a decrease, in inputs. Through this increase in the output/input ratio, a change encouraged by national economic development and the change in configuration of consumer demand and relative factor supplies and prices, resources have been freed from agriculture in order that still greater growth can be experienced in nonfarm sectors. Had resource productivity in agriculture declined over the period 1911-61 as suggested for 1911-20, the industry would have had to add a large amount of resources (see Chapter 5), thus detracting from national economic development.

A more detailed and technical estimate of sources of increases in farm output is presented in Table 2.14. These imputations refer to specific resources, but technical change or innovation is embodied in each. From 1919 to 1940 the main source of output increase came from release of resources represented by farm-produce power and in the shift to resources representing tractors and their technical complements. After 1940 the main source was in the collection of capital resources representing new technology for crop production. In the later period, the second important source was the technology and specific resource changes adopted for livestock. Being more specific, the estimates suggest that the index points in yield increases for crops came roughly 10 percent from hybrid corn, 45 percent from fertilizer, 6 percent from irrigation and 37 percent from improved seeds, cultural practices and similar practices for all other crops.[10]

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[10] Based on the midpoint of the range given by Durost and Barton, (see footnote to Table 2.14). For additional discussion of past sources and future potential for increasing farm output see Nelson, L. B. Physical potentials for crop production. Chap. 8. In Iowa State Center for Agricultural and Economic Development. Dynamics of Land Use — Needed Adjustments. Iowa State University Press. Ames. 1961.

Table 2.14. Average Annual Change in Index Points of Total Output and Percent Change in Total Output From Specified Sources, 1919-55 (1947-49 = 100)*

	Change in Index Points per Year		Percent of Total Output Increased Due to Source	
Source of Change	1919-21 to 1938-40	1940-41 to 1955	1919-21 to 1938-40	1940-41 to 1955
Shift from farm to tractor power	.39	.44	51	23
Change in technology and product added livestock	.12	.47	15	25
Change in pasture consumed by livestock	.03	.04	4	2
Shift in use of cropland	-.03	.13	-4	7
Change in crop technology	.26	.82	34	43
Total change in index per year	.77	1.90	100	100

*Based on Durost, D. D., and Barton, G. T. Changing sources and farm output. Prod. Res. Report No. 36. USDA 1960.

Returning to a more aggregate comparison, Figure 2.5 suggests the changing composition of inputs to produce a unit of output over the period 1935-60. These figures do not, of course, indicate changes in the portion of total product, or in portion of growth in total product, imputable to different resources. They suggest more nearly the relative changes for the particular resource in respect to its contribution to unit output, rather than the relative importance among inputs.

IMPACT OF FACTOR DEMAND STRUCTURE ON COMMUNITY SECTORS

Economic growth and change in the structure of an industry does not necessarily distribute gains and sacrifices of progress symmetrically over all resource and commodity groups which attach to this progress. Gaining directly are those who own or produce resources which increase in farm use because of changes in prices or marginal productivities which favor their use. Sacrificing as part of this progress are owners or producers of resources which decrease in magnitude because price ratios and substitution ratios change, causing the demand for particular inputs to decline. In this complex of those who benefit and sacrifice also are farmers and the nation's consuming society in a market characterized by (a) commodity supply growing more rapidly than commodity demand and (b) a low short-run supply elasticity of selected resources in agriculture. Under these conditions, and with low price elasticity of demand as in agriculture, revenue of agriculture declines but the total real cost of food is lessened for

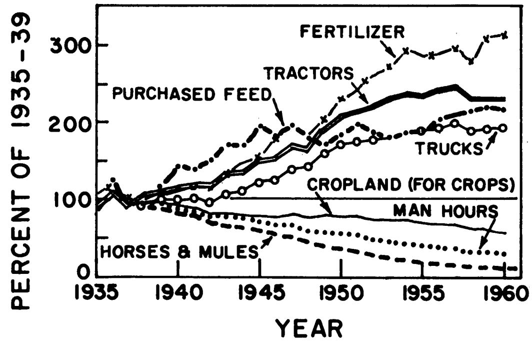

Figure 2.5. Index of resources used per unit of output, 1935-60. (Source: USDA.)

consumers. In contrast to those who gain from greater demand for particular resources, are individuals and firms selling consumer goods to farm people. As the agricultural labor force declines, the farm population also declines. The nonfarm sectors in these communities thus often find the demand for their commodities and services declining.

While farm employment and population decreased for all regions (Table 2.15) but the Pacific from 1940 to 1960, the decline was more extreme in some regions. (Farm employment and population increased in the Pacific region up to 1940 but decreased after that.) The farm population and employment decline was most rapid in purely agricultural regions where greatest change took place in growth of farm size and in substitution of capital for labor. In these purely rural areas, total population declined along with farm population because there were fewer farm families to be serviced. Change in the pattern of resource demand in agriculture thus also causes change in demand for resources in related sectors. The extent of this adjustment is generally greater

Table 2.15. Percent Decrease in Farm Employment and Farm Population by Census Regions, 1920-60*

Region	Employment	Population
New England	48.7	31.8
South Atlantic	51.3	34.0
Middle Atlantic	50.0	22.2
E. North Central	36.4	24.4
W. North Central	37.2	38.7
E. South Central	58.6	33.8
W. South Central	26.5	51.4
Mountain	37.2	34.4
Pacific	+12.1	+15.6

*Agricultural Marketing Service, USDA.

in particular areas and counties than in states as a whole because some growing industrial areas can absorb displaced farm and farm-related population. Table 2.16 suggests the magnitude of some of these adjustments within states. States whose economies rest most on agriculture have a majority of counties with a decline in total population.

Both farm and nonfarm sectors in commercial farming communities geographically detached from industrializing urban centers have problems associated with economies of scale and the need to spread fixed costs over more production units. Capital prices which are low relative to labor price have caused farmers and other types of businesses and activity units in the rural community to become more mechanized. The situation is then the same as in farming: volume must be large if unit costs are to be sufficiently low for profitable operation. Hence, there is room for fewer businesses in the market of the trade area or community. Less labor and fewer families are required for the particular retailing or service sector of the farm community. This aspect of economic growth, the change in factor prices and technology to favor

Table 2.16. Number of Counties With Population Decrease and Increase, Selected States 1940-60

State	Number of Counties With: Decline in population	Increase of less than 10%	Increase of 10% or more
Colorado	35	6	22
Idaho	21	6	17
Illinois	51	16	35
Indiana	16	19	57
Iowa	61	22	16
Kansas	70	6	29
Michigan	13	13	57
Minnesota	41	20	26
Missouri	77	10	18
Montana	30	6	21
Nebraska	73	7	13
North Dakota	44	3	6
Ohio	12	9	67
Oklahoma	65	1	11
South Dakota	50	6	12
Texas	144	11	102
Utah	13	2	14
Washington	9	5	25
Wisconsin	34	10	27
Wyoming	10	3	11

substitution of capital for labor and consequent cost economies lead to larger and fewer units in most major phases of rural community life. It is reflected in grocery retailing as well as in farming. Grocery retailing now involves a large investment in capital equipment and labor-saving or self-serve devices. For a volume sufficiently large to provide low cost and some profit per unit, there is room for only one supermarket in many rural towns. In smaller towns, the traditional trade area contains too few consumers to support even one grocery store; at least with competitive returns to labor and management.[11]

These consequences of factor prices and scale economies which emerge at high levels of national economic development are repeated in all important economic and social sectors of rural areas even though they are separated geographically from the major growth industries. They "bite deeply" in rural communities because industrial development is lacking at rates to absorb the labor and families released in the more general substitution of capital for human effort. Because of the scale economies and the thinning of labor force and population, the boundaries of the rural trading areas must expand. This applies not only in the farm production and consumer retailing sectors, but also in sectors providing public and social services. Schools must be on a larger scale in respect to geographic coverage. Churches and other institutions similarly find it desirable to extend their bounds in rural communities. Together, these sum effects of economic development and structural change in agricultural and surrounding sectors of farming communities cause severe social and adjustment problems.

FARM FINANCIAL STRUCTURE

The changing pattern of agriculture not only changes the mix of specific resources used by farmers but also changes the fiscal and financial structure of agriculture. As pointed out previously, the substitution of capital items for land and labor increases the proportion of inputs which are purchased. Cash costs rise relative to sales. Because of declining gross returns, greater managerial skill and detail are required to meet cash expenses and costs for family living. The value of assets required per dollar of net income has increased also in the highly commercialized agriculture. Table 2.17 shows that value of assets per dollar of net income rose from \$4.73 in 1944 to \$11.54 in 1959, with the latter somewhat above the trend because of depressed income. In the same period cash expenditures as a percentage of cash farm income rose from 50.8 to 75.3. While management input is not easily quantified and expressed, it is certainly growing in relative importance in agricultural production. In assets used per worker, growth was from \$3,400 in 1939 to \$21,235 in 1960, an amount greater than for the

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[11] For the nation, scale in sales volume doubled per store and increased by 50 percent per worker from 1948 to 1958.

Table 2.17. Production Assets, Net Farm Income and Ratio of Assets to Net Income in the U.S. for Selected Years*

Year	Production Assets	Net Farm Income	Assets per Dollar of Net Income	Cash Expenditures as a Percent of Cash Farm Income
	mil. $	mil. $	$	percent
1944	61,933	13,080	4.73	50.8
1949	98,043	14,276	6.87	66.2
1954	121,842	14,223	8.26	68.5
1959	154,767	13,407	11.54	75.3

*USDA Outlook Charts, 1961.

average of U.S. manufacturing which increased from $5,300 in 1939 to $19,900 in 1960. In contrast, however, total capital of the agricultural industry rose by only 307 percent, against 341 percent for manufacturing industry in the period 1939-60. Yet it is still true that management is much less a specialized resource in agriculture than in many other industries which are less capital intensive but have broader opportunities in credit supply through equity financing and lower price of borrowed funds.

Table 2.18 depicts additional changes in the financial structure of

Table 2.18. Assets, Liabilities and Equity of U.S. Agriculture, 1930-60 (Current Dollars)*

Item	1930	1940	1950	1960
Total assets (bil. $)	68.4	53.0	130.8	202.9
Real estate (bil. $)	47.9	37.6	75.3	129.1
Percent of total assets	70	63	58	64
Nonreal estate physical (bil. $)	16.3	15.2	39.6	55.5
Percent of total assets	24	29	30	27
Financial (bil. $)	4.2	4.2	15.9	18.3
Percent of total assets	6	8	12	9
Total liabilities (bil. $)	14.6	10.0	12.5	24.1
Real estate debt (bil. $)	9.6	6.6	5.6	12.3
Percent of total debt	66	66	45	51
Nonreal estate debt (bil. $)	5.0	3.4	6.9	11.8
Percent of total debt	34	34	55	49
Proprietor's equity (bil. $)	53.8	43.0	118.3	178.8
Equity ratio (equity/liabilities)	3.4	4.3	9.5	7.4

*Economic report of the President. U.S. Government Printing Office. Washington. 1961. P. 208; and USDA Agr. Info. Bul. 247. 1961.

farming from 1930 to 1960. Estimates of assets, liabilities and equity are given in current dollars, hence inflationary trends in the data preclude comparisons in the real quantities over time. However, some comparisons among asset "quantities" within a given year are possible. The relative importance of real estate in the asset structure declined from 1930 to 1950, then increased in 1960. The increase may perhaps be explained by the tendency to capitalize into land values (a) residual returns from profitable inputs such as fertilizer and (b) economies of scale associated with farm mechanization. Trends in the value of real estate may also reflect growing competition among large numbers of potential beginning farmers for available farms. The rising importance of nonreal estate assets from 1930 to 1950 results primarily from the growing investment in farm machinery.

The real estate debt declined from two-thirds of total liabilities in 1930 to one-half in 1960 (Table 2.18). Because of large capital requirements for purchases of livestock, machinery, seed, fertilizer and other nonreal estate capital, a growing share of farm loans became of the short-term type.

The monetary value of farm liabilities rose appreciably from 1940 to 1960 (Table 2.18). The increase in the value of farm assets was much larger, however, and consequently the equity ratio (equity/liabilities) increased from 4.3 in 1940 to 7.4 in 1960. The rising equity ratio resulted from inflated values of farm assets and also from a decade of especially favorable farm incomes which enabled farmers to pay off mortgages and other debts in the 1940's. The equity ratio, as a measure of financial health, indicates that the credit structure of the farm industry by 1960 vastly improved over 1930 but became less favorable than in 1950.

INCOME EFFECTS

The foregoing analysis indicates major change in the resource organization and structure of agriculture over the past several decades, especially since 1940. Change of important magnitude has been made in the mix of resources used by the industry and in the quantity of particular factors employed. This change in use of resources has greatly increased the productivity and supply quantity of the industry. While the aggregate quantity of all inputs scarcely increased in the 1950's, output increased by 26 percent. Even with large-scale foreign surplus disposal and price support programs, with the latter backed up by mammoth public accumulation of stocks, farm prices and income were depressed during that time.

The exodus of labor has been large, with employment in agriculture declining by 43 percent between 1930 and 1960 and by 27 percent between 1950 and 1960. The decline in the farm population since 1910 has been large, and the population of agriculture as a percent of the national population declined from 34.9 in 1910 to 24.9 in 1930 and to 11.4 in 1960

(8.7 percent in 1960 by the new definition of the farm population). Similarly, the proportion of the total national income originating in agriculture was 16.3, 8.4 and 4.3 percent in 1910, 1935 and 1960, respectively. The rate of labor outflow was not enough to give earnings comparable with labor and other resources in nonfarm sectors. With an increase in purchased production factors and general inflation, farm expenses increased more rapidly than sales in the postwar period (Table 2.19).

Table 2.19. Average Annual Gross Income and Expenses of Agriculture; and per Farm and per Capita Incomes, 1941-60*

Years	Gross Farm Income	Production Expense	Net Income		Per Capita Farm Income		Per Capita Income of Nonfarm Population
			Amount	Percent of gross	From farming	All sources	
	bil. $	bil. $	bil. $	percent	$	$	$
1941-45	21.2	10.8	10.4	49	440	586	1,147
1946-50	32.7	17.6	15.1	47	649	840	1,464
1951-55	36.1	22.0	14.0	39	677	936	1,909
1956-60	36.5	24.7	11.8	32	652	959	2,247

*USDA Agricultural Statistics and Outlook Charts.

With farm output increasing more rapidly than food demand, income from farming has declined even in the presence of price supporting policies. Production expenses have absorbed a growing percentage of gross farm income, and per capita income has been maintained only through growth in off-farm employment by farm families. At the end of 1960, farm income per capita was about as low relative to nonfarm income as it was two decades before. The structural revolution characterized by the use of new resource forms and more capital did not relieve the income problems arising from the interrelated large commodity supply and low supply prices of land and labor for agricultural use.

Earnings of agricultural labor have been extremely low as indicated in Table 2.20. In 1958 and 1959, hourly earnings of factory workers were respectively $2.07 and $2.13. The average rate went up to $2.29 in 1960. In 1960 average annual farm income per worker was $2,056 as compared to an average annual wage for nonfarm workers of $4,727. Capital in the form of new technologies has moved into agriculture rapidly and increased the gross productivity of farm labor (see Table 2.6). Labor has declined rapidly but its input is so large relative to needs vis-a-vis the low short-run demand elasticity for farm commodities, that its return is meager.

The economic development of agriculture has, of course, contributed greatly to national and consumer welfare. As shown in Table 2.21, the real cost of food at the "farm gate" has declined greatly since 1940 — about two-thirds as measured against factory worker annual wage rates and by over one-third in the amount of inputs to produce a unit of output.

Table 2.20. Return per Hour of Labor by Types of Farm*

Type of Farm	Return per Hour of Labor 1958	Return per Hour of Labor 1959
Dairy farms		
Northeast	.79	.70
Eastern	.46	.16
Corn Belt farms		
Hog-dairy	1.02	1.22
Hog-beef raising	.65	.87
Hog-beef fattening	1.25	2.19
Cash grain	.73	.59
Poultry, New Jersey	-.12	-.13
Cotton farms		
Piedmont	.24	.49
Black Prairie, Texas	.13	.57
High Plains, Texas	1.89	2.60
Delta, small	.28	.25
Delta, large	.62	.98
Tobacco		
Kentucky	.56	.69
North Carolina	.45	.78
Wheat		
Spring (average)	.79	1.17
Winter (average)	1.88	1.85
Ranches		
Cattle (average)	.27	1.18
Sheep (average)	.15	1.17

*USDA Agricultural Statistics 1959. P. 489.

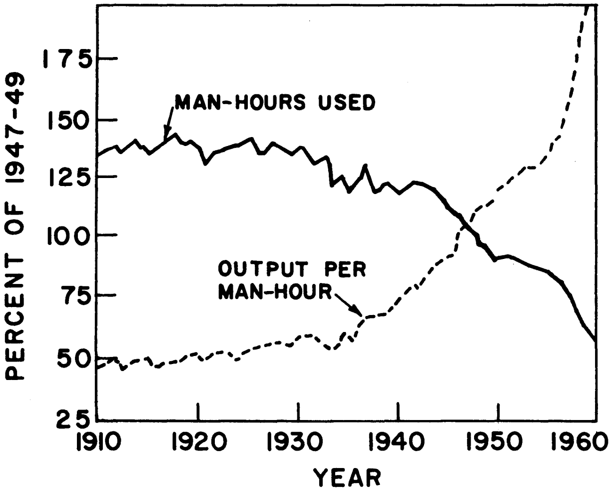

Figure 2.6. Index of man-hours worked in agriculture and output per man-hour (USDA Stat. Bul. 233).

Table 2.21. Index of Real Cost of Farm Products and Index of Input per Unit of Output, and Persons Supplied by One Farm Worker, U.S. 1910-60

Year	Real Cost of Farm Products*	Input per Unit of Output†	Persons Supplied per Farm Worker‡
	1910-14=100	1910-14=100	
1910	104	96	7.07
1920	85	87	8.27
1930	57	97	9.75
1940	43	86	10.69
1950	45	73	14.56
1960	28	59	26.21

*Index of factory wage rates relative to prices of farm commodities. The measure is in terms of food price at the "farm gate" and not at retail including processing services. Computed from USDA Agricultural Statistics.

†Index of input required per unit of output. Conditions of individual years cause figures to deviate from trend which is downward with certainty over the period. Computed from USDA Stat. Bul. 233. 1961.

‡From USDA. Changes in farm production and efficiency. Stat. Bul. 233. 1961.

Nearly four times as many persons were supplied by one farm worker in 1960 as in 1910. Hence, the consumer can allocate a smaller proportion of his budget to food and a greater proportion of the nation's resources can be allocated to more general economic development and to commodities of greatest marginal consumer urgency. The real gain from the change in the forms, mixes and structure of resources used in agriculture has been great for society as a whole.

The decline in the proportion of total consumer disposable income spent on food was not nearly as spectacular as the decline in what farmers received for their products. The proportion spent on food dropped approximately 1 percent during each of the decades from 1910-60 and stood at 20 percent by 1960. Consumers are spending an increasingly greater proportion of their food budget on processing and packaging services originating in the nonfarm sector. In 1960 the farmers' share of consumer food expenditures dropped to 39 percent. The income elasticity is relatively high for additional processing of food, consequently the processing and marketing industries for farm products have not experienced depressed returns similar to the farm sector. This fact is substantiated by the following estimates: for 1960 the average hourly earnings of farm workers was $.82 per hour, of workers in food marketing industries $2.14 per hour and of workers in factories $2.29 per hour. Hence the wage structure of nonfarm food industries is more nearly similar to other nonfarm industries than to agriculture.

Farm income per worker, as a percent of factory income per worker, was 63 in 1910, 38 in 1930, 52 in 1950 and 44 in 1960. If the gains in farming efficiency had been retained by farm workers (a suggested policy in industry labor-management negotiations according to national pronouncements), workers in agriculture would have been prosperous indeed. Although the market structure of agriculture dictates that gains in productivity be passed on to the consumer, Table 2.22 indicates that the current of economic development has not completely eluded farmers.

Table 2.22. Measures of Living Standards of Farmers, 1940 to 1960 (U.S. Average in 1945 = 100)*

Year	Level of Farm Living†					Real Farm Income‡
	North-east	North-central	South	West	U.S.	U.S.
1940	115	104	49	102	79	48
1945	138	128	65	127	100	100
1950	152	147	92	145	122	78
1956	169	165	119	167	145	74
1960	§	§	§	§	§	85

*Statistical Abstract of the U.S. 1961. P. 634; and USDA. The farm income situation. FIS-183. P. 38.

†Based on percent of farms with electricity, telephone and automobiles and on returns from products sold.

‡Index of average annual farm income per worker deflated by the index of prices paid by farmers for items used in family living.

§Not available.

Although it may be concluded that the relative farm income is low, Table 2.22 indicates that the absolute or real level of farm income improved markedly from 1940 to 1960. The level of living in the South was appreciably lower than in other regions throughout the entire period, but the differences among regions are declining. The region with the highest level of living in 1940, the Northeast, experienced the least increase, 47 percent, by 1956. The South, the region having the lowest standard of living in 1940, increased 143 percent by 1956, the greatest percentage increase among areas. For the entire United States, Table 2.22 indicates a continual increase in level of farm living as measured by the number of household conveniences and income. An alternative measure of real farm income, the net income per farm worker deflated by prices paid by farmers for items used in living, provides a less "optimistic" trend. The index of real farm income is considerably higher in 1960 than in 1940 but the general postwar trend has been downward. The higher value in 1960 than in 1956 indicates that this trend may be reversing, but it may not be possible to generalize from a single observation.

The aggregate measures of income do not reflect the gains that have existed for farmers able to change the quantity and form of their resources sufficiently to realize innovation gains. For the farm industry in aggregate, however, agricultural development with high supply elasticity and demand for some resources and low supply elasticity for other resources has caused relative price and income depression. Hence, it is important to analyze further the conditions of supply and demand which surround resources and give rise to this dilemma.

3.

Some Basic Theory of Resource Structure

WE HAVE examined changes taking place in the organization of resources and output in U.S. agriculture. Quantities and prices of factors and products are determined by parameters such as supply, demand and production elasticities in the resource structure. If we are to understand commodity supply and resource returns, we must know the conditions of resource demand and supply for the industry. The organization of the industry, in sizes and numbers of farms and in the amounts and proportions of resources used, rests heavily on resource demand and supply functions. This chapter will present some elementary but important theory of resource structure.

THE THEORY OF RESOURCE DEMAND

The static theory of the competitive firm is a useful starting point for construction of a structural model since: (a) in some respects agriculture is best represented by the purely competitive market structure, and (b) the firm is a logical beginning point for analysis of more general, dynamic market phenomena. We begin with the assumptions that the decision maker maximizes profits in an environment of known input/output and price ratios, instantaneous adjustments, divisibility of commodities (inputs or outputs) and unlimited capital. Furthermore, prices are given; individual decisions are assumed to have no influence on price under these competitive conditions.

For purposes of brevity and simplicity in presentation, we suppose that the factor demand and commodity supply functions for the industry are simply the summation of those for m firms. Hence, with X_{ik} being use of the i-th resource by the k-th firm and Y_k being the output of the k-th firm, we have the total employment of the i-th resource in (3.1) and the total output in (3.2).

$$X_i = \sum_{k=1}^{m} X_{ik} \quad (i = 1,2,\ldots n) \tag{3.1}$$

$$Y = \sum_{k=1}^{m} Y_k \tag{3.2}$$

We illustrate our discussion with factor demand conditions for the firm, but will not carry the subscript k. The static framework is an oversimplification of resource demand relationships for agriculture or any other industry. Space, however, restrains presentation of institutional and economic details relating to intricacies of supply and demand. Later in this chapter we summarize some elementary dynamic models, and in later empirical chapters we employ dynamic models which are major deviations from the simple ones presented in this chapter. These deviations are employed in an attempt at practical and realistic quantitative estimation of resource demand and supply relationships, in conformity with the time series observations available and limitations of regression models applied to these data. One of our ultimate interests is to measure the quantities defining the elasticity of demand of the i-th resource with respect to its own price and the cross elasticities of demand of this resource with respect to prices of the j-th factor and the product. Since these elasticities vary with time and the decision environment, they must be related eventually to dynamic models.

Profit Maximization and Resource Demand

The production function is (3.3) where $X_1, X_2, \ldots X_n$ are resources used in the production of output Y. From the production function, profit π can be defined in (3.4) as gross revenue, the magnitude of output Y multiplied by product price P_y, less the sum of costs. Costs are defined as the sum of resource prices P_i multiplied by resource quantities X_i.

$$Y = f(X_1, X_2, \ldots X_n) \tag{3.3}$$

$$\pi = f(X_1, X_2, \ldots X_n)P_y - \sum_{i=1}^{n} P_i X_i \tag{3.4}$$

Profit is maximized when all resources are used at levels such that their net marginal return is zero: use of more of the i-th resource would increase costs by a greater absolute amount than gross revenue. Hence, the conditions of profit maximization are defined in (3.5) by setting the partial derivatives of profit with respect to each resource equal to zero.[1] Alternative specifications of profit maximization, derived from equations (3.5), are presented in equations (3.6) to (3.9). Equation (3.6), found by shifting factor price P_i to the right side of equations (3.5), is the value of marginal product equated to factor price. If (3.6) is divided by product price P_y, the profit maximizing condition is defined as the marginal product equated to the inverse

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[1] Cf. Heady, Earl O. Economics of Agricultural Production and Resource Use. Prentice-Hall, Inc. New York. 1952. pp. 1-200.

price ratio (3.7). The ratio of (3.7) for two resources, X_i and X_j, gives (3.8), which is the marginal rate of substitution of resource X_j for X_i equated to the inverse price ratio of the two resources. Equation (3.9) is a generalization of equations (3.5) when n resources are used to produce product Z in addition to Y. In static equilibrium, the value of marginal product of each resource must equal its price. Furthermore, (3.9) indicates that the marginal value product of a given resource must be equal for any product Z as well as for Y. A departure from these conditions must necessarily reduce profits.

$$\frac{\partial \pi}{\partial X_1} = \frac{\partial Y}{\partial X_1} P_y - P_1 = 0 \tag{3.5a}$$

$$\frac{\partial \pi}{\partial X_2} = \frac{\partial Y}{\partial X_2} P_y - P_2 = 0 \tag{3.5b}$$

$$\vdots$$

$$\frac{\partial \pi}{\partial X_n} = \frac{\partial Y}{\partial X_n} P_y - P_n = 0 \tag{3.5c}$$

$$\frac{\partial Y}{\partial X_i} P_y = P_i \tag{3.6}$$

$$\frac{\partial Y}{\partial X_i} = \frac{P_i}{P_y} \tag{3.7}$$

$$-\frac{dX_i}{dX_j} = \frac{P_j}{P_i} \tag{3.8}$$

$$\left(\frac{\partial Y}{\partial X_1} P_y\right)/P_1 = \left(\frac{\partial Y}{\partial X_2} P_y\right)/P_2 \ldots = \left(\frac{\partial Z}{\partial X_1} P_z\right)/P_1 \tag{3.9}$$

$$= \left(\frac{\partial Z}{\partial X_2} P_z\right)/P_2 \ldots = \left(\frac{\partial Y}{\partial X_n} P_y\right)/P_n = 1$$

We have outlined the quantities which define the demand for resources where capital is unlimited. The magnitude of input of each factor depends on the technical coefficients in the production function (3.3) and the magnitude of prices for resources and products. Any change which increases the marginal rate of transformation of the i-th resource relative to the j-th resource, or to the product, will increase the demand for the first resource. A decrease in the price of the factor or an increase in the price of the product will increase the demand quantity of the factor, while an increase in resource price or decrease in product price will reduce the quantity.

In a static framework of perfect knowledge, capital would not be limited and the resource magnitudes, found by solving for X_i in (3.5), would specify the firm's demand for and use of resources. In agriculture the size of the farm in acres, as measured by a particular X_i, would be so specified. The amount and relative proportion of labor and capital, or particular capital items, would be similarly specified. However, without transition to dynamic and uncertainty models, we can specify the level of factor demand where capital is limited. (Presumably, capital is limited only under uncertainty.) Suppose that the firm has a given amount of funds, K, to spend on or invest in resources. Profit can be maximized and factors can be purchased or hired only under the restraint that total outlay does not exceed K. The profit equation then is redefined in (3.10) where λ is a Lagrange multiplier and the condition $\lambda(K - \sum_{i=1}^{n} P_i X_i)$ is used to restrain resource use so that expenditure does not exceed K. The magnitude of $\sum_{i=1}^{n} P_i X_i$ cannot exceed K, or the difference is set to equal zero, in the steps which follow. The partial derivatives of π with respect to X_i and λ for (3.10) are then set to equal zero as in (3.11).

$$(3.10) \qquad \pi = f(X_1, X_2, \ldots X_n)\, P_y - \sum_{i=1}^{n} P_i X_i + \lambda(K - \sum_{i=1}^{n} P_i X_i)$$

The equations in (3.11) are solved for the value of the X_i and λ. The magnitude of any resource quantity then depends on the technical relationships in production (3.3), the prices of factors P_i and P_j, the price of the product P_y, and on the amount of funds K, available for investment. Dividing (3.11a) by P_1 and transposing $1 + \lambda$ to the right side of the equation, (3.12a) is formed. Equations (3.12) indicate that maximum profit is obtained when the ratio of the value of marginal product to the resource price is equal to $1 + \lambda$ for all resources. The condition, summarized in equation (3.13), indicates that λ is the rate of return on resource expenditures. Comparing equations (3.9) and (3.13) it is apparent that when capital is unlimited the rate of return λ is zero. As K becomes smaller the value of λ rises. A decline in the price ratio $P_i P_y^{-1}$, which increases income and equity of the firm and allows a larger K either from owned assets or from a larger borrowing base, will affect the quantities and combination of resources used.

$$(3.11a) \qquad \frac{\partial \pi}{\partial X_1} = \frac{\partial Y}{\partial X_1} P_y - P_1 - \lambda P_1 = 0$$

$$(3.11b) \qquad \frac{\partial \pi}{\partial X_2} = \frac{\partial Y}{\partial X_2} P_y - P_2 - \lambda P_2 = 0$$

$$\vdots$$

$$(3.11c) \qquad \frac{\partial \pi}{\partial X_n} = \frac{\partial Y}{\partial X_n} P_y - P_n - \lambda P_n = 0$$

$$(3.12a)\qquad \left(\frac{\partial Y}{\partial X_1} P_y\right)/P_1 = 1 + \lambda$$

$$(3.12b)\qquad \left(\frac{\partial Y}{\partial X_2} P_y\right)/P_2 = 1 + \lambda$$

$$\vdots$$

$$(3.12c)\qquad \left(\frac{\partial Y}{\partial X_n} P_y\right)/P_n = 1 + \lambda$$

$$(3.13)\qquad \left(\frac{\partial Y}{\partial X_1} P_y\right)/P_1 = \left(\frac{\partial Y}{\partial X_2} P_y\right)/P_2 = \ldots \left(\frac{\partial Y}{\partial X_n} P_y\right)/P_n = 1 + \lambda$$

The above relations specify the first-order conditions required for profit-maximizing use of resources. In specifying the quantities of resources, output also is specified through the production function in (3.3). These conditions and relationships are directly important and relevant for the firm and the agricultural industry in respect to capital items of biological nature, such as fertilizer, seed and insecticides. The conditions also suggest the size and number of farms in the sense that X_i represents the land resource. For the individual firm, resources and organization are subject to considerable changes in the long run and it is relevant to specify second-order conditions for profit maximization. The second-order conditions are especially important for specifying the size of the firm and, hence, the number of firms in the industry, even though the industry is based on relatively fixed input of a resource such as land. Setting n = 2, to simplify the presentation, the second-order conditions require that the second partial derivative of profit with respect to inputs for (3.5) is negative and in general that the principal minors of the corresponding Hessian determinant alternate in sign:[2]

$$(3.14)\qquad \frac{\partial^2 \pi}{\partial X_1^2} < 0, \quad \text{and} \quad \begin{vmatrix} \dfrac{\partial^2 \pi}{\partial X_1^2} & \dfrac{\partial^2 \pi}{\partial X_1\, \partial X_2} \\ \dfrac{\partial^2 \pi}{\partial X_1\, \partial X_2} & \dfrac{\partial^2 \pi}{\partial X_2^2} \end{vmatrix} > 0$$

Expanding the second determinant of (3.14), we have:

$$(3.15)\qquad \frac{\partial^2 \pi}{\partial X_1^2}\frac{\partial^2 \pi}{\partial X_2^2} - \left(\frac{\partial^2 \pi}{\partial X_1\, \partial X_2}\right)^2 > 0$$

to guarantee that π, profit, is decreasing with use of more of any single factor.

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[2] For complete second-order conditions for profit maximization see Hicks, J. R. Value and Capital. Oxford University Press. London. 1946. p. 320.

First-order conditions such as those in (3.5) and second-order conditions such as those in (3.14) are expected to have particular relevance in respect to the agricultural firm. In the first place, capital typically is limited. The individual farm accumulates capital during its life and thus can extend the expenditure and investment restraint. Enlargement of the restraint, K, is, for most production functions, likely to cause resource proportions to change along with output as the capital amount, K, in (3.10), grows, even where product and factor prices remain constant and the existing technology prevails. The proportional use of factors will change as K is increased, as long as the isocline $X_i = f_{ij}(P_i^{-1} P_j , X_j)$ is not linear through the origin of the input plane.[3] In a period such as 1940-55 when farm savings and assets grew rapidly and lifted the effective magnitude of K, we would expect the proportions as well as magnitudes of resources to change, even in the absence of new technical knowledge and change in price relatives. The isocline is not linear through the origin for farm resources, and a major change in the combination of resources did take place in the postwar period. A part of this change undoubtedly stemmed from a lifting of the capital restraint. At the same time, of course, prices of factors were changing relative to each other, changing the proportions of factors (3.8). Similarly, with commodity prices generally rising relative to factor prices in the war and immediate postwar years, increased input of resources are expected through (3.7). If the rise in productivity of a factor, X_i, is sufficiently large, inputs of X_i may increase even in the face of rising factor price P_i. An increase in P_y relative to the P_i is expected to change the proportions in which resources are used, as well as their amount, as the general price ratio $P_i P_y^{-1}$ declines, so long as the isoclines are not linear. Equally important, technology or the production function has changed over time to alter the dX_i/dX_j, causing factors to be substituted for each other in a manner suggested elsewhere in this study. Decrease in the $P_i P_j^{-1}$ price ratio, through a decline in P_i, is expected to have two effects: a substitution effect, X_i replacing some X_j as suggested in (3.8) and an expansion effect, with the magnitude of $\Sigma P_i X_i$ in (3.10) being lowered relative to K and the values of the X_i for (3.11) being larger.

When the productivity of a given resource is influenced strongly by the level of a second resource, the second-order condition (3.14) is particularly relevant. Although $d\pi/dX_i = 0$ for a given type and stock of machinery and cropland on a particular farm, it may be possible to increase profit by increasing farm size. Larger machines, with great labor replacement capacity, have given rise to increased productivity and profitability of machine investment. These conditions can prevail, of course, only if land input is extended to allow realization of the improved productivity of larger machines. Despite the increase in land price, it has been necessary for farms to extend land input if the joint

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[3] Cf. Heady, Earl O., and Dillon, John L. Agricultural Production Functions. Iowa State University Press. Ames. 1961. Chaps. 1-4.

effect of greater use of machines and land is to be reflected and the conditions of (3.14) are to be approached or attained. Later empirical analysis shows that the demand for larger acreages to obtain cost economies is important in explaining the rise of land prices.

The Implicit Resource Demand Function

The demand functions for resources are found by solving the "equilibrium" equations (3.5) for X_i. The implicit demand function for the i-th resource (3.16) may be expressed as a function of the technical conditions of production, the factor/product price ratios and the level of fixed factors of production X_k.

$$X_i = f\left(\frac{P_i}{P_y}, \frac{P_j}{P_y}, X_k\right) \tag{3.16}$$

Prices, P_j, of <u>variable</u> resources are included in the demand function but quantities X_k of <u>fixed</u> inputs are included. Only prices or quantities of resources which interact with X_i are included in the demand function. The equations in (3.5) must be solved simultaneously for the X_i if interaction is present. If resources are independent in production, each equation (e.g., 3.6) can be solved individually for X_i and the resulting static demand function contains neither the price nor quantity of the unrelated j-th resource. With modifications for time lags and other real world conditions, (3.16) is the general basis for many of the empirical models of factor demand in this study.

It is generally agreed that farm commodity supply functions have low response to changing product prices in the short run, the response being lower in periods when commodity prices fall than when they rise.[4] Commodity supply response depends ultimately on factor quantities X_i; thus one reason for low commodity supply elasticity can be discussed in terms of equation (3.16). If X_i is supplied from nonfarm sources, factor price P_i is likely to be very stable and a rise in product price P_y would reduce the ratio P_i/P_y. Hence, X_i and output are reduced. But many factor prices are flexible in the short run and may have an imputed rather than a given, set price. The flexible price may be a function of product price, and consequently the two prices are highly correlated. The result tends to be a stable factor/product price ratio and input quantity despite changes in product price.

Small year-to-year variation in X_i or product could prevail where the prices of resources are flexible, with their movement being highly parallel or positively correlated with farm commodity prices.[5] Many factor prices are flexible in the short run. Examples are land and

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[4] Barker, R. L. The Response of Milk Production to Price: A Regional Analysis. Unpublished Ph.D. thesis. Library, Iowa State University. Ames. 1960.

[5] Heady, <u>op. cit.</u>, Chap. 23, and Johnson, D. Gale. The nature of the supply function for agricultural products. American Economic Review. 40:539-64. 1950.

buildings rented on a share basis and feed and livestock prices (with some lag related to the decision and production period). Resources or resource services with such flexible short-run prices are those which are produced, or have their origin, in the industry. Under these conditions, the commodity supply function can have high elasticity, but output will fluctuate little because of the conditions of factor pricing. But why are these factor prices so flexible? Generally because the supply functions, to be discussed later, of the resources themselves have low price elasticity.

Some controversy exists over the appropriateness of price ratios in empirical demand studies. Static theory (3.16) suggests the use of price ratios; dynamic economic theory raises doubts about the appropriateness of such forms. Farmers must make decisions of how much X_i to use on the basis of expected rather than actual product prices because of the length of the farm production period. The expected or normal price is a subjective estimate made by farmers on the basis of the permanent and transitory components of current and past prices. These components are of a different nature in output and input prices. It can be argued that the permanent component, the component upon which decisions tend to be based, is a much greater proportion of input price than of output price. When production plans are made, considerable uncertainty may exist about output price due to the time lag in production. Planning the level of use, purchasing and applying inputs are nearly concurrent acts, hence there need be little uncertainty about input prices. Also, the historic stability of input prices tends to create a large permanent component relative to the transitory component of input prices. The symmetric nature of price ratios implies that if output and input prices increase or decrease by the same proportion, the demand quantity remains unchanged. However, if farmers make decisions on the basis of the "permanent" component of price changes, a proportional increase in actual output and input prices could be expected to decrease the demand quantity since the permanent component of input prices is greater. For these reasons the use of price ratios in dynamic models does not appear justified in all cases.

Price ratios have certain advantages in statistical time series applications: (a) avoidance of errors from use of general price deflators (e.g., the wholesale price index), (b) reduction of multicollinearity and (c) increased degrees of freedom. Although use of price ratios is not strictly correct from a logical standpoint, the advantages may justify the use of ratios if the errors are not large. The results of empirical studies to date provide conflicting support for the hypothesis suggested by static theory that the price ratio is the decision variable used by farmers. The decision to use price ratios depends on the circumstances. If the sacrifice in higher intercorrelations, loss of degrees of freedom and errors from general deflators is considered less than forcing a symmetric response to input and output prices, the separate input and output price variables should be included in regression estimates.

Specific Forms of Resource Demand Functions

To provide a more specific model of resource demand variables and conditions, we now use a particular algebraic form. A Cobb-Douglas production function is selected for these illustrations, not since it typifies agriculture but because it minimizes space for presentation and algebraic manipulations.[6] Some conclusions drawn from it apply to other algebraic forms.

The production function of concern is (3.17) where the variables have the meaning specified earlier and n = 2. The corresponding marginal rate of substitution is (3.18) and the isocline equation derived from the latter is (3.19). (For the Cobb-Douglas function, the isocline is linear, the proportion of resources remaining fixed as more are used with a rise in P_y relative to the P_i and P_1 and P_2 remaining in fixed ratio. This condition does not necessarily prevail for other algebraic forms.)

$$Y = aX_1^{b_1} X_2^{b_2} \tag{3.17}$$

$$\frac{dX_1}{dX_2} = -\frac{b_2 X_1}{b_1 X_2} \tag{3.18}$$

$$X_1 = b_1 b_2^{-1} P_1^{-1} P_2 X_2 \tag{3.19}$$

With X_1 in (3.19) defined as a function of the technical coefficients, the prices of factors and X_2, the production function can be redefined as in (3.20). Since (3.19) defines the optimum or least-cost combination of the two resources, (3.20) defines output as a function of X_2 when resources are always so combined.[7]

$$Y = ab_1^{b_1} b_2^{-b_1} P_1^{-b_1} P_2^{b_1} X_2^{b_1+b_2} \tag{3.20}$$

Multiplying (3.20) by P_y, the price of product, to define the total value product, TVP, the marginal value product of the resource is defined as the derivative of TVP with respect to X_2 in (3.21).

$$\frac{d(TVP)}{dX_2} = (b_1 + b_2)\, ab_1^{b_1} b_2^{-b_1} P_1^{-b_1} P_2^{b_1} X_2^{b_1+b_2-1} P_y \tag{3.21}$$

Setting (3.21) to equal the factor price, P_2, to specify the profit maximizing use of the resource, and dividing both sides of the equation by P_2 and $X_2^{b_1+b_2-1}$, the static factor demand function is derived in (3.22). It specifies demand quantity for the resource as a function of the

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[6] Heady and Dillon, op. cit., Chaps. 2-4.

[7] The steps employed here to derive factor demand are convenient for a two-variable production function. While they could be repeated for more variables, a more appropriate approach might be to solve the equations in (3.5) simultaneously for X_i. Insert these expressions $f(P_i/P_y)$ into the production function to form the product supply function.

technical coefficients of production, the prices of the resources and the price of the product. In general, an increase in the price of the particular resource will lower its use. Increase in the price of the product will increase demand quantity for the resource. The demand function (3.23) for X_2 variable, X_1 fixed, is derived by equating the marginal product dY/dX_2 from (3.17) to the price ratio $P_2 P_y^{-1}$ and solving for X_2. Note that when X_1 is variable (3.22), the price ratio $P_1 P_y^{-1}$ is included, but when X_1 is fixed (3.23), the quantity is included in the demand function.

$$(3.22) \qquad X_2 = \left[(b_1 + b_2)\, a b_1^{b_1} b_2^{-b_1} P_1^{-b_1} P_2^{b_1-1} P_y\right]^{\frac{1}{1 - b_1 - b_2}}$$

$$(3.23) \qquad X_2 = (a b_2 X_1^{b_1} P_2^{-1} P_y)^{\frac{1}{1 - b_2}}$$

From the static resource demand function in (3.22), the elasticities in respect to price may be derived. The price elasticities of resource demand indicate the percentage change in use of the factor associated with a 1 percent change in a particular price.

$$(3.24) \qquad e_{2,2} = \frac{dX_2}{dP_2}\frac{P_2}{X_2} = \frac{b_1 - 1}{1 - b_1 - b_2}$$

The elasticity of demand for X_2 with respect to its own price, $e_{2,2}$ (3.24), is the derivative of (3.22) with respect to P_2 multiplied by the ratio $P_2 X_2^{-1}$.[8] For the Cobb-Douglas production function in (3.17), the elasticity is a constant. The magnitude of the elasticity depends only on the coefficients of production, not on prices, the quantity of product produced and the amounts of factors used. For other algebraic forms, however, the elasticity is influenced by the magnitude of prices, output and other resources.[9] The elasticity of demand with respect to the resource's own price is negative where b_1 and b_2 individually, and in sum, are less than unity. If technology changes so that the productivity of the particular factor increases, the demand elasticity of the factor also increases for the logarithm type of demand function.

The demand response for a particular factor relative to the price of other factors also is important in determining the rate and magnitude

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[8] The elasticity of X with respect to price P is defined as $\frac{dX}{dP} \cdot \frac{P}{X}$ or as $\frac{d(\log X)}{d(\log P)}$. The latter definition is useful for finding elasticities of Cobb-Douglas functions. For example, to compute $e_{2,2}$, simply take the log of (3.22), i.e. $\log X_2 = \log C + \frac{b_1 - 1}{1 - b_1 - b_2} \log P_2$. The elasticity is $\frac{d(\log X_2)}{d(\log P_2)} = \frac{b_1 - 1}{1 - b_1 - b_2}$.

[9] For example, see the elasticities derived in Chapter 6 for fertilizer production functions. For a comprehensive discussion of the influence of algebraic forms on demand and supply quantities and elasticities see Tweeten, Luther G., and Heady, Earl O. Short-run corn supply functions and fertilizer demand functions based on production functions derived from experimental data; a static analysis. Iowa Agr. Exp. Sta. Res. Bul. 507. 1962.

by which the structure of an industry changes. The cross elasticity of demand $e_{2,1}$, for X_2 in respect to price of competing resource P_1, and the cross elasticity $e_{2,y}$, with respect to product price P_y, are given respectively in (3.25) and (3.26), where the derivatives are from (3.22) and each is multiplied by the appropriate price/factor ratio.

$$e_{2,1} = \frac{dX_2}{dP_1}\frac{P_1}{X_2} = \frac{-b_1}{1 - b_1 - b_2} \tag{3.25}$$

$$e_{2,y} = \frac{dX_2}{dP_y}\frac{P_y}{X_2} = \frac{1}{1 - b_1 - b_2} \tag{3.26}$$

Relative Elasticities

As pointed out above, resource demand elasticities for all algebraic forms of production functions depend on the magnitudes of the technical coefficients. The resource demand elasticities computed from functions other than the Cobb-Douglas form also depend on the magnitude of factor and commodity prices and/or the amounts used of the particular resources. This point can be illustrated with the production function in (3.27).

$$Y = aX_1 + bX_2 - cX_1^2 - dX_2^2 \tag{3.27}$$

Following the steps in (3.17) through (3.22), we obtain the resource demand quantity for X_2 in (3.28).

$$X_2 = .5d^{-1}(b - P_2 P_y^{-1}) \tag{3.28}$$

Demand quantity is a function of technical coefficients of resources and of both factor and commodity prices. The corresponding elasticities of static demand for X_2 are given in (3.29) in respect to its own price, in (3.30) with respect to price of X_1 and in (3.31) with respect to commodity price.

$$e_{2,2} = \frac{1}{1 - b P_y P_2^{-1}} \tag{3.29}$$

$$e_{2,1} = 0 \tag{3.30}$$

$$e_{2,y} = -e_{2,2} \tag{3.31}$$

In general, the elasticity of demand for the resource declines as its own price P_2 decreases or as commodity price P_y increases. In comparing the two different functions in (3.17) and (3.27), the elasticity differs not only with magnitude of production coefficients for the latter but also with the form of production function characterizing each commodity.[10]

The elasticities for the Cobb-Douglas function in (3.17) and the quadratic form (3.27) show a uniformity. The cross elasticity of factor demand with respect to product price is equal numerically, with the sign changed, to the sum of elasticities of factor demand with respect to factor prices.[11] Thus, (3.31) is equal to the sum of (3.29) and (3.30) multiplied by -1. Also, for the Cobb-Douglas function, (3.26) is equal to the sum of (3.24) and (3.25) multiplied by -1.

This relationship stems from the fact that demand quantity for a resource is more exactly a function of the commodity/factor price ratio $P_y P_i^{-1}$. Regardless of the absolute magnitude of P_i or P_y, resource quantity will be identical for equal ratios. With the generalized demand function for resource X_1 in (3.32), the corresponding total derivative is (3.34), and the elasticity of demand with respect to commodity price is (3.35). The derivative and elasticity of demand for X_1 with respect to the price of the i-th variable factor are (3.36) and (3.37) respectively. The sum of the individual elasticities of X_1 with respect to all input prices P_i is equal to the elasticity of demand for X_1 with respect to the product price P_y (3.35), with sign reversed (equation 3.38).

$$X_1 = f\left(\frac{P_1}{P_y}, \frac{P_2}{P_y}, \dots \frac{P_n}{P_y}\right) \tag{3.32}$$

$$f_i' = \frac{\partial X_1}{\partial(P_i / P_y)} \tag{3.33}$$

$$\frac{dX_1}{dP_y} = - f_1' \frac{P_1}{P_y^2} - f_2' \frac{P_2}{P_y^2} - \dots - f_n' \frac{P_n}{P_y^2} = - \sum_{i=1}^{n} f_i' \frac{P_i}{P_y^2} \tag{3.34}$$

$$e_{1,y} = \frac{dX_1}{dP_y} \frac{P_y}{X_1} = - \sum_{i=1}^{n} \frac{f_i' P_i}{P_y X_1} \tag{3.35}$$

$$\frac{dX_1}{dP_i} = \frac{f_i'}{P_y} \tag{3.36}$$

$$e_{1,i} = \frac{dX_1}{dP_i} \frac{P_1}{X_i} = \frac{f_i'}{P_y} \frac{P_i}{X_1} \tag{3.37}$$

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[10] If an interaction term, e $X_1 X_2$, is included in (3.27), the demand elasticity $e_{2,2}$ in (3.29) becomes a function of the magnitude of X_1 as well as of prices and coefficients. See Tweeten and Heady, ibid.

[11] These statements about cross elasticity of factor demand with respect to product price apply, of course, only to resource demand functions "built from the ground up" from underlying production functions. This exact connection does not exist among elasticities estimated statistically from time series where the observations do not directly express exact functional relationships among technical quantities and price.

(3.38) $$\sum_{i=1}^{n} e_{1,i} = - e_{1,y}$$

(3.39) $$e_{1,1} = - e_{1,y}$$

If factors other than X_1 are fixed, (3.39) indicates that the elasticity of demand with respect to product and factor price are equal but opposite in sign. Assuming as in (3.32) that resource X_1 is used only in production of Y, a given percentage increase in the prices P_i of all variable and related resources has the same influence on the quantity demanded X_1 as an equal percentage decrease in product price P_y. A proportional change in all prices leaves X_1 unchanged; the static demand function is homogeneous of degree zero. Stated alternatively, the sum of the demand elasticities with respect to own-price, the price of competing resources and commodity price is zero. It follows that a given percentage change in commodity price likely will cause a greater change in resource demand quantity than will an equal percentage change in the price of any single resource in the static demand function.

Elasticity of Substitution

The elasticity of substitution of resource i for resource j is defined as the percentage change in X_i associated with a 1 percent change in X_j, and mathematically is expressed as $e_{i,j} = \frac{dX_i}{dX_j}\frac{X_j}{X_i}$. Equation (3.8) indicates that in equilibrium $-\frac{dX_i}{dX_j} = \frac{P_j}{P_i}$. Multiplying this expression by X_j/X_i, it is apparent that the ratio of expenditures on X_i and X_j is equal to the elasticity of substitutions, i.e., $- e_{i,j} = - \frac{dX_i}{dX_j}\frac{X_j}{X_i} = \frac{P_jX_j}{P_iX_i}$. Since $\frac{dX_i}{dX_j} = - \frac{\partial Y}{\partial X_j} / \frac{\partial Y}{\partial X_i}$, and defining the elasticity of production e_i as $\frac{\partial Y}{\partial X_i}\frac{X_i}{Y}$, it follows that in equilibrium $-\frac{e_j}{e_i} = - e_{i,j} = \frac{P_jX_j}{P_iX_i}$. The ratio of production elasticities is equal to the elasticity of substitution and ratio of expenditures. The result indicates that introduction of a new input j with a high production elasticity and low supply price is likely to change appreciably the resource mix as equilibrium amounts are approached. If the ratio of production elasticities e_j/e_i is greater than one, in equilibrium more will be spent on the new input j than on input i. In agriculture, technologically improved purchased inputs have tended to have a large production elasticity relative to resources originating in agriculture such as labor. The consequence has been a sizeable substitution of capital for labor and consequent reduction in the factor share of labor. From the Cobb-Douglas production function (3.17), the elasticity of substitution of X_1 for X_2 is the respective ratio of production elasticities, or $-(b_1/b_2)$.

PRODUCT SUPPLY AND ITS RELATION TO FACTOR DEMAND

Resource demand functions indicate the quantities of resources that will be used by the firm at given factor/product price ratios. The production function dictates how much product will be forthcoming, given the above demand quantities of resources. If the demand equation for X_2 (3.22) and a similar function for X_1 are substituted into the production function (3.17), the Cobb-Douglas supply equation (3.40) is formed. If X_1 is considered fixed and the demand equation (3.23) for X_2 is substituted into the production function, (3.41) is formed.

$$(3.40) \qquad Y = \left[a b_1^{b_1} b_2^{b_2} (P_y P_1^{-1})^{b_1} (P_y P_2^{-1})^{b_2} \right]^{\frac{1}{1 - b_1 - b_2}}$$

$$(3.41) \qquad Y = a\left[(ab_2)^{b_2} X_1^{b_1} (P_y P_2^{-1})^{b_2} \right]^{\frac{1}{1 - b_2}}$$

Supply function (3.40), as the demand function discussed earlier, is homogeneous of degree zero in prices. The elasticities of supply computed from (3.40) with respect to P_1, $e_{Y,1}$; P_2, $e_{Y,2}$; and P_y, $e_{Y,y}$ are equations (3.42), (3.43) and (3.44), respectively.

$$(3.42) \qquad e_{Y,1} = -\frac{b_1}{1 - b_1 - b_2}$$

$$(3.43) \qquad e_{Y,2} = -\frac{b_2}{1 - b_1 - b_2}$$

$$(3.44) \qquad e_{Y,y} = \frac{b_1 + b_2}{1 - b_1 - b_2}$$

The elasticity of supply with respect to P_y is equal to the negative sum of the elasticities with respect to factor prices.[12] An equal proportional increase in product price and decrease in factor prices leaves the supply quantity Y unchanged.

Since the supply quantity is a function of the input magnitude and the technology of the production function, one might anticipate an exact theoretic relation between input demand, product supply and the production function. Tweeten and Heady show that the elasticity of supply $e_{Y,y}$ is equal to the sum of the cross elasticities $e_{i,y}$ of inputs X_i with respect to output price P_y times the elasticity of production $e_{Y,i}$ as in (3.45).[13]

$$(3.45) \qquad e_{Y,y} = \sum_{i=1}^{n} e_{i,y}\, e_{Y,i}$$

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[12] For a general proof see Tweeten and Heady, ibid.

[13] Ibid.

It is therefore possible to express output supply elasticity from knowledge of the production and factor demand functions. Equation (3.45) can be made dynamic and can be used to express elasticities over various periods of time by placing time subscripts on the supply elasticity $e_{Y,y}$ and on the input demand elasticity $e_{i,y}$. The relationship indicated by (3.45) is apparent in the simple case when only one factor, X_i, is variable (3.46).

$$e_{Y,y} = \frac{dY}{dP_y} \cdot \frac{P_y}{Y} = \left(\frac{dX_i}{dP_y}\frac{P_y}{X_i}\right) \cdot \left(\frac{dY}{dX_i}\frac{X_i}{Y}\right) \tag{3.46}$$

$$e_{i,y} = \frac{dX_i}{dP_y} \cdot \frac{P_y}{X_i} = - \frac{dX_i}{dP_i} \cdot \frac{P_i}{X_i} = - e_{i,i} \tag{3.47}$$

When only X_i is variable, the cross elasticity of demand $e_{i,y}$ for X_i with respect to product price is equal to the negative elasticity of demand $e_{i,i}$ for X_i with respect to input price (3.47). It follows that when one factor is variable, the static elasticity of supply is equal numerically to the elasticity of demand multiplied by the elasticity of production (3.48).

$$e_{Y,y} = - e_{i,i} e_{Y,i} \tag{3.48}$$

If the firm is operating at the beginning of stage II (average product at a maximum), the elasticity of production is unitary ($e_{Y,i} = 1$) and the elasticity of product supply and factor demand numerically are equal but opposite in sign. As more X_i is used, the elasticity of production declines and the elasticity of supply is less than the elasticity of demand. As stage III (total product at a maximum) is approached, the elasticity of production approaches zero and the output supply elasticity $e_{Y,y}$ is very small relative to the factor demand elasticity $e_{i,i}$. A large percentage increase in factor or product price raises output very little when the increase occurs after input, output and relative prices $P_y P_i^{-1}$ already are very high. Since most production takes place in stage II, factor demand is expected to be more elastic than product supply.

The general relationship (3.45) may be verified in the specific example of the Cobb-Douglas production, cross-demand (3.26) and supply (3.44) elasticities. The production elasticities, b_1 and b_2, multiplied by the cross-input demand elasticities, $\frac{1}{1 - b_1 - b_2}$, do indeed equal the product supply elasticity in (3.49).

$$\frac{b_1 + b_2}{1 - (b_1 + b_2)} = b_1\left(\frac{1}{1 - b_1 - b_2}\right) + b_2\left(\frac{1}{1 - b_1 - b_2}\right) \tag{3.49}$$

If the firm is in equilibrium and the value of marginal product of the i-th factor is equal to its price (3.50), then the factor share F_i (3.51) is equal to the elasticity of production $e_{Y,i}$ (3.52). The value of marginal product from (3.50) is substituted for P_i in (3.51) and the result (3.52) indicates that in equilibrium the factor share is equal to the elasticity of production.

$$\frac{\partial Y}{\partial X_i} P_y = P_i \tag{3.50}$$

$$F_i = \frac{X_i P_i}{Y P_y} \tag{3.51}$$

$$F_i = \frac{X_i}{Y P_y} \left(\frac{\partial Y P_y}{\partial X_i}\right) = \frac{\partial Y}{\partial X_i} \frac{X_i}{Y} = e_{Y,i} \tag{3.52}$$

$$e_{Y,y} = \sum_{i=1}^{n} E_{i,y} F_i \tag{3.53}$$

The equilibrium assumption permits substitution of F_i for $e_{Y,i}$ in (3.45) to form (3.53). The elasticity of product supply is equal to the sum of the cross elasticities of demand multiplied by the factor shares for each resource.

RESOURCE SUPPLY AND ELASTICITY

The resource structure of an industry depends not only on the nature of factor demand functions but also on the nature of the supply functions for resources. Commodity supply functions may have high or low elasticity depending on the supply elasticity of the factors which are used in agricultural production. With low supply elasticity of factors we expect high commodity prices and favorable resource returns when commodity demand increases relative to commodity supply, but the opposite when commodity supply increases more rapidly than commodity demand. Hence, the particular quantities and mix of resources used, with their effect on the commodity supply function, can be completely specified only if we know the supply functions of resources. The importance of factor supply functions to the mix and return of resources in agriculture can be illustrated with a few examples.

Consider the example of a supply equation (3.54) for a resource, X_1, used in the production of output Y where P_1 is the input price and b is the input supply elasticity.

$$X_1 = a\, P_1^b \tag{3.54}$$

Assume the production function is the Cobb-Douglas type (3.55) where output Y is produced by input X_1 and d is the elasticity of production.

$$Y = c\, X_1^d \tag{3.55}$$

Solving for P_1 in (3.54) and X_1 in (3.55) and substituting these into the total cost equation (3.56), the total cost becomes a function of variable cost $P_1 X_1 = f(Y)$ and fixed cost C. The derivative of TC with respect to Y is equated to product price from the assumption of profit maximization. Solving for Y in terms of product price P_y, the supply function (3.57) is formed. The elasticity of supply, $e_{Y,y}$, is specified in (3.58).

$$TC = P_1 X_1 + C \tag{3.56}$$

$$Y = \left[a^{\frac{1}{b}} c^{\frac{1+b}{bd}} \frac{bd}{1+b} P_y \right]^{\frac{bd}{1+b-bd}} \tag{3.57}$$

$$e_{Y,y} = \frac{bd}{1+b-bd} \tag{3.58}$$

Several characteristics of the product supply elasticity are of interest. The two parameters which determine $e_{Y,y}$ are the input supply elasticity b and the production elasticity d. As the input supply elasticity b approaches zero, the product supply elasticity $e_{Y,y}$ also approaches zero. As the input supply elasticity becomes large and approaches infinity, the product supply elasticity becomes a function of the production elasticity d only and approaches $d/1-d$. A product supply equation (3.41), derived earlier without explicitly recognizing the input supply equation, provided the same estimate $d/1-d$ of $e_{Y,y}$. The common practice of assuming input prices are given is comparable to assuming that the input supply elasticities are infinite. But from the example (3.58), it is apparent that for a given production elasticity d, the output supply elasticity is an increasing function of the input supply elasticity b. Ceteris paribus, the greater the value of b, the greater the value of $e_{Y,y}$. With constant returns to scale ($d=1$), then $e_{Y,y} = b$, and the input and output supply elasticities are equal.

To further illustrate the impact of factor supply elasticity upon employment and resource returns, we employ the following highly simplified empirical industry example where we do not detail production relationships relating factors and commodities, and our functions are linear. In (3.59) we suppose the consumer or commodity demand function, where demand quantity is a function of certain exogenous variables and magnitudes summarized in the constant and the commodity price.

$$Y_d = 1500 - 50P_y \tag{3.59}$$

$$Y_s = -240 + 150P_y - 50P_x - 40P_z \tag{3.60}$$

(For simplicity, cross-demand elasticities with respect to other commodities are not considered.) The commodity supply function is (3.60).

Short-run supply quantity is, given the production relationships, a function of product price and prices for two factors, X and Z. The conforming demand functions for the two resources are (3.61) and (3.62).

$$X_d = 2000 - 900P_x + 150P_z + 20P_y \tag{3.61}$$

$$Z_d = 2500 + 200P_x - 250P_z + 10P_y \tag{3.62}$$

(The factor demand functions are assumed to depend, given prices, on the production function in transforming factors into product.)

$$X_s = -200 + 600P_x \tag{3.63}$$

$$Z_s = 1800 + 50P_z \tag{3.64}$$

The supply functions for factors are (3.63) and (3.64) where we suppose quantity supplied to the industry to vary only with own-price of the factor. (In this oversimplification which does not allow simultaneity of factor supply quantities, or of factor supply price or income and commodity demand, we might suppose X to be fertilizer or machinery and Z to be labor.) The resource supply elasticities, in respect to their own prices, are respectively (3.65) and (3.66), the latter being smallest relative to equilibrium quantities determined later.

$$e_x = 600P_x X_s^{-1} \tag{3.65}$$

$$e_z = 50P_z Z_s^{-1} \tag{3.66}$$

Now, letting Y be the equilibrium demand and supply quantity of the commodity, X be the equilibrium demand and supply quantity of the first factor and Z be the same quantity for the second factor, equilibrium quantities of the market are specified by the matrix equality in (3.67). Designating the coefficient matrix as A, the vector of market prices and quantities as Q and the vector of constants as K, the equilibrium quantities are defined in (3.68) where A^{-1} is the inverse of the coefficient matrix.

$$\begin{bmatrix} 1 & 50 & 0 & 0 & 0 & 0 \\ 1 & -150 & 0 & 50 & 0 & 40 \\ 0 & -20 & 1 & 900 & 0 & -150 \\ 0 & -10 & 0 & -200 & 1 & 250 \\ 0 & 0 & 1 & -600 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -50 \end{bmatrix} \begin{bmatrix} Y \\ P_y \\ X \\ P_x \\ Z \\ P_z \end{bmatrix} = \begin{bmatrix} 1500 \\ -240 \\ 2000 \\ 2500 \\ -200 \\ 1800 \end{bmatrix} \tag{3.67}$$

$$Q = A^{-1} K \tag{3.68}$$

The equilibrium quantities so computed from (3.68) are included in column 1 of Table 3.1. At equilibrium, the supply elasticity of X with respect to its own price is $e_x = 1.2$ while that for Z is $e_z = .1$.

Table 3.1. Equilibrium Quantities and Prices for Example

Quantity	First Equilibrium (1)	Second Equilibrium (2)	Third Equilibrium (3)	Fourth Equilibrium (4)
Y	1000	1130	923	1073
P_y	\$10.00	\$9.45	\$9.48	\$10.49
X	1000	1359	994	1005
P_x	\$2.00	\$2.60	\$1.99	\$2.01
Z	2000	1980	1999	2001
P_z	\$4.00	\$3.60	\$3.98	\$4.02

Commodity demand now grows to (3.69) because of population increase, commodity supply grows to (3.70) because of change in technology, and the resource demand equations change to (3.71) and (3.72).

$$Y_d = 1650 - 55P_y \tag{3.69}$$

$$Y_s = -300 + 187.5P_y - 62.5P_x - 50P_z \tag{3.70}$$

$$X_d = 3000 - 1017P_x + 200P_z + 30P_y \tag{3.71}$$

$$Z_d = 2400 + 150P_x - 264.7P_z + 15P_y \tag{3.72}$$

The new equilibrium quantities are those of the second column of Table 3.1. Input of X has grown and its price has increased to \$2.60. Input of Z has declined and its price has fallen to \$3.60. While input of X has increased by 36 percent, input of Z has declined by only 1 percent because its supply elasticity is extremely low.

To further emphasize the effect of factor supply elasticity on input quantity and resource price or returns, suppose that commodity demand declines from (3.59) to (3.73) while all other supply and demand functions in (3.60) through (3.64) remain unchanged.

$$Y_d = 1350 - 45P_y \tag{3.73}$$

The equilibrium quantities then are those in the third column of Table 3.1. The equilibrium input and price of X drop .6 and .5 percent respectively from those in column 1. The equilibrium input for Z drops by .05 percent, as compared to the first equilibrium. Because the supply elasticity for Z is low, a relatively large quantity of Z continues to be employed even though the factor has a "large" decline in price or returns. Alternatively, suppose that all other demand and supply functions remain unchanged, but that commodity demand increases from (3.59) to (3.69). The equilibrium inputs and resource prices are those of the fourth column in Table 3.1. The quantity of Z increases but little while the price (return) increases because supply elasticity is low for this resource. Input of X increases by a larger percentage, but its price increase is expected to be relatively small because it has a higher supply elasticity.

Our example with a series of distinct short-run functions has been simple, setting forth certain outcomes for static-oriented market relationships for a competitive industry. Yet, it illustrates some of the basic structural problems relating to resource structure and factor income in an industry such as agriculture which has similar characteristics. Adding conditions to convert the model to a dynamic one would only accentuate the differences between resources X and Z where the former has high supply elasticity and increases in marginal productivity relative to the latter.

Problems of overcapacity and low resource returns have roots in the nature of input supply functions and elasticities in agriculture. The process leading to overproduction and low returns on conventional farm resources can be described as follows: New inputs and improved conventional inputs representing advanced technology have a high marginal product (high marginal rate of substitution) relative to other conventional inputs. The new inputs often are supplied by nonfarm industries and the supply is highly elastic. Because the value of marginal product is high relative to input price and because input supply elasticity is large, the new inputs are introduced into agriculture at a rapid rate. Furthermore these technological inputs such as fertilizer and weed and insect sprays are easily introduced because they are divisible, do not require extremely large capital outlays and their adoption does not conflict with the value or institutional structure of farming. The rapid adoption results in increased farm output and depressed farm product prices and incomes. If the agricultural economy functioned perfectly, the depressed product prices would lower resource returns and cause conventional inputs to move into other industries until returns are equalized. But conventional farm inputs such as labor have a low supply elasticity because of values, institutions and training, and because of external factors such as national unemployment. Opportunities for supplies of farm real estate to move into nonfarm uses are extremely limited in the short run. The price may fall very far before large quantities of the resources leave agriculture, i.e. the supply elasticity is low.

For another major conventional farm resource, machinery, the supply is discrete or discontinuous and irreversible. When machinery quantities are moving into agriculture the supply elasticity is large, but when farm prices fall the machinery supply elasticity is low and essentially is governed by the rate of depreciation. The above conventional farm resources therefore tend to remain in agriculture during depressed periods, and accept low returns. The resulting cost-price squeeze may in some ways only enhance the difficulties. The late adopters of technologically improved inputs might be content to continue with old methods. But for the firm to survive in the face of falling incomes may require greater economies. Because the productivity of technologically improved inputs is great, the ratio of value of marginal product to input price may remain high despite a large drop in product price. The result is that perhaps the only way late adopters can raise income is to use more of the new inputs and consequently to increase output despite falling product prices. Those who have adopted new and improved inputs and techniques move only gradually to the profit maximizing level of use. The result is increased use of new inputs and rising output although prices received by farmers are falling. Because the supply of new inputs tends to be more price elastic than the supply of conventional inputs, the conventional inputs are unable to adjust to the influx of new inputs. Problems of low relative returns and overcapacity in agriculture result.

Because the farm labor supply elasticity is low relative to the rate at which commodity supply increases, labor has a lower imputed price than resources such as fertilizer, machinery and other items whose (a) supply elasticity is greater, (b) reservation price is high because of alternative uses in nonfarm sectors and (c) demand quantity increases even in a depressed industry. (Our simple example did not detail these interrelationships between economic sectors. Our quantitative estimates of later chapters attempt to do so, however.) In any case, our relatively simple example indicates the impact of factor supply elasticities on the quantities of resources used and their pricing or return. These parameters are equally important with those of resource demand functions in determining the resource structure of an industry such as agriculture.[14]

Resources Supplied by Nonfarm Industries

Because of the increasing importance in agriculture of inputs produced in other industries, and because of certain implications for empirical economic models of factor demand, it is desirable to discuss some characteristics of the supply function for nonfarm inputs.[15] The supply of nonfarm, nonhuman resources has been described as highly elastic in this chapter. Considerations which support this hypothesis might be summarized into the categories: (a) the historic input price-quantity relationships, (b) empirical studies of the cost structure of nonagricultural industries, (c) the type of competition among input-supplying firms, (d) the goals of these industries and (e) the relative importance of agricultural purchases in the sales of nonfarm firms.

The historic short-run stability of input prices gives some evidence that input supply is highly elastic. The fact that shifts in input demand due to weather and product price changes have not resulted in

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[14] For other relationships of supply and demand elasticities for factors relative to change in production technology and consumer demand, as these relate to factor inputs and returns, see Heady, Earl O., Agricultural Policy Under Economic Development. Iowa State University Press. Ames. 1962. Chaps. 5 and 11.

[15] The elasticity of input supply may dictate whether a single or simultaneous model of factor markets in agriculture is necessary.

appreciable input price changes implies a high input supply elasticity, at least in the short run.

Empirical studies of major nonfarm firms reveal nearly constant or slowly rising average and marginal cost curves. Because the short-run industry supply curve is the horizontal summation of firm marginal cost curves, industry supply is likely to be highly elastic. Further, competition among nonfarm suppliers of agricultural inputs tends to be less than perfect. The actions of suppliers are interdependent, and in such instances of oligopoly, emphasis is placed on nonprice competition. The result tends to be a stickiness of prices at various quantity levels due to fear of recrimination by other suppliers.

Some economists indicate that goals other than maximum total profit are important in business decisions.[16] These goals include securing public good will, earning a stable return on investment, a fixed margin on costs of production and other goals. Despite an increase in marginal cost at higher output, a firm may not increase price for fear of losing public good will. When agricultural demand for an input increases, a supplier concerned with earning a stable return on investment may find it possible to maintain this return by maintaining or possibly by decreasing price. The latter case could give rise to a negative (but high in absolute terms) supply elasticity. If the manufacturer desires a cost-plus markup, the tendency could be to increase the supply elasticity. For example, a fixed margin above the marginal cost results in a "supply curve" more elastic than the marginal cost curve.

Finally, the importance of agricultural purchases in the total sales of the input supplier may influence the magnitude of supply elasticity. If a manufacturer sells only a small portion of his output to agriculture, an increase in agricultural demand may allow him to supply the increased quantity with little impact on the firm's cost structure. The change in input demand may be almost unnoticed, and the result is likely to be a highly elastic input supply. Since many firms supplying inputs to agriculture also supply inputs to other economic sectors, the declining nature of agriculture relative to other industries tends to increase supply elasticity. On the other hand, nonfarm inputs are substituting for farm produced inputs. Use of nonfarm inputs is increasing relative to farm output, and is rising in absolute amounts. This tendency, along with increased specialization of manufacturers in producing farm inputs, tends to reduce supply elasticity.

It seems reasonable to conclude that the supply of nonfarm inputs is highly elastic. A distinction might be made between supply at the industry and farm levels. Assuming a constant or decreasing margin at high prices, the industry supply is less elastic than supply at the farm level.

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[16] Cf. Baumol, William. Business Behavior, Value and Growth. Macmillan and Company. New York. 1959.

Resources Supplied within Agriculture

The supply function for many farm resources is best described as (3.74) where the total supply is an aggregate of that from two sectors: from outside the industry, $f_N(P_i)$, and from inside the industry, $f_F(P_i)$.

$$X_i = f(P_i) = f_F(P_i) + f_N(P_i) \tag{3.74}$$

The total supply is a function of supplies from the two sectors because: (a) nonfarm supplies such as motor fuel, fertilizers, etc., are used to produce feed and livestock inventories — a complementary relationship, and (b) nonfarm supplies substitute for farm inputs, e.g., commercial fertilizer and farm manures or crop residues, tractor and horse power; commercial seeds and farm seeds. Furthermore machinery supply potential in a given period is composed of farm machinery inventories plus possible nonfarm purchases.

Resources supplied from outside agriculture have a higher supply elasticity than those furnished from within the industry. Despite the high supply elasticity of fertilizer, motor fuels and other inputs used to produce farm feed and livestock inventories, the input supply elasticity of feed and livestock resources is low in the short run. A long production period is required to increase inventories of breeding stock, and it is physically impossible to increase stocks of these resources rapidly in response to large price increases. Also the supply elasticity of intermediate farm resources such as livestock and feed is low because they are produced by farm resources such as real estate services with a very low supply elasticity.

Within restricted limits machinery and real estate services can be adjusted to price changes by inter-period shifts. In part, more services can be used next year and less this year. But an important part of machinery services, and almost entirely those of labor and buildings, are forthcoming at a constant rate in various years and little can be done, once they are fully employed, to squeeze more service out of them in a particular year. If these resources are highly specialized to agriculture, as labor skilled to farm production but little else, or steel forged into cultivators, their reservation price for use in agriculture is low because they have few alternative employment opportunities — or alternative opportunities provide low prices to the resources. A small amount of land can be furnished from the outside, but the major portion is furnished from within agriculture with low price elasticity and reservation price.

The implications of these different resource supply functions and their shifters can be illustrated as follows for a given period. Two sector supply functions exist for the resource measured by X_i. The supply function from the nonfarm sector is (3.75), the function for the farm sector is (3.76) and the total supply function of the resource to agriculture is (3.77) where P_x is price of resource (or service) for the period.

(3.75) $$X_n = bP_x - a$$

(3.76) $$X_f = 8bP_x - 4a$$

(3.77) $$X_t = 9bP_x - 5a$$

Corresponding elasticities of resource quantity in respect to own-price are given in (3.78) to (3.80).

(3.78) $$e_n = \frac{bP_x}{bP_x - a}$$

(3.79) $$e_f = \frac{bP_x}{bP_x - .5a}$$

(3.80) $$e_t = \frac{bP_x}{bP_x - (5/9)a}$$

While the supply elasticity is high for "outside" resources, it is low for "inside" resources and for resources in total.

An alternative view of the same phenomenon is the "pure" example of short-run resource supply functions in Figure 3.1. Disregarding the initial stock or supply of resources from inside agriculture, suppose that rs_1 is the supply function of resources from outside agriculture for a particular period. The resources may be machinery, buildings, breeding stock or similar durable items. The quantity purchased for the period is that indicated at q_1. These resources then, because they

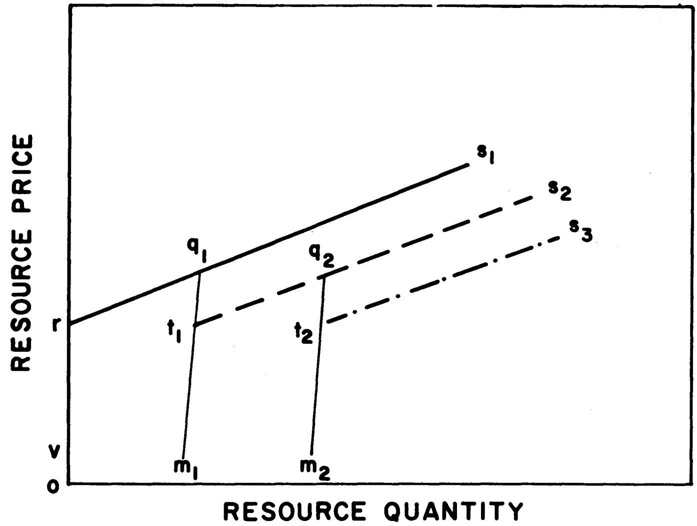

Figure 3.1. Resource supply functions from "outside" and "inside" sectors.

are specialized to farming, provide a "stock" of services within agriculture and their supply function becomes m_1q_1 for the next period.[17] Hence, even if "outside" resources were banned from agriculture in the next period, a supply of m_1q_1 would still exist. Consequently, the supply function of agricultural commodities will be the sum of these two factor supply functions. In expansion during the first period, the commodity supply function will have high elasticity, as does rs_1 for resources. But the commodity supply function in the second period is not also reversible from q_1 to r. Instead, it follows m_1q_2. In a second period where economic conditions encourage further expansion in resources used, the resource supply function becomes $m_1t_1s_2$. If the resource is used at the level q_2 in the second period, the "inside" resources provide the supply function m_2q_2 in the second period. The third period supply function is the sum of m_2q_2 and t_1s_2 and is $m_2t_2s_3$. But m_2q_2 supply will exist even if no resources are purchased from "outside" agriculture. Because the short-run resource supply functions are not reversible after particular resources are added to agriculture, the commodity supply functions similarly are not reversible. Consequently important differences will prevail between short-run and long-run commodity supply elasticities as well as factor supply elasticities.

INDUSTRY SUPPLY, DEMAND, INTERDEPENDENCE AND CAUSALITY

Economic theory of the competitive industry introduces additional concepts which must be considered in any empirical estimation of the resource structure. For a small segment of agriculture, the price of nonfarm inputs may be assumed as given or exogenous in the input demand functions. That is, the actions of a small group of farmers have little influence on the prices of resources supplied by the nonfarm sector, and input supply is perfectly elastic. The action of one farmer or a small group of farmers also has little influence on the prices they receive for farm products. Thus, prices may be assumed exogenous, i.e., determined by forces outside the system being examined. Only farm output and resource inputs are endogenous (determined within the system), and the quantity of any input may be estimated as a monocausal function of prices and fixed factor levels as in demand equation (3.16). Also, the supply of farm products from a small group of farmers may be considered a simple function of prices and other exogenous variables.

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[17] Figure 3.1 has meaning only for durable resources. The assumption is that depreciation is negligible. If depreciation is sizeable, a portion of m_1q_1 would be to the left of that indicated in Figure 3.1. For resources such as fertilizer or seed which have a high "depreciation," m_1q_1 would move to the vertical axis and rs_1 would again be the supply curve for the second period. The irreversibility of the supply curve depends on the extent of durability in resources.

The most general model of industry supply and demand is the Walrasian general equilibrium system. According to the Walrasian system, prices and quantities of commodities are determined interdependently by a system of demand and supply equations. The complete Walrasian system includes demand and supply functions in the entire economy. Even if the simultaneous system is considered pertinent, empirical models necessarily must abstract from the more remote markets in the entire economy and must emphasize the markets for agricultural inputs and outputs.

The type of economic (and statistical) model chosen to represent the market structure of agriculture depends strongly on the underlying causal framework. A direct relationship exists between the nature of causality specified in the economic model and the type of statistical model chosen to estimate the parameters. For present purposes we avoid an extended discussion of the ontological aspects of causality. Rather we consider only the immediate, pragmatic aspects of causality and emphasize those considerations necessary in constructing economic models.

The static equilibrium models of Walras, Marshall and others stress the interdependence of supply and demand in determining equilibrium price and quantity. The early econometric analysis of supply and demand from time series, however, assumed a monocausal relationship. That is, price (or quantity) was chosen as the dependent (effect) variable, and was considered a function of the quantity (or price) and other independent (causal) variables. Econometricians such as H. Schultz and Working were uncomfortable with this simple cause-effect relationship.[18] They realized that only under certain conditions could the structural demand or supply function be identified using the single equation, least-squares statistical model. This led to the development of statistical procedures which allowed for the simultaneous determination of price and quantity by supply and demand, and thus for the identification of structural economic relationships in an interdependent system.[19]

The new statistical techniques satisfied the basic premise of interdependence derived from static economic theory, and economists hailed the new methods as a greatly improved tool for analyzing supply and demand. Possibly due to the computational burden and other shortcomings of the newly developed statistical techniques, economists began to re-examine the adequacy of least-squares single equations.[20] The

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[18] Schultz, Henry. The Theory and Measurement of Demand. The University of Chicago Press. Chicago. 1938. pp. 72-114; and Working, E. J. What do statistical "demand curves" show? Quarterly Journal of Economics. 41:212-35. 1927.

[19] Cf. Haavelmo, Trygve. The statistical implications of a system of simultaneous equations. Econometrica. 11:1-12. 1943.

[20] Bentzel, R., and Hansen, B. On recursiveness and interdependency in economic models. Review of Economic Studies. 22:153-68. 1954-55; Bentzel, R., and Wold, H. On statistical demand analysis from the viewpoint of simultaneous equations. Skandinavisk Aktuarietidskrift. 29:95-114. 1946; Fox, Karl A. Econometric Analysis for Public Policy. Iowa State University Press. Ames. 1958.

nature of the causal structure underlying economic variables in the real world was the fundamental point in the re-examination. In particular, the Stockholm school questioned the basic premise of simultaneity in dynamic economics. The fact that decisions take time led them to conclude that economic decisions are not made simultaneously. Instead, they conceive of the recursive model as the most fundamental at an abstract level of economic theory. The recursive model is composed of a sequence of causal relationships.[21] The values of economic variables during a given period are determined by equations in terms of values already calculated, including the initial values of the system.

Much intuitive appeal lies in the disequilibrium nature of the recursive system. For example, in agriculture it seems logical that the current supply quantity often is determined by past price, and the current year price is a function of the predetermined current quantity. Commodity cycles, conceptualized in this type of recursive system — the cobweb model — give strong support for the disequilibrium model in agriculture.[22] Simultaneous equations that include only current price and quantity are dynamic equilibrium models, and may not be appropriate where production is predetermined and cycles are apparent. The conclusion is that if the economic model is sufficiently detailed and adequately specified, and if the time period is sufficiently short, the recursive model may be appropriate.

Surprisingly, the real basis for interdependent models does not seem to arise from the static economic equilibrium models of Walras et al., but from the exigencies of empirical data. One example is aggregation of data over time. Suppose that A determines B, B determines C, and C determines D through time. If A is aggregated with C, and B with D, then a joint "causal" relationship exists between the aggregate A C and B D.

SIMPLE DYNAMIC MODELS

Resource employment in agriculture does not respond immediately to changes in factor prices and technical coefficients. Even where quantities do change, the extent of short-run response is seldom consistent with the magnitude of change in price and production coefficients. Several years pass before the industry adjusts fully to a new set of price relatives or marginal resource productivities. There are many reasons why this is true. Time itself and the durability of resources help to prevent it. Farmers do not discard a building, machines and power units as soon as more efficient ones are developed,

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[21] There may be more than one endogenous (jointly determined within the system of equations) variable in a recursive equation. The matrix of coefficients of endogenous variables must be triangular, however.

[22] For an example of an industry strongly characterized by cobweb-type cycles see Tweeten, Luther G. Variability in Broomcorn Prices and Land Use Adjustments in Southcentral Oklahoma. Unpublished M.S. thesis. Library, Oklahoma State University. Stillwater. 1958.

partly because those already employed have further use, and especially because the supply elasticity and price of those already in use merit their employment as substitutes for the new items. Capital limitations, as these revolve around time and uncertainty, also prevent immediate adoption of new input forms where large new investments are required. The existence of uncertainty also discourages "immediate adoption" where the return on a durable resource purchased in the current period depends on product prices and productivities (weather, technology) in future periods. To varying degrees, farmers wait for more information to better predict the outcome of a new technology and price trends. Many resources are fixed to the firm and complement another resource which emerges as a new technology. Consequently, use of the new capital form awaits sufficient depreciation of the "fixed" resources (actually resources with low reservation prices and low supply elasticity to agriculture). While new feed handling or livestock equipment may be productive, full investment in and use of it may await depreciation of an old barn and investment in a new one. The input of one resource will generally affect productivity of others. Hence, as the "fixity" of some durable resources is relaxed, demand will grow for other resources.

The process of acquiring knowledge gives rise to lagged response for agriculture in aggregate as it responds to changes in prices and production coefficients. On an aggregate basis, farmers undoubtedly acquire knowledge or form expectations in a manner described by a logistic curve: A few with proper knowledge and favorable expectations react immediately, but the process picks up speed with increasing and "chain reaction" contacts among farmers. Eventually, the rate of change slows as the majority of farmers have adopted the resource or practice and the remaining farmers adopt the resource slowly and reluctantly. Too, the uncertainty in expectations of an individual farmer causes him to use only a small amount of some new resources (or resources with lowered prices) in a first period. He may use slightly more in a second period, then move towards a profit maximizing quantity in a later period. The purely psychological resistance to change affects the time path of adjustment to new stimuli. Institutional arrangements in farm size, tenure and contract arrangements and other customs also alter the time path describing response in inputs and outputs to changes in technical and economic variables. Decisions in agriculture also are complicated by the fact that specific investment decisions are made at many points in time, and each investment affects the productivity of past, current and future investments.

These considerations and others cause a distributed lag in adjustment of resource purchases to changes in price, technical coefficients, knowledge and other variables in the economic environment. They cause the response elasticity to be greater in the long run than in the short run.

Adjustments in use or demand for particular resources may follow numerous adjustment paths. Some alternatives are illustrated in

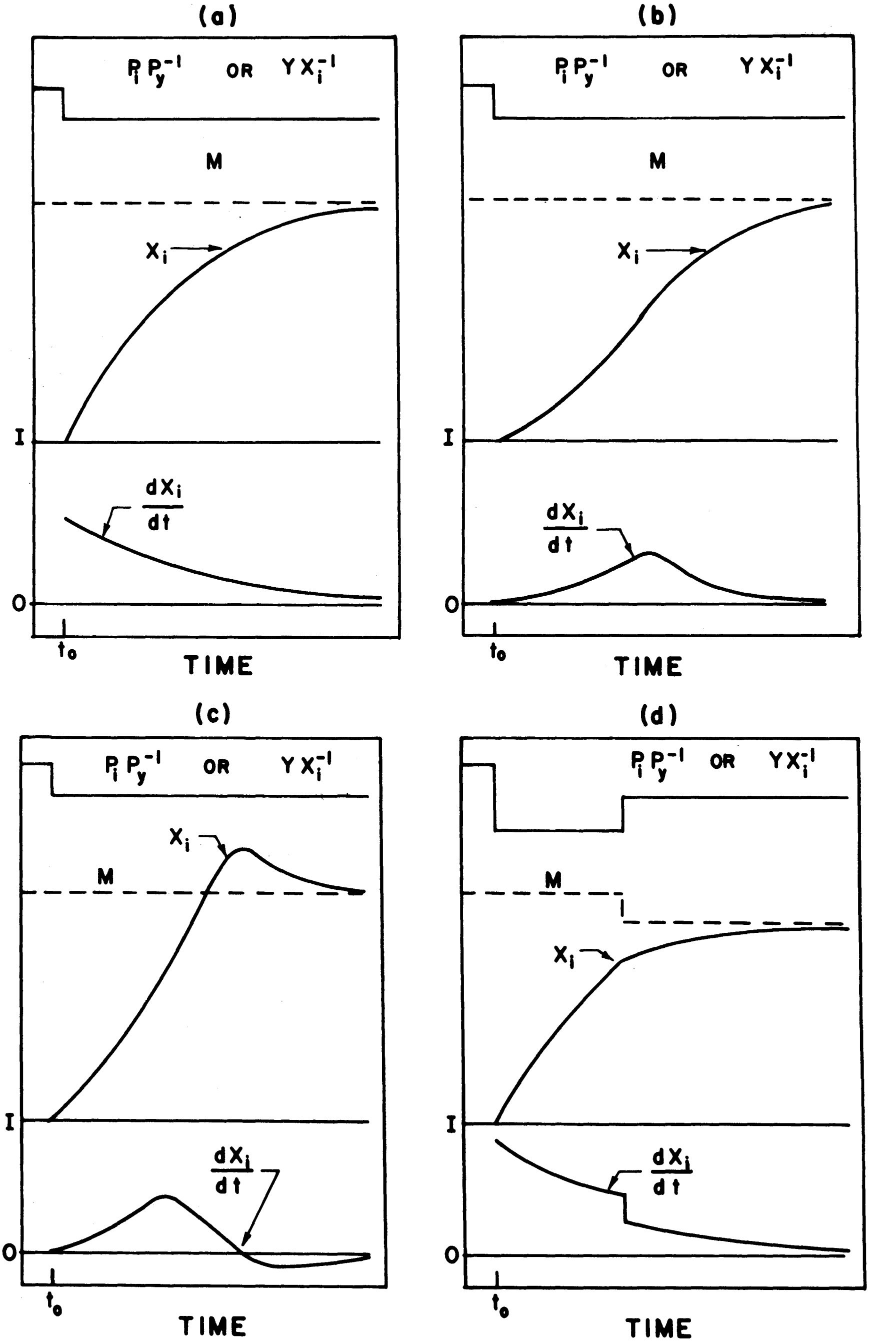

Figure 3.2. Some alternative adjustment rates and time paths in resource demand.

Figure 3.2 which includes four quantities: (a) the magnitude of the factor/product price ratio, $P_i P_y^{-1}$, or the magnitude of the output/input coefficient, YX^{-1}, (b) the optimum level, M, of resource use under the new price or technology, (c) the quantity of the resource used, X_i, and the change in resource use relative to time, $\frac{dX_i}{dt}$. For purposes of generality, we suppose changes in X_i and $\frac{dX_i}{dt}$ to be continuous, although we lift this assumption in later discussion to emphasize realistic conditions for agriculture. We suppose that X_i is at an initial equilibrium level at time, t_o, but that the new equilibrium level, M, exists as price and technical coefficients change. Following Koyck, the X_i curve is the adjustment path and $\frac{dX_i}{dt}$ is the time shape of the reaction of X_i to $P_i P_y^{-1}$ or YX_i^{-1}.[23] Graph (a) illustrates the type of adjustment an individual firm might make, due to the numerous restraints mentioned above, to a reduction in factor price or the input/output ratio or an increase in product price. (The adjustment for the firm would be discrete movements for a resource represented by separate units such as a tractor or building and for fertilizer where the production period is discrete, but would represent a "smooth curve" for the industry.) With the price or technical change taking place at time t_o, a new optimum or profit maximizing quantity of the resource comes about and is represented by line M. The firm, however, does not adjust input immediately to this level, but gradually approaches it with time. As illustrated by $\frac{dX_i}{dt}$, the rate of change slows down with the passage of time. Alternatively, the firm may adjust as illustrated in graph (b). Here the rate of adjustment speeds up initially due to increased knowledge, lessening of "fixed factor" restraints and others. After reaching a peak, the rate of adjustment slackens and approaches zero as use of the resource approaches the optimum level. While graph (a) might represent the adjustment path for the firm, graph (b) may represent the corresponding path for the industry. This would be the case where a "chain reaction" exists in adoption of a new practice: the rate picks up as more "neighbors" are contacted, but declines as there are fewer remaining farmers who have not adopted the practice.

Graph (c) illustrates a possible outcome as farmers overestimate the productivity of a practice relative to prices, or the realized magnitude of $P_y P_i^{-1}$. Investment exceeds the optimum level in a short time period, then declines towards the profit maximizing level after improved knowledge is acquired. (Graph [c] also may depict the outcome for a resource with zealous salesmen.) While elasticity of expectations is not discussed, graph (c) might relate to particular elasticities of expectations attached to the initial change. Graph (d) suggests the break in the adjustment path as the price or technical effect is first extremely

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[23] Cf. Koyck, L. M. Distributed Lags and Investment Analysis. North-Holland Publishing Co. Amsterdam. 1954. Chap. 2.

favorable; then becomes less favorable, but still remains at levels above that at t_0. The X_i curve in graph (c) also might describe the path of adjustment when the factor price or output/input coefficient first declines, then rises to a level more favorable than at the outset.

These few illustrations suggest the many different time patterns resource adjustment might take. It is fortunate for a geographically dispersed industry such as agriculture that the distributed lag pattern is followed. With an instantaneous change in resource demand as implied in equations (3.22) and (3.23), a tremendous social and economic shock and uprooting would take place. Labor and families would be displaced from agriculture more rapidly than could be absorbed by communities and employment opportunities. This statement means not at all that magnitudes of prices and technical coefficients are unimportant in resource demand, but only that some period of time, depending on the resource and its period of production, are required before adjustment to these various stimuli approach their limit in effect and change. Of course, the time paths in Figure 3.2 best explain the adjustments when the discrete change in coefficients is expected to endure. Where coefficients are subject to repeated change and great uncertainty is attached to their values, full adjustment is even less likely because of strategies adopted to meet risk. Too, precautions to meet uncertainty give rise to patterns and discounts in adjustment which depart from those illustrated in Figure 3.2.

Algebraic Examples

Lag in adjustment to price and technical coefficients, or even to institutional and other variables affecting resource demand, will be distributed in various algebraic forms. Suppose that the demand function of a resource is the general equation (3.81) where P can be taken as a resource price, although it also can refer to other variables of the demand function. The magnitude of resource use in the current time period is X_t and is a function of resource price in the current period, P_t; in the previous year, P_{t-1}; and in general the i-th previous period, P_{t-i}.

$$(3.81) \qquad X_t = f(P_t, P_{t-1}, \ldots P_{t-i}, \ldots P_{t-n})$$

Linear in original observations, or in logarithmic transformation, the distributed lag function can be written as

$$(3.82) \qquad X_t = a_0P_t + a_1P_{t-1} + a_2P_{t-2} + \ldots + a_iP_{t-i} \ldots$$

$$+ a_nP_{t-n} = \sum_{i=0}^{n} a_iP_{t-i}$$

where the a_i (the $\frac{dX_i}{dt}$ values in Figure 3.2 if we consider continuous changes in X), are the extent of change in X_t associated with each P_{t-i}, and initial equilibrium is disturbed as P changes to a new but constant level after a disturbance. In other words, X_t is the sum of adjustments occurring in the current year, the previous year, through t-n year. The series Σa_i in (3.82) converges as X approaches equilibrium level, with a_n approaching the limit zero when n becomes large (or $a_n \rightarrow 0$ as $n \rightarrow \infty$ and the value of P remains constant after an initial change.

As pointed out previously, the adjustment to a rise in the factor/product price ratio may be quite different from a decline. This condition prevails particularly for multiperiod resources such as machines, buildings and breeding stock. Suppose that a_i is the reaction coefficient for a ratio decline in $P_i P_y^{-1}$, and b_i is the reaction coefficient for a rise in $P_i P_y^{-1}$ and that $a_i = b_i$. Then the adjustment path or curve, X_t, will be symmetric and reversible: a given decrease in $P_i P_y^{-1}$ will cause the same absolute change in X_t in a subsequent period as would the same rise in $P_i P_y^{-1}$. This condition is very unlikely for agricultural resources, even those such as fertilizer and new seeds. It is possible for the inequality $a_i \neq b_i$ to prevail but still for $\Sigma a_i = \Sigma b_i$. In this case, the adjustment path or curve of X is asymmetric but reversible. If, however, $a_i \neq b_i$ and $\Sigma a_i \neq \Sigma b_i$, the X_t curve or adjustment path is asymmetric and irreversible. The condition of asymmetry and irreversibility does not mean that a reversal of $P_i P_y^{-1}$ will not cause an opposite change in the value of X_t, but only that the declining phase of the adjustment path will not be a "mirror image" of the rising phase. Figure 3.3a provides an example. Starting from the initial level I, the resource quantity X_i increases over time with a lag

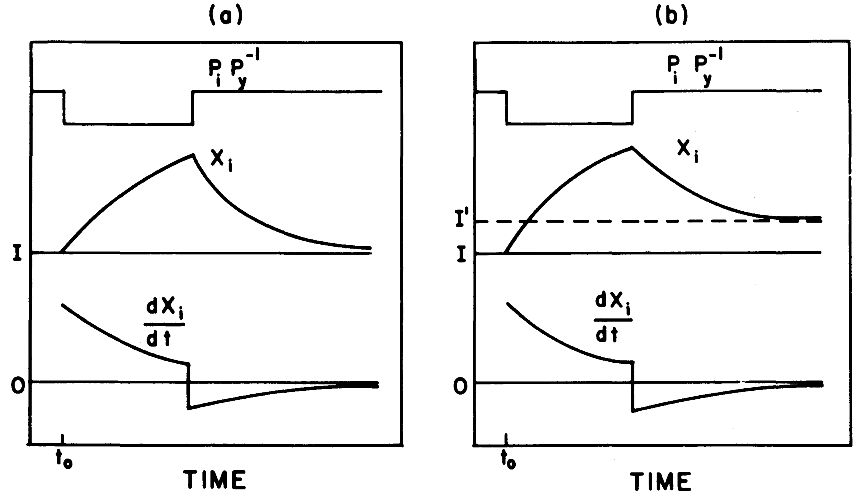

Figure 3.3. Asymmetric and irreversible adjustment paths in resource demand.

in response to an initial decline in $P_i P_y^{-1}$. However, an absolute increase in $P_i P_y^{-1}$ of the same magnitude gives a slower decline in X_i, because it is a multiperiod resource, must be used with other resources with longer lives and is restricted by custom or institutions. The case characterizing many resources of agriculture is that of Figure 3.3b. While the initial level of X_i is I, resource input does not converge towards this level, but is I′ after $P_i P_y^{-1}$ first falls then rises. Its failure to fall to I results from the reasons enumerated earlier, or because other variables such as knowledge, complementary resources or psychological restraints are changed. As outlined earlier, this type of irreversibility causes the commodity supply to have low elasticity and to remain greater during a period of rise in $P_i P_y^{-1}$ than during a period of decline in the ratio.

The adjustment paths and time shape for resource use in Figures 3.2 and 3.3 suggest that the elasticity of demand will change among production and investment periods. The elasticity in reaction or adjustment of X_i with respect to the price ratio $P_i P_y^{-1}$ will have the value over the first period in (3.83) and over the first and second periods in (3.84). These are short-run elasticities.

$$e_1 = a_0 P_i P_y^{-1} X_i^{-1} \tag{3.83}$$

$$e_2 = (a_0 + a_1) P_i P_y^{-1} X_i^{-1} \tag{3.84}$$

The long-run elasticity is (3.85). (Tinbergen restricted short run to refer to the elasticity in [3.83] and the long run to that of [3.85].)[24]

$$e_L = (a_0 + a_1 + \ldots + a_\infty) P_i P_y^{-1} X_i^{-1} \tag{3.85}$$

Obviously, then the relative elasticity or reaction in demand for a factor relative to prices and other variables can differ greatly between short-run and long-run periods.

The analysis above does not link the prices on which plans are made for one period with prices of other periods. Instead the time aspects are reflected in the physical, psychological and institutional factors which link outputs of different periods. In farming particularly, the prices among periods are themselves linked, not only in the structure of the economy, but also in the expectations of farmers.[25] Viewed in alternative fashion, we can compare short-run and long-run adjustment and elasticity coefficients for particular resource demand functions. We can attempt to link prices on which plans are based and prices of other periods. In the preceding figures and equations, changes in price were assumed to be known and permanent. (This assumption also was

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[24] Tinbergen, Jan. Long-term foreign trade elasticities. Metroeconomica. Vol. 1. 1954. pp. 20-31.

[25] For example, see Heady, Earl O. Economics of Agricultural Production and Resource Use. Prentice-Hall. New York. 1952. pp. 475-95. Some of the simple models presented here are perhaps more widely used than those discussed later in the book.

implied in the classical static demand analysis presented earlier.) But in dynamic models it is necessary to search for the price expectations which are relevant to resource demand quantities. One concept in relevant price is that of expected normal price.[26] Here we will concern ourselves with factor/product price ratios and let $R = P_i P_y^{-1}$ be the actual price ratio where we designate it as R_t, R_{t-1}, ... for the current period, the preceding period, etc. The average or long-run expected normal price level is designated as $\overline{R}$. As one alternative, the expected normal price of the current period, $\overline{R}_t$, may then be related to the expected normal price, $\overline{R}_{t-1}$, and the actual price, R_{t-1}, of the previous period as in (3.86) and (3.87) where e is the elasticity of expectation and $0 < e \leq 1$.

$$\overline{R}_t - \overline{R}_{t-1} = e(R_{t-1} - \overline{R}_{t-1}) \tag{3.86}$$

$$\overline{R}_t = eR_{t-1} + (1 - e)\overline{R}_{t-1} \tag{3.87}$$

In terms of (3.86) the relationship between expected price for year t and t-1 is the difference between the actual price and expected price in period t-1 multiplied by e. If e is zero, the actual price of previous periods have no effect on expected price.

On the other hand, if e = 1, expected normal price would be equal to the t-1 actual price. In other words, the expectation model then is simply one which extends the value of the current year into the future. The error, E, of this expectation model can, in classical statistical terminology, be indicated as (3.88),

$$E = 2\sigma^2(1 - \rho) + b^2 \tag{3.88}$$

the mean square difference between realized price and expected price, and σ^2 is the equivalent of the usual variance computation. This outcome is specified between the extremes of no trend and a linear trend. If there is no trend, with ρ as the correlation coefficient for price observations between years, and b, the regression coefficient of price on time, are both zero, the expectational error is $2\sigma^2$. The farmer would be better off to use the mean price (perhaps of a previous period, if this population were to be repeated in the future) as his expectation of price since its error measured in the same manner would be only σ^2. If the farmer used a normal price, based on concept of normality in a particular period, and the normal price differed from the mean of the price universe by c, the expectational error, measured as the mean square difference between R_t and R_{t-1}, over time would then be (3.89).

$$E = \sigma^2 + c^2 \tag{3.89}$$

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[26] Cf. Nerlove, Marc. The Dynamics of Supply: Estimation of Farmers' Response to Price. Johns Hopkins Press. Baltimore. 1954. pp. 25-27; and Hicks, J. R. Value and Capital. Oxford University Press. Oxford. 1946. pp. 204-6.

In cases such as this, we would expect the magnitude of E (c and b) to affect the rate at which resource input is altered in response to price change because of the error and uncertainty involved. Hence, the e in (3.86) cannot completely explain the price upon which decisions are based, R_t likely being discounted in relation to input decisions depending on the value of E. While these considerations and the use of other expectation models are of obvious importance in linking the prices and resource investments of different periods, we continue the discussion in the somewhat less realistic framework which does not incorporate them.

Seldom, of course, are the prices of one period linked only to those of the previous period. Given the value of R_t in (3.87), we would expect the similar linkage for $\overline{R}_{t-1}$ in (3.90).

$$\overline{R}_{t-1} = eR_{t-2} + (1 - e)\overline{R}_{t-2} \tag{3.90}$$

Continuing the linkage and substituting (3.90) into (3.87), the value of $\overline{R}_t$ then is logically (3.91).

$$\overline{R}_t = eR_{t-1} + e(1 - e)R_{t-2} + (1 - e)^2\overline{R}_{t-2} + \dots \qquad 0 < e \leq 1 \tag{3.91}$$

We now define a resource demand function in period t as (3.92) where $\overline{X}_t$ is the desired or optimum level of input, given the expected factor-product price ratio $\overline{R}_t$.

$$\overline{X}_t = a + b\overline{R}_t \tag{3.92}$$

If input or resource demand in t is (3.92), (for the purpose of simplicity we do not include the random error term u in the demand equation of this chapter), the expression for $\overline{R}_t$ from (3.91) is substituted into (3.92) to form (3.93), where desired input level is linked to price ratios of the past.

$$\overline{X}_t = a + b[eR_{t-1} + e(1 - e)R_{t-2} + (1 - e)^2\overline{R}_{t-2} + \dots] \qquad 0 < e \leq 1 \tag{3.93}$$

Many other values might exist for $\overline{R}_t$, in its linkage to the past, as in (3.94) for example.[27]

$$\overline{R}_t = n + e(R_{t-1} - R_{t-2}) + e^2(R_{t-2} - R_{t-3}) + \dots \qquad 0 < e \leq 1 \tag{3.94}$$

We could substitute the equivalent expectation values of R_{t-1}, R_{t-2}, ... into equation (3.94). Eisner and others have applied such alternatives.[28]

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[27] The resource demand equation in period t then becomes:

$$X_t = a + bn + b[e(R_{t-1} - R_{t-2}) + e^2(R_{t-2} - R_{t-3}) + \dots]$$

[28] Eisner, R. Expectations, plans and capital expenditures. Conference on expectations, uncertainty and business behavior. (Edited by M. J. Bowman, Univ. of Chicago); and Yeh, M. H. Fertilizer Demand Functions. Unpublished Ph.D. thesis. Library, Iowa State University. Ames. 1958.

However, for purposes of brevity, we consider further only some of the more orthodox expectation and lag models below.

The fact is, even apart from the expectation of price in the decision period and its linkage to the past, inputs may be linked between production periods as illustrated in (3.82). A model paralleling the earlier price model also may be relevant and facilitates the explanation of differences between short-run and long-run elasticity coefficients. For any one price situation, a long-run normal or desired (some concept of optimum) resource input, $\overline{X}_t$, may exist. It is not, as pointed out above, attained in a single period. We also suppose that the actual input for the current or short-run period X_t, that being planned, will be related to both (a) this optimum or desired level, $\overline{X}_t$, in the long run and (b) the actual input, X_{t-1}, of the previous period.

$$(3.95) \qquad (X_t - X_{t-1}) = g(\overline{X}_t - X_{t-1}) \quad 0 < g \leq 1$$

In (3.95) the difference between actual input in t and actual input in t-1 is stated to be a g proportion of the difference between desired input in t and actual input in t-1. We will call g the adjustment coefficient. This formulation supposes a given price level, with a gradual adjustment of input X to the desired level of use. The adjustment is gradual because of physical, psychological or institutional restraints. As the difference between $\overline{X}_t$ and X_{t-1} becomes smaller with time, the ΔX_i or resource addition for a particular year also will decline. By defining X_{t-1}, X_{t-2}, ... in a similar manner to (3.96), X_t can be defined as a function of inputs in a sequence of other periods, although the particular algebraic form may have less logic for agriculture than many other models (see Chapter 10) which can be specified.

$$(3.96) \qquad X_t = X_{t-1} + g(\overline{X}_t - X_{t-1})$$

At the outset of some innovations, investment in successive years may be an increasing function of resource use in early years, with the increment of investment later declining. This might be the expected case as the farmer "makes some tries" and initially gains experience plus increased capital for further investment. It is possible to combine the adjustment and expectation models by substituting the value of X_t in the resource demand equation (3.93) into (3.96) to obtain the value of X_t taken with a distributed lag. Resource input in the current period is linked to those of previous periods and in relation to a rate of input adjustment indicated by g and an expected current price ratio linked to past price ratios by an expectation coefficient e.

$$(3.97) \qquad \overline{X}_t = a + b\overline{R}_t + c\overline{F}_t$$

Instead, we extend the demand equation to (3.97) where $\overline{R}_t$ is the expected ratio of price of the i-th factor to commodity price, $\overline{R} = P_i P_y^{-1}$, and $\overline{F}_t$ is the expected ratio of the i-th factor price to the j-th factor price, $F = P_i P_j^{-1}$, for the period t and $\overline{X}_t$ is the desired or optimum level of inputs. Substituting this resource demand function into the equation (3.96), we obtain:

$$(3.98) \qquad X_t = ag + bg\overline{R}_t + cg\overline{F}_t + (1 - g)X_{t-1}$$

Demand or input in the current period, then, is a function of the expected factor/product and factor/factor price ratios of the same period and of the actual input of the previous period. Where the quantity and price ratios are measured in logarithms, bg is the short-run elasticity of resource demand with respect to the expected factor/product price ratio, and cg is the short-run elasticity with respect to the expected factor/factor price ratio. With knowledge that $1 - g = \lambda$ (λ estimated as a regression coefficient in quantitative analysis), we can compute the adjustment coefficient as $g = 1 - \lambda$. From (3.98) it is apparent that when g is zero, adjustments are never made and the demand quantity in the current period is equal to that of the previous period. If g equals 1, all adjustments are made in the current period and current resource demand is not directly linked to the value of X in the previous period. The long-run elasticities b and c in equation (3.97) can be found merely by dividing the least-square coefficients bg and cg in (3.98) by the adjustment coefficient g (the variables are assumed to be in logarithms). If g is small (λ is large), the long-run elasticity is much greater than the short-run elasticity of resource demand relative to factor/product or factor/factor price ratios. A large value of g means that most of the adjustment in resource input is made in the first period and the long-run demand elasticity is only slightly larger than the short-run elasticity.

We have outlined some simple models suggesting the linkage of resource demand in one period with inputs and prices of earlier periods. These simple dynamic models are perhaps elementary in respect to those most appropriate for real world situations. They are, however, realistic steps: (a) beyond the static models discussed earlier in explaining changing demand and use of resources over time, and (b) exposing some possible models for quantitative estimates. (Where the variables in (3.98) are not measured in logarithms, elasticities must be computed other than directly as the coefficients of the variables.) In later chapters empirical estimates of resource demand functions and other relationships relating to commodities and factors are made by numerous variations of both the static and the dynamic models outlined in this chapter.

Additional Conditions Suggesting the Need for Expectation and Adjustment Models

Aside from uncertainty, trends in economic growth and factor prices also change demand for specific factors through their effect on resource structure and scale economies. Physical and institutional restraints cause lagged adjustment in resource employment even where subjective certainty exists in the minds of decision makers. Under economic growth, prices of capital items fall relative to the price of labor. Because machinery and equipment come in large, discrete units, they have greater advantage than horse or manpower only when used with greater inputs of complementary resources such as land. The supply of land is fixed in farming communities, and firms can expand only as other farm businesses are liquidated and their land is relinquished. Individual farms can only add to land input in discrete and discontinuous fashion, and the aggregate of remaining farms can only distribute this adjustment over time as farm operators retire or themselves express distributed lag reaction in their eventual decision to sell at higher land prices.

Additions of complementary resources such as more land or livestock typically take place only as investment capital availability is increased. For both individual farms and the aggregate of remaining farms, the adjustment is distributed with a lag over time, thus causing a similar lagged pattern in increased demand for resources specialized to particular products, in the size and numbers of farm business units and in the size of the farm work force.

4.

Changes in Factor Prices and Production Functions Under Economic Development

CHANGES taking place in the organization and structure of agriculture over the last several decades were summarized in Chapter 2. Chapter 3 outlined some basic theory of resource structure and suggested variables and parameters which are expected to be important in determining demand quantity of specific resources and, hence, the organization of agriculture. This chapter analyzes and summarizes some of the major changes taking place in these variables and parameters, and the forces behind these changes. The major changes in the resource structure of agriculture relate to (a) the marginal productivity of particular classes of resources and (b) the prices of these resources. The direction of change for both sets of these quantities has been causing a shift in agriculture from a labor intensive basis to a capital intensive basis over the last half century.

To be certain, the farm decision maker does not adjust immediately or optimally to gain maximum profit from a new set of prices and production coefficients. One reason he does not respond in the short run *exactly* as suggested by the theory in Chapter 3 is lack of knowledge and certainty of production coefficients, commodity prices and factor costs. Also, institutional variables cause supplies of some factors to be absolutely restrained for him. In the extreme short run, the structure of agriculture rests heavily on the stock of durable assets or fixed resources. The quantity of these multiperiod resources and decisions to use them relate to prices and production coefficients of earlier periods. Too, certain psychological variables restrain the rate at which resource demand changes in the short run. Finally, the farmer's objective function (system of goals and values) includes motives other than profit maximization.

Even though these qualifications exist, farmers do react broadly in the long run about as the theory specifies. As the marginal productivity of some resources has increased relative to that of other resources, increased quantities of the former have been used to replace the latter. Similarly, changes in relative prices increased the use of some resources at the expense of others. Refined regression models need not be derived to illustrate that relative change in the price and production coefficients of various farm resources has greatly altered the demand for them. Resources such as open-pollinated corn and draft horses are extreme examples. They have virtually vanished from farming as their prices have increased relative to their substitutes, hybrid seed corn and tractors, and as the greater marginal productivity and substitution rates of the latter have become known to farmers. But even between broader classes of resources such as capital and labor, or capital and land, real prices and productivities have changed to cause large substitution of the first for the second category.

DEVELOPMENTAL BASE

Besides reviewing changes in the variables and parameters in the resource structure of agriculture, we wish to examine the broader set of development forces giving rise to changes in these quantities. The two sets of major quantities theoretically expected to bring change in agriculture, relative resource prices and technical coefficients, were extremely favorable to transformation of agriculture after 1935.

Economic Growth, Factor Prices and Productivity Coefficients

Even without research investment through public institutions and nonfarm industrial firms, farmer education and experience would have continued to be a source of innovation and technical change over the last century. However, the rate of technical change would have been slow without public and private investment in new resource forms and their productivity. These investments in research have come largely in the last half century. The variables determining the organization of U.S. agriculture prior to this time probably were resource prices. The gaining of knowledge about production coefficients in newly settled regions was extremely important. However, the supply elasticities and prices of labor and land perhaps dominated in the early development of U.S. agriculture. Even though this is true, the supplying of knowledge about capital resources and their productivity is not independent of factor prices. We now examine some of these possible interrelationships at various levels of economic development.

At early stages of economic development, labor supply is large relative to capital supply. Labor provided over three-fourths of the total value of inputs used by U.S. agriculture in the first century of the nation. A nation at a low stage of development with a large labor supply and a small land supply will, of course, have a relatively large proportion of total input value represented by land. In initial stages of U.S. development, however, the supply of land also was great. With large supply elasticities for both labor and land, and with low real prices of these two resources, a capital intensive structure of agriculture was not encouraged. The major capital items employed were the feed, seed, power and breeding stock originating within the industry. Nutrients for plant growth were supplied mainly from livestock manure, virgin soil fertility and crop rotations.

Demand for farm capital items produced outside agriculture is small under these conditions of resource supplies and prices. Consequently, since the market in agriculture for capital inputs is small, little research is conducted in the private nonfarm sector to uncover the productivity of new agricultural capital forms. Similarly, the private sector does not invest heavily in the discovery of new capital materials, or in improving the technology and prices in supplying these new capital forms.

Given sustained economic growth and progress to high levels of development, however, the relative supplies and prices of resources turn to favor substitution of capital for labor. The result is a general increase in the demand for capital. With a larger market for capital items in agriculture, the private nonfarm sector has greater profit motive in research on capital items. This research affects agricultural structure from two directions. (a) The magnitude of productivity and substitution coefficients. As new capital forms are discovered and their productivity coefficients for farms are established, demand for them increases. Both direct and indirect substitution of capital for labor and land is favored. (b) The magnitude of capital prices. Research by nonfarm firms on the processing of their own product may lead, under sufficient competition, to a lower supply price for it as an input to agriculture. Hence, a decline in the real price of capital items is encouraged and further growth in demand for new technologies is expected, with further direct and indirect substitution of capital items for labor and land. Changes in the relative factor prices and resource productivities thus are simultaneously encouraged as economic development progresses.

Nowhere is this process more evident than under the high level of development in the U.S. economy. The private sector has increased greatly its investment in discovering new capital materials to be used in agriculture, in estimating the farm productivity of these materials and in communicating the knowledge to farmers. It also has invested in research and development to improve the fabrication and distribution of these inputs and to lower their relative supply prices. The efforts and investment of the private sector in this direction may outweigh that of the public sector through its investment in the research and educational services of the land-grant universities and the USDA. Fundamental and major discoveries and development by the private sector have come to dominate such capital items as insecticides, machinery, fuel, hybrid seed corn, basic ingredients of livestock rations, improved poultry strains and others. This tendency is likely to continue (see Chapter 1) as the total value inputs of agriculture become dominated even more by capital.

Rapid change in knowledge of new technology was provided through the public sector in early stages of development when capital markets and incentives for private investment in agriculture were limited. The void in private sector investment, or the slower and restrained discovery rate by farmers, was recognized by the U.S. public a century ago.

Consequently, social machinery for discovering and communicating new knowledge on resource productivities and substitution possibilities was established. This public investment, one not paralleled for other industries, continues and is represented in the agricultural colleges of the land-grant universities and the USDA.

Development and Technology in Relation to Resource Prices

Even apart from changes in knowledge about the agricultural production function, change in the resource structure of agriculture would have occurred under the national developmental forces of the nineteenth century. Relative change in the supply quantities of labor and capital in the national economy altered relative supply prices in a manner to bring about substitution of capital for labor and land. These types of changes would have occurred even had the production function of agriculture been known in full detail a century ago. Given complete knowledge of the production function, capital would have been progressively substituted for labor as the real price of the former declined relative to that of the latter.[1] Suppose, for example, that technological or physical production possibilities are known in the sense of an invariant production function or family of production isoquants as in Figure 2.4 (page 29). Here we suppose that the production function is "general" in the sense that capital can change in specific form as its quantity is extended. Given the relative factor prices of an "early" period in development, as denoted by iso-outlay curve r_2, the factor mix will be "long" in labor and "lean" in capital. Even without further change in knowledge of the production function and with constant factor price ratios, growth in demand for food would cause the resource mix to increase in capital proportion. For example, if output were, because of growth in population and commodity demand, extended from isoquant q_1 to q_2, the proportion of capital would shift towards this resource if the over-all isocline were of the nature of I in Figure 2.4. At another period in time and at a level of economic development where capital price has declined relative to labor price, as indicated by the slopes of iso-outlay line r_1, any given output, such as q_1, is expected to be produced with more capital and less labor. This change should come about purely in a factor substitution sense, and independent of changes in knowledge of the production function. The expansion effect, resulting to the extent that a lower real price of the optimum resource mix is realized, is likely to carry the capital demand to higher levels, with the final proportions of labor and capital determined by the relevant isocline. Table 2.13 (page 31) roughly suggests changes in resource use which stem from both the "expansion" effect and the "substitution" effect.

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[1] For added detail, and illustration along the capital-labor isoquant of agriculture where technology is known, see Heady, Earl O. Agricultural Policy Under Economic Development. Iowa State University Press. Ames. 1962. Chap. 2.

Value Productivity at High Developmental Levels

The use of capital, encouraged through decline in its real price, has varying impact on the productivity of other resources. It increases the marginal physical productivity of labor, but generally tends to depress the value productivity of this resource because the product price falls. Some labor which remains in agriculture, complemented with sufficient capital, can increase in both physical and value productivity. Other labor, however, is made surplus because a greater farm output and inelastic demand for food cause product prices to fall. These workers who do not increase productivity at a rapid rate find their value earnings declining relative to those of farm and nonfarm workers who are more highly employed. Similarly, capital items such as fertilizer and improved seed have differential impact on value productivities of land and labor. While they increase physical productivity of both, these improved capital forms may increase the value productivity of land in an area where the yield response is high and lower it in an area where yield response is low. The outcomes cited for both land and labor, with value productivity increased for one stratum but decreased for another, are especially possible where the new capital item contributes unequally to the physical productivity, the price elasticity of demand for the commodity is less than unity and output continues to increase because of low short-run supply elasticity for labor and land.

Capital in the form of mechanization also may have the effect of increasing the net marginal productivity of the land with which it is used. The result is a growth in the per farm demand for land, with fewer and larger farms resulting. The data on land purchases for farm consolidation cited in Chapter 2 and the empirical results in Chapter 15 are expressions of this phenomenon. Agricultural capital in its mechanical forms tends to be supplied in "lumpy" or discrete units, such as 4-plow tractors, 6-row planters, 12-foot combines, etc. With an important proportional element of depreciation due to obsolescence, rather than directly from annual transformation of resource services into product, fixed costs of machinery have tended to increase in recent decades as a percentage of total farm costs. Spread over a larger land input, per acre fixed and total costs initially decline sharply with increase in farm size. Hence, a second 80 acres of land, purchased to complement machinery, has greater net marginal value productivity than an initial 80 acres owned by a small farmer. Similarly, a second 160 acres has a greater net value productivity than an initial 160 acres. This decline in per acre costs as a function of farm size, of course, is of important absolute magnitude only until per acre costs approach the lower mathematical limit. With larger machines, representing greater initial investment and higher annual fixed costs, the per farm input of land over which per acre costs decline sharply has been increasing.

As factor prices favor a greater substitution of mechanical capital for labor, and since tools and machinery come in large units, the magnitude of land input to (a) give fairly complete realization of per unit cost reduction due to spreading of fixed costs and (b) full employment to the laborer complementing the machines, increases. Growth in size and decline in numbers of farms is then encouraged. Given the same technical knowledge in all countries, but with different prices of labor relative to capital among countries, we would thus expect to find quite different agricultural technologies and farm sizes to prevail. Labor technology is used in India, not because large-capacity machines and crawler tractors are completely unknown, but because the large supply and low price of labor to agriculture cause technology resting on human effort and simple animal power to be most efficient in a factor cost sense. Similarly, horsepower in Spain and garden tractors in Japan are used in preference to a large tractor and a 5-bottom plow, not because of absolute ignorance but because the prevailing technology approaches optimality under existing factor prices.

CHANGE IN FACTOR PRICES UNDER ECONOMIC DEVELOPMENT

Demand for and use of resources in the U.S. nonfarm economy have come to exceed greatly that in the farm economy over the last half century. Hence, to the extent that economic development and related factors alter the relative prices of resources in the national economy, real prices of factors also will change for agriculture. Economic development is highly synonymous with growth in the supply of capital relative to labor and a decline in price of capital relative to labor. Simultaneously in the total economy capital accumulation will continue to increase the marginal productivity of labor, thus maintaining and increasing nonfarm wages under conditions of full employment. These effects will encourage further substitution of capital for labor on farms.

Trends in Prices of Basic Materials

Figure 4.1 illustrates long-run national trends in the prices of some major categories of basic or material capital resources relative to the price of labor. Since the early 1890's the price of pig iron, chemicals, fuels and lighting (energy) and metal products have declined relative to the price of labor (with the latter expressed as the industrial wage rate).[2] The basic and material capital items represented are those which have been important ingredients in the new technologies of agriculture. The prices of these capital items have declined relative to labor, especially from 1930 to the 1960's. This is the period in which

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[2] The wage rate used for the comparison in Figure 4.1 is the hourly earnings of manufacturing employees. The indices represent the price indices of pig iron, fuel, chemicals and metal products divided by the index of hourly earnings by manufacturing employees, 1910-14 = 100.

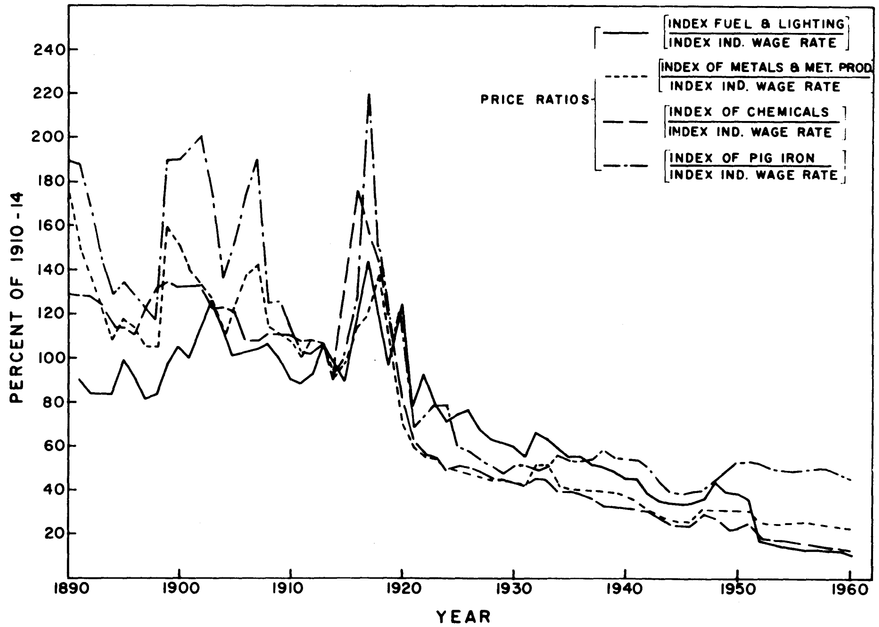

Figure 4.1. Relative prices of basic capital materials and labor, U.S., 1890-1960 (1910-14=100).

technical and structural change of agriculture has been most rapid. Economy-wide change in these relative factor prices brought parallel changes to agriculture, in the cost of capital items for innovation relative to farm labor price and returns. Paralleling this favorable price setting, technical knowledge of agriculture also has been accentuated during this period. Greatest increase in research findings and applications, and especially in extension education, occurred after 1935.

Figure 4.2 indicates that even the cost of credit or investment funds relative to the price of labor in agriculture also has declined in a manner paralleling that of the national economy. Farmers are expected to use more capital accordingly, causing labor to come into greater surplus because of the inelastic demand for farm commodities. Also, a lower price for borrowed funds is expected to increase the per farm demand for land, and to cause the size of farms to increase. (Our specifications in later models do not allow us to "quantitatively pick up" this effect, however, for durable capital items.)

Changes in Relative Prices of Farm Resources

Changes in the price of farm resources have generally paralleled those of the general economy. The largest substitution which has taken

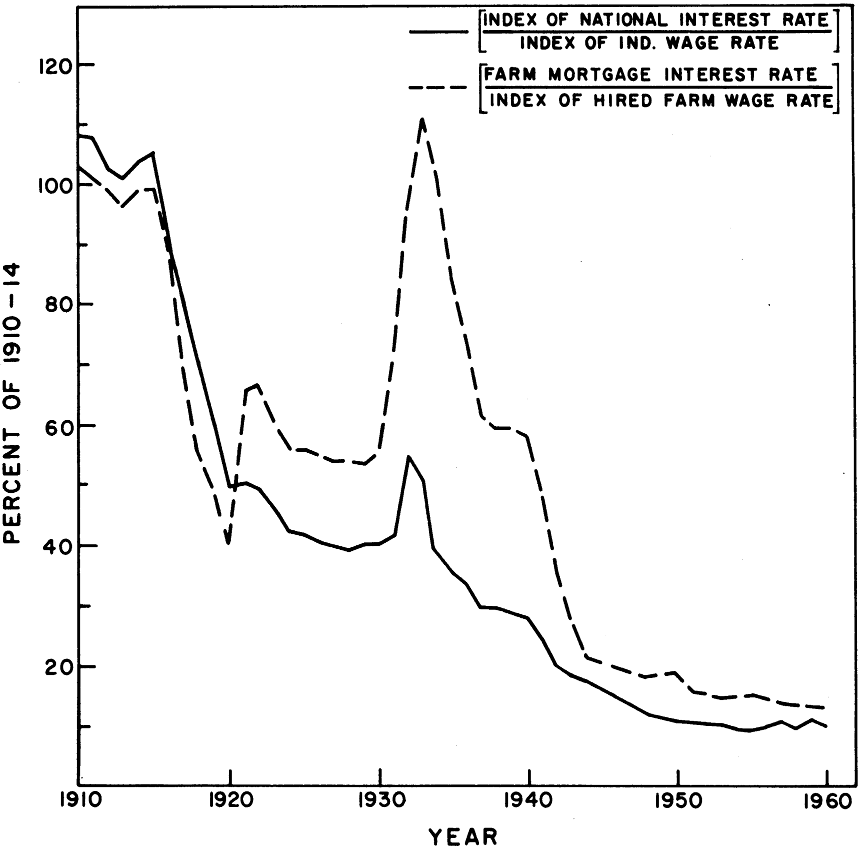

Figure 4.2. Indices of the ratio of interest rates to wage rates.

place in agriculture has been that of capital for labor. Prices of mechanical and chemical forms of capital used in agriculture have declined relative to labor price. Chemical prices also have declined greatly relative to farm product prices. As Figure 4.3 indicates, the price of mechanical capital forms has been low relative to farm labor price since 1940.

Mechanical forms of agricultural capital have not declined in real price in the same magnitude as biological and chemical forms. In relative terms, the prices of machinery, motor vehicles and supplies, farm operating supplies and building materials have increased as compared to seeds, fertilizer, breeding stock and feeding animals, and compared to farm product prices. Still, mechanical capital forms have declined in relative price with labor, their direct substitute. By 1960, the relative price of farm machinery as compared to labor (Figure 4.3) was only 60 percent of 1910-14 level.

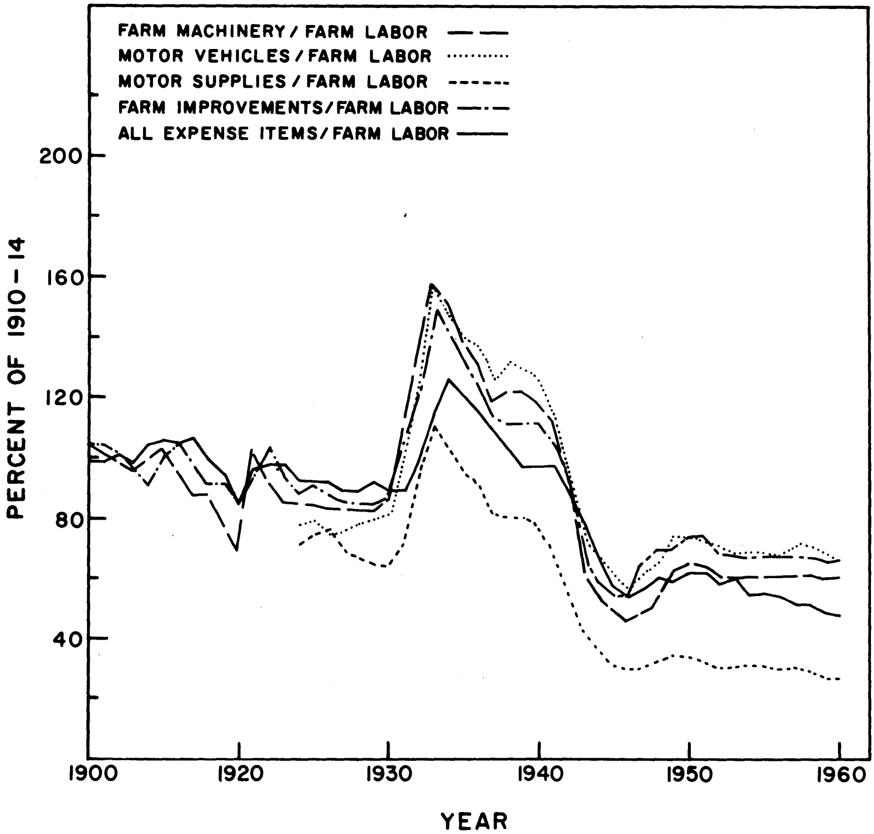

Figure 4.3. Relative prices of selected farm capital items and farm labor (ratio of price indices, 1910-14=100).

From 1930 to 1960 mechanical capital was rapidly substituted for hired labor. In respect to family labor, mechanization has two immediate and direct effects: (a) in allowing a given amount of labor to produce more crops and livestock on the same farm and (b) directly replacing farm labor of family members. Even with a given number of farms, some family labor would have been directly replaced as more farmers took part-time jobs. But because mechanical capital generally has high fixed costs and allows given family labor to handle more animals and acres, there are severe pressures for farm consolidation. Typically, the operator who extends acreage need not add as much labor as that used by the operator who leaves.[3] Also, the investment in selected buildings declines in absolute amount as farm size is expanded and fewer building sites are retained. The Iowa study showed that under

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[3] Hoffman, R. A., and Heady, Earl O. Production, income and resource changes from farm consolidation. Iowa Agr. Exp. Sta. Res. Bul. 502. Ames. 1962.

farm consolidation, the capital mix changed to include a smaller proportion of machinery and buildings and a greater proportion of fertilizer, improved seeds, insecticides and similar items. In the total resource mix, of course, labor declined both in absolute amount and relative to capital and land.

CHANGE IN THE PRODUCTION FUNCTION

An important source of this new knowledge, information causing change in productivity coefficients and factor demand, has come from public investment in the USDA and the land-grant colleges. This investment has extended over a century, but its amojnt and effect have been greatest since about 1910. Research and extension education were not supported at a high level until this time.

Market development and foreign demand caused farm product prices to be favorable to capital prices over much of the period 1850-1910. These market sources of capital gain, from a land supply which had very low real prices to farmers, did allow growth of farmer equity and the use of more capital resources. Loomis and Barton show that as an average over the complete period 1870-1920, the major source of increased farm output was greater inputs, productivity of inputs evidently declining during part of the period.[4] Since 1920, however, the dominant source of output increase has been the change in the productivity of resources, rather than from the increase in the *value-weighted* amount of resources. It must be emphasized, however, that while the *value-aggregated* index of resources has changed relatively little since 1920, the make-up of this aggregate has changed greatly. Not only has labor been displaced by capital, but also specific capital forms have been entirely replaced by other capital forms.

Table 4.1 indicates the magnitude of growth in U.S. public outlays to create and extend technical knowledge to agriculture. In terms of the coefficients and variables changing resource demand and commodity supply functions as suggested in Chapter 3, perhaps no other set of forces has been so influential in the years since 1920. However, the private sector now makes an immense contribution to growth in knowledge of new agricultural technology. This growing investment by the private sector is encouraged especially at high stages of economic development where the major portion of farm inputs turns to capital. The private sector then has the much larger market mentioned earlier in supplying inputs to agriculture, as compared to lower stages of economic development. Future economic development will be associated with continued efforts of the private sector to extend knowledge of the agricultural production function.

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[4] See Loomis, R. A., and Barton, Glen T. Productivity of agriculture, United States, 1870-1958. USDA Tech. Bul. 1238. p. 9.

Table 4.1. Public Expenditures for Research and Education in Agriculture for Selected Years, 1910-59 (Million Current Dollars)*

Year	Agricultural Research	Agricultural Extension	Vocational Agriculture
1910	6.5	--	--
1920	14.5	14.7	2.4
1930	31.6	24.3	8.7
1940	41.3	33.1	17.0
1950	104.3	74.6	38.5
1959	225.4	136.0	66.7

*USDA and U.S. Department of Health, Education and Welfare.

Changes in Transformation Rates

Having summarized some long-run trends in relative factor prices and research developments, we now turn to trends in production functions and resource transformation rates. Ideally, we would like to predict a series of production functions at many points in time for many agricultural commodities. Paucity of data prohibits this approach. As a crude alternative, we have experimented with estimating some average aggregate production functions for U.S. agriculture over the period 1926-59. A priori, we expected little success in this attempt and, hence, were not greatly disappointed in our results. Certain of the empirical findings, within the complex of limitations which they possess,[5] are of qualified use and somewhat consistent with results from other estimates presented later. Hence, we feel brave enough to present our estimates. Tables 4.2 and 4.3 contain six aggregate average production functions for U.S. agriculture estimated by least squares from time series. The variables are defined as follows for the function in Table 4.2:

O = the dependent variable, the production of crops and livestock on U.S. farms during the current calendar year for eventual human consumption. The measure is corrected for intermediate use of resources such as farm-produced power, for feed fed to livestock, etc.

Q'_{RE} = real estate input, measured as the constant dollar value of annual services required to maintain the input at the current level, including interest, depreciation, damage and repairs, and taxes on real estate, i.e., land and buildings.

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[5] For a general discussion of the algebraic forms and limitations of production functions see Heady, Earl O., and Dillon, John L. Agricultural Production Functions. Iowa State University Press. Ames. 1961. Chaps. 2-5.

Table 4.2. Average Aggregate Production Functions for U.S. Agriculture Estimated by Least Squares With Annual Data From 1926 to 1959; Showing Elasticities of Production, Standard Errors (in Parentheses) and Related Statistics

				Regression Coefficients and Standard Errors					
Equation	R^2	d*	Constant	Q'_{RE}	Q_D	Q_T	Q'_O	W	T
(4.1)	.98	1.95	.066	.47	.038	.16	.28	.345	.0024
				(.49)	(.127)	(.22)	(.10)	(.062)	(.0015)
(4.2)	.98	1.89	1.13	.40			.294	.331	.0014
				(.18)			(.051)	(.055)	(.0010)
(4.3)	.98	1.78	.69	.50	-.024		.373	.309	
				(.33)	(.108)		(.048)	(.058)	
(4.4)	.98	1.79	.58	.44			.363	.313	
				(.18)			(.015)	(.055)	

*The Durbin-Watson autocorrelation statistic d.

Q_D = input of durable capital, measured as the services, required to maintain the input at the current level, including interest, depreciation, insurance and taxes on productive machinery, livestock, feed, horse and mule inventories plus license fees on the productive motor vehicles. The repairs, fuel and lubrication requirements for farm machinery are included in operating inputs Q'_O not in Q_D.

Q_T = total farm employment in 1,000 workers, including hired and family laborers during the current calendar year.

Q'_O = inputs of operating items, including fuel, oil and repairs for machinery, electricity, blacksmith repairs and hardware expenses, binding materials, dairy supplies, ginning costs, the nonfarm share of feed, seed and livestock purchases, fertilizers and interest on operating capital.

W = Stallings' index of the effect of weather on farm output in the current year. Indices for 1958 and 1959 were estimated as deviations from a linear yield trend.[6]

T = time, an index composed of the last two digits of the current year.

Variables, except T, are logarithms of national aggregates. Quantities other than Q_T are aggregated by 1935-39 prices prior to 1940, by 1947-49 prices after 1940. After aggregation, the variable is expressed as the "physical volume" of input in 1947-49 dollars by splicing the two weighting periods on the basis of the overlapping values for 1940.

The independent variables explain a high portion of the variation in farm output and, based on the Durbin-Watson d statistic, autocorrelation

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[6] Stallings, James L. Weather indexes. Journal of Farm Economics. 42:180-86. 1960.

Table 4.3. Average Aggregate Production Function for U.S. Agriculture Estimated per Unit of Farm Labor by Least Squares From Annual Data; Showing Elasticities of Production, Standard Errors (in Parentheses) and Related Statistics

Equation	Time Period	R^2	d*	Constant	Regression Coefficients and Standard Errors					
					Q'_{RE}/Q_T	Q'_M/Q_T	Q_{LF}/Q_T	Q'_O/Q_T	W	T
(4.7)	1910-39	.90	1.56	.66	.69 (.44)	.042 (.098)	-.14 (.15)	.21 (.16)	.247 (.069)	.0019 (.0013)
(4.8)	1926-59	.99	2.05	.42	.45 (.21)	.049 (.060)	.14 (.10)	.200 (.071)	.384 (.064)	.0028 (.0015)

*The Durbin-Watson autocorrelation statistic d.

is not serious. The elasticity of production of the real estate input is about .4 or .5, consistently larger than other elasticities. Production elasticities of labor, Q_T, and durables, Q_D, are low. If these results were accepted, they would indicate labor or durables such as machinery, livestock and feed inventories to have little marginal influence on farm output. The elasticity of production of the operating input variable is .3 or .4. Based on the known influence of such inputs as fertilizer and protein supplements on production, elasticities of these magnitudes are not surprising. The combined elasticities of two inputs, real estate and operating items, totals approximately .8. If the hypothesis of constant returns were accepted for agriculture, other inputs would have a combined elasticity of approximately .2 and, therefore, only a small influence on output. The variables in Table 4.2 are highly correlated and the coefficients are sensitive to changes in specification. Therefore, caution is suggested in their interpretation, not only because of imperfect specification, but also because of errors in statistics for labor and inputs of durable capital.

Table 4.3 includes an alternative specification. The quantities in the input variables are revised slightly. But more important, the input and output variables are specified per unit of labor. Even if the elasticity of production for labor is not zero, the revised specification does not necessarily lead to autocorrelation in the residuals. Consider the following logarithm production function (4.5) where X_3 is labor, Y is output per unit of labor, X_1 and X_2 are inputs per unit of labor and u is the residual. The total aggregate production function is

$$X_3Y = b_0\ (X_3X_1)^{b_1}\ (X_3X_2)^{b_2}\ X_3^{b_3}\ u. \tag{4.5}$$

Estimating the production function on a per unit basis theoretically does not leave any component of X_3 for the residual if $b_1 + b_2 + b_3 = 1$, i.e., if the production function is homogeneous of degree one. Dividing equation (4.5) by X we have

$$Y = b_0\, X_1^{b_1}\, X_2^{b_2}\, X_3^{(b_1+b_2+b_3-1)}\ u. \tag{4.6}$$

If we have constant returns to scale, the exponent of X_3 equals zero, and the least-squares estimate of equation (4.6) with X_3 excluded has the desired properties, assuming equation (4.5) has these properties, even though b_3 is not equal to zero. Equations (4.7) and (4.8) in Table 4.3 are estimated to (a) increase the stability of the parameter estimates and (b) allow for the fixity of labor inputs in agriculture. The variables are defined as follows:

O/Q_T = output of crops and livestock per unit of labor employed in agriculture.

Q'_{RE}/Q_T = real estate input Q'_{RE} less taxes per unit of labor.

Q'_M/Q_T = machinery input (interest and depreciation) per unit of labor.

Q_{LF}/Q_T = interest on productive livestock and feed inventories per unit of labor.

Q'_O/Q_T = operating inputs per unit of labor.

The weather, W, and time, T, variables are defined previously. All variables except T are logarithms of national aggregates. Equations (4.7) and (4.8) in Table 4.3, if taken as useful estimates, would indicate that the elasticity of production of real estate has declined. In general, the size of the elasticities in Table 4.3 are comparable to the estimates in Table 4.2. Again the responsiveness of output to inputs primarily is shown to be a function of real estate and operating inputs. The marginal productivity of livestock is predicted by equations (4.7) and (4.8) to be low. Weather exerts a consistent influence on output, the coefficient approximating .3 and being significant. If the time coefficient is .002, the production function has shifted upward at approximately .5 percent per year. That is, the efficiency of farm inputs has in aggregate increased an average of one-half of 1 percent each year according to equations (4.1) and (4.7). A neutral shift in the production function occurs from a simultaneous increase in the productivities of all resources. For example, a neutral shift might arise because improved farm management or specialization uniformly raises the marginal products of other resources. The management resource is not explicitly included in the production function. Aggregate resource productivity increased approximately 1.5 percent per year from 1926 to 1959. If equations (4.6) and (4.7) provide meaningful estimates of the neutral shift, then output per unit of input increased 1 percent or more per year through substitution of more productive inputs for less productive inputs. The remaining portion, .5 percent or less, of the annual increase in productivity stems from neutral shifts in the production function over time.

The limited usefulness of these production function estimates is quite obvious and arises from problems in data availability, aggregation, collinearity, specification and others. Aggregate production functions estimated for alternative time periods and input specifications provided less acceptable results. Hence, we turn our final summary of changes in the agricultural production function to less formal data.

Descriptive Measures of Productivity

Several techniques and concepts for measuring changes in productivity are available. Conceptually, production functions provide all necessary information, but such functions often are impractical because of statistical limitations. Consequently, less sophisticated measures of productivity are used in the following pages.

The most commonly used measures of productivity are net or marginal productivity and gross or average productivity. Net productivity, dY/dX_i, is less than gross productivity, Y/X_i, when the latter is falling and is greater than average productivity if Y/X_i is rising. The absolute productivity of X_i in terms of contribution to output, $\frac{\partial Y}{\partial X_i} X_i$, is not likely to be reflected in measures of gross productivity. The relative productivity $\left(\frac{\partial Y}{\partial X_i}\right) X_i /Y$ of resource X_i is the elasticity of production, the coefficients of the Cobb-Douglas production functions presented in Tables 4.2 and 4.3. The theory presented in Chapter 3 indicates that in equilibrium under competitive conditions, the production elasticity of X_i is equal to its factor share, X_iP_i/YP_y. While the equilibrium assumption is not met, it seems reasonable that trends in factor use continually manifest a movement toward the profit maximizing position. The productivities of resources constantly are changing, hence equilibrium is never achieved. However, a brief examination of factor shares in agriculture can give some indication of trends in relative productivity of resources over time.

Factor Shares in Agriculture

Ruttan and Stout[7] indicate that the factor share of operating inputs rose from .31 in the 1925-28 period to .42 in the 1954-57 period. Between the same periods the factor share of real estate decreased from .27 to .18. The factor share of nonreal estate capital increased from .10 to .15 and of labor decreased from .32 to .26 between the two periods. The results indicate a decline in the relative productivity of labor, and an increase in the productivity of operating inputs and nonreal estate capital. The results are consistent with those in Table 4.3 in indicating a decline in the relative productivity of real estate. Comparing the factor share of labor with the production elasticity suggests that movements toward equilibrium will result in an even lower factor share for labor. However, the questionable reliability of the production elasticities in Tables 4.2 and 4.3 suggests that no strong inferences can be made.

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[7] Ruttan, Vernon W., and Stout, Thomas T. Regional differences in factor shares in American agriculture. Journal of Farm Economics. 42:52-68. 1960.

Gross Measures of Technologies of Agriculture

Figure 4.4 provides crude or gross information on changes in transformation rates for three basic resources in agriculture. The three

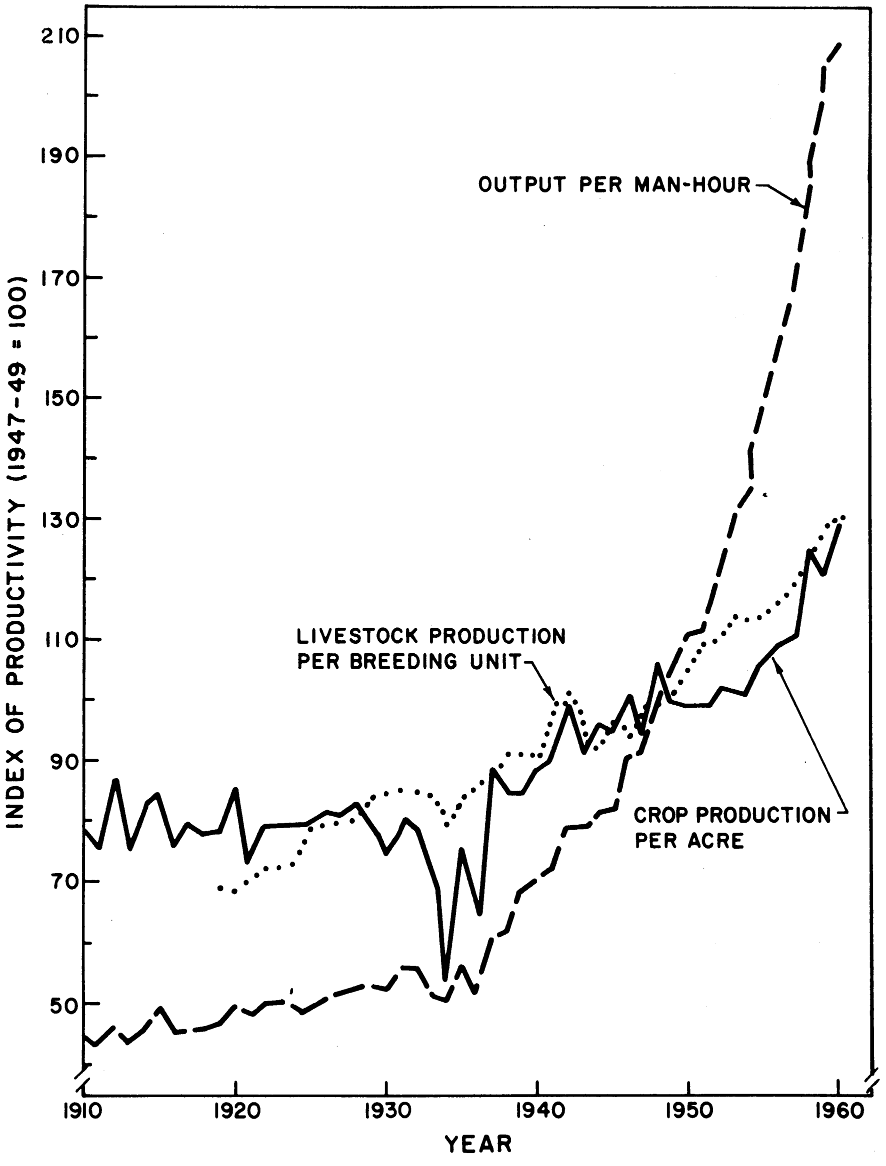

Figure 4.4. Gross transformation rates per unit of labor, land and livestock for U.S. agriculture, 1910-1960. (Source: USDA Stat. Bul. 233.)

resources against which productivity is measured are necessary in either crop or livestock output. While they clearly have substitutes, it is not possible to completely replace either land, labor or livestock breeding units. The very rapid rise in production per unit for the three resources began around 1935, evidently with the accumulation of scientific knowledge to that time, and the fabrication of capital items reflecting this knowledge. Major momentum in combined results of public research and educational facilities probably was not attained much before 1925. The 1930's depression with its turn to unfavorable relations between product and resource prices, plus the extreme restraint on capital and credit supply during the period, gave rise to great potential in technological change with the outset of the war. After 1935, the especially during and after the war, equity positions of farmers, the supply of technical knowledge and price relatives favored an upsurge in technological change which has not yet abated. While the ratio of resource/product prices recently has not been as favorable as during the war and the immediate period following, the ongoing rush of technical knowledge and changed productivity coefficients evidently has been equally important in causing further adoption of capital representing particular new technologies. Too, the farmer as a resource has changed, with operators possessing a different level of managerial ability and being more prone to adopt innovations which have favorable transformation and substitution rates relative to prices.

The most rapid growth in productivity of the three basic agricultural resources represented in Figure 4.4 is for labor. This is true because both mechanical and biological-chemical forms of capital representing innovations serve to increase the productivity and act as substitutes for labor. While mechanical innovations to some extent have indirect biological and chemical effects on crop and livestock yields, the effect is minor in comparison with labor.

The sharp upward trend in gross productivity of the three resources in Figure 4.4 obviously originates, in important extent, from new practices and technical knowledge embodied in capital items. However, not all of the gross change in output per resource unit can be so imputed. Gross output from basic resources could increase from change in price relationships alone, the production function remaining unaltered or given. As a simple illustration suppose that the production function is known, as in Figure 2.4 (page 29). If the initial factor price is r_2, gross labor productivity will increase greatly as a new least-cost resource mix, oc_1 of labor and od_2 of capital, is selected to conform with the price ratio represented by r_1. (See discussion in Chapter 2.) Knowledge of the production function has not changed, but a change in factor price resulting in the substitution of capital for labor can result in the same output being produced with much less labor. This very set of phenomena has contributed to the upsurge in output per hour of labor illustrated in Figure 4.4. A similar phenomenon also can apply to resources such as land and breeding units. The initial input combination in Figure 2.4 may be oc_2, with land being represented on the vertical axis and capital resources such as fertilizer on the horizontal axis. If now the capital resource declines in relative price so that it is extended along ae relative to a fixed unit of land, oc , the output per unit of land input increases from q_1/oc_2 to q_2/oc_2, the result coming from a change in the factor/product price ratio, rather than from change in knowledge of the production function.

Changes in the production function, as well as in relative prices, have increased the amount of livestock products produced per unit of inputs such as breeding stock, buildings, feed, labor and land. Increase in output per animal and bird has been especially rapid since 1940, as illustrated in Figure 4.5. Taking one of these biological resource units as fixed, greater output could be obtained from more input of variable resources such as feed. Some opportunity to thus increase output through greater inputs did exist prior to 1940. Observation and knowledge would certainly indicate, however, that these changes in resource

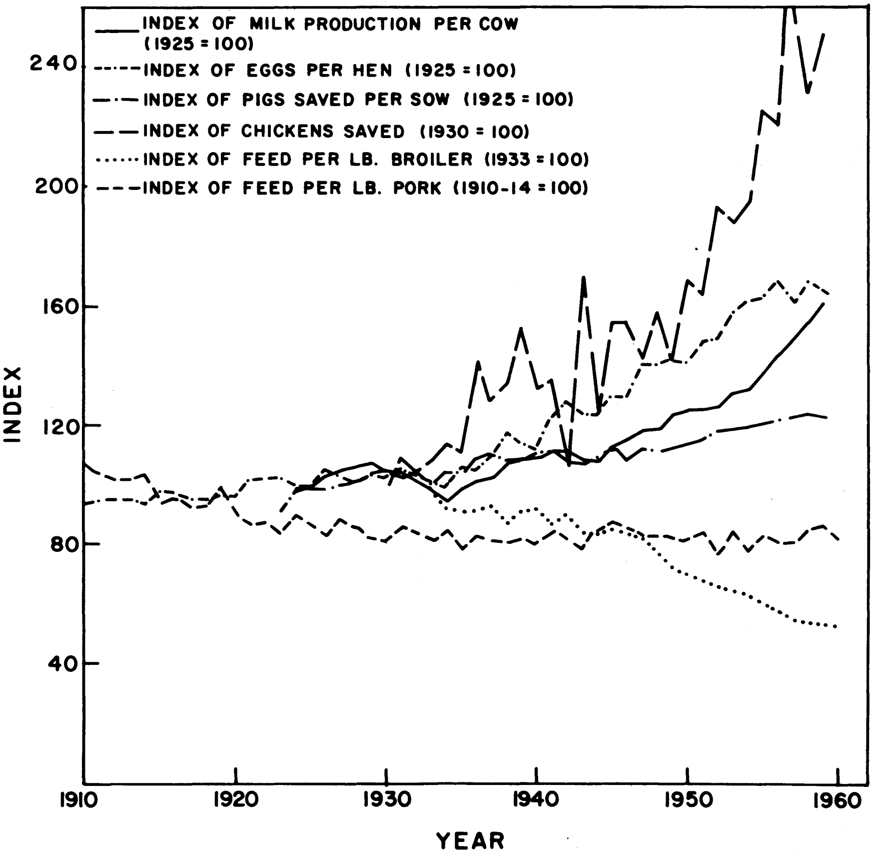

Figure 4.5. Output per animal and bird, and feed per pound of broilers and pork. (Source: Agricultural Statistics.)

productivities for livestock production did not result simply from more conventional variable resources being used per unit of conventional fixed resources. New physical forms of "variable feeds," such as antibiotics and trace ingredients of rations, were developed and became recognized by farmers. Even the "fixed resources" changed, as new breed strains and management changed the factor represented by animals and fowls. The favorable price of feed in the 1950's caused a higher level of feeding for cattle and hogs, with some diminished productivity of grain accordingly. However, even in light of this, feed per pound of pork declined by nearly 20 percent between 1910 and 1960, while feed per pound of broiler declined by 42 percent between 1933 and 1960.

The data in Table 4.4 suggest some rates of technical innovation and change in the hog-feed production function. The figures, for commercial Corn Belt producers, estimate the total pounds of feed to produce 100 pounds of pork at each date, with indication of the major forces over each time interval in allowing this attainment. The estimates show, at each time point, the estimated attainment possible by efficient management, aside from price relationships favoring greater feed input per hog, the technical change allowed more than a halving of feed to

Table 4.4. Feed Requirements per 100 Pounds of Pork Produced, Past and Projected, With Major Source of Improvement*

Year	Technical Source of Improvement	Pounds Feed To Produce 100 Pounds of Pork
1910	Corn and minerals	800
1920	low quality protein	540
1930	mixed protein	400
1945	B vitamins	370
1950	antibiotics	340
1955	improved proteins and amino acids	300
1960	Swine testing stations	
	best lots	260
	average lots	295
	Projected	
1965	Temperature control and management	250
1970	Disease and "germ" free	225
1975	Cumulative breeding improvement	205
1980	Improved nutrition, cumulative	190
	management gains, cumulative	175

*Kiehl, E. R. Present and future livestock production. In Center for Agricultural and Economic Development. Adjustment in Agriculture – a National Basebook. Chap. 17, Iowa State University Press. Ames. 1961.

produce 100 pounds of pork between 1910 and 1960. Another reduction by one-third is expected to be possible by 1980. Similarly, a third reduction is predicted to be possible for beef cattle and sheep.[8]

Specific technologies such as those suggested for Table 4.4 allow large changes in the resource mix for a particular aggregate of products such as livestock and poultry. For example, a growing national output of these products has taken place paralleled by a very great change in the combination of feed and livestock inputs to produce it. As Figure 4.6 indicates, the ratio of breeding inputs of livestock to feed inputs used by livestock has declined importantly since 1935. But within the feed category, the ratio of high protein to grain has increased.

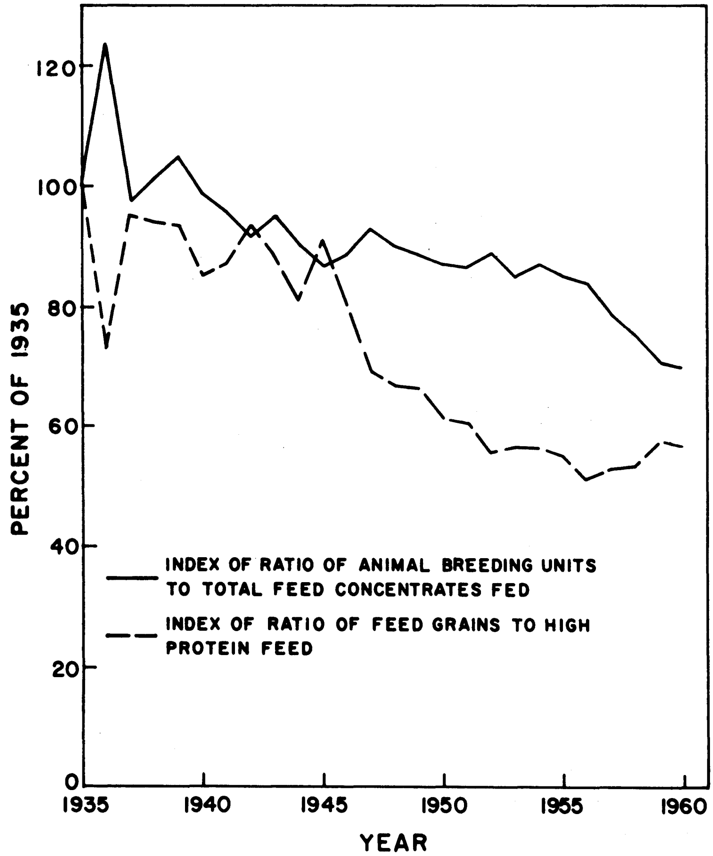

Figure 4.6. Ratios of animal units to feed and of feed grains to high protein feed, 1935-60 with 1935=100. (Source: USDA.)

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[8] Kiehl, E. R. Present and future livestock production. In Center for Agricultural and Economic Development. Adjustment in Agriculture — A National Basebook. Iowa State University Press. Ames. 1961. P. 30.

Changes in eggs layed per hen, chicks saved per hen, or pigs weaned per sow, such as illustrated in Figure 4.5, result largely from new technical knowledge. These have been important trends in agricultural technology over the recent decades and, with pure price variables, have caused the demand functions for factors to change and the resource structure of agriculture to be altered. More pigs weaned per sow, for example, reduces the amount of feed required to produce a unit of pork and lessens the amount of breeding stock used for a given pork output. With a raised transformation rate of feed into pork, the marginal rate of substitution of feed for brood sows is increased and more of the former is used relative to the latter. While the change has been less spectacular, a somewhat similar trend has taken place in percent of calf and lamb crops saved. In all of these cases, rate of transformation of buildings and labor, as well as for feed and breeding stock into livestock, is raised.

Trends in Crop Production Technology

The extremely important trends in technology for crop production have been those relating to improved varieties, fertilization, insecticides and pesticides and cultural practices such as summer fallow of wheat. These involve new capital inputs, especially with biological or physiological effects in transforming the more or less given inputs (availability) of climate, sunlight and specific soil ingredients into crop output. In some regions, direct change in climatic effects through irrigation has been important.

While the line of crop output per unit of land input in Figure 4.4 could result from known technology and simple extension of conventional inputs per acre because of a decrease in the resource/product price ratio, very little of the trend results from this "pure" type of change alone. Nearly all of the inputs applied to land are distinctly different from those applied several decades previous. Hybrid corn not only is a different resource than open-pollinated seed, but also recent hybrid varieties are not the same resource as the earlier varieties under this innovation. The form, analysis, composition and placement of chemical fertilizer also has changed to allow a greater response from a given tonnage of this capital input. Furthermore, its response tends to be greater in interaction with new crop varieties which have potential in raising yields beyond virgin soil fertility levels. Cultural methods which conserve moisture similarly raise the potential yield response of new seed varieties and fertilizer.

Relative Prices of Agricultural Resources and Factor Substitution

The first impact of improved prices or knowledge for biological or chemical capital forms is to cause more of them to be used in agriculture. The individual farmer does not typically use more improved seed, insecticides, fertilizers or feeds, and release some labor in the process. Instead, he uses the improved capital forms with the labor and land resources on hand. As the masses of farmers do so and output increases faster than demand, against an inelastic demand, labor returns decline relative to nonfarm incomes and migration of labor is fostered.

Use of biological capital forms is initiated because their value productivity is high relative to their price, either because the real price has declined or the marginal productivity has increased. The real price of numerous biological forms of capital has declined in recent decades. As data in Chapter 7 indicate, the price of fertilizer declined importantly relative to crop price from 1930 to 1960. (The price of fertilizer nutrients declined even more because the analysis, or nutrient content, of fertilizer increased.) In 1960, for example, the price of fertilizer relative to the price of crops was a third less than in the period 1910-14, even though crop prices had pressed downward and fertilizer prices upward during the 1950's. The price of all chemicals also declined relative to farm product prices and in 1960 was a third less than in 1910-14.[9] Modern farm chemicals represent entirely different resources than the livestock medicines, insecticides and other forms of earlier days.

In contrast, prices of farm seeds have not declined greatly in real price. Pricing and production is much more closely related for seeds and crops than for fertilizer and crops. The use of new seed varieties has been rapid and widespread, however, due to the very great increase in their physical productivity. Used together in an appropriate manner, fertilizer and improved seeds have much greater productivity than when used alone, as in earlier days. As the slope of the production function is "lifted," more of both resources then can be used. If the price ratio remains the same, profit is maximized when the new marginal physical product is driven to the level of that for the "old form" of the resources.

To the individual farmer, these biological forms of capital generally are cheap and productive when he invests in them. He expects to use them in addition to his previous bundle of resources, except for the obsolete forms which they replace. With low price elasticities of demand in the farm commodity sector — unless price is sufficiently supported by government policy — the sector value productivity of the resource is negative in the short run. But even though this is true, the value productivity of the resource for the individual farmer generally is still high. If he did not use the innovations or new varieties, his income depression would be even more after industry output is increased and aggregate revenue is decreased. In aggregate, some land and labor then can move out of production, and a greater proportion of capital is used relative to labor and land because of (a) the initial added investment in the former and (b) the eventual release from the industry, through the market, of the latter (especially labor).

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[9] The retail prices of chemicals for farm use embodied more labor and were not quite as favorable as indicated by the wholesale index.

These are "extremely lagged effects" which occur in the farm resource structure. Judgment would suggest that it is not easy to identify and measure these in empirical models which must be based on time series observations. While we have some success in later chapters in relating farm resource demand to specific price and behavioral variables, the regression estimates obviously are incapable of measuring these time lags between developments in technology at one point in time and demand quantities of a resource at a later time.

INSTITUTIONAL FACTOR SUPPLY CHANGES

Any discussion of forces related to change in behavior variables would not be complete without reference to policy or institutional considerations. New technology developed through public research investment falls in this category. However, there are many other policy elements which have influenced resource supply and demand quantities and prices.

Two such examples are irrigation and rural electrification, both importantly related to public investment which made them available to farmers at prices greatly increasing their use. From 1935 to 1959, farm consumption of electrical energy increased by 1,500 percent. Total acreage of land irrigated doubled in the 20-year period 1939-1959, with the greatest proportion of this increase coming in the 17 Western States. Without public investment to lower the supply price of these inputs, their farm consumption would be much lower. Similarly, the demand for capital items which serve as technical complements with them would be lower in the regions of their concentration.

In the early history of the United States, public policies kept land price low and labor supply abundant. In more recent decades, however, government policy to lower supply prices of resources has related largely to knowledge retailed through the land-grant colleges and the USDA, to credit furnished by various public agencies, to prices for improved land and crop technology as reflected in professional assistance by the SCS and monetary assistance by the ACP and to irrigation development. More emphatically, however, government policy has attempted to increase the supply price and lower the supply elasticity of resources to agriculture. This element of factor pricing has been reflected through public policy relating to acreage reduction and production control, marketing quotas and federal marketing orders. Benefits of government programs capitalized into land values or payment to a farmer for taking land out of production cause the reservation price of this resource to increase to agriculture.

Various government policies often contradict themselves in respect to factor prices and use. Government subsidy, production and dissemination of knowledge, credit and farm practice payments lower cost or price especially for new capital items. Acreage controls increase the effective price of land in farm production. Theoretically, this change in price ratios is expected to cause a substitution of capital for land and perhaps for some labor. This substitution does take place in some sectors of agriculture. In other cases and locations, the one set of forces causes the relative price of capital to be lowered while a control program such as the Conservation Reserve applied on a partial farm basis lowers the productivity of capital which must be used with a smaller amount of land. To an extent, the two policy elements are expected to cancel one another in their effect on demand quantity. In cases where the latter was dominant, localities and congressmen even asked for cancellation of the Conservation Reserve Act of 1956 which caused whole farms to be withdrawn from production. Withdrawal of land obviously lessened annual purchase of capital items, and local merchants suffered accordingly in retail sales.

In terms of the simple theoretical models illustrated in Chapter 2, we expect any government policy which lowers the supply price of a resource to cause more of this resource and its technical complements to be employed. Hence, government subsidy of land and improvement costs through ACP and SCS payments increases use of certain inputs. Government activity in lowering the supply price of credit tends to encourage capital intensity and to lessen total farm labor input. Similarly, public production and communication of technical knowledge, through the land-grant college and the USDA, serve to increase the demand for new capital inputs, and to decrease demand for previously known resources which serve as substitutes.

Because of rapid economic growth which has increased productivity and decreased supply prices of particular resources, with resources of low reservation price remaining in agriculture, income of agriculture has been depressed. Thus, government policy has been initiated in an attempt to offset these developmental effects by the production controls and resource restraints outlined above.

Institutional variables are specified in the resource demand models in later chapters. Aggregated into a simple crude variable, however, it is not possible to identify the effects of the particular policy elements outlined above. Unlike other "slowly changing variables" such as knowledge and technological change, which are aggregated under time, it is not easy to identify the effects of institutional variables on demand at the national level. This result, perhaps, arises because policy elements are sometimes conflicting in their effect on resource demand quantity, or because incomplete specification causes their effect to be included with that extremely broad set of variables aggregated under time.

5.

Resource Substitutions in Agriculture

CHANGES in agricultural production functions and relative factor prices have had important impact on demand for all specific resource categories in agriculture. In general, capital in its aggregate form has served as a substitute for both labor and land. But, as mentioned previously, the many specific categories of capital have served as substitutes among themselves. For example, as Figure 5.1 indicates, total farm power inputs have been highly stable relative to the substitutions which have taken place between mechanical and farm produced sources. In most of the analysis which follows, we are interested in highly aggregative categories of capital, such as operating inputs and farm machinery. But changes in prices and productivities within these categories, with increase in demand for one specific capital item and decline for another, has had important impact on the organization of agriculture as measured by the size of the work force, the demand of the individual farm for land and hence the size of farms, etc. The "first round" and simple substitution of one specific capital item such as hybrid seed for another such as open-pollinated corn has had the "second round" effect of causing capital in the form of seed to be substituted for labor, and even for land. That is, fewer units of labor and land are needed to

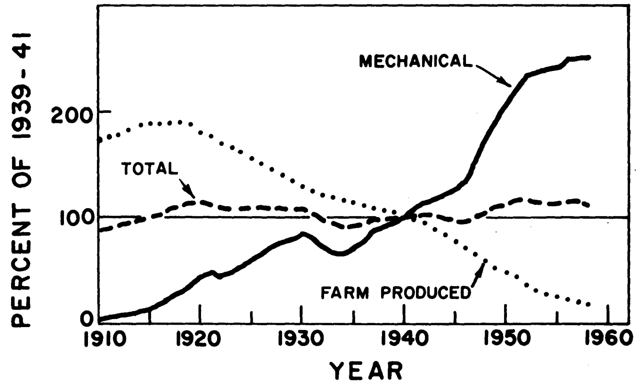

Figure 5.1. Trends in farm power from mechanical, farm-produced and total sources. (Source: USDA.)

produce rather "fixed" quantities of farm products demanded by consumers. The "first round" substitution of mechanical power for horse power has had the "second round" effect of causing machine capital to be substituted for land, as fewer crops were needed for farm production of power and could be diverted more directly to food use. Similarly, the substitution of large-capacity field machines for smaller or horse-drawn equipment also eventually allowed capital to be substituted for labor. But because of the nature of the cost economies involved, and the economic complementarity between machinery and land inputs for the firm, the individual farm demand for land grew, causing the size of farms to increase while the number declined.

BROAD STRUCTURAL CHANGE

If we were to explore fully the forces which have changed the structure of agriculture, we would need to examine all of these particular resource categories. For an over-all analysis of the organization of agriculture, particularly in respect to labor employed and the size and number of farms, this degree of refinement is not necessary. It is of concern, however, to the numerous firms which supply the inputs used by agriculture. The substitution of tractors for horses directly reduced the demand for the product of harness-making firms. The supply price of harness could not be lowered sufficiently to retard the complete mechanization of agriculture, with the result that harness firms either went bankrupt or shifted to other products with higher income demand elasticities in a growing economy. In contrast, the substitution of genetically superior seeds for farm selected ones caused the demand for the products of the commercial seed sector to grow, and probably to decline in price elasticity. Genetic improvement of both crops and livestock have lifted the restraint of the growing plant or animal on production, increasing the potential productivity and demand for insecticides, herbicides, antibiotics and other drugs and chemicals. But this growth in productivity and demand again decreases the amount of land and labor in farming to meet a given food demand quantity for the nation.

In general, an empirical approach which leads to examination of only broad aggregates of resources, or only of the aggregates which have continued to be employed in agriculture, causes us to overlook or misinterpret some of the important structural changes which relate to agriculture. The growth of the agribusiness sector of the economy, particularly firms supplying inputs, is a result of the substitution of some particular capital categories for others, and of capital in aggregate for land and labor in farming. One type of labor skill has been substituted for another as production of tractors replaced production of horses and as energy sources shifted from farm crops to petroleum and electricity. Capital inputs for producing farm resources have shifted from horse barns to tractor factories. In 1910 nearly all power used was produced on farms. But by 1960 less than 10 percent came from this source and over 90 percent came from power produced in the business sector. Demand for college-trained personnel, and the type of training most appropriate, has shifted relatively from primary agriculture to the agribusiness sector which provides a growing proportion of inputs for the farm sector. These are part of the structural changes which surround and relate to agriculture. As in the new combinations of resources used within agriculture as a result of economic development, this shift from the farm to factory production of inputs for agriculture also is largely a function of changing factor prices and technical knowledge or coefficients.

While changes in substitution coefficients directly affect the demand for products of particular firms and sectors which supply inputs to agriculture, the resources of this study do not allow interpretation of them. Instead, we examine and illustrate some substitutions among particular categories of resources. We also examine some of the broad substitutions which have taken place during the period from 1910 to the 1960's as these relate to possible resource savings in meeting the nation's demand for the output of agriculture.

FORMAL SUBSTITUTION ESTIMATES

If accurately specified and aggregated production functions were available over time for the particular crop and livestock commodities of farms operating under specific soil and climatic environments, we could better measure the effect that technological change has had on factor demand and on the product imputable to increase or decrease in specific categories of resources.

Derivation of Substitution Rates for Land

For purposes of national policy and programming, it would be useful if we had definite knowledge of the marginal rates at which capital in its various technological forms, labor in its various skilled capacities and land of various types can and do substitute for each other. Currently, aggregative data cannot be easily "decomposed" to provide these specific quantities. We are, however, able to estimate some gross marginal rates of substitution between certain factors in agriculture under specified conditions. A resource which has served as an effective substitute for both land and labor has been fertilizer. It substitutes for land since a given product can be produced with less land if fertilizer is used on the remaining acreage. It also substitutes for labor in this physical manner: fertilization of an acre boosts yield but increases labor requirement by a very small absolute amount, and as a minute fraction of (a) the total labor used per acre and (b) the relative increase in per acre yield. A given aggregate of product can be thus produced with less labor, as well as with less land.

We examine some gross substitution rates, indicating marginal replacement rates between fertilizer and land where we do not concern ourselves directly with other "minor" capital forms which also are concerned. The purpose is to provide some initial estimates of substitution rates among specific factor categories. The marginal rates of substitution between fertilizer and land are derived from experimental data. They refer to particular soil, climate and other environmental factors. As more data become available, important insight can be obtained on realized and potential substitution rates between resources such as land, fertilizer and labor. This type of information is useful in a developed economy such as the U.S., but especially so for less developed countries where food supply is low and where limited land area restrains production under current technology.

Numerous fertilizer production function studies have been conducted under experimental conditions. These studies show the response in yield per acre when various quantities and mixes of fertilizer nutrients are applied per acre; i.e. land is held constant while fertilizer is varied. Output then is specified as a function of fertilizer alone as in (5.1) where Z is yield and X is fertilizer input per acre. A more exact form of (5.1) is (5.2), where Y is total output, A is acres and F is total fertilizer.

$$Z = f(X) \tag{5.1}$$

$$Y/A = f(F/A) \tag{5.2}$$

Total output per acre (yield) Y/A is a function of total fertilizer input per acre F/A. Multiplying both sides of (5.2) by A, total output is expressed as a function of A acres and F inputs of fertilizer. We illustrate this transformation by a simple algebraic form (5.3) common in production function studies. (The same procedure may be used with other algebraic forms.)[1]

$$Z = a + bX - cX^2 \tag{5.3}$$

$$(Y/A) = a + b(F/A) - c(F/A)^2 \tag{5.4}$$

$$Y = aA + bF - cF^2A^{-1} \tag{5.5}$$

Since Z and X are per acre quantities, (5.3) appropriately is written as (5.4). The per acre production function with land fixed in (5.4), the type of function estimated from an experiment, is transformed to the "long-run" function in (5.5) with total output Y a function of variable land inputs A and total fertilizer inputs F by multiplying (5.4) by A. If the number of acres and the amount of fertilizer are increased by a given

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[1] For a discussion of various algebraic forms of production functions, see Heady, Earl O., and Dillon, John L. Agricultural Production Functions. Iowa State University Press. Ames. 1961.

proportion in (5.5), total output increases by that same proportion. Two hundred bushels of corn can be produced with 2 acres and 100 pounds of fertilizer, or 100 bushels can be produced with 1 acre and 50 pounds of fertilizer. This assumption of constant returns to scale arises from the method of estimating production functions under experimental conditions. The function (5.3) or (5.4) applies to a given acre and, to generalize for A acres as in (5.5), the assumption is that the original conditions are replicated on each additional acre.[2] Thus (5.5) embodies the assumption that each land input contains the "fixed" experimental conditions including temperature, rainfall, soil structure, seed, machinery, etc. Similarly each fertilizer input is accompanied with appropriate labor, machinery and other inputs necessary for applying fertilizer. Under these conditions, constant returns to scale in (5.5) is a reasonable assumption.

The isoquant equation (5.6) is computed by solving (5.5) for A.

$$(5.6) \qquad A = \frac{Y - bF + \sqrt{4acF^2 + (Y - bF)^2}}{2a}$$

The isoquant equation indicates the various combinations of land and fertilizer which will produce a given output Y. Taking the derivative of (5.6) with respect to F, the "gross" marginal rate of substitution of fertilizer for land can be computed. The term "gross" is used because, as indicated above, "fixed" inputs such as seed, machinery, labor, etc., are associated with land A, and "variable" inputs such as additional labor and capital required to apply fertilizer are included with F. The equation defining the marginal rate of substitution in terms of F and A (the negative ratio of partial derivatives with respect to F and A from [5.5]) is given in (5.7). If A = 1, the equation for gross marginal rates of substitution is (5.8).

$$(5.7) \qquad \frac{dA}{dF} = \frac{2cFA^{-1} - b}{a + cF^2A^{-2}}$$

$$(5.8) \qquad \frac{dA}{dF} = \frac{2cF - b}{a + cF^2}$$

Numerous estimated production functions include more than one variable input as in (5.9) where X and Z are different nutrients. Many proportions or mixes, including those which trace out the expansion path, can be derived from such functions.

$$(5.9) \qquad Y = a + bX + cF - dX^2 - eZ^2 + fXZ$$

To reduce the tremendous detail necessary to select the optimum mix

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[2] The procedure does not require that fertilizer be used in fixed proportion to land. By holding A constant in the equations, we can still vary fertilizer and obtain diminishing productivity.

of nutrients for each level of output, a mix is used equal to the proportion of nutrients historically used or recommended in the location where the data are derived. The conversion is as follows where r units of Z are specified for each one of X, or $Z = rX$ to produce one unit of F or fertilizer. With F, X and Z all measured in pound units, a given quantity of fertilizer is composed as in (5.10). Or, the values of X and Z, in terms of F, are those in (5.11) and (5.12).

$$F = X + Z = (1 + r)X \tag{5.10}$$

$$X = \frac{F}{r + 1} \tag{5.11}$$

$$Z = \frac{rF}{r + 1} \tag{5.12}$$

Now, substituting (5.11) and (5.12) into (5.9), we obtain (5.13), with the function defined in terms of a single fertilizer mix. Simplifying equation (5.13), we obtain (5.14), the type of equation used later for deriving marginal rates of substitution of fertilizer for land, when the fertilizer mix is that common to the location of the data.

$$Y = a + \frac{bF}{r + 1} + \frac{crF}{r + 1} - d\left(\frac{F}{r + 1}\right)^2 - e\left(\frac{rF}{r + 1}\right)^2 + f\left(\frac{F}{r + 1}\right)\left(\frac{rF}{r + 1}\right) \tag{5.13}$$

$$Y = a + \frac{b + cr}{r + 1}F + \frac{fr - d - er^2}{(r + 1)^2}F^2 \tag{5.14}$$

Equation (5.14) is still in the form of a "per acre" production function. To incorporate land into the production function, the method in equations (5.3) to (5.8) is used.

Labor Substitution

Since fertilizer also is a substitute for labor, the marginal rate of substitution of fertilizer for labor can be defined somewhat similarly. For purposes at hand, labor and land can be considered as technical complements, with k units of labor used per acre of land. (Under other formulations and aggregations, they are substitutes in producing food supply.) The increment of labor used to apply fertilizer and harvest the added yield is small for U.S. mechanized farming. Hence, land and labor here will be considered as fixed in the proportions $L = kA$ or $A = k^{-1}L$ where L is hours of labor used and k is hours required per acre.[3] Substituting $A = k^{-1}L$ into equation (5.5), the production function

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[3] We could compute substitution rates similarly if we supposed a quantity of labor $L = kA$ as a "fixed requirement" per acre, but also considered the variable labor quantities $L = f(F)$ and $L = g(Y)$ where labor is respectively a function of fertilizer applied and per acre yield. However, since these are small quantities, we do not add the details here.

in (5.15) is obtained where output is a function of the amount of labor and fertilizer used, based grossly on simple experiments.

$$Y = ak^{-1}L + bF - ckL^{-1}F^2 \tag{5.15}$$

The isoquant equation of the gross marginal rate of substitution of fertilizer for labor is (5.16).

$$\frac{dL}{dF} = \frac{2ckL^{-1}F - b}{ak^{-1} + ckL^{-2}F^2} \tag{5.16}$$

Since labor and land are considered to be technical complements here, the labor quantities (5.15) and (5.16) are always associated with $k^{-1}A$ units of land.

Empirical Estimates of Substitution of Fertilizer for Land

As mentioned above, the substitution rates derived are not predictions of those which have existed in the history of U.S. agriculture. Instead, they represent substitution rates under the specific natural and environmental conditions of the data and thus refer to a specific set of physical potentials. The sample of functions is not necessarily typical or representative for the nation in respect to soils, weather and similar phenomena. Our purpose is not to predict for time and the nation, but to indicate potential fertilizer/land marginal substitution rates under particular conditions. In relation to bias in estimating substitution rates under actual farm conditions, the physical considerations discussed in Chapter 6 for static demand functions also apply here.

All estimates are for corn. Derivation of gross marginal rates of substitution are made for the following soil types, years and nutrients: (a) Iowa Clyde soils for K and P in ratio 1:2 as an average over 1950, 1953 and 1956; (b) Mississippi Experiment Station soils for N as an average for the years 1921, 1926, 1931, 1936 and 1941; (c) Kansas Verdigras soil for nitrogen in 1958; and (d) North Carolina Coastal Plain soils for nitrogen in 1957.[4] For convenience, only two isoquants are considered for each state and soil, both isoquants representing a yield level attainable on a single acre (but not restricted to an acre as a fixed input magnitude). The isoquant levels for each state and soils are those falling at the yield level (a) a quarter of the way up the production surface due to fertilizer response and (b) three-quarters of the way up.[5]

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[4] In the order given, the basic production functions are reported in (a) Iowa Agr. Exp. Sta. Bul. 424; (b) Tramel, T. Fertilizer Response Functions at Stoneville, Miss. Ph.D. Thesis, Iowa State University; (c) Kansas Agr. Exp. Sta. Bul. 94; and (d) North Carolina Agr. Exp. Sta. Bul. 126.

[5] If an experiment shows a yield of 40 bushels without fertilizer but the experimental inputs carried yield to a maximum of 56 bushels, the response is 16 bushels. Hence, our first isoquant is at 40 + 4 = 44 and the second is at 40 + 12 = 52 (the first having 1/4 and the second 3/4 of response added to the constant).

An example of the empirical quantities is provided below where (5.17) is the production function, (5.18) is the isoquant and (5.19) is the equation indicating gross marginal rates of substitution from the Iowa data.

$$Y = 35.6A + 1.40F - .015A^{-1}F^{2} \tag{5.17}$$

$$A = -.02F + .014\left[Y + \sqrt{2.147F^{2} + (Y - 1.404F)^{2}}\right] \tag{5.18}$$

$$\frac{dA}{dF} = \frac{.030A^{-1}F - 1.404}{35.60 + .015A^{-2}F^{2}} \tag{5.19}$$

Similar equations were derived for the other three locations. The resulting data for isoquants and marginal rates of substitution are given in Tables 5.1 and 5.2. For a 33.8 bushel isoquant in Mississippi the isoquant is represented by the fertilizer quantities under F and the land quantities under A, starting with 1.13 acres. The Mississippi isoquant

Table 5.1. Isoquants and Gross Marginal Rates of Substitution Between Land (A) and Fertilizer (F) Nutrients for Iowa and Mississippi

Lb. F	Iowa				Mississippi			
	43.8 bushels		60.1 bushels		33.8 bushels		41.6 bushels	
	A	MRS	A	MRS	A	MRS	A	MRS
0	1.23	-.0394	1.69	-.0394	1.13	-.0171	1.39	-.0171
10	.88	-.0283	1.33	-.0323	.98	-.0138	1.23	-.0145
20	.69	-.0109	1.06	-.0204	.86	-.0095	1.10	-.0112
30	--	--	.92	-.0082	.79	-.0049	1.01	-.0074
40	--	--	.88	-.0005	.76	-.0016	.96	-.0038
50	--	--	--	--	--	--	.94	-.0010

Table 5.2. Isoquants and Gross Marginal Rates of Substitution Between Land (A) and Fertilizer (F) Nutrients for Kansas and North Carolina

Lb. F	Kansas				North Carolina			
	73.8 bushels		82.6 bushels		42.4 bushels		76.9 bushels	
	A	MRS	A	MRS	A	MRS	A	MRS
0	1.06	-.0045	1.19	-.0045	1.69	-.0302	3.06	-.0302
20	.98	-.0037	1.11	-.0038	1.11	-.0293	2.47	-.0287
40	.92	-.0027	1.04	-.0030	.68	-.0158	1.92	-.0258
60	.88	-.0016	.99	-.0019	.49	-.0043	1.45	-.0128
80	.85	-.0006	.96	-.0010	.45	-.0002	1.12	-.0063
100	--	--	.95	-.0003	--	--	.93	-.0025
120	--	--	--	--	--	--	.85	-.0005

for a 41.6 bushel yield is represented by the quantities under F at the left and under A, starting with 1.39 acres. The corresponding marginal rates of substitution (MRS) are in the columns. Similar isoquants, over their negative sloped portion, and MRS data for two yield levels are defined for each set of data.

A 42.4 bushel output is obtained for the North Carolina soil location with 1.69 acres of land and no fertilizer, 1.11 acres of land and 20 pounds of fertilizer, .45 acre of land and 80 pounds of fertilizer, etc. With the combination of 20 pounds of fertilizer and 1.11 acres of land for a 42.4 bushel output, a pound of fertilizer substitutes for .0293 acre of land. Hence, a ton of fertilizer nutrients spread similarly over more acres is estimated to substitute for 58.6 acres of land (i.e., 2,000 x .0293). With 60 pounds of fertilizer nutrients and .49 acre to produce 42.4 bushels, a ton of fertilizer nutrients substitutes for 8.6 acres of land. At the combination of 40 pounds of fertilizer nutrients and .96 acres to produce a 41.6 bushel output for the Mississippi data, a ton of fertilizer nutrients substitutes for 7.6 acres of land. For Iowa a ton of fertilizer nutrients substitutes for 56.6 acres of land when the combination is 10 pounds of nutrients and .88 acre of land to produce a 43.8 bushel output. However, when .88 acre of land and 40 pounds of fertilizer is used to produce a 60.1 bushel output, a ton of fertilizer substitutes for only 1.0 acre of land.

Corresponding differences also are obvious for other isoquant combinations which involve approximately the same land input (as 1.11 and 1.12 acres for the two yield levels of North Carolina). For the data shown in Kansas, the marginal rates of substitution vary from the equivalent of a ton of fertilizer for 9.0 acres of land (starting from zero fertilizer and 1.06 acres of land to produce a 73.8 bushel output) to a ton of fertilizer for .6 acre (100 pounds of fertilizer and .95 acre to produce an 82.6 bushel output).

Obviously, the gross marginal rate of substitution of fertilizer nutrients for land varies with the soil type, rainfall, crop, climate and other environmental factors — as well as with the ratios in which fertilizer and land are combined under any unique combination of these factors. As an average for all isoquant combinations of the four locations shown in Tables 5.1 and 5.2, the gross marginal rate of substitution of fertilizer nutrients for land is .0118 or a ton of nutrients for 23.6 acres of land. (This average of the MRS's has no weighted or predictive value, but is mentioned as a summary illustration.) The MRS value ranges from .0002 (a ton of fertilizer for .4 acre of land) with 80 pounds of fertilizer and .45 acre of land to produce 42.4 bushels of output in North Carolina, to .394 (a ton of fertilizer for 67.8 acres of land) starting at zero level of fertilization in Iowa. The rate at which fertilizer substitutes for land also varies with the level of fertilization of each acre of land.

As we mentioned previously, these are "gross" marginal rates of substitution in the sense that resources which complement fertilizer and land also are involved. For example, x tons of fertilizer which might replace z acres of land in meeting a given level of food requirement also would allow less machinery to be used for a smaller acreage. Less labor also would be required since a given output produced on fewer acres with a higher per acre yield requires less labor than the same output on more acres with lower yield. Hence, a single major factor seldom is substituted for a single other factor in agriculture. However, the "gross" marginal rates of substitution of fertilizer (as a technology and resource) for land are of importance or relevance. Given a favorable supply price for the "fringe" resources which complement either fertilizer or land, national policy or planning still is concerned about the rate and extent to which a major resource such as fertilizer can substitute for a "fixed" resource such as land.

Substitution of Fertilizer for Labor

Using average labor requirements per acre of corn as reported by the USDA for 1959, we now estimate marginal rates of substitution between fertilizer nutrients and labor. The marginal rates of substitution are obvious from previous equations and data. Here we refer to labor which is associated marginally with land, in the sense that if we replace an acre of land by fertilizing remaining acres at a higher level, we also displace the constant quantity of labor required to handle the "displaced" land. As a given output is produced by diverting some land from production and producing more on fewer acres at a higher yield, some of the displaced labor (attached to the displaced land) is offset by the added labor required to harvest and handle the higher yield on the remaining acres, as well as by some added labor for applying the fertilizer. However, under U.S. mechanized farming, the incremental labor to apply the fertilizer and harvest the greater yield is trivial and can be neglected in aggregative importance (or can be recognized in the sense that the substitution rates we present in Table 5.3 for Iowa and Kansas are slightly greater than the actual "net" rates).

Again the rates of substitution of fertilizer for labor depend on environmental conditions at each location, as well as the proportions in which labor and fertilizer are combined (i.e., the per acre rate of fertilization). With 20 pounds of fertilizer for the Kansas data, 5.60 hours of labor are required to produce 73.8 bushels, while 6.32 hours are required for 82.6 bushels. The corresponding marginal rates of substitution are 1 pound of fertilizer for .021 hour of labor in the former and .022 hour of labor in the latter case. Starting from zero level of fertilization for the Iowa data, 1 pound of fertilizer substitutes for .304 hour of labor. With 40 pounds of fertilizer and 6.78 hours of labor (and also the .96 acre of land in Table 5.1) to produce 60.1 bushels in Iowa, a pound of fertilizer substitutes for only .004 hour of labor. Put on the basis of the equivalent of a ton of fertilizer, these two extremes in Iowa represent the substitution of a ton of fertilizer for 608 hours and 8 hours of labor, respectively. In other words, at the first

Table 5.3. Isoquants and Marginal Rates of Substitution for Fertilizer Nutrients and Land for Iowa and Kansas Data

	Iowa				Kansas			
Lb.	43.8 bushels		60.1 bushels		73.8 bushels		82.6 bushels	
F	L	MRS	L	MRS	L	MRS	L	MRS
0	9.47	-.304	13.00	-.304	6.04	-.026	6.78	-.026
10	6.44	-.213	8.70	-.246	--	--	--	--
20	3.42	-.006	8.16	-.154	5.69	-.021	6.32	-.022
30	--	--	7.08	-.062	--	--	--	--
40	--	--	6.78	-.004	5.24	-.015	5.93	-.017
60	--	--	--	--	5.02	-.012	5.64	-.011
80	--	--	--	--	4.67	-.009	5.47	-.006
100	--	--	--	--	--	--	5.46	-.002

combination, a ton of fertilizer nutrients substitutes for 76 eight-hour days of farm labor. In the second case, on the "gross" basis described earlier, a ton substitutes for one day. For the Kansas data, the range is 6.5 to .5 days of labor replaced by a ton of fertilizer nutrients.

While the data above are for experimental conditions and may somewhat overestimate the rate at which fertilizer substitutes for land and labor, the marginal replacement rates obviously are high. Of course, as mentioned in earlier chapters, the individual farmer does not buy more fertilizer and use less land, as he might in the case of machinery and labor. He purchases the fertilizer and uses it on a given land area. In an aggregate sense and over time, however, fertilizer does become a substitute for these two resources (and their technical complements in producing an acre of crop) since the given output can be produced with fewer acres. Trends in the use of more fertilizer, connected with the substitutability for land, and government policies which kept land in production, contributed to surpluses and public stocks over the previous decade.

These rates are for corn and would not necessarily apply to a random sample of farms or to other crops and locations. Yet they illustrate the magnitude that substitution rates may take as a capital technology is substituted for land and labor. Other innovations or capital technologies serve as similar substitutes. For the United States, Thompson et al. estimated that 40 percent of the per acre increase in corn yield between 1940 and 1958 was due to improved seed and 34 percent to fertilizer.[6] On this basis, the capital associated with use of improved seed and fertilizer on one acre would substitute on the average for around .6 acre of other land. In other words, approximately 1.6 acres of land under the technology of 1940 was necessary to produce as

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[6] Thompson, L. M., et al. Some causes of recent high yields of feed grains. Proceedings, Feed and Livestock Workshop. Center for Agricultural and Economic Development Special Report No. 24. Ames, Iowa. 1959.

much as one acre under the technology of 1956. Even if yields are discounted somewhat due to favorable weather in the latter year, these estimates would indicate that few pounds of improved seed and perhaps less than 30 pounds of fertilizer nutrients (and the capital used with them and in developing and supplying them) per acre substitute, in an average context, for .5 acre of land. In other terms, the use of 30 percent less land and 25 percent less labor than otherwise would have been necessary to produce the nation's 1958 corn output. To these substitution rates for capital which relate to feed grains must be added those which relate to livestock production. The increase in gain per bird or animal illustrated in Chapter 4 from various new capital technologies also allows a given output to be produced (since less feed is required) from a smaller input of land and labor. These substitutions take place in the farm production process, as a result especially of new knowledge defining the relative productivities and profits of the new capital forms.

Substitution of Water for Land

Table 5.4 indicates yield isoquants and marginal rates of substitution of water, W, for land, L, in production of corn. The left side of Table 5.4 is based on the judgment production function (5.20) for Colorado.[7] W is acre-inches of irrigation water but also includes fertilizer

Table 5.4. Isoquants and Gross Marginal Rates of Substitution Between Irrigation Water and Land for Colorado and Indiana

Inches of water W	Colorado				Indiana			
	24.8 bushels		74.3 bushels		32 bushels		95 bushels	
	A	MRS	A	MRS	A	MRS	A	MRS
3					.274	-.0687	--	--
4					.252	-.0000	--	--
5					.261	.0134	--	--
5.25	.258	-.0698	--	--				
5.50	.251	-.0108	--	--				
5.75	.250	.0035	--	--				
10					--	--	1.1733	-.2837
12					--	--	.9937	-.0267
14					--	--	.9742	.0017
16	--	--	.763	-.0357				
16.5	--	--	.752	-.0108				
17	--	--	.750	.0000				
17.5	--	--	.752	.0063				

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[7] Whittlesey, Norman K. Valuing Irrigation Water in the Uncompaghre Project. Unpublished M.S. Thesis. Library, Colorado State University. Fort Collins. May 1960.

in amounts appropriate to make application of water feasible. The right side of Table 5.4 is based on production function (5.21) which was derived from an irrigation experiment on Fox Sandy Loam Soil, Sullivan County, Indiana, in 1956.[8] The stand and fertilizer levels were fixed at their respective means and W refers to acre-inches of irrigation water.

$$Y = -203 + 26.64W - .5878W^2 \tag{5.20}$$

$$Y = -238 - 23.25W + 184.27W^{1/2} \tag{5.21}$$

The highly negative intercepts in (5.20) and (5.21) indicate that appreciable inputs of water are required to make Y greater than zero.

The isoquants and marginal rates of substitution in Table 5.4 are derived by the same steps outlined in (5.1) to (5.7). The relevant economic range, where the isoquants have a negative slope and the MRS is negative, is narrow for both areas. According to Table 5.4, inputs of water must be considerably greater than zero before the relevant economic range is approached because of the negative intercepts in (5.20) and (5.21). That is, neither land nor water can produce corn without the other input and the relevant land/water ratio is narrow. Output of 74.3 bushels of corn can be produced, for example, with 16 acre-inches of water and .76 acre of land in the Colorado location. The application rate per acre is 16/.763 = 21 acre-inches. Because of the properties of the production function (5.20), water must be applied at approximately this rate for maximum efficiency. The gross marginal rate of substitution of water for land when W = 16, A = .76 is -.0357. One hundred acre-inches of water substitute for 3.57 acres of land, or 1 acre of land substitutes for 28 acre-inches of water. If 17 acre-inches of water and .75 acre of land are used to produce 74.3 bushels of corn, an additional acre-inch of water does not substitute for any land.

The Indiana data show that 95 bushels of corn can be produced with approximately 1 acre of land and 12 acre-inches of water. When A = 1.17 and W = 10, the Indiana data show that 1 acre-inch of water will substitute for approximately 1/4 acre of land, i.e. MRS = -.28. Opportunities for substituting water for land diminish rapidly as with the Colorado data. The corn yield isoquant slopes upward when W = 14 and Y = 95 for the Indiana data.

Table 5.4, while not necessarily representative nor a random sample of production units, gives a crude indication of the potential corn production from irrigated acres. Nelson estimates that about 18 million acres of potentially irrigatable land remains in 17 Western States, and approximately 29 million acres in the East.[9] Although these acres conceivably could be irrigated if necessary, expansion of irrigation on

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[8] Kadlec, John, Smith, LaVon and Niehouse, Ralph. Authors, Unpublished work sheets. Department of Agricultural Economics, Purdue University. Lafayette, Indiana. 1962.

[9] Nelson, L. B. Physical potentials for crop production. Chap. 8. In Iowa State Center for Agriculture and Economic Development. Dynamics of Land Use — Needed Adjustments. Iowa State University Press. Ames. 1961.

these acres is likely to come slowly, the actual rate depending on food prices resulting from population pressure and other sources. Under certain assumptions Nelson estimates that irrigated acreage in the West will be 11.2 million acres greater, in the East 4.7 million acres greater, by the year 2000. If, as implied by functions (5.20) and (5.21), this added land without water is unproductive but will yield 100 bushels per acre with from 15 to 25 acre-inches of water and appropriate fertilizer, the potential for increasing corn output is very great (roughly one-third of the current total corn output). However, the potentials thus derived may not be meaningful for the additional acreages because: (a) irrigation would need to be extended to units less suited and less responsive than the above to irrigation water, (b) the most limiting resource may be water and management, rather than land and (c) many of the added acres would be used for crops other than corn.

The foregoing estimates of yield isoquants and marginal rates of substitution indicate how technologies and capital such as fertilizer and irrigation water substitute for land and labor. The estimates characterize some of the changes which have already occurred in agriculture but also are indicative of sizeable opportunities for increases in output per unit of labor and land in the future.

All data indicate that opportunities for substituting capital and technology for conventional resources offer considerable future promise for further increasing the productivity of land and labor.[10] The foregoing estimates are largely normative, indicating what "could be." We now examine some aggregate measures of actual substitutions which have taken place in the resource mix of agriculture.

HISTORICAL SHIFTS AND SUBSTITUTIONS IN THE AGGREGATE AGRICULTURAL PRODUCTION FUNCTION

As mentioned in Chapter 3, broad estimates for the nation suggest that yield increases per annum for all crops in the United States over the last several decades came 10 percent from hybrid corn, 45 percent from fertilizer, 6 percent from irrigation and 37 percent from improved seeds, cultural practices and similar innovations. In majority these several sources represent new resources activated in the nation's agricultural production function for crops. In earlier decades the existence of many of these specific capital items was not known and the productivity coefficients of others were not yet established. In a rough manner these data suggest the rate at which knowledge of change in productivity coefficients have been communicated to farmers, and adopted by them. The rate of adoption of new resources is conditioned

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[10] Estimates of future potential for increasing crop output from use of fertilizer and irrigation are found in Nelson, L. B. Physical potentials for crop production. Chap. 8; and Ibach, D. B. Economic potentials of agricultural production. Chap. 9. In Iowa State Center for Agriculture and Economic Development. Dynamics of Land Use – Needed Adjustments. Iowa State University Press. Ames. 1961.

by the institutional, psychological and economic restraints. New and improved inputs would not have been adopted had their supply price been prohibitive, but neither would they have been adopted had they or their productivity coefficients been unknown.

The entire physical production function, and knowledge about it, can be represented as in (5.22) where there are n possible resources of specific form. Each seed variety, for example, represents a different X_i, as does water at different times of the year, various types of machines, power, fertilizer, labor, soil type, etc.

$$(5.22)\quad Y = f(X_1, X_2, \ldots X_g, X_{g+1}, \ldots X_h, X_{h+1}, \ldots X_k, X_{k+1}, \ldots X_n)$$

At one extreme are those resources represented by $X_{k+1} \ldots X_n$ the existence of which is not yet established. Fundamental research is required to establish them. In the next category are capital or material items $X_{h+1} \ldots X_k$ of which the existence is known but the productivity coefficients have not been established. Technical research is required to establish or extend knowledge of their productivity. Inputs included in the category $X_{g+1} \ldots X_h$ are those in which productivity is known and are used in the production process to the extent that their output coefficients and prices are favorable. In category $X_1, \ldots X_g$ are resources which have been released from the production process because their productivity is low relative to their own price and that of substitute resources. In the latter category are oxen power, open-pollinated corn, threshing machines and other resources of an earlier era in U.S. agriculture. The pricing structure is important in moving resources from the second to the first category of resources, but technical knowledge is basic in moving them from the fourth to the third and from the third to the second categories. Certainly this has been an extremely powerful force in causing the productivity of U.S. agriculture to grow as specific categories of resources have been substituted for others.

Data availability does not allow refined estimates of marginal productivities for all major new forms of capital developed in recent decades. Neither do we have aggregate production functions estimated over time which allow us to make "safe" predictions for broad aggregates of resources. From the production functions in Table 4.1 we can derive the estimate (from equation 4.1) that the marginal rate of substitution of operating inputs, Q_O, for real estate, Q_{RE}, increased from 1.04 in 1930 to 3.11 in 1959. While these are realistic substitution quantities in terms of the more specific examples cited in the previous section, we prefer to use more aggregative and less refined estimates based on other data.

The quantities in Table 5.5 show the annual inputs of resources for U.S. agriculture in 1910 and 1960. The last column shows resource requirements had the technology of 1910 been projected to 1960, with the output in the latter year composed of the same mix of outputs and produced with the same mix of inputs as in the former year. The 1960 output level is assumed, corrected slightly for weather (with 1960 output

Table 5.5. Annual Input Quantities, Resource Stocks and Employment, 1910, 1960 and 1960 Projected on 1910 Technology and Mix*

Annual input or resource	1910 Actual	1960 Actual	1960 Required With 1910 Mix and Technology
		(million 1947-49 dollars)	
Farm labor			
Value	15,016	6,866	30,783
Hours	22,547	10,310	46,181
Real estate	3,408	3,750	6,986
Machinery and power	1,109	5,557	2,273
Fertilizer and lime	166	1,561	340
Plant nutrients (1000 tons)	856	7,571	1,754
Livestock inputs	624	903	1,280
Crop inputs	379	623	777
Operating capital	116	306	248
Miscellaneous inputs	732	1,307	1,500
All inputs	20,643	25,292	42,318
Employment and physical stock (1947-49 dollars)			
Labor employment (mil.)	13.6	7.1	27.9
Horses and mules (mil.)	24.2	3.0	49.6
Tractors (1000)	1	4,780	2.1
Cropland (mil. acres)	330	356	677
Real estate (mil. $)	56,065	65,825	114,933

*USDA Statistics. For the general source, see Loomis, R. A., and Barton, G. T. Productivity of agriculture. United States, 1870-1958. USDA Tech. Bul. 1328. 1961. Taxes are included in all inputs. Without taxes, the quantities for all inputs are, respectively, for the three columns: 20,141; 23,987; 41,289.

equal to 2.05 times 1910 output). The same relative mix of inputs would be continued over time only if the production function were fixed and one with linear isoclines passing through the origin of input space, relative product and factor prices remained unchanged, the supply elasticity of factors remained constant among resource categories and consumer demand held commodities in fixed proportions in respect to quantities and qualities. None of these conditions has prevailed exactly, and they would not have even in the absence of economic development and a perfectly elastic land supply. Hence, the last two columns tend to distort changes in resource mix or structure which have occurred in comparison to those which would have prevailed in the absence of technological change. Despite this, the data generally do suggest absolute changes which have taken place in resource structure. Under the assumed conditions, the substitution of technologically improved capital for conventional input has resulted in "savings" of annual inputs approximating $17 billion. (The figures are perhaps conservative because the mix of products consumed has higher resource requirements than the commodity mix consumed in 1910.) If we take the differences between the last two columns as a basis of comparison of "increments" and "decrements" to produce the 1960 output, the data show that $10,380 million in annual machinery, power (4.6 million tractors), fertilizer and lime, and operating inputs substituted roughly and in aggregate for an annual input of $193 million in miscellaneous inputs, 20.8 million persons employed, 347 million acres of cropland, 46.6 million horses and mules and $49,108 million of physical real estate stock. Or, the $10,380 million in annual inputs of the first category substituted for $27,817 million in annual inputs of the second category. (The "increments" and "decrements" again are comparisons between columns 3 and 4.) Even discounted to a quarter or a half of these quantities, the magnitudes of substitution have been large and it has been possible to effectively save much labor, land and farm-produced capital through extension of the first category of inputs.

Without change in technical knowledge, the resource mix would not have remained at the 1910 proportions. For one thing, the supply price of factors would have changed relatively. Land with a low supply elasticity would have increased greatly in price and substitutions would have been made through fertilizer, higher seeding rates, more intense applications of labor, irrigation developments and similar extensions of conventional inputs in the context of a given knowledge and production function. Output also would have been lower, with a higher price for farm commodities and absence of surplus stocks. Even extension of inputs with a given production function would have caused the proportions of resources to change from the 1910 standard since the isoclines of the aggregate production function in agriculture are not linear through the origin. A likely hypothesis is that the configuration of this isocline would have taken the input mix proportionately more in the direction of fertilizer and irrigation capital, and less in the direction of farm machinery, nonfarm energy, general operating inputs and buildings. (This is comparison with the 1910 mix projected to 1960 under implied assumptions of linear isoclines through the origin of the input plane.)

In this chapter we have shown some substitution rates among resources as they relate to some highly micro relationships, resource categories and samples, and to some highly aggregated categories for the over-all farm sector.[11] The estimates are examples of substitution potentials in agriculture. They do not explain the behavior of farm entrepreneurs in demand for resources relative to changes in explanatory variables. In later chapters we estimate demand for numerous

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[11] With more success in formal estimation of aggregate time series production functions such as those attempted in Table 4.1, we could similarly derive static aggregate factor demand and product supply relations. For the numerous reasons discussed elsewhere (multicollinearity, data and specification biases, changes in factor form and quality, etc.), we are not able to do so with any reasonable degree of reliability.

aggregates of resource inputs in relation to factor prices and imperfect indices of technical change. However, before we examine these, we now turn to estimates of static factor demand and product supply functions and elasticities based again on a restricted sample of data and resource categories. We make these specific examinations, partly to offset the "overly broad" categories and aggregate relationships of later sections but more particularly to provide knowledge of potential factor demand elasticities and conditions as they relate to a restricted type of physical production function. As is illustrated elsewhere in this study, farmers' resource demand response rests not only on technical coefficients but also on prices, objective functions, psychological settings, equity position and others.

6.

Static Fertilizer Demand and Corn Supply

THIS CHAPTER examines short-run static demand functions for a particular resource fertilizer. The demand functions are static relationships derived from technical production functions, hence the demand parameters do not measure or reflect the actual behavior of farmers. The term "static" is used since the functions are derived to indicate demand quantities for various commodity and factor prices when it is supposed that these prices and the production function are known with certainty. That is, factor demand is derived in the manner of the algebraic illustrations and theory in Chapter 3.

Useful information about the level and elasticity of factor demand has important implications for farm policy proposals. One policy question posed is: How far would a return to free market prices or lower support prices reduce farm output, particularly that of feed grains? Adjustment to lower factor prices could come from either or both a shift in land out of the specified crops and less intensive production of the same crops on land remaining in production. The less intensive production would result as fewer inputs such as fertilizer are used on each acre.[1] Of course, a counterpart question is: Would further decreases in the real price of a resource such as fertilizer add as much to economic development (the use of more capital with given or less land and labor, with an extension of relative commodity supply) as it has in the decades of 1940-60? The answers to both questions depend on the elasticity of demand for the specified resource with respect to its own price, and its cross elasticity of demand with respect to commodity price. The commodity will be similarly related to the supply elasticity with respect to its own price, and the cross elasticity with respect to factor price. Accordingly, commodity supply functions, paralleling the factor demand functions, also are derived in this chapter.

The static demand and supply functions are not derived for national

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[1] We are aware that most farmers do not use a resource such as fertilizer to a point where marginal cost equals marginal revenue. Hence, a decline in commodity price need not give rise to per acre adjustment of resource use in the magnitude suggested by short-run static demand functions of the nature derived in this chapter. On the other hand, we believe that if our static demand functions prove to have low elasticity in relevant ranges, the actual farm demand functions will equally have low elasticity.

or regional or state aggregates. Rather they are functions derived for a single acre, if input-output and price ratios are known and the objective were actually that of maximizing profits. The writers are well aware of the difference between these functions and those which arise from behavioral relations of farmers, and between these functions and the ones derived in later chapters.[2] They are aware of the fact that not all farmers are in a position to maximize profits and that many of them maximize other objectives. It also is known that, in fact, resources other than fertilizer are involved and that the production functions used in this study do not represent a random sample from the "population" of production units. Other cautions could be voiced. Yet, we consider the empirical derivations to be useful. No previous estimates have been derived, showing the possible relation of factor demand and product supply to physical production functions. They provide some unique insights into factor demand, not obtainable from later chapters based on time series data. Similarly, we believe that these functions are not, and will not be, unrelated to farmers' decisions and resource use. The functions derived are extremely micro, short-run, normative, physically oriented, or whatever else the reader may wish to call them. Still, they do show the potential structure of fertilizer demand and corn supply for the particular locations and environmental conditions under which the basic production functions were derived. The terms "long run" and "short run" as used in this chapter have an entirely different meaning from the same terms used in later chapters.

This chapter relates agricultural technology, as expressed in production functions estimated from experimental data, to the market phenomena of factor demand and product supply. The objective is to examine the nature of corn supply and fertilizer demand functions for a within-season period. The functions specify the yield component of demand or supply elasticity, or the supply elasticity assuming corn acreage is fixed and fertilizer is the variable resource. The analysis may be termed normative since the functions indicate what the supply and demand would be, based on production functions derived from fertilizer experiments, if farmers maximized profits under conditions where capital, institutional and behavioral restraints are unimportant. Such normative concepts are referred to simply as "static supply" and "static demand." Because farmers operate in a dynamic world in which prices and input-output relationships are not known with certainty and because the physical conditions on farms do not entirely parallel experimental conditions, the static supply and demand elasticities estimated in this study do not entirely parallel quantities expressed in the market and estimated in later chapters as aggregate behavior relations. Analysis of these differences suggests that the elasticity estimates in this study represent the upper boundary of the

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[2] These and other considerations are discussed in Tweeten, Luther G., and Heady, Earl O. Short-run corn supply and fertilizer demand based on production functions derived from experimental data; a static analysis. Iowa Agr. Exp. Sta. Res. Bul. 507. June 1962.

actual short-run supply and demand elasticities. As such, the estimates indicate the maximum short-run production response which might be expected from farmers to changes in price for a given range of factor/commodity price ratios.

Ten production functions fitted to experimental data obtained in Iowa, Kansas, Michigan, North Carolina and Tennessee provide the basis for inferences about static supply and demand curves and elasticities. Because the sample of physical production functions is small, no attempt is made to aggregate functions and to infer quantitative results for U.S. agriculture. Instead, the procedure in the empirical section is to examine the degree of consistency of the estimated quantities with certain hypotheses suggested by economic and agronomic theory. The results of the analysis are consistent with the possible hypothesis that short-run static fertilizer demand and corn supply, in the framework of this chapter, are highly inelastic for farmers using average or profit-maximizing quantities of fertilizer. For all soil and weather conditions, and for all prices considered later, static corn supply elasticity is low. Without exception, supply is inelastic for corn prices over 40 cents per bushel and current fertilizer prices. The supply elasticity ranges from zero to less than .3 for corn prices above $1 and from zero to less than .2 for corn prices above $1.20 per bushel. Supply tends to be most elastic in situations where the soil is low in fertility but is otherwise satisfactory for corn production, i.e., adequate rainfall, good soil structure, etc. The analysis supports the hypothesis that considerable variation in supply elasticity exists among soil types and years within a given area such as Iowa.

The study shows that static corn supply and fertilizer demand elasticities increase as the price of corn falls or fertilizer increases. Because of limited data, demand and supply elasticities estimated for historic results of actual response by farmers to price changes generally consider the elasticity to be single valued. Thus, normative models of the type used in this study, which provide information on supply outside the range of historic data, are a useful supplement to descriptive or positive supply analysis which follows later. Static factor demand tends to be more elastic than static product supply as derived in this chapter. The price elasticity of short-run demand for nitrogen, for example, lies between .2 and 1.7, with the exception of one soil, when the price of nitrogen is .13 per pound. The demand for K_2O is more elastic than the demand for P_2O_5 which, in turn, is more elastic than the demand for nitrogen.

FRAMEWORK OF ESTIMATES

This chapter deals with supply and demand relationships for an extremely short-run period and for a single product and a restricted set of resources. More specifically, it provides estimates for normative supply functions for corn and normative demand functions for fertilizer as these are expressed in controlled experiments. The "length of run" considered supposes land and other resources to be fixed while only fertilizer is considered to be variable. Product supply functions and factor demand functions then are derived from the physical production functions estimated under experimental conditions. The general purpose of this approach is to determine whether potential response in production of a particular crop and use of a particular resource might be large or small, per acre, in relation to price changes.

Empirical supply and demand functions are derived separately for each year and location of the experiments explained later. No attempt is made to aggregate the functions or generalize the results for U.S. agriculture. Only corn-fertilizer production functions estimated under dryland conditions are used in this study for several reasons. First, a number of such functions have been fitted which represent various soil, moisture and other conditions influencing parameters of product supply and factor demand. These functions provide a more meaningful foundation for analysis of supply and demand than do the very limited number of functions fitted for other farm products and factors. Second, fertilizer inputs primarily determine the short-run (fixed acreage) corn supply response within the control of farmers. Agronomic experiments indicate that it is possible to increase corn yields by as much as 50 percent or more by application of fertilizer.[3] The opportunity within a year for farmers to adjust corn output per acre depends largely on fertilizer application. A third reason for selection of corn-fertilizer production functions is the importance of corn supply in the feed-grain surplus and the possible effect that various price policies might have on feed input and quantity of resources used. Although corn output is potentially responsive to fertilizer, farmers do not base production decision on physical possibilities alone. Their action is determined by a complex of conditions including input-output and price ratios, behavioral and institutional factors. For purposes of this chapter, we define short-run supply of a farm product as the various quantities which farmers would produce at all possible prices (a) if they maximized profits, given the production function and prices of inputs and outputs and (b) all factors but fertilizer (and its technical complements) were fixed. In subsequent sections of this chapter, this concept of short-run supply of a farm product is called "static supply."

A distribution of production functions exists for the various soil, technological and weather conditions found on farms throughout the country. The production functions contained in this study were estimated under experimental conditions where the variety, soil type and weather were "fixed." That is, each production function was estimated with various levels of fertilizer, but with given moisture, soil, seed variety, etc. These fixed conditions were probably more favorable for use of fertilizer than conditions found on most farms because:

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[3] Heady, Earl O., Pesek, John T., and Brown, William G. Crop response surfaces and economic optima in fertilizer use. Iowa Agr. Exp. Sta. Res. Bul. 424. 1955. p. 304.

(1) experiments are likely to take place on soils where yields are responsive to fertilizer and (2) experimental data showing little or no yield response from fertilizer are often not published. Hence, the production functions cited in this study probably represent an above-average response to fertilizer (above-average marginal product of fertilizer) in terms of the total distribution of functions on farms.

There appears to be little clear a priori basis for expecting demand and supply elasticities computed from data showing above-average yield response to overestimate or underestimate static supply elasticity on farms. The elasticity is influenced by experimental conditions through a base effect and a slope effect. The base effect is due to the position of the static supply or demand curve, given the slope. If static supply is estimated under more favorable moisture or other conditions than found on farms, the actual demand and supply curves are likely to "lie further to the left" than are the static curves. Assuming the slopes are the same, the elasticity of the farm static supply or demand curve is underestimated. That is, the absolute change in supply quantity (slope effect) will be the same, but the percentage change in quantity computed from experimentally derived functions will be smaller because it is computed from a larger base.

The slope of the static supply curve relates to the production function through the slope of the marginal physical product. If the marginal product falls sharply to the right, the slope of the supply curve is steep. If resources other than fertilizer are not as limiting under experimental conditions as those found on farms, the marginal productivity of fertilizer may not fall as sharply, and therefore the supply curves may rise less steeply. The result of this condition is a tendency for the slope effect to overestimate the static supply elasticity on farms. In summary, if experimental conditions are more favorable for fertilizer response than those found on farms, the result may be underestimation of static supply elasticity on farms through the base effect and overestimation through the slope effect. These effects may offset one another to some extent.

Failure to specify all relevant economic factors in the production function which are variable in the short run may cause static supply elasticity on farms to differ from supply elasticity estimated from production functions. "Relevant" economic factors are those which potentially influence production, can be controlled by farmers and have a price. In this chapter static supply is estimated from production functions with only one, two, and in one instance, three variable factors, all of which are fertilizer nutrients. In general, only those fertilizer nutrients which gave no response were excluded. But other inputs, including measures to control weeds and insects, are relevant economic inputs in the short run on farms. Farmers can exhibit greater responsiveness to price changes when more inputs are variable. Hence, failure to specify inputs in the production function may cause underestimation of static supply elasticity on farms.

Production functions do not specify the effect of competing and complementing crops on corn output. The functions do not indicate how corn production would change in response to legume or soybean production through physical effects on corn yield. Also, the extent of residual response from fertilizer application is not specified. Although some fertilizer remains in the soil for longer periods, the production functions indicate only the corn yield response the same year the fertilizer is applied. Individual static demand and supply curves exist for the second and subsequent years of residual response. The "total" of static curves can be considered the sum of these annual curves. The "single year" curve necessarily would lie to the left of the total supply or demand curve, if response in all years were considered. Due to the base effect, the first-year curve likely would be more elastic than the total static supply or demand curve. The estimation of static supply and demand also depends on the adequacy of the algebraic forms used to express the physical relationships found in nature and the economic relationships in the market. The algebraic forms of the supply and demand relationships assume that corn and fertilizer are independent of other outputs and inputs in the market.

The marginal value product relates to static demand in the same way that marginal cost relates to static supply. Marginal cost and marginal value product are expressions of respective costs and returns which may be derived with knowledge of the production function and prices. These concepts do not indicate what farmers will do, but only describe quantities existing in nature. When the assumptions of profit maximization, etc., are made, these concepts form the basis for projected behavior of farmers. Defined as static supply and static demand, these concepts form an expository link between physical relationships and market prices.

PRODUCTION FUNCTIONS USED FOR ESTIMATES

The production functions used in this chapter represent broad soil, weather and other conditions which influence yield response and also supply and demand parameters. The production functions do not represent all of the corn-fertilizer functions which have been fitted to data and which are available. Some were considered inappropriate, due to an insufficient range of fertilizer application in the experimental treatments and were omitted. The analysis was restricted to published functions. In some instances it was necessary to select the most appropriate function from several acceptable functions fitted to the same data. Also, it was sometimes necessary to fix the level of factors such as moisture in the production function at "mean levels." Certain details of the functions are important in understanding the nature of the parameters which they estimate. In the following paragraphs the basic production functions used are presented, along with brief comments on the soil, weather and other pertinent conditions. The original sources may be consulted for further details. All functions and quantities are on a per-acre basis. Unless otherwise specified, Y is predicted bushels of corn, N is pounds of nitrogen, P is pounds of P_2O_5 and K is pounds of K_2O.

Equation (6.1), a quadratic form with three independent variables, was fitted to data from a 1954 experiment on Clarion silt loam in Iowa.[4]

$$(6.1) \quad Y = 58.7647 + 0.2088N + 0.1388P + 0.0825K - 0.000511N^2 - 0.000859P^2 - 0.000499K^2$$

Application of P_2O_5 and K_2O ranged up to 160 pounds. Nitrogen application ranged up to 320 pounds. Rainfall was limited, and marginal yields diminished rapidly.

Equation (6.2) was fitted to the data[5] from a 1953 experiment on calcareous variant Webster silty clay loam in Wright County, Iowa.

$$(6.2) \quad Y = 76.9263 - 0.1632N - 0.1430P + 3.6048N^{1/2} + 1.4606P^{1/2} + 0.1803N^{1/2}P^{1/2}$$

Nitrogen, P_2O_5 and K_2O were applied at rates up to 240, 120 and 80 pounds, respectively. None of the K_2O terms were significant and hence were omitted from the equation. Rainfall was adequate during most of the growing season.

Equation (6.3) was derived from a 1953 experiment with nitrogen, P_2O_5 and K_2O variable on Carrington silt loam in Iowa.[6] Nitrogen was applied up to 240 pounds; P_2O_5 and K_2O up to 120 and 80 pounds, respectively. The soil was highly fertile and a large response from fertilizer was not anticipated. P_2O_5 did not have a significant response, except interacting with K_2O, and was dropped from the equation.

$$(6.3) \quad Y = 99.223 - 0.04453N + 0.3162K + 0.9190N^{1/2} - 0.001813K^2$$

Data for equation (6.4) were obtained from a 1955 experiment also on Carrington silt loam.[7]

$$(6.4) \quad Y = 73.67811 + 0.06731P + 0.03000K - 0.000177P^2 - 0.000213K^2 + 0.000080PK$$

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[4] Doll, John P., Heady, Earl O., and Pesek, John T. Fertilizer production functions for corn and oats; including an analysis of irrigated and residual response. Iowa Agr. and Home Econ. Exp. Sta. Res. Bul. 463. 1958. p. 367.

[5] Stritzel, Joseph Andrew. Agronomic and Economic Evaluation of Direct and Residual Crop Responses to Various Fertilizer Nutrients. Unpublished Ph.D. thesis. Iowa State University Library. Ames. 1958. p. 33.

[6] Brown, William G., Heady, Earl O., Pesek, John T., and Stritzel, Joseph A. Production functions, isoquants, isoclines and economic optima in corn fertilization for experiments with two and three variable nutrients. Iowa Agr. Exp. Sta. Res. Bul. 441. 1956. p. 809.

[7] Doll, Heady and Pesek, op. cit., p. 390.

Nitrogen was included in the experiment, but none of the direct and interaction effects of nitrogen was significant above the 50 percent level and they were therefore not included in the equation. The low rainfall in 1955 caused the yield response from nitrogen to be more limited than the response from other nutrients. Heaviest application of nitrogen was 240 pounds; P_2O_5 and K_2O, 160 pounds.

Equation (6.5) results from an experiment conducted on Wisner loam soil in the "thumb" area of Michigan in 1956.[8]

$$(6.5) \qquad Y = 104.1 + 0.07370N + 0.05002P - 0.0003316N^2 - 0.00005602P^2 - 0.00002546NP$$

The magnitude of the constant term indicates that the fertility level was probably high without any fertilizer application. The maximum application of nitrogen was: K_2O, 320 pounds and P_2O_5, 640 pounds. The small numerical values of the coefficients of the linear and squared terms suggest very little response to fertilizer. The interaction term, though negative, does not differ significantly from zero. Only 16 percent of the variability in yield was explained by nitrogen and P_2O_5.

In addition to the two-nutrient equations just listed, the square root equation (6.10) fitted to Ida silt loam data was used for this particular soil and year.[9]

An experiment conducted on the coastal plain of North Carolina provided data for equation (6.6).[10]

$$(6.6) \qquad Y = 15.4 + 0.6900N - 0.0029N^2$$

Nitrogen was applied in 20-pound increments up to 180 pounds. Weather was described as "dry."

Equation (6.7) was estimated from a 1955 experiment on Norfolk-like soils in North Carolina.[11]

$$(6.7) \qquad Y = 36.55 + 0.2369N - 0.00094N^2$$

The experiment included nitrogen, P_2O_5 and K_2O, but little response was exhibited to any nutrient except nitrogen. Equation (6.7) is a

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[8] Sundquist, W. B., and Robertson, L. S., Jr. An economic analysis of some controlled fertilizer input-output experiments in Michigan. Michigan Agr. Exp. Sta. Tech. Bul. 269. 1959. p. 40.

[9] Heady, Pesek and Brown, op. cit., p. 304.

[10] Johnson, P. R. An Economic Analysis of Corn Fertilization in the Coastal Plains of North Carolina. Unpublished Ph.D. thesis. North Carolina State College Library, Raleigh. 1952.

[11] Hurst, D. C., and Mason, D. D. Some statistical aspects of the TVA North Carolina cooperative project on determination of yield response surfaces for corn. p. 213. In Baum, E. L., Heady, Earl O., Pesek, J. T., and Hildreth, C. C., eds. Economic and Technical Analysis of Fertilizer Innovations and Resource Use. Iowa State University Press, Ames. 1959. pp. 209-16.

simplified decoded form of the three-nutrient equation with P_2O_5 and K_2O fixed at their average level, 75 pounds. The heaviest application of nitrogen was 250 pounds.

Equation (6.8) was estimated from a 1956 experiment on Verdigris soil in eastern Kansas.[12]

$$Y = 69.38 + 0.311N - 0.001379N^2 \tag{6.8}$$

Nitrogen, P_2O_5 and K_2O were applied up to 120, 80 and 40 pounds, respectively. Rainfall was adequate and almost ideal conditions prevailed during most of the growing season. An analysis of variance indicated that nitrogen was significant at the .99 percent level. P_2O_5 and K_2O were nonsignificant and were omitted from the equation.

Equation (6.9) represents a production function derived from Lintonia soil in Tennessee over the years 1954-56.

$$Y = 92.95 + 0.4834N - 0.0010N^2 - 0.5981D - 0.0028ND \tag{6.9}$$

For the lowest moisture level, the drouth index D equals 103.[13] Finally, production function (6.10) is from a 1952 experiment on calcareous Ida silt loam in western Iowa. Rainfall was adequate and the soil was highly deficient in nutrients.

$$Y = -5.68 - .316N - .419P + 6.35N^{1/2} + 8.52P^{1/2} + .341N^{1/2}P^{1/2} \tag{6.10}$$

All of the preceding production functions are for corn.

Short-Run and Long-Run Functions

We now examine the nature of short-run and long-run static fertilizer demand and corn supply derived from the preceding functions. The term "short run" is used to indicate that a single-fertilizer nutrient is variable, a modification of the usual economic conventions in terminology. The term "long run" similarly is used to indicate that more than one nutrient is variable. Both concepts are short run in the usual terminology, since inputs other than fertilizer would be variable in the conventional meaning of long-run supply.

The restraints imposed by algebraic forms of the production function particularly affect the estimates of static supply elasticity at very high or very low prices. To avoid extreme prices, the supply curves and elasticities for corn are illustrated for corn prices ranging from 40 cents to $1.20 per bushel. Nitrogen, P_2O_5 and K_2O prices are 13 cents, 8 cents and 5 cents per pound, respectively, for variations in

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[12] Orazem, Frank, and Smith, Floyd W. An economic approach to the use of fertilizer. Kans. Agr. Exp. Sta. Tech. Bul. 94. 1958. p. 9.

[13] Parks, W. L., and Knetsch, J. L. Corn yields as influenced by nitrogen level and drouth intensity. Agronomy Journal 51:363-64. 1959.

corn price over this range. The corn price range of 40 cents to $1.20 appears adequate to illustrate magnitudes of static supply elasticity which are relevant. In examining static fertilizer demand and elasticities, however, we have used a much wider relative range of fertilizer prices.

STATIC FACTOR DEMAND

Both short-run and long-run static demand for fertilizer are estimated in this section, in the framework outlined above. Static demand is derived with the price of corn fixed at $1.10 per bushel. It is possible to generalize for other corn prices by considering the fertilizer/corn price ratio since the demand quantity is a function of this ratio. The demand quantity when corn price is $1.10 per bushel and nitrogen is 11 cents per pound, for example, is the same as when corn is 80 cents per bushel and nitrogen is 8 cents per pound. Throughout the analysis, emphasis is placed on the conditions which influence the level and elasticity of static demand.

Short-Run Demand

A family of short-run static demand curves can be generated from a given production function for different levels of the fixed resource. The data are made manageable in the following presentation by setting the "fixed resource" at the several levels indicated as in the supply analysis. For space conservation we present only the derived demand, supply and elasticity functions which correspond to production function (6.10).[14] The short-run demand function for N so derived is (6.10a) where P_n is the price per pound of nitrogen, corn price is set at $1.10 per bushel and P_2O_5 is fixed at 80 pounds per acre. The elasticity equation of static nitrogen demand function with respect to its own price is (6.10b).

$$N = 26.7289(P_n + .3476)^{-2} \tag{6.10a}$$

$$E_n = -2P_n(P_n + .3476)^{-1} \tag{6.10b}$$

The parallel short-run demand function and elasticity equations for P_2O_5 are (6.10c) and (6.10d), respectively, with nitrogen fixed at 80 pounds per acre.

$$P = 40.4496(P_p + .4587)^{-2} \tag{6.10c}$$

$$E_p = -2P_p(P_p + .4587)^{-1} \tag{6.10d}$$

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[14] The algebraic form of the production function used to express the physical experimental data have an important impact on the demand curves and elasticities. For a discussion, see Tweeten and Heady, op. cit.

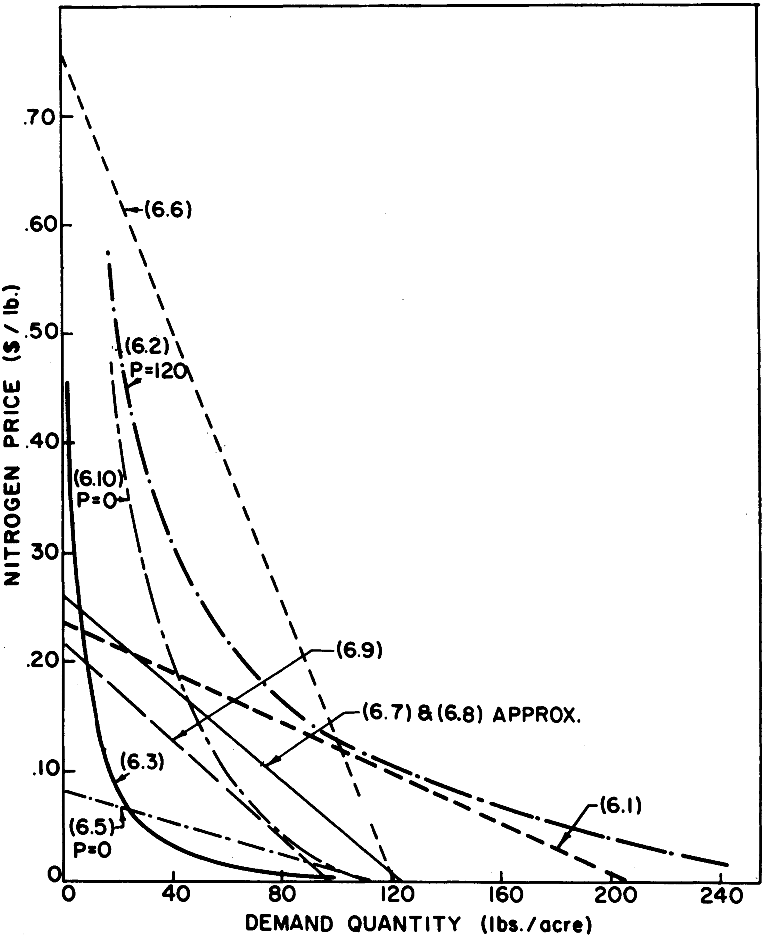

Figure 6.1. Per acre short-run static nitrogen demand curves (corn price = $1.10).

Obviously, the static demand functions have an algebraic form corresponding to their underlying production function. The "fixed resource" is set at the level giving the highest estimate of static demand elasticity for the quadratic and square root forms. Figure 6.1 includes static short-run demand functions for nitrogen derived from the production functions mentioned earlier. The numbers on the demand curves correspond to the number of the production function equations. Where the same number is used for two curves, different demand curves have been estimated for more than one level of the "fixed resource" P_2O_5. The level of the latter is indicated accordingly.

The striking feature of Figure 6.1 is the lack of uniformity in the level of static demand derived from the various production functions.

This is expected, of course, because of the wide geographic spread from which the production functions are derived over the nation, with a large variation in climate and soil productivity. At a price of 13 cents per pound for nitrogen, the demand quantity ranges from zero to 100 pounds of nitrogen per acre when phosphate is at the levels indicated (P). The possible sources of the divergent pattern of static demand are the algebraic form of the function, the moisture pattern, and the initial fertility and other properties of the soil.

The square root production functions consistently give rise to higher demand quantities than the quadratic functions only as the curves approach the price axis. Moving farther to the right from the price axis, no pattern is apparent for either algebraic form.

The computation of static demand is independent of the constant in the production function and is, therefore, not directly affected by the initial nutrient level of the soil. The initial fertility influences the demand quantity indirectly, however. A high level of nitrogen demand reflects a large response of corn yield to additional inputs of nitrogen (marginal physical product). The marginal physical product upon which static demand quantity rests is likely to be large if (a) the soil is not initially satiated with nitrogen and (b) other factors such as P_2O_5, K_2O and moisture are not limiting. The level of demand indicated by each curve in Figure 6.1 may be explained by (a) or (b).

Although rainfall was adequate in 1953, the static curve for function (6.3) depicts a low demand quantity. The yield response to nitrogen was low for (6.3) because the initial fertility level of the Carrington soil was high (i.e., the constant of the production function was 99 bushels). The low demand for nitrogen on Wisner soil (6.5) is also explained by the high fertility level of the soil (104 bushel yield without fertilizer). On such soils, a large response to fertilizer application usually is not anticipated.

Demand curve (6.6), derived under dry conditions on Norfolk-like soil in North Carolina, has relatively large quantities because the soil was initially low in nitrogen but contained adequate amounts of other nutrients. The result was a considerable response to nitrogen despite the low moisture. The demand curve for function (6.2) indicates the lowest level of demand at low nitrogen prices, and was derived under favorable moisture conditions and adequate amounts of P_2O_5 and K_2O (120 pounds) on Webster soil in Iowa.

The slopes of the static demand curves indicate the "intensity" of diminishing fertilizer productivity. If marginal corn production falls off rapidly with additional units of nitrogen, the demand curve for nitrogen drops sharply to the right. The slope and the level of the demand curve (Figure 6.1) determine the elasticity (Figure 6.2 where the numbers again refer to the production functions). The magnitude of elasticity is directly related to the slope and inversely related to the level of demand or the base effect described earlier. Changes in the level of the fixed factor cause compensating changes in the position and slope of the square root form of demand. The static demand elasticity

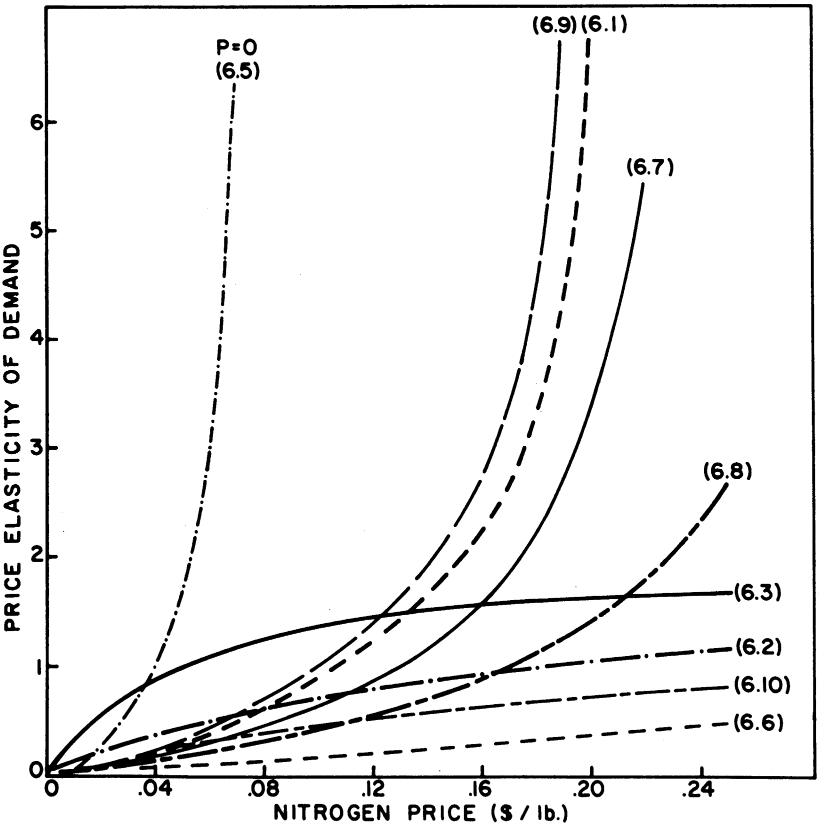

Figure 6.2. Price elasticity of static nitrogen demand curves in Figure 6.1.

consequently is constant at all levels of the fixed factor. If interaction is positive, the quadratic form of the demand curve shifts to the right and the elasticity decreases with higher fixed factor levels.

The elasticities of the static demand curves for nitrogen are quite uniform for low nitrogen prices to about 13 cents per pound. (In Figure 6.2 the horizontal axis is the nitrogen price.) If price of nitrogen is 13 cents, the elasticity ranges from .20 to 1.70 except for function (6.5). Demand becomes considerably more elastic and highly divergent above 13 cents. The divergence is explained by the algebraic forms and by the experimental conditions under which the curves were estimated. The elasticity of the quadratic equations (the linear static demand functions in Figure 6.1) approaches infinity and of the square root functions (the curved lines in Figure 6.1) approaches two at high factor prices. The four curves indicating the highest elasticities in Figure 6.2 are based on quadratic forms of production functions. Three of the four curves indicating the lowest elasticities are based on square root forms of production functions.

The low elasticity for function (6.6) in Figure 6.2 is due to the high level and steep slope of the demand curve in Figure 6.1. The level of demand is high because the soil was initially low in nitrogen; the slope is steep because low moisture restricted the yield response from large applications of nitrogen. The demand curve for function (6.5) is highly elastic when the price of nitrogen is greater than 6 cents. As the nitrogen price approaches the intersection of the demand curve with the price axis at 8 cents in Figure 6.1, the elasticity approaches infinity in Figure 6.2. Wisner loam for function (6.5) is a heavy rich soil, and the yield response to nitrogen was low. Demand curve for function (6.9) also was very elastic at most nitrogen prices. The production function contains a drouth index which was set at a low moisture level to give the demand curve illustrated in Figure 6.1. Had the index been set at a high moisture level, the elasticity would have been lower. We conclude

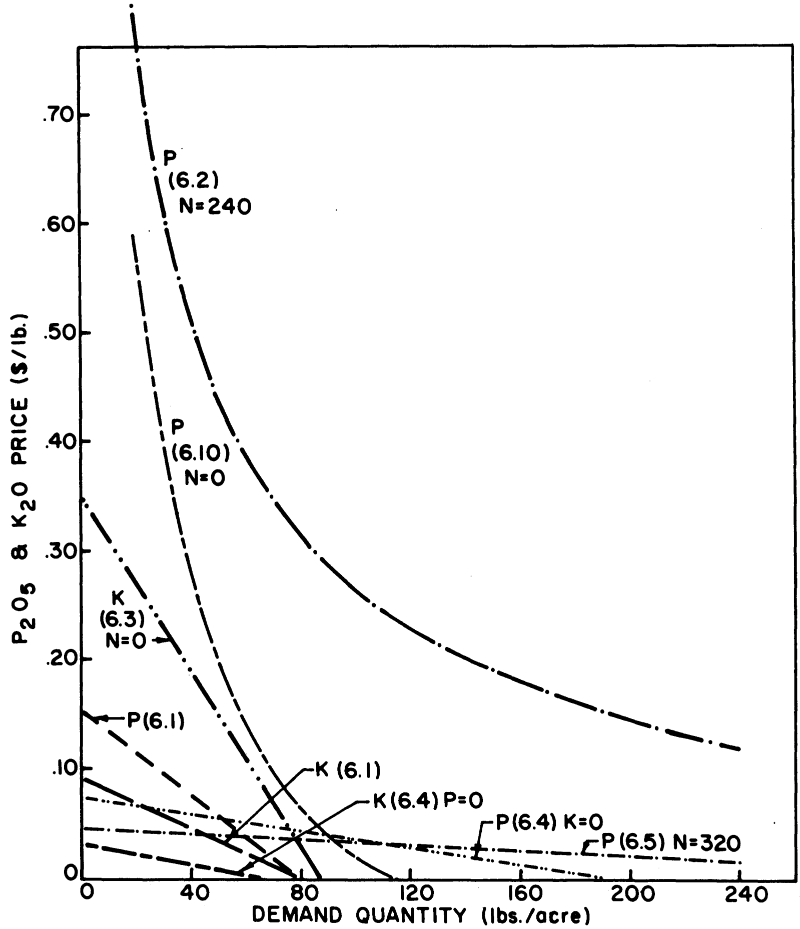

Figure 6.3. Per acre short-run static demand functions for P_2O_5 and K_2O (corn price = $1.10).

that demand is most elastic under conditions where nitrogen fertilizer has little effect on yield because the soil initially contains adequate nitrogen or because the yield response is limited by lack of moisture or other factors.

Considerable variation also is apparent in the levels of short-run static demand for P_2O_5 and K_2O illustrated in Figure 6.3. (P and K on the curves indicate the static demand for P_2O_5 and K_2O, respectively.) The divergent level of demand is explained by the nutrient and moisture conditions of the soils for which the production functions were derived. Curves (6.4) for P_2O_5 and K_2O depict two of the lowest demand levels. Both were estimated from an experiment on Carrington soil in 1955 when the yield response was severely limited by low rainfall. Demand curve (6.2) for P_2O_5 indicates the highest level of demand. It was derived from a 1953 experiment on Webster soil when rainfall was adequate. The high level of nitrogen (N = 240 pounds) also shifted demand curve (6.2) to the right. A high level of demand is also depicted by curve (6.10). It was estimated from a 1953 experiment on Ida soil in Iowa. Moisture generally was sufficient in 1953, and the soil gave a significant yield response to use of nitrogen and P_2O_5.

The curves depicting the highest level of demand had the lowest price elasticity as indicated in Figure 6.4. The static demand curves

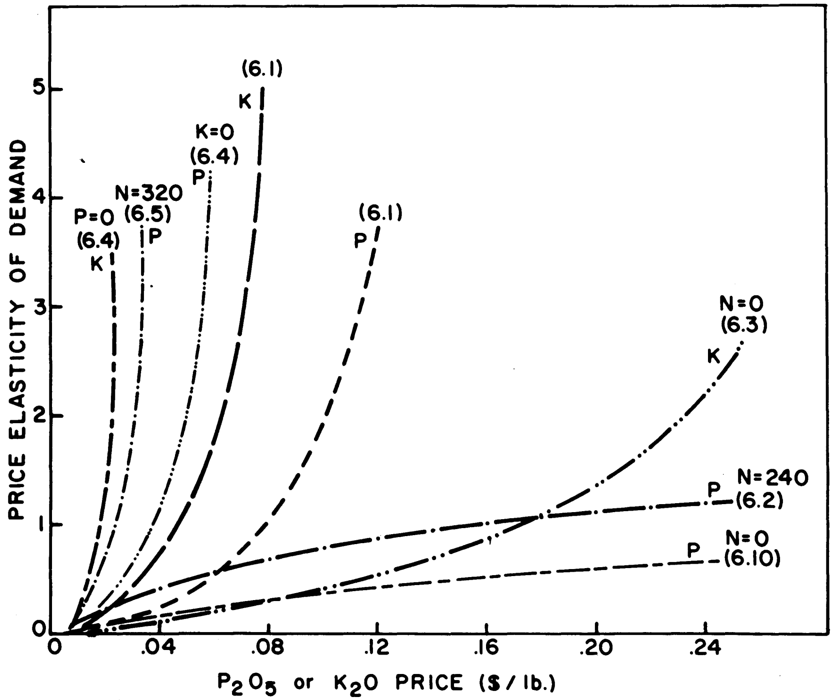

Figure 6.4. Price elasticity of the static demand curves for P_2O_5 and K_2O in Figure 6.3.

of greatest elasticity are those indicating the lowest level of demand, (6.4) and (6.5). The flatter slopes of (6.4) and (6.5) also contributed to the high elasticity. Some of the difference is due to the restraints imposed by the square root form on the elasticities of (6.10) and (6.1). The difference, however, mainly is attributed to the conditions under which the functions were estimated.

The elasticities of the P_2O_5 and K_2O demand curves are greater and more divergent than the elasticities of demand for nitrogen illustrated in Figure 6.2. Much of the difference in the magnitude is due to the lower levels of demand for P_2O_5 and K_2O. For example, five demand curves in Figure 6.3 for P_2O_5 and K_2O intersect the price axis below 20 cents. But only one demand curve (6.5) for nitrogen intersects the price axis below 20 cents.

Long-Run Demand

The long-run static demand functions for N and P_2O_5, corresponding to production function (6.10), are presented in equations (6.10e) and (6.10f).

(6.10e) $$N = 26.5225(P_n + .3494)^{-2}$$

(6.10f) $$P = 36.7236(P_p + .3850)^{-2}$$

Both functions represent demand quantity as a function of the same nutrient's price where we suppose prices for the alternative nutrient are fixed at the levels for (6.10a) and (6.10c), but that the alternative nutrient can be varied to its most profitable level, its price fixed, while the price of the particular nutrient is varied.

Figure 6.5 provides long-run demand curves for nitrogen derived as explained earlier. Factors other than nitrogen, i.e., P_2O_5 and K_2O, are not fixed as in Figures 6.1 and 6.3, but are allowed to vary as the price of nitrogen changes. Figure 6.5 also includes demand curves from production function (6.6) to (6.9) which contain only one variable input. While these curves are termed long-run because all factors in them are variable, they do not differ from the short-run curves in the manner of the other functions.

Figure 6.5 illustrates the effects of moisture and soil type on static long-run demand as defined here. Production functions (6.10), (6.2) and (6.3) were estimated in 1953 in Iowa. Since the rainfall was somewhat uniform among these experiments, the level of demand differs mainly due to soil type. Demand curve (6.10) from Ida soil data depicts one of the highest demands, and curve (6.3) from Carrington data depicts one of the lowest demands. The elasticities of these curves display more uniformity, however, as indicated in Figure 6.6.

The effect of moisture is apparent from production functions (6.3) and (6.4) estimated in 1953 and 1955, respectively, on Carrington soil.

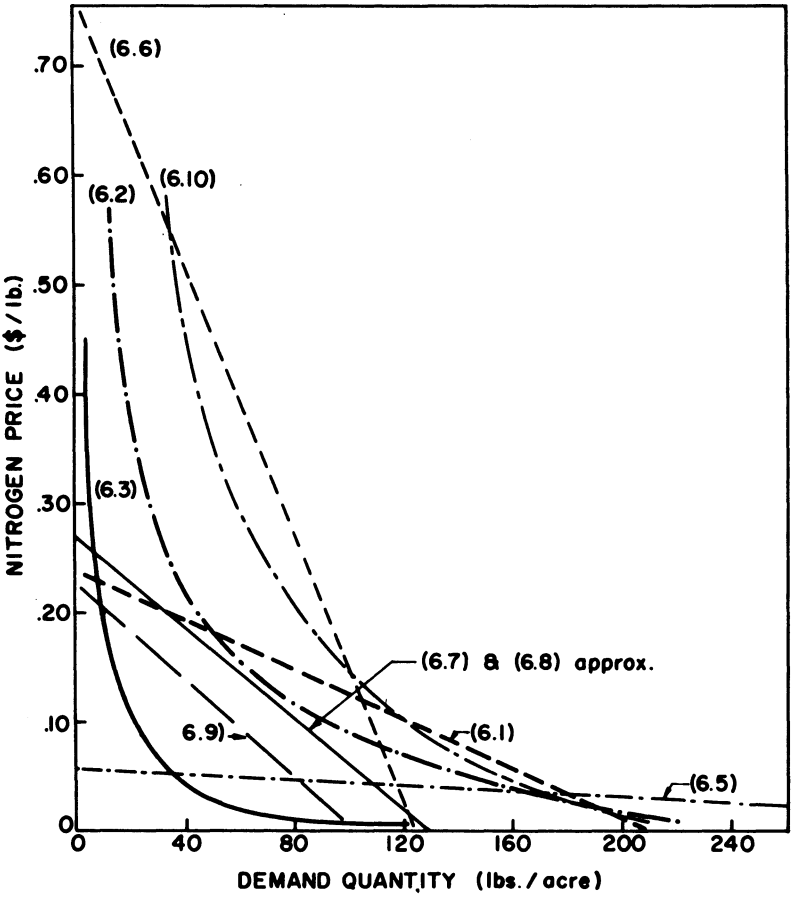

Figure 6.5. Per acre long-run static demand curves for nitrogen; other nutrients variable as in production functions (corn price = $1.10).

The demand curve for nitrogen is indicated in Figure 6.5 for the year 1953 only. In 1955 nitrogen gave no response due to low rainfall. Hence, the demand quantity for nitrogen in 1955 was essentially a zero.

In general, the Iowa functions depict a greater static demand quantity for nitrogen, at a given price, than do the other functions except (6.6). Demand curve (6.3) from Iowa data indicates a very low demand, however. The slope as well as the level of the static demand curve relates to the soil fertility and moisture conditions. The two quadratic forms displaying the greatest and least slopes are (6.6) and (6.5) in Figure 6.5. Demand curve (6.6) was estimated on soil with sufficient nutrients other than nitrogen, but with limited moisture. The first units of nitrogen gave a large yield response but, due to insufficient moisture, the marginal product declined rapidly. The flattest demand curve (6.5) was estimated for heavy Wisner soil. Because the initial

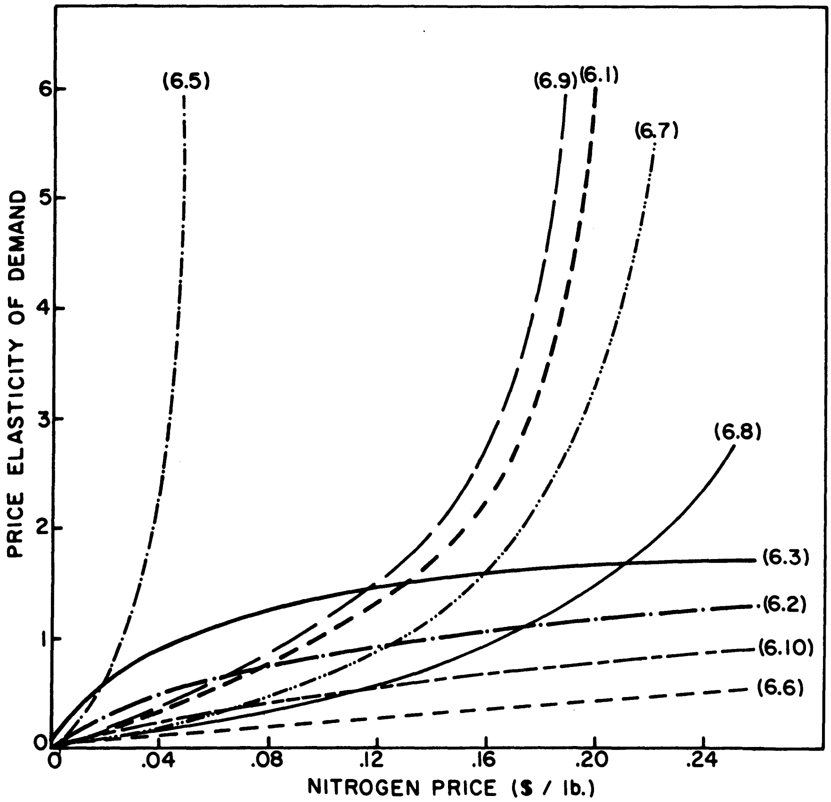

Figure 6.6. Price elasticity for nitrogen static demand curves in Figure 6.5.

nitrogen level in the soil was high in relation to the available moisture, the first units of nitrogen added little to the yield. The marginal product remained almost constant as more nitrogen was applied due to adequate amounts of other nutrients and moisture-holding capacity of the heavy soil. These results conform with the general observation from Figure 6.5 that the demand curves denoting the largest quantity at a given price also decline most rapidly in slope. The possible reason is: fertile soils, such as those represented by (6.1) and (6.5), which do not exhibit a large initial response to nitrogen fertilizer, sustain some response, with application of greater amounts of nitrogen, due to the high levels of other nutrients and moisture-holding capacity of the soil.

The demand curves derived from Iowa data appear to have lower elasticity than those from other areas. Much of the difference is due to the algebraic form and the production elasticity at lower nitrogen inputs. Comparisons are more realistic at the mid-range of nitrogen prices. Considering only the six demand curves with the lowest elasticity, every other one was derived from Iowa data. The differences in

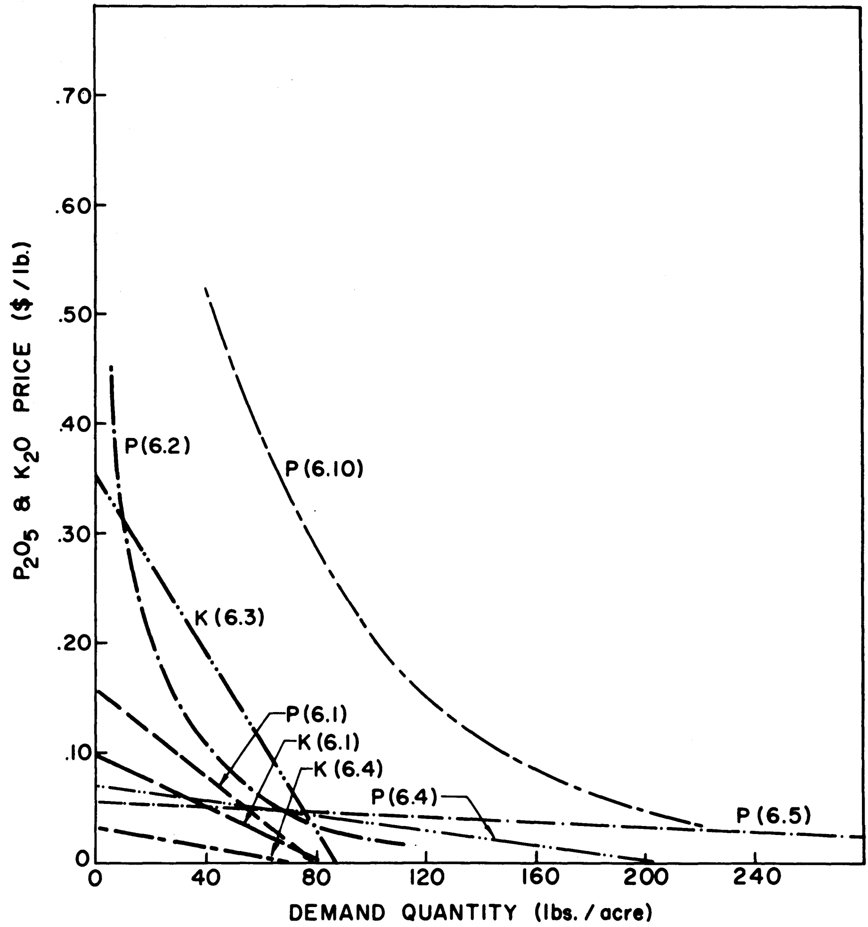

Figure 6.7. Per acre static long-run P_2O_5 and K_2O demand curves (corn price = $1.10).

elasticities are perhaps better explained by soil and moisture conditions rather than by areas. Demand elasticity tends to be lowest for soils which are low in nitrogen and where rainfall and other fertilizer elements are plentiful.

The level of long-run demand for P_2O_5 and K_2O illustrated in Figure 6.7 is somewhat lower than the long-run demand for nitrogen in Figure 6.5. Figure 6.7 also suggests that, for the particular experimental production functions and environmental conditions, the demand for K_2O is less than the demand for P_2O_5 at a given price. In several instances P_2O_5 and K_2O were included in the controlled experiments from which the production functions were derived but did not give significant responses. The P_2O_5 and K_2O variables omitted from the functions in such instances represent a zero demand for the nutrient.

Demand curve for function (6.1) for Clarion soil in Iowa illustrates the differences in demand levels for the three nutrients in a given year. Demand quantity, at a given price, for nitrogen in Figure 6.5 is greater than for P_2O_5 in Figure 6.7, which in turn is greater than that for K_2O.

All of the static demand curves except (6.5) in Figure 6.7 are from Iowa data. The divergent pattern in Figure 6.7 again suggests the wide variation in demand existing within a given area. Static demand curve (6.3) for K estimated in 1953 indicates much larger quantities than (6.4) for K estimated in 1955 although both are for Carrington soil. Demand curve (6.3) for K is also less elastic than curve (6.4) for K in Figure 6.8. The elasticity of long-run static demand for P_2O_5 and K_2O tends to be high and divergent. The price elasticity is greatest on soils giving little response to fertilizer because of an initially high nutrient level or inadequate moisture. For example, curve (6.5) estimated on a heavy, rich soil gave little response to fertilizer and the elasticity is high. Demand curve (6.10), estimated on a soil with ample moisture and low P_2O_5, gave a large response to fertilizer. The elasticity of demand functions estimated for the data explained earlier for equation

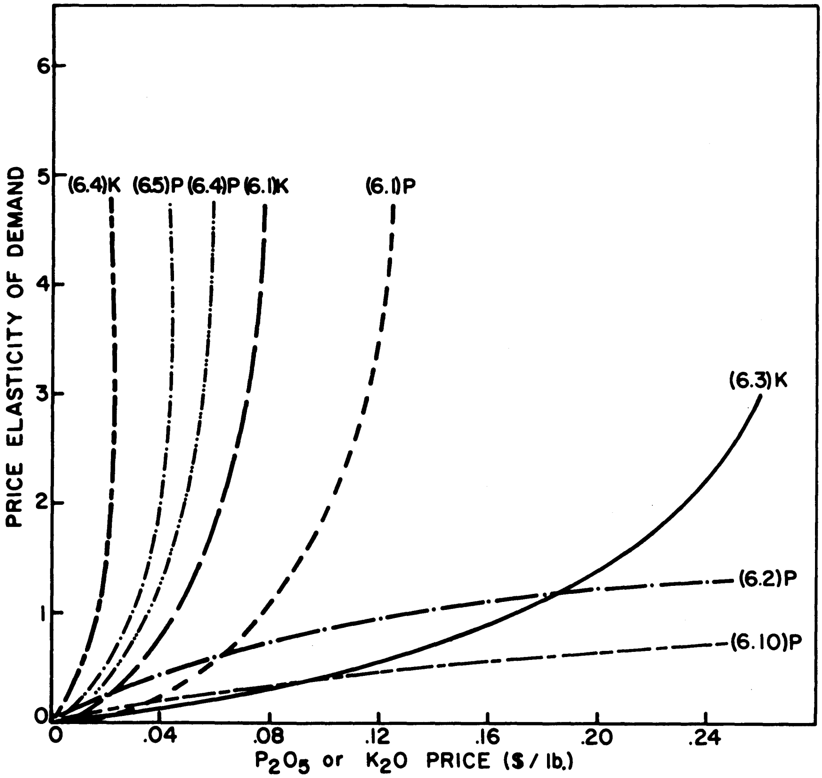

Figure 6.8. Price elasticity for long-run static P_2O_5 and K_2O demand curves in Figure 6.7.

(6.10) was low when either a square root or quadratic production function was used. To the limited extent that it is possible to generalize from the small sample, a change in the price of fertilizer would have the greatest proportional impact in areas such as the Great Plains. The least percentage change in fertilizer consumption would occur in the Corn Belt and Southeast where response to fertilizer is very large. Of course, the largest absolute change in fertilizer consumption likely would occur in areas where fertilizer is being used in the largest amounts. It is useful to consider the impact of fertilizer price changes by soils rather than by areas since the analysis indicates that the demand elasticity varies greatly by soil and year within areas.

The static factor demand functions above provide some insight into the manner in which physical production functions might condition the demand elasticities for a particular resource fertilizer. A change in crop price or fertilizer cost is expected, in terms of the static and physical basis outlined, to cause greatest change in fertilizer demand in the "more marginal areas" of use.

In the foregoing analysis, the demand for K_2O is more elastic than the demand for nitrogen. Fertilizers are often sold in fixed ratios, and it may not be meaningful to consider independently the demand for a single element. Assuming demand to be independent, however, a fertilizer manufacturer of all three elements likely would find the purchase of K_2O more responsive than that of nitrogen to a lowering of both nutrient prices by the same percentage. The demand curve for nitrogen, P_2O_5 and K_2O in fixed ratio would fall to the right of the demand curve for any one element. It follows that the demand for a fixed ratio of the three elements probably would be less elastic than the demand for any one element.

The price elasticity of static demand with respect to the price of fertilizer or with respect to the price of corn is equal but opposite in signs. Inferences about the response of fertilizer purchases to fertilizer prices also apply to corn prices. For example, a fall in the corn price would be expected to reduce fertilizer purchases proportionately more than the decline in corn production. The results of the static analysis are also consistent with the hypothesis that a change in corn price has the greatest percentage impact on fertilizer sales in marginal areas, but the greatest absolute impact in traditional areas of corn production.

The static analysis indicates fertilizer demand is more elastic than corn supply. Because of diminishing returns, successive inputs of fertilizer add smaller and smaller increments to corn output. Thus, fertilizer consumption must increase by a larger percent than corn output in response to a favorable corn price. The reduction in demand to the fertilizer industry, from a decline in corn price and in terms of static analysis, is expected to be greater than the decrement in corn output.

The static analysis provides some basis for forming hypotheses of future trends in the demand for fertilizer. If the price of fertilizer falls relative to the price of corn, the largest proportional increase in fertilizer consumption in the short run is expected in marginal areas of fertilizer use. However, the largest total increase would still likely be in areas where fertilizer is used in large amounts. As the fertility level of the soil declines because of cropping and erosion, the demand curve for fertilizer is expected to shift to the right and probably become less elastic. Although the demand for fertilizer will increase, the relative short-run responsiveness of fertilizer consumption to changes in the price of corn or of fertilizer probably will diminish. Introduction of irrigation and other technological improvements also will influence the demand elasticity of fertilizer. To the extent that these technological changes substitute for fertilizer, the fertilizer demand elasticity will increase. To the extent that innovations such as new crop varieties only shift the demand for fertilizer to the right, the fertilizer demand elasticity will decrease.

STATIC SUPPLY FUNCTIONS

Based on the same production functions, and with the same limitations in illustration and prediction, static corn supply functions are presented in this section. While this book emphasizes resource demand and structure in agriculture, the basic study is made as a step in better explaining agricultural supply and related price and income problems. Some of the possible interrelationships between resource demand and commodity supply are illustrated below, as they stem from the static analysis and physical production functions. The numbers shown on the supply functions which follow, like those for demand, refer to the production functions from which they were derived.

Short-Run Static Supply

Presentation of a complete family of short-run supply curves for many values of the fixed nutrients is impractical when two or more nutrients are included in the production function. The short-run static supply function for corn, corresponding to production function (6.10), is (6.10g) where N is variable, P_2O_5 is fixed at 80 pounds per acre and N is priced at 13 cents per pound and Y is bushels per acre. The corresponding elasticity equation is (6.10h).

$$Y = 37.12 + \frac{22.98P_y + 27.93P_y^2}{.0676 + .329P_y + .399P_y^2} \tag{6.10g}$$

$$E = \frac{5.97P_y}{Y(.26 + .632P_y)^3} \tag{6.10h}$$

As explained earlier, for the analysis which follows, the fixed resource or nutrient is set at the level giving the highest estimate of elasticity within the range of the experimental data for the variable resource. A low level of the fixed resource generally results in the highest elasticity of supply for the variable resource. The low "fixed factor" levels do not affect the slope, but shift the quadratic supply curves to the left, increasing the elasticity. The static supply curve for the quadratic equation (6.5) was an exception since the coefficient for interaction between nutrients was negative. In the square root equations (6.10), (6.2) and (6.3) the level of the fixed factor exerts opposite influences, through the base and slope effects discussed previously, on elasticity. The base effect overshadows the slope effect in (6.10) and (6.3) and results in the highest elasticity of static supply at low "fixed factor" levels.

With nitrogen as the only per acre variable input, the positions of the supply curves are widely dispersed, but the slopes are very "uniform," as shown in Figure 6.9. (The K and P values on the curves indicate the level at which these two factors are fixed.) The level of supply varies as much as 100 bushels per acre. The wide range is explained largely by (a) the soil fertility, (b) moisture conditions and (c) the level of the fixed nutrient. The value of the constants in the production function is the predicted yield level of the soil without application of fertilizer. It reflects the initial fertility level of the soil

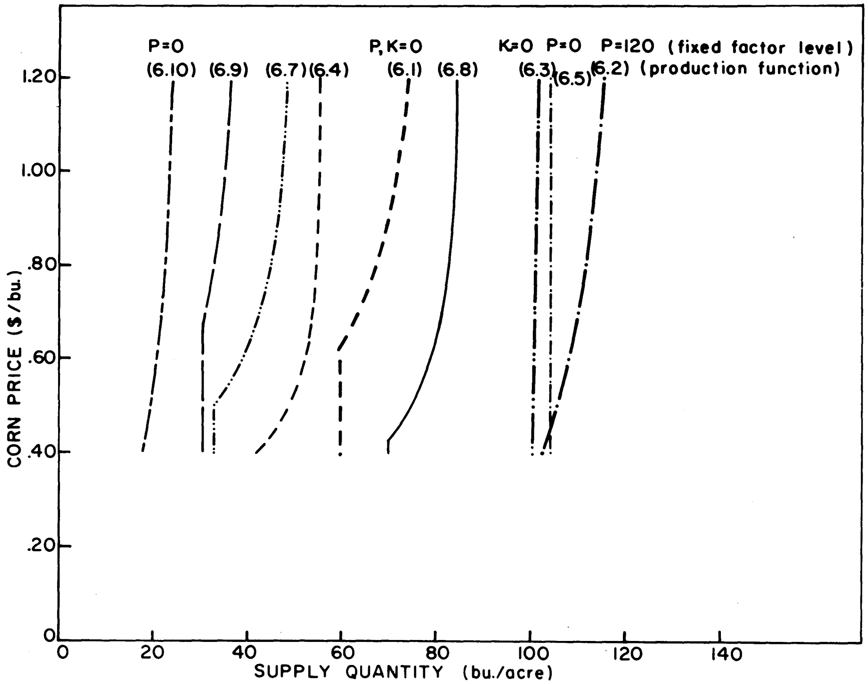

Figure 6.9. Per acre short-run static supply curves for corn (nitrogen price = $.13).

and moisture conditions, or (a) and (b). The supply curves farthest to the right, (6.2), (6.3) and (6.5), represent production functions with high values of the constant (i.e., 77, 99 and 104 bushels per acre, respectively). The initial yield level of the supply curve farthest to the left (6.10) is almost zero. If all curves are adjusted to a common constant and fixed factor level, the range of supply quantities at any price is very small.

The steep slopes of the curves indicate that a change in price would result in but little change in quantity under the conditions for deriving the static supply functions. Supply curve (6.5) for Wisner loam in Michigan is a vertical straight line. Nitrogen would not be used until

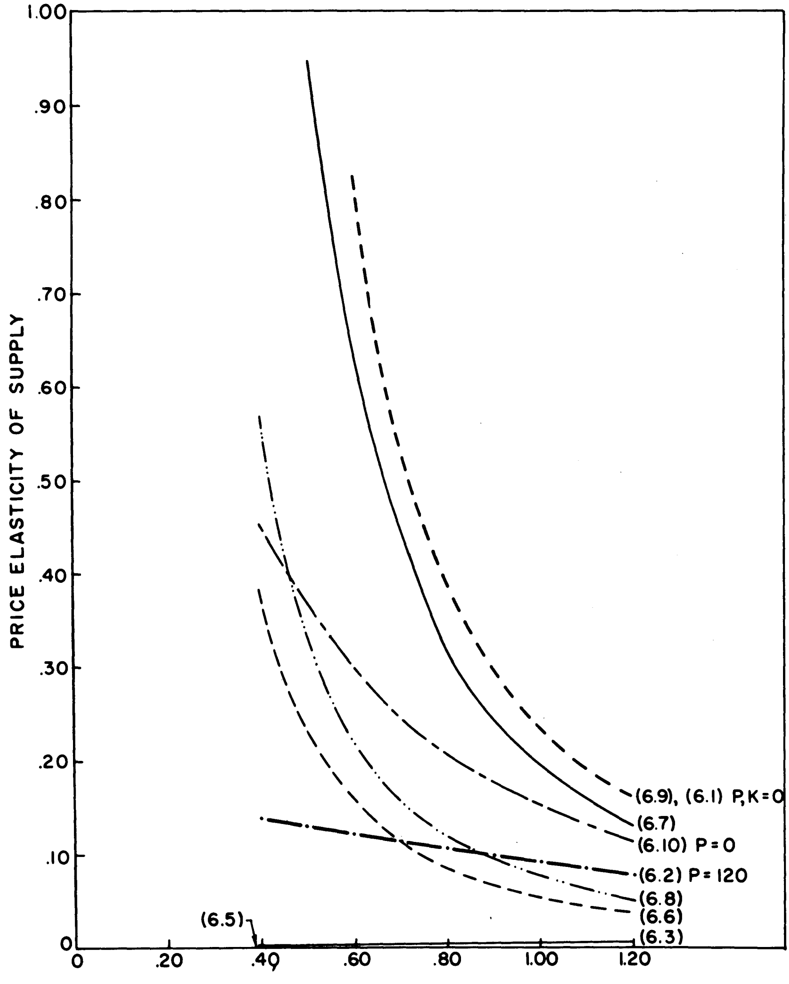

Figure 6.10. Price elasticities for static short-run supply curves in Figure 6.9.

corn reaches $1.80 per bushel. The supply quantity at all indicated prices is the initial yield, 104 bushels. Curves (6.1), (6.7), (6.8) and (6.9) display vertical straight line segments. These segments indicate use of nitrogen to be unprofitable up to the corn price when the static supply curves have slopes less than infinity. The supply quantity in these segments is the initial yield or constant value in the production function equation. (The vertical segments do not extend to the quantity axis since, at some nonzero corn price, harvesting of the initial yield would be unprofitable.) The cost per bushel to harvest corn is well below the 40 cents per bushel minimum of Figure 6.9 and need not concern us.

The steep slopes of the static supply curves in Figure 6.9 reflect their low elasticities as illustrated in Figure 6.10. All supply curves have a price elasticity less than 1.0 when the corn price (horizontal axis) is above 40 cents. Moving from right to left in Figure 6.9, the elasticities of curves (6.1), (6.7) and (6.9) rise sharply. The elasticity of some static supply functions would be greater than unity with a corn price of less than 40 cents, but nitrogen no longer is profitable. Static supply elasticity drops to zero when the corn price is below 62 cents, 50 cents and 67 cents for curves (6.1), (6.7) and (6.9), respectively. The elasticity of all supply curves is less than .5 when corn price is above 80 cents. At a corn price of $1.20, the elasticities range from zero (6.5) to .16 (6.1 and 6.9). We conclude that the elasticity is low for all static supply curves throughout the wide range of prices considered in the analysis.[15]

Figure 6.11 depicts static corn supply curves with either P_2O_5 or K_2O as the only variable factor. (The variable factor is indicated by P or K below each static supply curve.) The curves indicate a considerable range of supply levels. The range would be somewhat less if the border curves (6.10) and (6.2) were estimated with nitrogen fixed at the same level. All curves except (6.5) were derived from Iowa data. Hence, there is little basis for comparisons among regions. Figure 6.11 demonstrates a broad range of static supply by soil types and weather within Iowa. Supply curves (6.3) and (6.4) were estimated

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[15] Figures 6.9 and 6.10 have wider application if price ratios, rather than absolute prices, are considered. The price of nitrogen, P_n, used to estimate the supply curves and elasticities was 13 cents per pound, but it is desirable to be able to generalize the supply quantities and the elasticities for other nitrogen prices. The corn price axes may be considered "price ratio" axes. For a corn price, P_c, of 90 cents per bushel, the ratio is $\frac{90 \text{ cents}}{13 \text{ cents}} = 7$. The supply quantity or the elasticity of supply remains the same for any absolute level of prices providing a price ratio is 7. But if P_n falls to 10 cents and P_c remains at 90 cents, the new price ratio is 9. To find the level of supply from Figure 6.9 or the elasticity from Figure 6.10 for P_n = 10 cents, P_c = 90 cents, we can compute the corn price which gives a price ratio of 9 when P_n = 13 cents; i.e., P_c = $1.17. Then the supply quantities and elasticities from Figures 6.9 and 6.10 for P_c = $1.17 can be determined. This method is limited when supply is computed with two or more variable factors. It is necessary to consider the price ratios among factors as well as between factors and products. The procedure described may be used as an approximate device if interfactor price ratios remain unchanged.

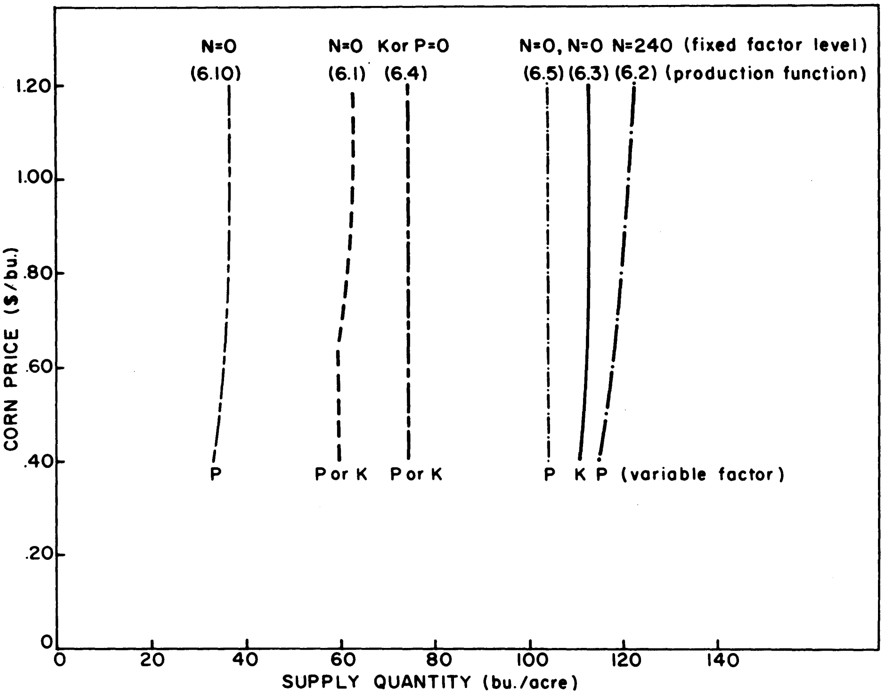

Figure 6.11. Per acre static corn supply (P_2O_5 price = \$.08 or K_2O price = \$.05).

from experiments on Carrington soil in 1953 and 1955, respectively, indicating the wide range in supply level among years for a given soil type.

The slopes are more uniform than the positions of the supply curves. In general, they rise even more steeply than the static supply curves when only nitrogen is variable as in Figure 6.10. Supply curves (6.4) and (6.5) are vertical in Figure 6.11. P_2O_5 is "not used" for (6.4) until the corn price reaches \$1.67 per bushel with nitrogen and K_2O fixed at zero pounds. K_2O is "not used" until the corn price is \$1.19 per bushel. With nitrogen fixed at the zero level in (6.5), P_2O_5 is not profitable until the price of corn reaches \$1.60 per bushel. Only the initial yield level, the constant of the production function, is assumed to be supplied until these prices are reached.

The elasticity of supply curve (6.1) up to 60 cents and of (6.4) and (6.5) is zero (Figure 6.12). All the static supply curves with only P_2O_5 or K_2O variable are highly inelastic. All have elasticities below .20 for a corn price of 40 cents. The elasticity declines with higher prices of corn and is less than .05 for all supply curves when corn is \$1.20 per bushel. Although the magnitude of static supply elasticity with only P_2O_5 or K_2O variable differs by soil type and weather, it is uniformly low over the range of corn prices considered. This conclusion is based primarily on Iowa data. In several other experiments of other states,

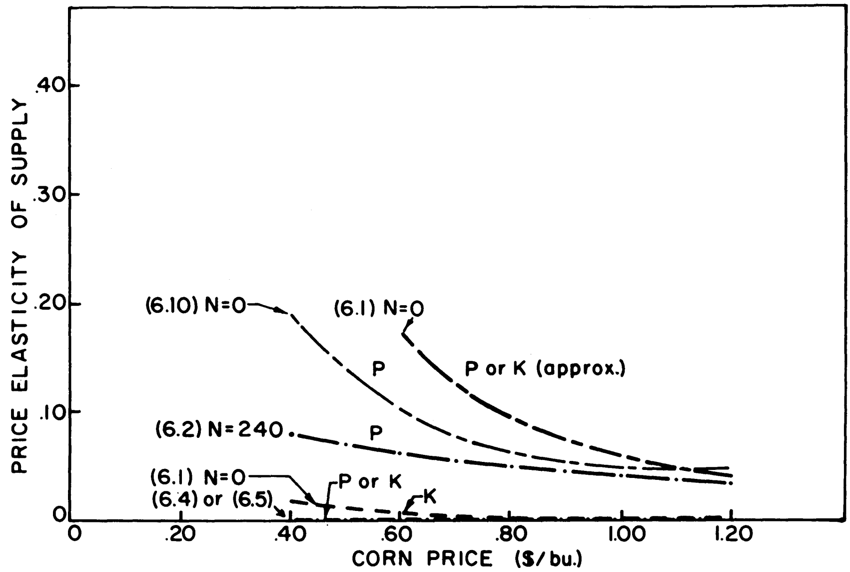

Figure 6.12. Price elasticities for supply curves in Figure 6.11.

P_2O_5 and K_2O were included but did not affect yield significantly. We may generalize that the static supply elasticity with only P_2O_5 and K_2O variable for the production function of the latter soil and weather conditions also is near or at zero.

All the supply curves in Figure 6.11 were derived from production functions which include two or three fertilizer nutrients as inputs. It is unlikely that either P_2O_5 or K_2O would be applied alone. Long-run static supply curves with P_2O_5 and K_2O varying with other nutrients provide a more meaningful estimate of static supply.

Long-Run Supply

As a single example, the long-run supply function where both N and P_2O_5 are variable for production function (6.10) is presented in (6.10i) where C has the value given in the footnote.[16]

$$\text{(6.10i)} \qquad Y = -5.682 - .316C_n^2 - .417C_p^2 + 6.351C_n + 8.516C_p + .341C_n C_p$$

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[16] The value of C is:

$$C_n = \frac{1.016P_y + 8.201P_y^2}{.042 + .318P_y + .411P_y^2}$$

$$C_p = \frac{2.814P_y + 7.548P_y^2}{.042 + .318P_y + .411P_y^2}$$

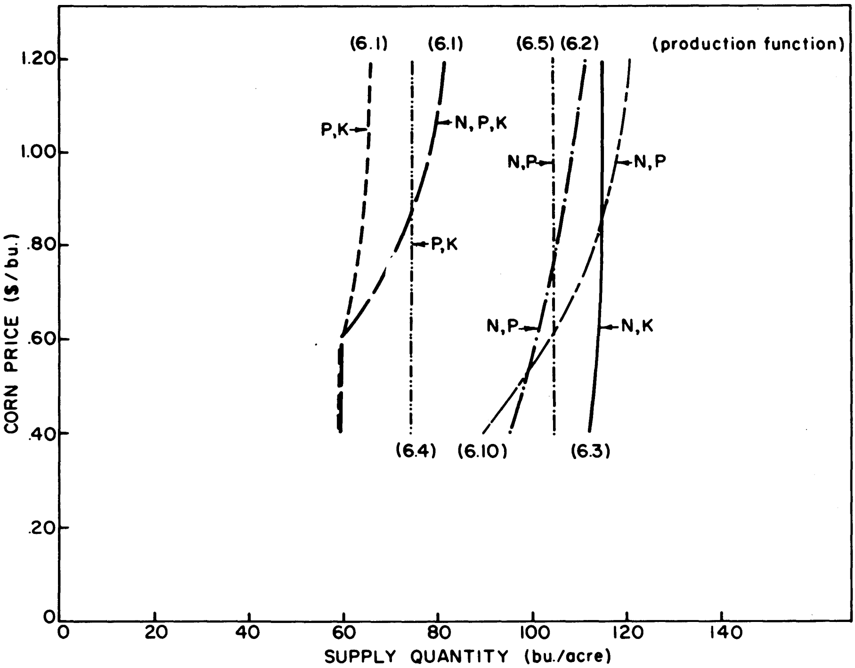

Figure 6.13. Per acre long-run static corn supply (nitrogen price = \$.13, P_2O_5 price = \$.08 and K_2O price = \$.05).

As in the case of other static demand and supply functions presented above, the form depends upon the underlying production function from which it is derived.

The range of supply quantities is not as broad and the curves are not as steep when more than one nutrient is variable for the static supply curves in Figure 6.13. Three fertilizer nutrients are variable in static supply curve (6.1) N, P, K; in the remainder only two nutrients are variable. The static supply curves (6.1) N, P for nitrogen and P_2O_5 variable and (6.1) N, K for nitrogen and K_2O variable are similar to (6.1) N, P, K and, consequently, are not illustrated. Addition of the third nutrient, P_2O_5 or K_2O in either case, causes little change in the supply curve. But adding nitrogen to (6.1) P, K shifted the curve sharply to the right. Obviously, nitrogen was the most limiting resource on the Clarion soil from which function (6.1) was derived.

Supply curve (6.1) N, P, K presents an interesting pattern. Nitrogen, P_2O_5 and K_2O individually become profitable (nonzero quantity) at corn prices of 62 cents, 58 cents and 61 cents, respectively. The slope of (6.1) is vertical until P_2O_5 is profitable at 58 cents. The segment of (6.1) N, P, K from 58 cents to 61 cents is the same as the short-run curve (6.1) P over the same price range in Figure 6.11. At 61 cents K_2O also becomes profitable and (6.1) N, P, K becomes "long-run" with two variable nutrients. It follows the curvature of (6.1) P, K until

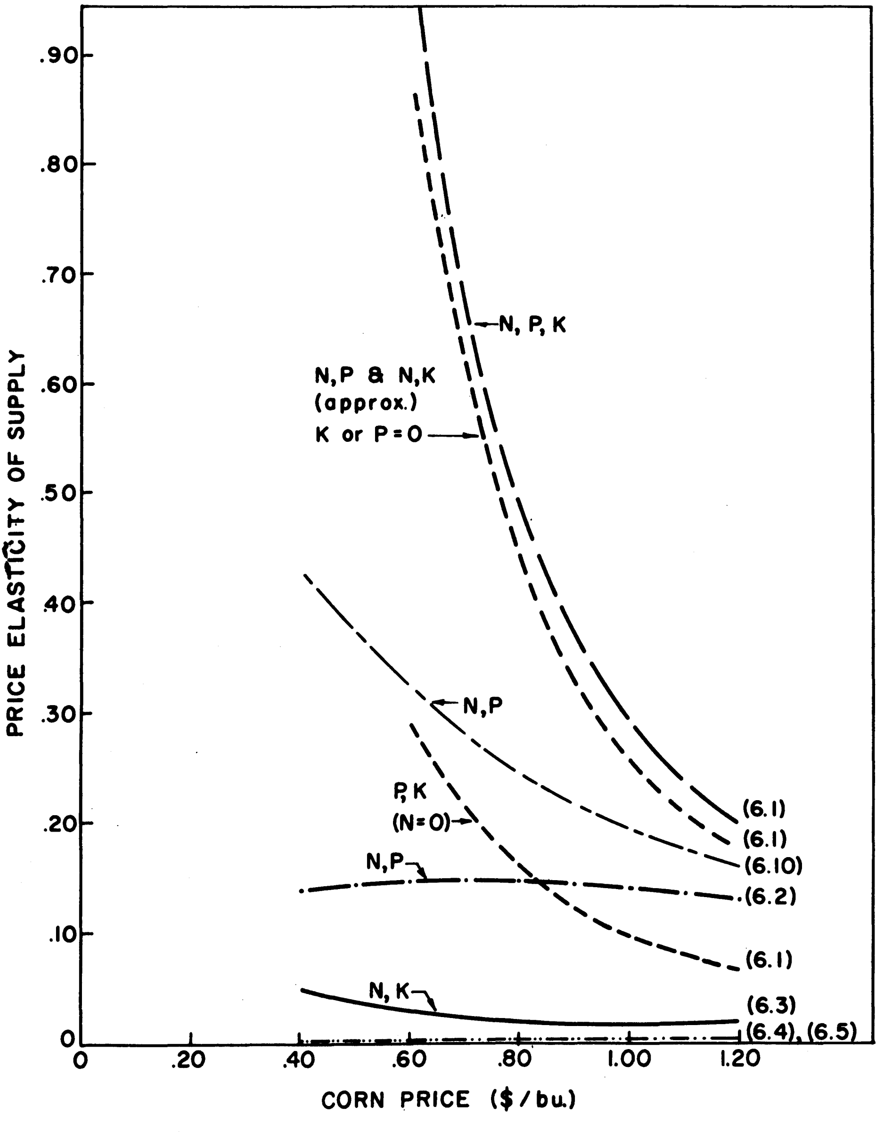

Figure 6.14. Price elasticities for supply curves in Figure 6.13.

nitrogen becomes profitable at 62 cents. When all three nutrients become variable at 62 cents, (6.1) N, P, K becomes separate from other static supply curves for (6.1).

All the static supply curves except (6.5) in Figure 6.13 are from Iowa data. While it is not possible to make interregional comparisons, it is possible to isolate some of the effects of supply of moisture and of soil fertility. Curves (6.3) and (6.4) were derived on Carrington soil

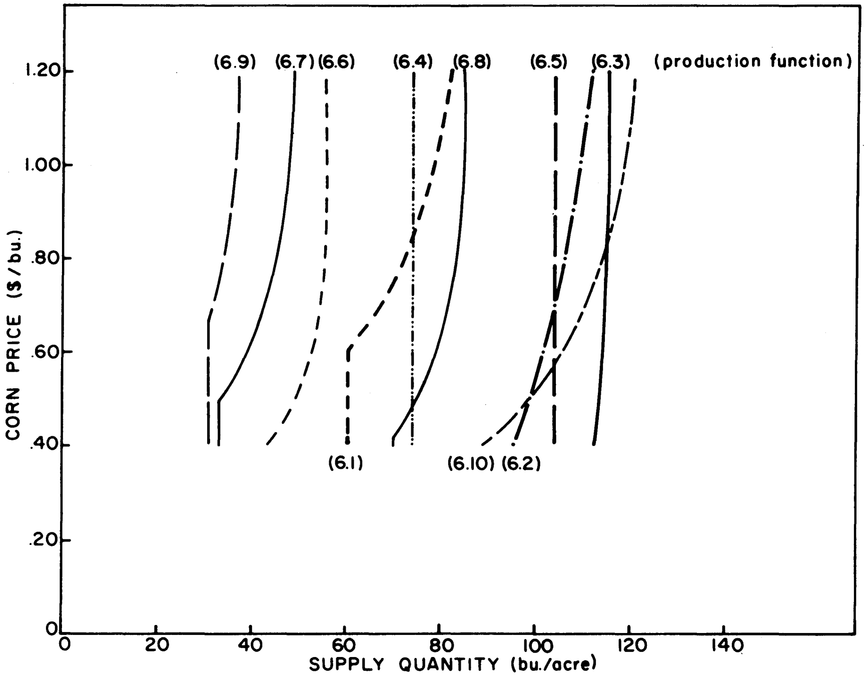

Figure 6.15. Summary of short-run and long-run static corn supply: All fertilizer nutrients included in the production function are variable. The prices of the variable factors, nitrogen, P_2O_5 and K_2O are 13 cents, 8 cents, 5 cents per pound, respectively.

in 1953 and 1955, respectively. Because of more rainfall in 1953, curve (6.3) lies considerably to the right of curve (6.4). Curves (6.10), (6.2) and (6.3) were estimated on different soils in Iowa but under similar moisture conditions in 1953. The curves depict nearly equivalent levels of supply. The results are consistent with the hypothesis that greater divergences in the level of supply arise because of differences in moisture than because of differences in soil type.

The moisture and fertility levels of the soil also explain the curvature of the supply curves. The greatest curvature is found in curves derived on soils low in fertilizer but otherwise favorable for corn production; i.e., with adequate moisture, good soil structure, etc. Curves (6.10) and (6.2), for example, were estimated under favorable moisture conditions. Curve (6.1), though estimated under limited moisture, lacked fertilizer, particularly nitrogen, and hence indicated considerable curvature.

On the other hand, supply curves (6.4) and (6.5) are vertical straight lines. The corn prices at which nutrients become profitable — the slope becomes less than infinite — for supply curve (6.4) are $1.23 and $1.51 for P_2O_5 and K_2O, respectively. For supply curve (6.5) it is profitable to use P_2O_5 when the corn price reaches $1.59 per bushel,

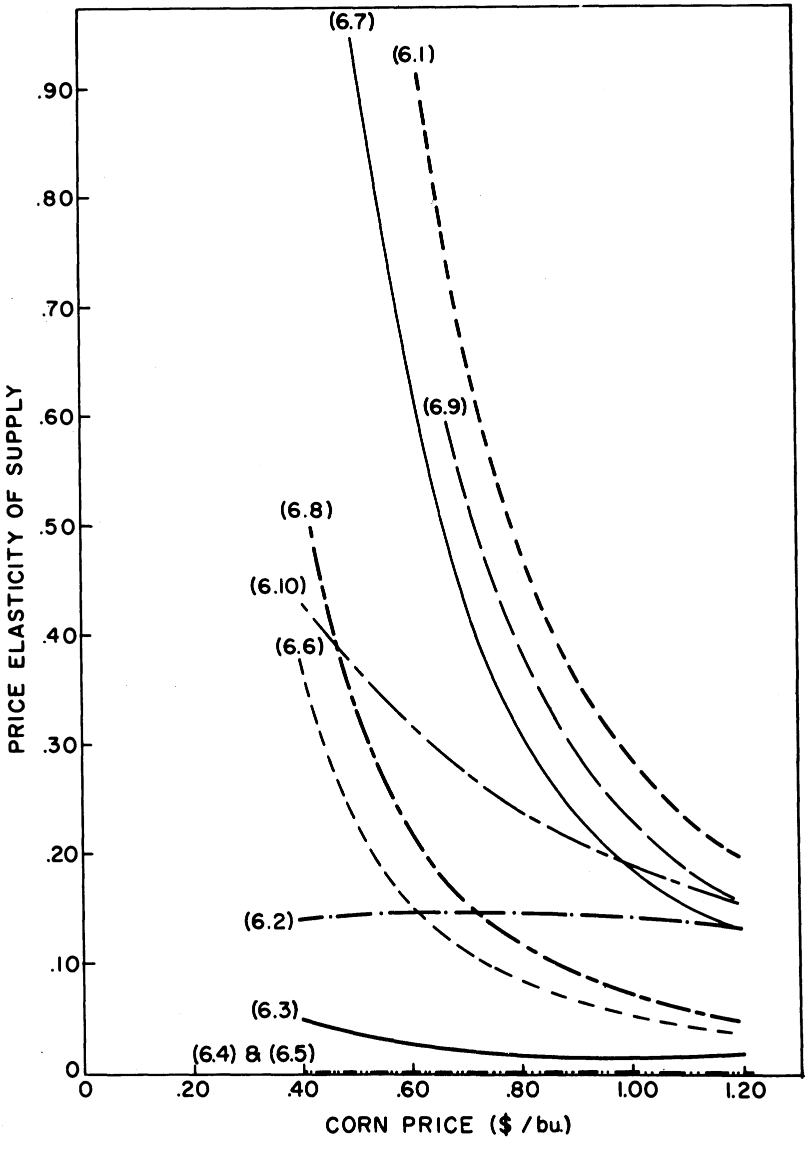

Figure 6.16. Price elasticity of short-run and long-run static supply curves illustrated in Figure 6.15.

but the price of corn must reach $1.79 per bushel before nitrogen becomes profitable. Lack of moisture severely limited the physical response to fertilizer for production function (6.4) in 1955. Wisner loam is a fertile, heavy soil, and the lack of curvature in (6.5) is due as much to the initial fertility of the soils as to limited rainfall.

The long-run static supply curves have higher elasticity (Figure 6.14) than have the short-run supply curves (Figure 6.12). Nevertheless, all the long-run curves are inelastic when corn is over 40 cents per bushel. The elasticity is less than .5 when the price of corn is greater than 80 cents and less than .20 when the corn price is $1.20 or higher. If (6.1) were omitted, the elasticity of the remaining curves would lie below .45 for all corn prices of 40 cents or more. Much of the elasticity of (6.1) is due to nitrogen; the elasticity with only nitrogen variable (Figure 6.10) is nearly as large as with three nutrients variable and is considerably more elastic (less inelastic) than with only P_2O_5 and K_2O variable. Clarion (6.1), a highly productive soil, lacked fertilizer, particularly nitrogen, for the site of the experiment.[17]

Figures 6.15 and 6.16 are included to provide a summary of the static supply curves when all nutrients included in the production functions are allowed to vary.

The elasticities of the static supply curves also do not show any important differences among areas (Figure 6.16). Static supply curves (6.1) and (6.4) from Iowa data rank lowest and highest in elasticity, indicating that greater differences may exist within an area than among areas. Despite differences within and among areas, the elasticities of all the curves are uniformly low. All of the static supply curves have an elasticity of less than unity for a corn price over 40 cents. The elasticity falls with high corn prices. It is less than .3 for a corn price greater than $1 and less than .20 for a corn price greater than $1.20. The elasticity of supply curves (6.3), (6.4) and (6.5) is zero or near zero in the price range of 40 cents to $1.20.

IMPLICATIONS

Figures 6.10 through 6.16 indicate that the elasticity of static supply is low for all soil and weather conditions, prices, short-run and long-run supply curves and algebraic forms considered. Without exception, static supply is less than unity for corn prices over 40 cents per bushel. The elasticity is less than .3 for corn prices above $1.00 and less than .2 for corn prices above $1.20. The "average" elasticity of the curves lies well below these values, since in many instances the elasticity is near zero or zero in the relevant price range. Furthermore, the estimates indicate the elasticity at the beginning of the growing season on a given acreage. As the season progresses, opportunities diminish for increasing yields in response to favorable prices, and the supply elasticity essentially is zero for <u>all</u> production units as the end of the growing season approaches. The results clearly indicate low static supply elasticity.

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[17] The long-run supply elasticities of Figure 6.14 give a more realistic estimate of static supply than do the short-run elasticities for the same production functions shown in Figures 6.10 and 6.12. A farmer seldom would use only a single nutrient when other nutrients give a significant yield response and also limit the response of the single nutrient.

7.

Time Series Demand Functions for Fertilizer

CHAPTER 6 provided a normative analysis of static demand functions for fertilizer based on experimental data. This chapter includes demand functions for total fertilizer and individual fertilizer nutrients for the United States and for ten separate regions. Numerous regression models are employed for these time series estimates. A set of national estimates presented in a later part of the chapter are based on regression models similar to those employed for operating inputs in Chapter 13. However, those presented in the early part of the chapter, and later for regions, represent rather distinct models applied alone for fertilizer.

INCREASE IN FERTILIZER INPUTS

One of the greatest changes in farm input demand since 1940 has been for fertilizer. From 1929 to 1959 annual inputs of fertilizer and lime increased by more than 300 percent. As for many other inputs examined in later chapters, the main force underlying this increase has been technological knowledge relating the response of crop production to fertilizer inputs, the favorable price of fertilizer relative to crop prices, increased knowledge and improved managerial skills of operators and a favorable equity or income position of farmers. Unfortunately, because of intercorrelation among important variables concerned, it is not possible to specify demand functions in the detail necessary to isolate quantitatively the absolute or relative effect of several of these variables. It is necessary to turn to that convenient catchall, a time variable, to express certain of these effects.

Variables other than those analyzed are important. Changes taking place in other variables alter the productivity of fertilizer, even apart from new knowledge of fertilizer per se. For example, new practices for crops have an interaction effect causing a given input of fertilizer to have greater productivity. Greater use of fertilizer is expected accordingly. Improved seed varieties, continuous row cropping on level land, modern planting rates, irrigation and other practices also tend to increase fertilizer productivity, just as use of fertilizer tends to increase the response of inputs representing these practices. Cropping of new regions initially drew nutrients from the virgin stores of nitrogen, potash and phosphate in the soil. While added fertilizer might have had little effect with a sufficient supply of virgin stores in the soil in the first century or less of farming, depletion of these stores increased the marginal response of applied fertilizer. Knowledge of the fertilizer production function, both by agricultural scientists and by farmers, has been under continuous change due to a myriad of such forces and variables relating to the production function. These changes together with price relatives explain increases in fertilizer demand, and it is impossible to separate the effects of these two dominant categories determining fertilizer use.

Fertilizer is highly divisible and has a short transformation period. In contrast to durable resources such as machines and buildings, a farmer can purchase fertilizer in ton or pound quantities. He can adjust purchases and use in desired amounts as price and weather variables change, or as other new information becomes available. Hence it is not surprising that fertilizer use has responded quite readily to changes in the major variables which are expected to affect demand for it (Figure 7.1). The figure illustrates that demand for all fertilizer and for particular nutrients has declined abruptly during and following periods of a sharp rise in the fertilizer/crop price ratio. The outstanding example is during the depression of the early 1930's; less violent

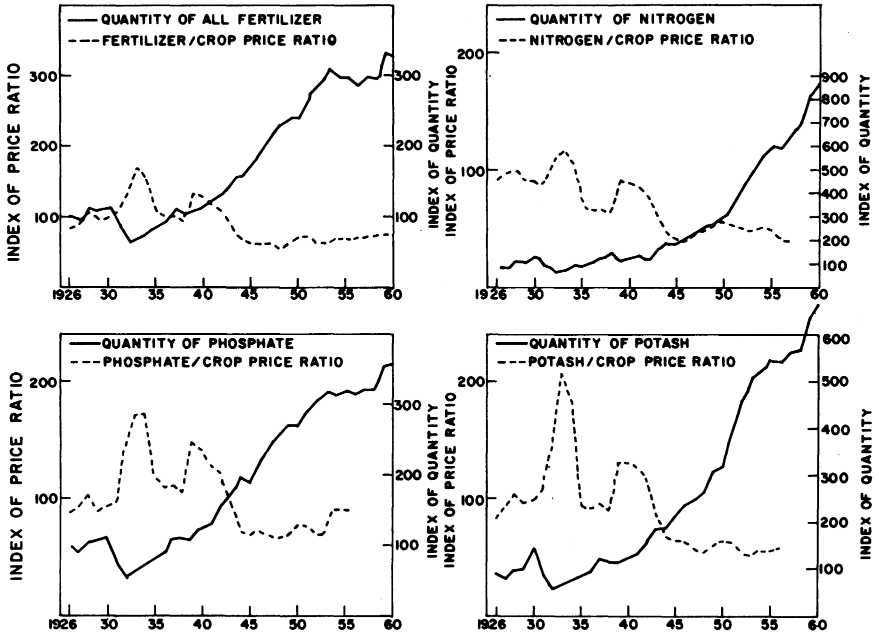

Figure 7.1. Indices of fertilizer use (tons) and fertilizer/crop price ratios for the U.S., 1926-60 (1926-30=100); including all fertilizer, nitrogen, K_2O and P_2O_5.

increases in the price ratio and decline in fertilizer purchases are apparent in the recent postwar period.

Changes in Knowledge and Prices

Figure 7.1 shows that the price of fertilizer was low, relative to the price of crops, during the postwar period when the greatest increase in fertilizer purchases took place. Quite high correlation coefficients and significant regression coefficients are obtained if fertilizer quantity, at the national level, is simply regressed on the fertilizer/crop price ratio. But also a simple regression model which relates fertilizer purchases to a time variable alone provides statistically significant coefficients. It is noteworthy in Figure 7.1 that fertilizer purchases continued to increase even after the price ratio began to level out or increase after 1950 (a tendency even more apparent in the consumption data for particular regions which follow). This phenomenon could occur if the fertilizer/crop price ratio only determined fertilizer inputs but with a distributed lag. It is highly unlikely, however, that postwar trends can be explained entirely in lagged response of fertilizer use to the price ratio. The numerous factors cited earlier, and reviewed in Chapters 1 to 4, effectively increasing the knowledge of the productivity coefficients, undoubtedly have been important in encouraging greater use of fertilizer. Information about fertilizer response over much of the Corn Belt and Great Plains, or even in the Far West, was somewhat meager until the postwar period. Too, the income and equity position of farmers has been favorable to extended resource use and substitutions since 1940.

At the same time, the real or effective price of fertilizer nutrients has been lowered through several developments. One such development has been research by private industry, TVA and some other public research agencies on new fertilizer materials and on the technology of their production. These developments, along with a trend towards higher nutrient concentration of fertilizers distributed to farmers, have had two important effects. Augmented with information on fertilizer rates, placement and time of application, they have helped increase the crop response realized from a given tonnage of fertilizer. In a more direct economic sense, they also have lowered the net real price per pound of nutrients purchased by farmers. Along with these developments in processing and improving basic materials used in fertilizers, the fertilizer industry has expanded in numbers of firms and in competition. Markham suggests that this growth in competition has been highly important in lowering the price of fertilizer relative to the crops for which it is used.[1] As illustrated more clearly in Figure 7.2, farmers do respond quite readily to changes in relative prices of

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[1] Markham, J. W. The Fertilizer Industry. Vanderbilt University Press. Nashville, Tennessee. 1958.

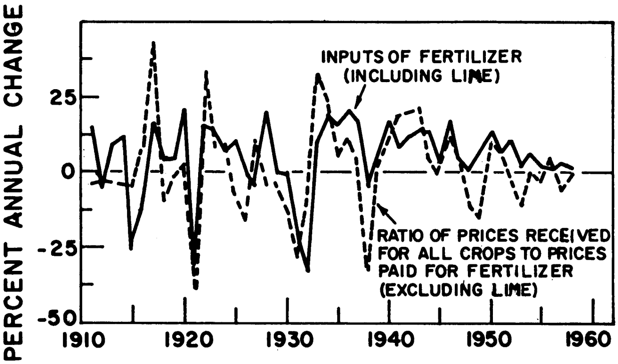

Figure 7.2. Percent annual change in fertilizer inputs and crop/fertilizer price ratio. (Source: USDA.)

fertilizer. However, in explaining the extremely large and extended trend in increased fertilizer use since 1940, it appears that technological variables stand at a level with price variables.

Individual Nutrients

Fertilizer is an aggregate resource composed of individual nutrients such as nitrogen, phosphate and potash. While it is purchased in aggregate form representing particular mixes, the individual nutrients or components also can be purchased separately. Given this flexibility, purchase or demand for individual nutrients has increased at different rates. Between 1929 and 1960, national use of phosphate increased by only 225 percent. For the same time period, the increase was nearly 620 percent for nitrogen and 315 percent for potash. Demand for nitrogen and potash, especially, appears to have increased under price relatives which are no more favorable than in earlier postwar years.

While the relative price of all fertilizers declined after 1940, the decline was greater for nitrogen and potash than for phosphate and fertilizer in aggregate. This difference would suggest that demand for the two nutrients should grow more rapidly than for the latter two categories. Agronomists suggest, however, that knowledge of response, from nitrogen especially but also from potash, probably increased relative to phosphate after 1935. Similarly, new cropping techniques, such as continuous row crops and irrigation, have increased response from nitrogen. New forms such as anhydrous ammonia have reduced the price and improved handling procedures. These also are developments expected to cause demand for nitrogen and potash to increase relative to demand for phosphate and fertilizer in aggregate.

Regional Trends

Important differences have occurred among regions in use of fertilizer. Prior to 1940, the heaviest users of chemical fertilizers were the Northeastern and Southern states. In 1910, the Northeast, Appalachian, Southeast and Delta regions used 93 percent of all commercial fertilizers in the United States. These regions were still using 82 percent of the national total in 1940. Although fertilizer inputs increased in these regions after 1940, in 1956 they were using only 55 percent of the nation's total. By the early 1960's, the remaining regions of the country had become the major user of all commercial fertilizer retailed in the nation.

Increase in fertilizer inputs by the four "older using regions" mentioned above ranged from 85 to 130 percent between 1926-30 and 1960. In the "newer using regions," however, the percentage increase for the same period was around 500 for the Southern Plains, 700 for the Corn Belt, 800 for the Lake States, 900 for the Mountain region, and 2,100 for the Pacific region (see Figure 7.3). Had relative prices been the only or major variable relating to growth in demand for fertilizer, somewhat parallel increases in demand would have been expected over all regions. Relatively more land has been withdrawn from farming in

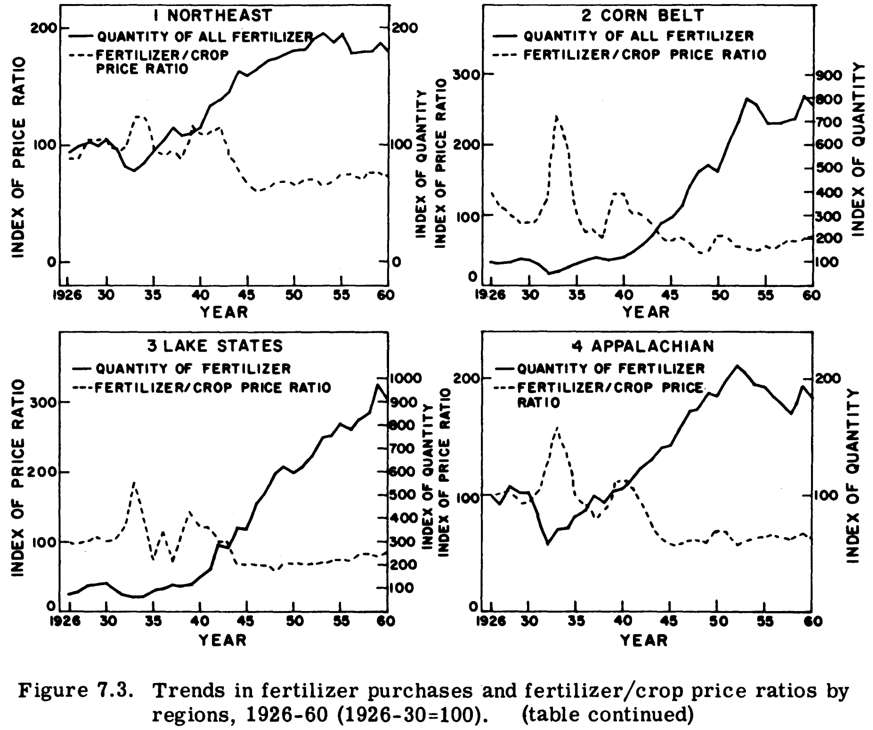

Figure 7.3. Trends in fertilizer purchases and fertilizer/crop price ratios by regions, 1926-60 (1926-30=100). (table continued)

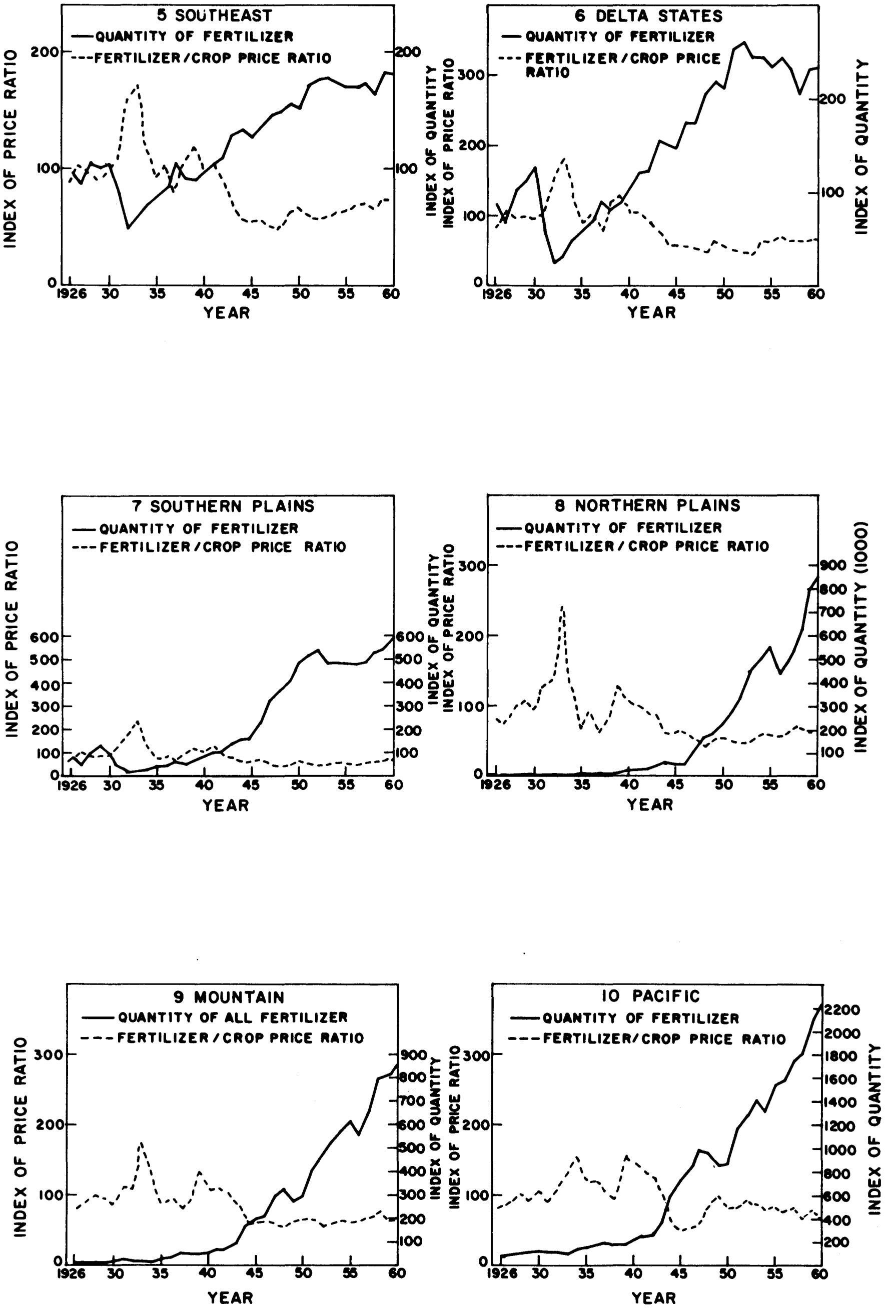

Figure 7.3. (continued

in some of the older using regions, as a result of nonfarm demand and production control programs. However, the difference in land withdrawal is not large enough to account for the differential rates among regions at which fertilizer demand has grown.

Certainly a major part of this difference in rate of increase in use of fertilizer must be attributed to growth in technological knowledge in the newer using regions from 1930 to 1960. As mentioned previously, prior to the war little research on crop response to fertilizer had been conducted in states west of the Corn Belt. These regions had not been farmed as long and leaching of soil nutrients was much less a problem than in the more humid and eastern regions. Hence, virgin soil fertility became a restraint on yields only at a much later date. Too, fertilizer restrained yields and became a more limiting resource in the new using regions with the advent of new or extended technologies such as hybrid corn, insecticides, irrigation, moisture conservation and others. Fertilizer use shows a much more distinct tendency to level off or even to decline slightly in the older using regions after 1955. Rather sharp declines in the other regions appear to follow years of unfavorable farm prices and income. However, continuance of the upward trend is much more apparent in the newer using regions, even though the fertilizer/crop price ratio has increased by about the same magnitude as in the older using regions. Again it appears that the variables of knowledge and technology mentioned above must have great importance in explaining these differences.

DATA AND METHOD

We now turn to regression estimates of fertilizer demand. Estimates are made for total fertilizer tonnage, total nutrient quantity, lime and for nitrogen, P_2O_5 and K_2O separately. The purpose of these demand estimates is an attempt to explain, quantitatively, the effect of fertilizer and crop prices, land prices, income, time and other variables on the use of fertilizer inputs by farmers.

This study of fertilizer demand was originally initiated in 1955. Some of the earlier findings from it have been reported elsewhere.[2] Simultaneously, with the original study and without knowledge of common endeavor, other studies which were being conducted[3] and reported somewhat similar quantitative findings. The estimates reported in this

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[2] See Heady, Earl O., and Yeh, M. H. National and regional demand functions for fertilizer. Journal of Farm Economics 41:332-48, Aug. 1959; Heady, Earl O., and Yeh, M. H. Regression estimates of national and regional fertilizer demand functions. TVA Annual Conference for Cooperators, May 1957 (Mimeo.); and Yeh, M. H. Fertilizer Demand Functions. Unpublished Ph.D. thesis, Library, Iowa State University. Ames. 1958.

[3] See Griliches, Zvi. The demand for fertilizer: an economic interpretation of a technical change. Journal of Farm Economics 40:591-606, Aug. 1958; and Griliches, Zvi. Distributed lags, disaggregation and regional demand functions. Journal of Farm Economics 41:94-103, Feb. 1959.

chapter bring previous estimates up-to-date. The earlier phase of this project, the other studies mentioned and the results reported are consistent in many aspects, particularly in significance of real price variables, time and technological knowledge in explaining growth in farm demand for fertilizer. However, as has been pointed out elsewhere, alternative interpretations of the relative importance of prices, farmer knowledge and the interaction of other technologies with fertilizer are possible in explaining demand growth for the latter.[4]

The parameters in national and regional demand functions are estimated by single equation least squares. The U.S. functions presented first are estimates of fertilizer demand apart from other inputs. Demand functions presented later for total fertilizer and lime consumption are more comprehensively specified and parallel the demand functions explained in later chapters.

The aggregate estimates presented, based on time series observations for the United States and selected agricultural regions, indicate only "gross" relationships between specified variables and farmer use of fertilizer. The analysis makes no attempt, largely because of lack of relevant data, to determine the exact variables and decision-making process which individual farmers use in deciding the quantities of fertilizer to employ. Linear programming analyses of individual farms, such as those in Iowa, have shown that the quantities of fertilizer which are profitable for an individual farmer depend on the managerial practices used in producing crops and livestock, the soil type and yield response from fertilizer, the amount of capital and labor available, the tenure arrangement under which farms are operated, and on the presence or absence of various types of production subsidies and acreage allotments. These variables are important ones, along with actual and expected levels of prices, in determining the kinds and amounts of fertilizer which are most profitable on an individual farm. The purpose of this study, however, is to predict the aggregate fertilizer demand of all farmers in the United States, or in a particular region, rather than to specify profitable levels of fertilizer input for individual farmers. Hence, inability to isolate the effect of certain of the variables mentioned above probably does not place an important restriction on the analysis which follows.

Source and Nature of Data

Data used in this chapter are from various USDA sources for the years 1926 through 1960. Since time series data were available only on a state basis, regions could be delineated only along state boundaries and they follow the conventional census regions. The states within the regions indicated in Table 7.1 have some similarity in type

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[4] See Renshaw, E. F. Distrubuted lags, technological change and demand for fertilizer. Journal of Farm Economics 43:955-61. Also, see Heady, Earl O., and Yeh, M. H. National and regional demand functions for fertilizer, op. cit., Dec. 1961.

Table 7.1. Regions Used for Demand Analysis

Region	States
1. Northeast	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware and Maryland
2. Corn Belt	Ohio, Indiana, Illinois, Iowa and Missouri
3. Lake States	Michigan, Wisconsin and Minnesota
4. Appalachian	Virginia, West Virginia, North Carolina, Kentucky and Tennessee
5. Southeast	South Carolina, Georgia, Florida and Alabama
6. Delta States	Mississippi, Arkansas and Louisiana
7. Southern Plains	Oklahoma and Texas
8. Northern Plains	North Dakota, South Dakota, Nebraska and Kansas
9. Mountain	Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah and Nevada
10. Pacific	Washington, Oregon and California

of farming, soil and climatic conditions. The crop price index, used in deriving national and regional demand functions for fertilizer, was computed for each region. Prices of the several crops are included in the regional indices (Table 7.2).

Table 7.2. Crops Used for Constructing Price Variables in Each Region

Region	Crops
1. Northeast	Hay, corn, oats, wheat and apples
2. Corn Belt	Corn, hay, oats, soybeans and wheat
3. Lake States	Hay, corn, oats, wheat and barley
4. Appalachian	Corn, hay, wheat, cotton, soybeans and tobacco
5. Southeast	Corn, cotton, peanuts, oats and tobacco
6. Delta States	Corn, cotton, hay, soybeans and rice
7. Southern Plains	Wheat, cotton, sorghum, corn and oats
8. Northern Plains	Wheat, corn, hay, oats, barley and flaxseed
9. Mountain	Wheat, hay, barley, corn, potatoes and sugar beets
10. Pacific	Wheat, hay, barley, oats, apples, peaches, oranges and pears

Specification of Demand Functions

The several demand specifications represent somewhat different hypotheses relating to the important variables (a) structurally meaningful and influencing farmer decisions on fertilizer use or (b) predictively appropriate in forecasting fertilizer use in future periods.

The variables specified for analyzing fertilizer demand are:

F_n = total national purchases of fertilizer materials by United States farmers in the current (t) calendar year prior to 1945, the crop year after 1945 and measured in thousands of tons.

F_i = total regional purchases of fertilizer materials by farmers in the i-th region in the current calendar year (i = 1, 2, . . . , 10).

F_w = the weighted index of total fertilizer consumption for the United States, with weights based on the 1947-49 prices of nitrogen, P_2O_5 and K_2O and 1926 = 100.

Y_n = total national purchases of plant nutrients (N, P_2O_5 and K_2O) by United States farmers in the current calendar year and measured in tons.

F_{na} = the pounds of fertilizer applied per crop acre for all cropland in the United States during the current calendar year.

N_n = total national purchases of nitrogen in the current calendar year and measured in tons.

N_i = total regional purchases of nitrogen in the i-th region in the current calendar year (i = 1, 2, . . . , 10).

P_n = total national purchases of P_2O_5 in the current calendar year and measured in tons.

P_i = total regional purchases of P_2O_5 by farmers in the i-th region in the current calendar year (i = 1, 2, . . . , 10).

K_n = total national purchases of K_2O in the current calendar year and measured in tons.

K_i = total regional purchases of K_2O in the i-th region in the current calendar year (i = 1, 2, . . . , 10).

Z_r = the index of the ratio of national fertilizer price to crop prices in the previous (t-1) calendar year, for the nation or regions as indicated.[5]

Z_f = the fertilizer price index in the previous calendar year, for the nation or regions as indicated.

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[5] A prime sign on Z_r refers to crop prices measured for the previous year but fertilizer price measured over the three months representing planting time as indicated elsewhere in the text.

Z_c = the crop price index in the previous calendar year, for the nation or regions as indicated.

Z_d = the United States price index for land in the previous calendar year.

Z_s = the ratio of fertilizer price to the price of land, the United States for the previous calendar year, expressed in index form.

Z_{cr} = the index of cash receipts of crops for the previous calendar year.

A_f = the number of crop acres per farm in the United States for the current year.

C = the total cropland acreage for the United States in the past calendar year.

R = the cash receipts from farming for the United States or regions as in the past calendar year. (Modifications of this variable will be explained where they are used.)

T = time measured as the last two digits of the current year.

S_{pt} = the stock of productive farm assets on January 1 of the current year, expressed in billions of 1947-49 dollars and including machinery, livestock, real estate, feed and cash held for productive purposes.

The above symbols, with t-1 following the subscript, refer to national or regional purchases lagged one year (of the past year). Using these variables, demand functions were computed for thousands of tons of fertilizer used, and tons of P_2O_5, K_2O, nitrogen and all plant nutrients for the United States, and ten agricultural regions as indicated later. Also, models estimating pounds of total fertilizer per crop acre were estimated for the United States. Additional estimates of aggregate fertilizer and lime purchases also were made for the United States. The variables used in specifying these demand functions will be explained later. The period used for estimating demand functions, except where otherwise noted, is 1926-60 with 1944-50 excluded. All prices are deflated by the index of wholesale prices for the corresponding year.

Several algebraic forms of equations were employed in estimating fertilizer demand functions. In some cases there appears to be little statistical basis for selecting between models which are linear in logarithms and those which are linear in original observations. In order to conserve space, most of the models presented in this chapter are estimated with observations transformed to logarithms. The demand functions presented represent only a portion of those estimated either for the United States or for the ten regions.

UNITED STATES DEMAND FUNCTIONS

This section includes demand functions estimated for the United States, with purchases measured in thousands of tons of all fertilizer purchased (simply termed fertilizer hereafter), tons of all plant nutrients (N, P_2O_5 and K_2O summed), tons of nitrogen, tons of P_2O_5, tons of K_2O and pounds of fertilizer per acre.

Total Fertilizer and Total Plant Nutrients

Chapter 5 quantitatively illustrated the substitution of fertilizer for land. Nationally, in meeting demand for food, it is possible for fertilizer to be substituted for land. (This process also is possible for the individual farmer. However, as mentioned earlier, the farmer typically purchases fertilizer to use on his given acreage, and not directly to substitute for land by reducing acreage.) Under a free market, with technology incorporating fertilizer increasing at a faster rate than food demand, this "more aggregate" substitution would be expected: farmers in more productive regions apply added fertilizer as land in less productive regions is withdrawn from crops. Given these "roundabout" and perhaps somewhat obscure effects of fertilizer-land substitution, one demand model was specified including variables for land price and total cropland acreage, along with fertilizer price, crop price and time. The resulting equation (7.1) is estimated under logarithmic transformation of variables.

$$(7.1) \quad \log F_n = 4.965 - \underset{(.431)}{1.531} \log Z_f + \underset{(.230)}{.704} \log Z_c + \underset{(.131)}{.371} \log Z_d - \underset{(.996)}{.171} \log C + \underset{(.003)}{.008} \log T$$

Standard errors are included in parentheses. The R^2 is .981, and the first three regression coefficients are significant at the .99 probability level and the last one at the .95 level. The standard error for the cropland variable is several times the magnitude of the regression coefficient. While the sign of the coefficient is as expected, denoting an increase in fertilizer consumption with a decrease in total cropland acreage, statistical indication of direct substitution is not apparent in the data.

The same function was estimated for a weighted index of total fertilizer consumption with F_w substituted for F_n in (7.2).

$$(7.2) \quad \log F_w = 7.17 - \underset{(.417)}{1.374} \log Z_f + \underset{(.222)}{.810} \log Z_c + \underset{(.126)}{.696} \log Z_d - \underset{(.962)}{1.073} \log C + \underset{(.003)}{.017} \log T$$

This estimate with an R^2 of .990 gave results similar to (7.1). All coefficients had signs consistent with theory, but the coefficient for total cropland acreage again was not significant. Dropping the latter variable, the estimated demand function is (7.3) where the R^2 remains at .990, and all the regression coefficients are significant at the .99 probability level and have signs consistent with theory.[6]

$$(7.3) \quad \log F_w = 4.99 - \underset{(.385)}{1.556} \log Z_f + \underset{(.205)}{.712} \log Z_c + \underset{(.126)}{.682} \log Z_d + \underset{(.003)}{.015} \log T$$

Given this short-run model with coefficients as constant elasticities for the time period covered, a 1 percent increase in fertilizer price, other things remaining equal, is predicted to reduce fertilizer purchases 1.6 percent. Similarly, a 1 percent increase in crop prices is predicted to increase fertilizer purchases .7 percent, and a 1 percent increase in land price is predicted to increase fertilizer consumption by .7 percent. From this equation, a 1 percent change in fertilizer price is predicted to have a greater relative effect on fertilizer purchases than a similar change in prices of crops or land. It is, of course, the fertilizer/crop price ratio which affects the profitability of fertilizer use. However, it is possible that farmers respond more to change in the price of an expense item than to a change in the price of a farm product. Later estimates suggest inability to measure differential effects of price changes for inputs and outputs. While the coefficient of land price has the expected sign and is statistically significant, it is doubtful that it has the "direct effect" implied. Doubt is based on the "roundabout" nature of the substitution effect and the possibility that land price is sufficiently correlated with time and general technological progress over the period to give the effect indicated in the above equations. Also the dubious causal framework may be reversed — land price may be a function of fertilizer inputs.

Therefore, as a further specification of fertilizer demand, the same equation was estimated deleting land price and adding the U.S. stock of productive farm assets, S_{pt}, a variable included in numerous of the demand function specifications in later chapters. Dropping the price of land from equation (7.3) resulted in equation (7.4) with a regression coefficient with a somewhat smaller R^2 and nonsignificant regression coefficients for crop price and time.

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[6] An equation the same as (7.3) except with the substitution of total cropland for land price had an R^2 of .987. Coefficients for all variables were significant at the .99 level of probability, except for cropland. The latter coefficient of -1.193 had a standard error of 1.07.

$$(7.4)\quad \log F_w = 1.88 - \underset{(.448)}{1.408} \log Z_f + \underset{(.220)}{.364} \log Z_c + \underset{(.617)}{2.632} \log S_{pt} + \underset{(.003)}{.007} \log T$$

The sign of the highly significant coefficient of S_p is positive and indicates a complementarity between fertilizer and durables.[7]

The specification in (7.3) also was used in estimating total demand for plant nutrients, with Y_n substituted for F_n. The resulting estimate, (7.5), is highly similar to (7.3), with an R of .987 and all regression coefficients significant at the .99 percent level of probability.

$$(7.5)\quad \log Y_n = 6.290 - \underset{(.427)}{1.593} \log Z_f + \underset{(.227)}{.719} \log Z_c + \underset{(.140)}{.578} \log Z_d + \underset{(.003)}{.014} \log T$$

In statistical tests the elasticities between the two functions do not differ significantly. Apparently a change in crop or fertilizer prices has had, as an average over time, the same proportional effect on total fertilizer and total plant nutrients purchased by farmers. For more recent periods, however, this relationship might not hold because of the upgrading of fertilizer analyses.

Table 7.3 includes other specifications of the U.S. demand function for fertilizer (F_n) over the period 1926-60 with 1944-50 excluded. The first three equations are "short-run" models in the sense that they do not include a lagged variable for fertilizer purchases. Equation (7.8) has a coefficient of determination of .970 and highly significant regression coefficients for time and the fertilizer/crop price ratio. This function attributes all of the increase in fertilizer use to the real price of fertilizer and to improvement in technological knowledge and other influences represented by a time variable. It is only slightly less efficient, in terms of the proportion of variance accounted for, than other specifications which include more detail and variables. When other variables are added to this function they do not reduce significantly deviations from regression. On the basis of this specification, fertilizer purchases are predicted, as an average over the time period analyzed and based on the elasticity coefficient, to decline (increase) by .94 percent for each 1 percent increase (decline) in the fertilizer/crop price ratio. When the effects of the two prices are predicted separately as in (7.6), the time variable is not significant — an unlikely condition considering its representation as an aggregate measure of technical knowledge and other "gradual" influences affecting fertilizer response.

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[7] Land price was excluded because of high intercorrelations. An equation with S_p and Z_d included was estimated but the coefficient of S_p was not significant.

Table 7.3. Statistics for Estimates of United States Demand Functions for Fertilizer (F_n); Including Regression Coefficients, Standard Errors (in Parentheses) and R^2

Equation	R^2	Log of Constant	Regression Coefficients					
			log Z_f	log Z_c	log Z_r	log Z_d	log T	log $F_{n,t-1}$
(7.6)	.975	6.28	-1.840 (.430)	.508 (.225)			.006 (.004)	
(7.7)	.979	4.62			-.979 (.084)	.422 (.126)	.012 (.001)	
(7.8)	.970	5.33			-.944 (.098)		.013 (.001)	
(7.9)	.985	4.60	-1.398 (.364)	.214 (.282)		.011 (.197)	.002 (.004)	.393 (.173)
(7.10)	.985	4.90	-1.480 (.296)	.118 (.124)		-.037 (.148)		.438 (.123)
(7.11)	.985	4.62	-1.400 (.356)	.203 (.193)			.001 (.003)	.401 (.101)
(7.12)	.985	4.97	-1.52 (.234)	.131 (.111)				.418 (.092)
(7.13)	.981	3.17			-.580 (.125)		.008 (.002)	.418 (.111)

Addition of the land price variable in (7.7) results in a regression coefficient which is significant at the .99 probability level and increases the coefficient of determination slightly. While this result again suggests that farmers substitute fertilizer for land, the previous qualifications regarding this process must be emphasized. In all of the equations where regression coefficients are estimated separately for crop prices and fertilizer prices, a change in the latter is predicted to have a greater effect on fertilizer purchases than a similar percentage change in the former. This result may arise because other related prices are not specified in the demand function.

The distributed lag models in (7.9) through (7.13) added very slightly to the portion of variance in fertilizer purchases explained. However, land price did not have a statistically significant regression coefficient in any of the equations with a lagged value of F_n. This result tends to confirm our hypotheses that the previous appearance of a significant coefficient for land price more nearly results, over a major part of the period studied, from a correlation of the land price variable with time and other variables. In the distributed lag models, $F_{n,t-1}$ apparently tends to take over this role and needs to be explained similarly. This possibility is further emphasized by the fact that the regression coefficient for time is not significant in (7.9) and (7.11). The lagged variable evidently is a stronger variable than time, and the two are correlated since fertilizer purchases displayed strong upward trend over most of the period analyzed. Equation (7.13), with a price ratio variable substituted for separate fertilizer and crop price variables, does have statistically significant coefficients for both time and $F_{n,t-1}$, however. Some multicollinearity is removed by eliminating a separate variable for deflated crop prices, since this variable increases with time and with the lagged value of fertilizer consumption over much of the period between 1932 and 1951. Equation (7.13) with a lagged value of F_n gives an elasticity of the price ratio only about half as large as for (7.8) without the lagged variable.

Short-run and long-run elasticities are included in Table 7.4 for equations (7.9) through (7.13). The several functions that separately specify the fertilizer price, consistently estimate the elasticity with respect to the variable to be -1.4 to -1.5 in the short run and -2.3 to -2.6 in the long run. The short-run fertilizer price elasticity, -.6, computed from the price ratio in (7.13), is more nearly consistent with the results from Table 7.9 presented later. Based on equations (7.9) to (7.13), the demand elasticity with respect to crop prices appears to be unusually low. Crop prices affect fertilizer demand indirectly through interactions with related inputs such as seed, irrigation, drainage, etc. These variables often are short-run complements of fertilizer, hence higher crop prices increase fertilizer sales indirectly through greater use of these inputs. Also, fertilizer demand is derived from sale of livestock as well as from crops, and inclusion of livestock prices would give a higher "product" price elasticity. Finally, demand may be more elastic with respect to fertilizer than to crop prices because of the greater stability and high permanent component (upon which farmers tend to base decisions — see Chapter 3) of fertilizer prices.

Table 7.4. Short-Run and Long-Run Elasticities for Distributed Lag Models of National Fertilizer Demand

	Short-Run Elasticity			Long-Run Elasticity		
Equation	Z_f	Z_c	Z_r	Z_f	Z_c	Z_r
(7.9)	-1.40	.21		-2.30	.35	
(7.10)	-1.48	.12		-2.63	.21	
(7.11)	-1.40	.20		-2.34	.33	
(7.12)	-1.52	.13		-2.61	.22	
(7.13)			-.58			-1.00

The adjustment coefficient, estimated as .6, suggests that 60 percent of the total long-run adjustment to the desired level is made in one or two years. Thus the long-run elasticity is about 60 percent greater than the short-run elasticity based on Table 7.4.

National Rates per Crop Acre

Previous functions allow predictions of total fertilizer use as it relates to the number of acres fertilized and the rate of fertilization per

Table 7.5. Statistics for Estimates of Fertilizer Demand per Acre (F_{na}) for the United States, Including Regression Coefficients, Standard Errors (in Parentheses) and R^2

		Regression Coefficients								
Equation	R^2	Log of Constant	Log Z_f	Log Z_c	Log Z_r	Log Z_s	Log Z_d	Log A_f	Log T	Log $F_{na,t-1}$
(7.14)	.981	3.78			-.810 (.086)	-.439 (.114)			.0105 (.0012)	
(7.15)	.986	3.64	-1.491 (.366)	.106 (.268)			-.008 (.192)		.0007 (.0038)	.413 (.172)
(7.16)	.983	3.34			-.637 (.146)	-.346 (.267)		-.269 (.544)	.0091 (.0022)	.262 (.174)
(7.17)	.982	2.69			-.637 (.144)	-.246 (.171)			.0085 (.0018)	.255 (.171)
(7.18)	.966	.85			-.305 (.152)					.862 (.079)
(7.19)	.981	1.78			-.640 (.196)		.145 (.250)		.0089 (.0025)	.335 (.190)

acre. We now estimate demand functions for the United States paralleling the static normative functions in Chapter 6. Estimate is of F_{na}, the quantity in pounds of all fertilizer purchased per acre. The estimated equations are included in Table 7.5. Except for (7.14), all specifications of the per acre demand function include a distributed lag. For the short-run per acre demand function in (7.14), the elasticity of fertilizer purchases per acre with respect to the fertilizer/crop price ratio is -.810, a magnitude comparable to the estimates for equation (7.8) for total fertilizer purchases. Since the elasticities with respect to the fertilizer/crop price ratio (Z_r) do not differ significantly between (7.8) and (7.14), it follows that a change in total fertilizer purchases results more from a change in rate per acre, rather than from a change in number of acres fertilized. (Data were not available for estimating a function for the number of acres fertilized.) It thus seems plausible that an increase in the price ratio, from an increase in fertilizer price or a decline in crop price, might cause farmers only to cut back on the rate per acre, rather than to reduce the acres fertilized.

The lagged variable of fertilizer per acre ($F_{na,t-1}$) did not have a significant regression coefficient when it was included with a time variable except in equation (7.15). Evidently the lagged quantity and time variables are so highly correlated that only one is useful in estimating per acre demand functions. Using (7.15) to compute elasticities, the short-run elasticity with respect to fertilizer price is -1.49 while the long-run elasticity is -2.54. Computed from (7.18), the short-run elasticity with respect to the fertilizer/crop price ratio is -.305 and the long-run elasticity is -2.21. Statistical basis does not exist for inferring that differences exist between short-run and long-run elasticities for total fertilizer demand (Table 7.3) and per acre purchases (Table 7.5). The difference between short-run and long-run elasticity magnitudes are quite large. However, the difference is less and the period of adjustment is shorter than for numerous of the resources analyzed in later chapters.

National Demand for Individual Plant Nutrients

Since total fertilizer is an aggregate farm resource, demand functions have been estimated separately for individual plant nutrients. It is true that much fertilizer is retailed as fixed mixes or with the three major nutrients in given proportions prescribed by agronomists, manufacturers and distributors. In this framework the nutrients might be considered to be technical complements which should be purchased in fixed proportions. These conditions would hold true in nature, of course, only if the fertilizer production function for any crop and soil had linear isoclines originating at zero over the nutrient plane. The slope of the isoclines, for a given nutrient substitution rate, would have to have the same slope for all crops and soils if fertilizer could be considered entirely as an aggregate resource composed of individual nutrients used in limitational ratios. However, statistics cited earlier in this chapter indicate that farmers have not held purchases over time to fixed ratios and the demand for some nutrients has not increased in constant proportions. This change in ratio of nutrients, as represented in total fertilizer purchases, has been possible because the grades, analyses and prices of nutrients have changed over time and also because the farmer can purchase fertilizers including only one nutrient. Too, rather extensive research on fertilizer production functions has indicated that the response map generally has isoclines which are not linear through the origin and which vary among crops, soils and other environmental factors.[8]

Demand functions for individual nutrients are included in Table 7.6 for N_n, 7.7 for P_n and 7.8 for K_n where the first variable in each table is the index of price of fertilizer, the third variable is the ratio of the index of fertilizer price to crop price and the variable with subscript t-1 is lagged purchases of the particular nutrient. Equations are of parallel form and specification in the three tables. Functions are similar in the sense that the fourth equation in each table has regression coefficients for both variables which are significant at the .99 probability level. Similarly, all of the last equations in each table have three regression coefficients acceptable at a 99 percent probability level. Signs on regression coefficients are consistent with theory for these two sets of equations. Similar uniformity in statistical estimates among nutrients did not exist for the other nutrient demand functions specified, except for the first and third equation in each table. Coefficients for all variables in the first equation were significant at a probability level of .95 or greater except for total cropland acreage (C). The latter variable had a negative coefficient for the nitrogen equation. All coefficients were significant at a .99 probability level for the third equation of each table except for cropland price for P_2O_5 in Table 7.7 where the regression coefficient was considerably larger than the

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[8] Cf. Heady, Earl O., and Dillon, John L. Agricultural Production Functions. Iowa State University Press. Ames. 1961.

Table 7.6. Statistics for Estimates of Total Nitrogen Demand (N_n) for the United States, Including Regression Coefficients, Standard Errors (in Parentheses) and R^2

			Regression Coefficients						
Equation	R^2	Log of Constant	Log Z_f	Log Z_c	Log Z_r	Log Z_d	Log T	Log $N_{n,t-1}$	Log C
(7.20)	.987	4.97	-1.254	.812		1.028	.021		-.471
			(.552)	(.294)		(.167)	(.004)		(.128)
(7.21)	.963	8.61	-2.105	.269			.015		
			(.776)	(.406)			(.006)		
(7.22)	.986	4.67			-.957	1.056	.023		
					(.103)	(.156)	(.001)		
(7.23)	.959	6.44			-.872		.025		
					(.172)		(.002)		
(7.24)	.989	3.85	-1.238	.405		.480	.010	.372	
			(.462)	(.294)		(.286)	(.006)	(.167)	
(7.25)	.987	5.36	-1.673	-.028		.118		.598	
			(.405)	(.164)		(.205)		(.110)	
(7.26)	.987	4.35	-1.276	1.067			.003	.611	
			(.480)	(.243)			(.004)	(.092)	
(7.27)	.987	5.05	-1.534	-.025				.640	
			(.320)	(.161)				(.082)	
(7.28)	.986	2.70			-.476		.009	.634	
					(.119)		(.003)	(.094)	

standard error. As for total fertilizer purchases, the result of the third equation for each nutrient would suggest a substitution of fertilizer for land as price of the latter resource increases. However, as mentioned earlier for this theoretically consistent result, the substitution is so "roundabout" that the variable may simply reflect part of the time-related effect of technological knowledge and economic growth.

Table 7.7. Statistics for Estimates of Total P_2O_5 Demand (P_n) for the United States, Including Regression Coefficients, Standard Errors (in Parentheses) and R^2

			Regression Coefficients						
Equation	R^2	Log of Constant	Log Z_f	Log Z_c	Log Z_r	Log Z_d	Log T	Log $P_{n,t-1}$	Log C
(7.29)	.976	10.69	-1.504	.718		.201	.009		-1.549
			(.525)	(.279)		(.159)	(.004)		(1.21)
(7.30)	.972	8.40	-1.903	.488			.007		
			(.477)	(.249)			(.004)		
(7.31)	.971	6.86			-.972	.253	.014		
					(.106)	(.160)	(.001)		
(7.32)	.967	7.29			-.952		.014		
					(.108)		(.001)		
(7.33)	.984	6.05	-1.447	-.082		-.254	-.002	.569	
			(.398)	(.270)		(.171)	(.004)	(.150)	
(7.34)	.984	5.76	-1.345	.015		-.217		.531	
			(.304)	(.130)		(.143)		(.116)	
(7.35)	.983	5.82	-1.424	.158			.001	.421	
			(.408)	(.221)			(.003)	(.114)	
(7.36)	.982	6.15	-1.550	.081				.441	
			(.280)	(.125)				(.103)	
(7.37)	.979	4.13			-.556		.008	.440	
					(.143)		(.002)	(.124)	

Table 7.8. Statistics for Estimates of Total K_2O Demand (K_n) for the United States, Including Regression Coefficients, Standard Errors (in Parentheses) and R^2

			Regression Coefficients						
Equation	R^2	Log of Constant	Log Z_f	Log Z_c	Log Z_r	Log Z_d	Log T	Log $K_{n,t-1}$	Log C
(7.38)	.982	4.15	-1.427 (.621)	.956 (.331)		.634 (.188)	.019 (.005)		.182 (1.43)
(7.39)	.973	7.37	-1.875 (.654)	.661 (.342)			.016 (.005)		
(7.40)	.982	5.79			-1.113 (.115)	.661 (.174)	.022 (.001)		
(7.41)	.971	6.90			-1.060 (.142)		.023 (.002)		
(7.42)	.983	4.78	-1.448 (.575)	.764 (.476)		.475 (.340)	.015 (.009)	.124 (.218)	
(7.43)	.980	7.26	-2.138 (.454)	-.036 (.194)		.001 (.230)		.458 (.124)	
(7.44)	.981	5.97	-1.663 (.565)	.264 (.320)			.006 (.006)	.379 (.122)	
(7.45)	.980	7.26	-2.138 (.388)	-.036 (.186)				.458 (.101)	
(7.46)	.979	4.53			-.736 (.168)		.014 (.003)	.364 (.126)	

In numerous equations including separate variables for fertilizer price and crop price, the coefficient for the latter had a negative sign. Also, this coefficient was seldom significant at a .90 level of probability even where it was positive. For practically all equations, however, the coefficient for fertilizer price was significant at a probability level of .95 or higher. Similarly, the fertilizer/crop price ratio was a highly significant variable in each equation where it was included. It is possible, because of the extended period between 1939 and 1955 when this price ratio was declining, that the fertilizer/crop price ratio variable relates to total nutrient purchases through the effect of time and greater knowledge — as well as to the expected "pure price effects" expected to be reflected in this variable. In equations with separate variables for crop and fertilizer prices, and where both are significant at a probability level of .80 or higher, the elasticity of nutrient purchase was much greater with respect to fertilizer price than with respect to crop price. As for the total fertilizer demand function, this result would suggest that a decline in fertilizer price has a greater relative effect in increasing nutrient use than does a similar percentage increase in crop price.

No clear conclusions can be drawn in respect to differences in relative response to price changes for the three nutrients. Using the fourth equation of each table, the elasticity with respect to the fertilizer/crop price ratio increases slightly from nitrogen to P_2O_5 and again slightly from P_2O_5 to K_2O, a result consistent with the last chapter. The short-run elasticity for the last equation in each table also increases in this same manner between individual nutrients. For functions with a separate variable for fertilizer price, the short-run elasticity for this variable is not uniformly greater for one nutrient, but it does tend to be highest for K_2O, with little difference between nitrogen and P_2O_5. Similarly, for functions where the sign of the coefficient is reasonable and it is large relative to its standard error, the elasticity with respect to crop price tends to be higher for potash than for phosphate and nitrogen. In general, however, the regression coefficients do not differ significantly between similar equations for the three nutrients. To the extent that any real difference exists in short-run elasticity with respect to price for potash, it may occur not because of reasons given in Chapter 6 but also because this plant nutrient has historically been more closely associated with forage. As prices change, particularly where they decline, farmers may be most inclined to cut back on fertilization of forage rather than of cash crops. On the other hand, nitrogen fertilization was especially affected from 1940 to 1960 by new knowledge indicating its response and productivity. Use of nitrogen and phosphate may have been particularly related to developments such as those showing that continuous row crops fertilized heavily can be substituted for grass-legume-crop rotations. These phenomena give more "strength" to knowledge and other influences related to the time variable. No clear difference is evident, however, for the elasticity of nutrient purchase with respect to time or lagged variables (the adjustment coefficient) among the three nutrients. The long-run elasticity exceeds the short-run elasticity by a greater ratio for nitrogen than for P_2O_5 and for the latter as compared to K_2O, if the last equation of each table is used for the comparison. (A somewhat similar tendency also exists for other equations with a lagged variable.) This condition would suggest that adjustment to a given price change has been made more rapidly for potash over phosphate, and for phosphate over nitrogen. While these differences cannot be established in a statistical probability sense, they are consistent with the above hypotheses of (a) a greater short-run price elasticity of potash purchases and (b) the "stronger effect" of new knowledge for nitrogen over the 1940-60 period. In Table 7.4 the price elasticities of demand for aggregate fertilizer, and the differences between short-run and long-run elasticities, tend to lie between those for the individual nutrients.

Aggregate Functions for Fertilizer and Lime

Lime is a farm resource having characteristics closely related to fertilizer. Aggregating these two resources, a demand function has been specified which attempts to predict annual purchases over the period 1926-59, with 1942-45 excluded. Estimates again are by least squares, but with observations entered in original, logarithmic or first difference form as indicated by O, L and F, respectively, in Table 7.9. The variables included are as follows:

Table 7.9. Statistics for Estimates of Total Fertilizer and Lime Demand (Y_s) for the United States, Including Regression Coefficients, Standard Errors (in Parentheses), R^2 and d Statistic

Equation and Transformation	R^2	d*	Constant	Z_m	E_p	S_p	G_t	W_t	T	$Y_{s,t-1}$
(7.47-O)	.996	1.32	-2707.45	-1.37	.37	33.71	-1.13	.27	11.24	
				(.32)	(1.64)	(2.78)	(1.23)	(.60)	(1.83)	
(7.48-O)	.996	1.43	-2987.01	-1.40	1.36	35.25		.35	11.49	
				(.32)	(1.24)	(2.21)		(.59)	(1.81)	
(7.49-L)	.984	1.11	-5.00	-1.18	1.33	3.49		.039	.0149	
				(.22)	(.66)	(.80)		(.166)	(.0024)	
(7.50-O)	.995	1.28	-2682.06	-1.14		34.10			10.55	
				(.17)		(1.84)			(1.61)	
(7.51-L)	.981	.85	-0.66	-.79		2.33			.0128	
				(.094)		(.56)			(.0023)	
(7.52-F)	.478	2.18	--†	-.82		25.05			17.42	
				(.32)		(6.33)			--†	
(7.53-O)	.993	1.58	-79.32	-.31					5.26	.907
				(.22)					(2.29)	(.061)
(7.54-L)	.983	1.30	1.62	-.38					.0095	.57
				(.14)					(.0028)	(.12)

*The Durbin-Watson autocorrelation statistic d.

†The intercept or constant coefficient in the first difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

Y_s = the weighted two-price aggregate of fertilizer and lime purchases for the U.S. in the current calendar year. The crop year estimates are unavailable except for recent years, but a major portion, 75 percent, of all fertilizer is sold in the first six months of the year.[9] The correlation is approximately .98 between recent values of the variable and fertilizer purchases on a crop year basis. The variable is in millions of 1947-49 dollars. A t-1 on the subscript denotes a one year lag of this variable.

Z_m = the past year index of the ratio of fertilizer and lime prices to the index of prices received by farmers for crops and livestock. Z_m rather than the equivalent of Z_r is used because fertilizer is applied on crops fed to livestock, and its profitability depends on livestock as well as crop prices.

E_p = the past calendar year index of the ratio of fertilizer and lime prices to the index of prices paid by farmers for items used in production, including interest, taxes and wage rates. Fertilizer price is a component of the latter (the denominator), but the influence is considered to be little because fertilizer is a small proportion of all inputs.

S_{pt} = the stock of productive assets on farms January 1 of the current year expressed in billions of 1947-49 dollars. Assets include real estate, machinery, livestock and feed, and cash held for productive purposes.

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[9] Griliches, op. cit., p. 601.

G_t = a current year index of the role of government policies on current input purchases with years of acreage allotments given the value -1. Years when farm prices are supported are given the value +1. If supports are fixed, an additional +1 is added. These values are summed to form the index G_t.

W_t = Stallings' index of the influence of weather on farm output in the current year.[10] Indices for 1958 and 1959 are constructed from an index of deviations from a linear trend of crop yields.

T = time, as explained previously.

Price indices are adjusted to 1947-49 = 100.

Table 7.9 contains statistics for these single-equation estimates of fertilizer and lime demand at the farm level. G is not significant in equation (7.47) and is dropped to form (7.48) and later equations. Since the effect of weather on fertilizer demand is not estimated to be significant, W is omitted in (7.50) and succeeding equations. The coefficient of the price variable, E_p, is somewhat unstable in the first two equations because of a high correlation ($r = .91$) with S_p. After this price variable and W are dropped, the remaining variables explain 99.5 percent of the variance in fertilizer purchases according to equation (7.50). The high R^2 is somewhat misleading since much of the variation is explained by the slowly changing and easily predicted structural variables S_p and T; a comment equally applicable to previous equations including variables for time and the lagged dependent variable.[11] Removal of the linear trends by a first difference transformation as in (7.52) reduces the R^2 approximately 50 percent.

Equation (7.50) suggests that fertilizer and lime demand can be explained largely by variables lagged no more than one year. If this equation is correctly specified, a distributed lag model does not seem appropriate. The addition of a lagged dependent variable representing past influences on Y_s increases the explanation of the current demand quantity very little, a point also apparent in previous estimates including a time variable. Since, as also is generally true for previous equations, the correlation between Y_s and $Y_{s,t-1}$ is high, the correlation between $Y_{s,t-1}$ and other dependent variables in equation (7.50) also would likely be high.

The first six equations essentially are short run because of the S_p or scale-of-plant variable. To estimate long-run elasticities and to test empirically the appropriateness of the distributed lag model, equations (7.53) and (7.54) are included. Again, a high percent of variance in the demand quantity is explained by the particular specification.

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[10] Stallings, James L. Weather indexes. Journal of Farm Economics. 42:180-86. 1960.

[11] An adjustment in the R^2 might also be made for added variables, since any set of n-1 independent variables each with n observations would give an R^2 of 1.00. Adjusted R^2's and exact sources of each variable in Table 7.9 and in later chapters are found in Tweeten, Luther G. An Economic Analysis of the Resource Structure of United States Agriculture. Unpublished Ph.D. thesis. Library, Iowa State University. Ames. 1962.

Equations (7.54) estimated in logs and (7.53) in original values provide quite different estimates of the adjustment coefficient. Because time, T, and lagged quantity are correlated to the extent r = .95, the coefficients of the variables are somewhat unstable with the lagged quantity dominant in (7.53).

The high R^2 values of equations and the highly significant regression coefficients for equations estimated in untransformed (original) observations suggest that a linear function is satisfactory for estimating the demand for fertilizer. The test for autocorrelation is inconclusive at the 95 percent probability level in equation (7.50). However, the hypothesis of zero autocorrelation is rejected in equation (7.51). The first difference transformation results in a considerable reduction in autocorrelation according to equation (7.52) since d is not significant. Although the magnitudes of the coefficients and standard errors are altered somewhat by the first difference transformation, the coefficients remain statistically significant. The values of d in (7.53) and (7.54) do not necessarily indicate reduced autocorrelation since the Durbin-Watson test tends to be inaccurate when lagged dependent variables are included. The autoregressive structure tends to be absorbed in the coefficients of the independent variables, and the coefficients may be biased for this reason.

Price Elasticity of Demand

The price elasticity of short-run demand for fertilizer and lime with respect to the price of fertilizer and lime alone (the numerator in Z_m) is -.26 from equation (7.50). The point estimate and 95 percent confidence interval of short-run price elasticity given by equation (7.51) are -.79 ± .19. An average of these estimates, -.5, compares favorably with the "lower results" in Table 7.3 and with those of Griliches.[12] We might, however, expect the lime component to have a somewhat different elasticity than the fertilizer component.

The simple correlation between Z_m and S_{pt} (or T) is approximately .70. Hence, there may be sufficient independent variation in price to justify computation of the short-run fertilizer price elasticity. The simple correlations between the trend variables S_p, T and $Y_{s,t-1}$ are quite high, however. This precludes placing a high degree of confidence in estimates of long-run price elasticities, whether estimated by (a) a recursive form such as equation (7.50) or (b) the distributed lag model such as equation (7.53). Long-run elasticities computed from these equations should be regarded as hypotheses rather than as "final" estimates. Equations (7.47) to (7.52) have long-run elasticities with respect to fertilizer price alone (the numerator in Z_m) which is no greater than the short-run elasticity. However, the elasticity with respect to prices received is much greater in the long run than in the

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[12] Griliches, op. cit.

short run because of its influence on productive assets. According to the results in Chapter 12, a sustained 1 percent increase in prices received raises the stock of productive assets S_p 1 percent in the long run. Equation (7.51) implies that a 1 percent increase in S_{pt} increases fertilizer consumption over 2 percent in the long run. Using the results and the method outlined in Chapter 13, the long-run (over 20 years) elasticity of fertilizer and lime purchases is more than two. The second estimates of long-run elasticities are found from the distributed lag equations (7.53) and (7.54). Since the adjustment coefficient of (7.54) is .43 and the short-run elasticity with respect to Z_m is -.4, the long-run elasticity is $-.4/.43 = -.9$. This relative difference between short-run and long-run elasticities is comparable to those in Table 7.3 through Table 7.8. Even with the difference in adjustment coefficients for equations (7.53) and (7.54), the estimated long-run elasticities with respect to Z_m are similar, i.e., -.8 and -.9, respectively.

Influences represented by S_p and T exert a large impact on the predicted demand quantity.[13] The results for Table 7.9 generally indicated that the relative impact of short-run price change is less than that of S_p and T on fertilizer consumption. For example, the standard partial regression coefficients of the variables in equation (7.48) are -.12 for Z_m, .67 for S_{pt} and .24 for T. The proportion of the secular increase in fertilizer and lime consumption attributable to a particular variable depends on the movement of the variable through time, as well as on the magnitude of the regression coefficient. The real price of fertilizer and lime, Z_m, declined slightly over 30 percent from 1926 to 1959. If the weighted real price of fertilizer and lime is set at the 1959 value and other variables are set at the 1926 values, equation (7.50) indicates a demand quantity only 30 percent greater than the predicted 1926 quantity. The implication from this equation is that over 400 of the actual 512 percent increase in weighted fertilizer and lime consumption from 1926 to 1959 remains to be explained by variables other than short-run price level. While the correlation between the price variable Z_m and the two trend variables S_{pt} and T is not high and does not preclude a reliable estimate of short-run price on the demand quantity, variables such as $Y_{s,t-1}$ and S_{pt}, included to allow estimation of long-run price effects, are highly correlated with other trend variables. It is necessary, therefore, to include the long-run price influences with other factors in an "aggregate" explanation of the secular rise in fertilizer consumption.

Many important "gradual influences," other than short-run price, are reflected in the coefficients of S_p and T. Some are technological, others must be classified more broadly. As the nutrient levels in virgin soils decline, the demand curve for fertilizer should shift upward.

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[13] S_p is correlated with the time variable. Both variables are correlated with gradual changes in the structure of fertilizer demand which, though important, could not be introduced into the demand equation. Since the specification is not complete, it is advisable to interpret the coefficients of the two variables collectively, rather than individually.

Introduction of hybrid seeds, drainage of wet areas and irrigation also increase the response of crops to fertilizer and raise demand. The efforts of commercial advertisers, extension services, of high school and college agricultural classes and other educational groups have brought an increasing awareness of potential returns from fertilizer. Improved farm machinery for applying fertilizer, liquid nitrogen and bulk spreading by commercial firms also should not be overlooked. Competition among fertilizer dealers lowers price and is another factor responsible for increased fertilizer consumption. Competition also influences farm demand since farmers who are not efficient tend to be forced out and gradually replaced by those who are more efficient — who use more fertilizer. (It should be noted that increases in farm size are correlated very highly with S_p.)

Figure 7.4 indicates that aggregated purchases of fertilizer and lime rose steadily from 1926 to 1960 with the exception of the depression years of the early 1930's. The increase is approximately linear during the postwar period. Barring changes in structure, a linear extension of the postwar trend might provide a useful estimate of demand quantities in the near future.

Equation (7.50) appears to predict aggregate fertilizer and lime purchases well over the period analyzed, although some tendency exists for this function to underestimate fertilizer purchases in recent years. Extrapolated estimates of 1960 purchases are made from equation (7.50) in Figure 7.4. This extrapolation underestimates actual

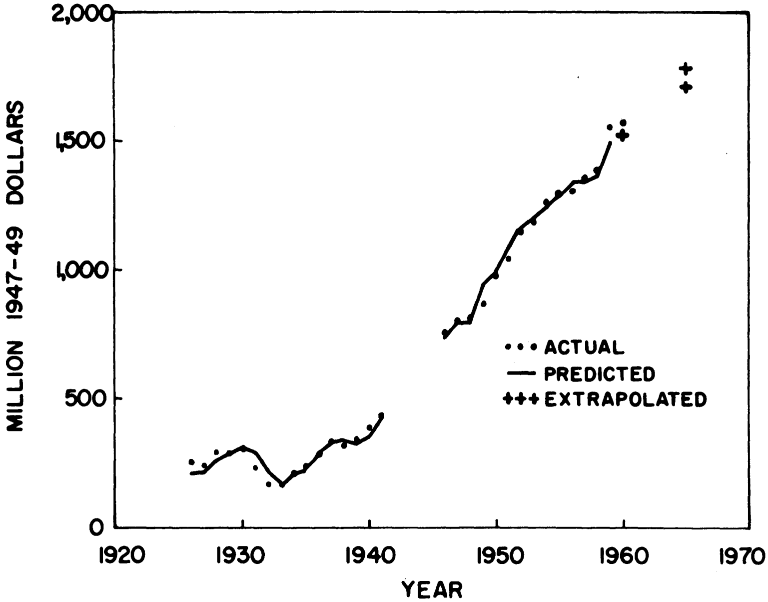

Figure 7.4. Trends in price-weighted purchases of fertilizer and lime from 1926 to 1960 (predicted and projected estimates from equation 7.50).

purchases by approximately 3 percent for 1960. Acreage restriction programs may have encouraged substitution of fertilizer for cropland in this and similar years, although our institutional variable was not significant.

Purchases also are projected to 1965 from equation (7.50), assuming prices are at the averages of the 1955-59 period. Two estimates of S_p are used in the equation for this projection: The lower estimate, based on USDA projections and on equation (12.23), Chapter 12, is 112.4 billion 1947-49 dollars by 1965.[14] The higher estimate, 114.4 billion 1947-49 dollars, is based on an investment function (12.28) which includes an accelerator coefficient. Stocks are estimated from this investment equation based on a USDA projection of an 8 percent increase in farm output by 1965.[15]

The projected estimates from equation (7.50) shown in Figure 7.4 are made on the assumption that parameters of the fertilizer demand function for 1926 to 1959 remain unchanged until 1965. Under the stated conditions, purchases of fertilizer in 1965 are predicted to be 12 percent and 17 percent over predicted 1960 levels for S_p values equal to 112.4 and 114.4, respectively. (Confidence limits of the estimates are not computed, but are expected to be large for extrapolations of several years.)

Figure 7.4 suggests clearly why time and lagged value of the dependent variable are so highly correlated and similarly tend to express the effect of technological knowledge or other variables which result in the "closely approached" linear trend in fertilizer consumption between 1933 and 1960. Similarly, if we compare the trend in the fertilizer/crop price ratio in Figure 7.1, it is obvious that it also has a fairly high correlation with time. This complex of interrelations causes a single variable such as time to be quite accurate as a predictor of fertilizer consumption since the 1930's, and especially since 1945 (but obviously failing to predict downturns following "sharp" breaks in price or income).

REGIONAL DEMAND FUNCTIONS FOR COMMERCIAL FERTILIZER

Theoretically, the two important variables affecting fertilizer use in an environment of profit maximizing goals and where capital limitations, tenure conditions and similar variables do not affect decisions on investments, would be expectations of the magnitudes of marginal product and price ratios. While this is not the true environment of farm decision making, production functions do differ greatly between regions because of soil types, climatic conditions, crops grown and the

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[14] Johnson, Sherman. Agricultural outlook in the 1960's. (Multilith.) USDA. Agricultural Research Service. Washington. 1960. p. 17.

[15] Ibid., p. 8.

natural stocks of nutrients in the soils. Because of these differences especially, and because research on and knowledge of fertilizer response has not moved ahead at equal rates in the various regions, demand functions for all commercial fertilizers have been estimated for 10 agricultural regions in the United States. These separate regional functions also have been computed to indicate the relative importance of several variables in the different regions.

Very little fertilizer was used in some regions in the prewar period, regardless of the fact that the fertilizer/crop price ratio was relatively as favorable at the time as in regions using more fertilizer. But with research, development and greater information in the hands of farmers of the yield increases from fertilizer, regions formerly using little fertilizer have increased consumption by a larger percentage than regions which used the largest amounts in prewar years. These differences have existed even though the real cost of fertilizer relative to crop prices has declined somewhat similarly for all regions. (See Figure 7.2.) Hence, variables other than fertilizer/crop price ratios and historic quantities of fertilizer used would seem important. For this reason, time again has been included as a variable in the regression equations which follow, to reflect, even imperfectly, changes in knowledge of yield response from fertilizer. Where appearing applicable, an income variable also has been included in short-run models. In some regions marked declines in income (for example, drouth in the Great Plains and low hog prices in the Corn Belt) appear to have had effects on fertilizer use beyond those expected from changes in fertilizer and crop price ratios. Generally, however, equations which have a significant income variable do not also have a significant crop price variable, since the latter is reflected partially in the former.

The main algebraic regression form used for both short-run and long-run models again is a power function. In addition, a first difference equation in logarithmic form, a linear function and a modified quadratic equation with a squared variable for time were used as alternatives. Different time periods also were used for some estimates, depending on the region. Variables are the same as those outlined previously. In short-run demand models, the variable to represent income from farming was selected according to the importance of cash receipts from crops and livestock. Livestock income was included for regions 1, 2, 3, 7 and 8, when income variables were specified in the demand functions.

Demand functions were estimated for total fertilizer, nitrogen, P_2O_5 and K_2O for each region. In total, over 200 regression equations were estimated for the 10 regions. Because of their bulk, it is not possible to present all of these estimates on the pages which follow.

Total Fertilizer Demand by Regions

The total fertilizer demand functions estimated by regions parallel those in equation (7.8) in Table 7.3 on page 168. The first regional

Table 7.10. Statistics for Short-Run Regional Demand (F_i) Functions for Total Commercial Fertilizer, Including Regression Coefficients (b), Standard Errors (s) and R^2, 1926-56 With 1944-50 Excluded

Region	R^2	Log of Constant	Log Z'_r		Log T	
			b	s	b	s
1. Northeast*	.868	7.69	-.844	.114	.154	.027
2. Corn Belt*	.737	8.10	-1.280	.280	.456	.122
3. Lake States	.779	8.17	-1.659	.373	.587	.114
4. Appalachian	.845	8.43	-1.100	.142	.063	.043
5. Southeast*	.852	8.07	-.862	.093	.056	.034
6. Delta	.818	8.60	-1.517	.202	.176	.074
7. Southern Pl.	.813	8.64	-1.912	.261	.316	.114
8. Northern Pl.	.819	8.49	-2.579	.458	.948	.192
9. Mountain	.947	7.22	-2.071	.285	1.314	.096
10. Pacific*	.851	7.54	-1.443	.288	.922	.090

*Regions 1, 2, 5 and 10 covered the entire period 1926 to 1956.

models estimated were simple ones which suppose farmers maximize profits and purchase fertilizer purely as a function of the fertilizer/crop price ratio and time as it reflects changes in knowledge about the production coefficient and productivity of fertilizer. This model, derived for the period 1926-56, excluded the years 1944-50 to examine the hypothesis that fertilizer supply was more "rationed" to farmers in this period than in the war period. Demand for fertilizer relative to fertilizer producing capacity grew more rapidly in the postwar period than during the war years.[16] The results of this model are presented in Table 7.10 by regions. For this particular model, Z'_r represents the ratio of fertilizer price (the average for the previous year) to crop price (that at planting time for the crops of the particular region). To avoid complexity in notation, we have not numbered the demand equations for regional estimates.

The R^2 values for this short-run model range from a low of .737 in the Corn Belt to .947 in the Mountain region. Regression coefficients for the fertilizer/crop price ratio were significant at the 99 percent probability level for all regions. Regression coefficients were larger than standard errors for time in all regions, and in all regions but 4, 5 and 6 the regression coefficient for time was significant at a .95 or higher probability level. The elasticities with respect to time are greatest for the regions with the most rapid rate of increase in fertilizer use since 1950. Also, the Great Plains, Mountain and Pacific regions have high price elasticities.

Results for a second set of short-run demand functions by regions are included in Table 7.11. These equations included five or six

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[16] For further details on these estimates, see Heady and Yeh, op. cit.; and Yeh, op. cit.

Table 7.11. Statistics for Short-Run Region Demand (F_i) Models for Total Commercial Fertilizer, Including Regression Coefficients (b), Standard Errors (s) and R^2, 1926-56 With 1944-50 Excluded

Region	R^2	Log of Constant	Log Z'_r		Log Z_c		Log R*		Log C		Log T	
			b	s	b	s	b	s	b	s	b	s
1. Northeast†	.970	5.15	-.425	.123	‡	‡	.342	.043	-.180	.218	.040	.022
2. Corn Belt	.981	6.94	-1.392	.402	‡	‡	1.075	.150	-1.073	.960	.037	.049
3. Lake States	.983	7.10	-.984	.367	.001	.155	1.069	.109	-1.285	1.249	.248	.047
4. Appalachian	.942	-4.21	-.563	.303	‡	‡	.463	.094	1.015	.450	.072	.039
5. Southeast†	.954	3.75	-.712	.176	.519	.090	.237	.057	.133	.155	.002	.025
6. Delta	.896	-6.50	-.893	.752	.176	.382	.875	.240	.827	.517	.070	.089
7. Southern Pl.	.958	-9.30	-1.245	.939	.360	.269	1.265	.200	.080	1.249	.080	.102
8. Northern Pl.	.980	2.03	-3.839	.761	‡	‡	1.222	.238	-.232	.577	.427	.091
9. Mountain	.971	-2.89	-1.266	.917	‡	‡	.718	.241	.354	.763	1.074	.104
10. Pacific	.982	-3.53	-1.057	.481	‡	‡	.757	.133	.563	.700	.378	.056

*Includes only cash receipts from crops and government payments for regions 4, 5, 6, 9 and 10, and cash receipts from farming (crops and livestock) in regions 1, 2, 3, 7 and 8.

†Regions 1 and 5 covered the entire period 1926 to 1956.

‡Variable not included in equation.

variables, depending on whether crop price was included in them. The R^2 value is upward of .90 for all regions. The regression coefficients for cash receipts were significant at the .99 probability level in all regions, and coefficients for the fertilizer/crop price ratio were significant at a probability level of .80 or greater for the 10 regions. The income variable probably expresses the quantitative effect of crop prices in the fertilizer/crop price ratio in most regions.

The elasticity of demand in respect to fertilizer/crop price ratio was greatest in the regions which have increased use mostly in recent years, namely the Corn Belt, Lake States, Great Plains, Mountain and Pacific regions. These elasticity coefficients ranged from -.425 in the Northeast to -3.839 in the Northern Plains. We can hypothesize that fertilizer price elasticities are expected to be lower in the South, or "old using" area, because farmers have been highly short on capital and have not used fertilizer to a point where its marginal product is driven to the level of the price ratio. Hence, they could still use fertilizer profitably, even with some increase in its relative price, but lack capital to use much more when the price falls. Perhaps also fertilization of hay crops for dairy feed more nearly dominates the picture in the Northeast, with responsiveness to the relative prices for fertilizer being greatest in the Midwest and West where grain and cash-crop production predominate.

In equations containing crop price, the elasticity, .52, in respect to it, was greatest in the Southeast region, although only four equations retained this variable after preliminary analysis. The demand for fertilizer was predicted to be significantly responsive to the price of cotton, tobacco, fruit and truck crops, but not to the price of small grains and hay in mixed farming areas. The coefficients (elasticities) for either cash receipts of farming or cash receipts from crops plus government payments in both the 5- and 6-variable equations, were significant at the 99 percent level in all regions. The elasticity of 1.27 was highest in the Southern Plains, followed closely by a coefficient of 1.22 in the Northern Plains. Both regions have incomes affected as much or more by weather as by crop and fertilizer prices. The income elasticity also was high in the Corn Belt and Lake States, but was lowest in the Northeast where livestock income predominates over crop income.

The elasticity for fertilizer purchases with respect to cropland acreage was negative in regions 1, 2, 3 and 8, and positive in the remaining regions. As mentioned previously, the negative coefficients might be taken as an indication of substitution of fertilizer for land, a situation which is not directly reflected for the other six areas. The coefficients are not significant in most of the regions where they are positive. Perhaps the negative coefficients for cropland represent a "confounded effect," for example, a shift of land from farm to urban uses in the Northeast at a time when the fertilizer/crop price ratio has had a downward trend. Similarly, expansion of irrigated land in the Western States, with greater use of fertilizer on this acreage, has taken place at a time when total cropland acreage has declined due to control programs.

The predicted elasticity of fertilizer use with respect to time, for the functions in Table 7.11, was highest, 1.07, in region 9, followed by .43 in region 8 and .38 in region 10. It was lowest, .002, in region 5. The coefficient was largest and most significant in the regions where use has increased most in recent years. Demand has shifted rightward most rapidly in areas where technical knowledge on fertilizer response is more recent, commercial nutrient needs have increased due to depletion of soil nutrient stocks, and where a creation of new varieties and practices has raised most rapidly fertilizer productivity. Heavy rainfall and leaching long ago reduced original soil nutrient supplies in the Southeast, and fertilizer response there was quite well known by 1920. While technical knowledge there also has increased, this change probably has been relatively less important than price ratio changes for fertilizer, especially as compared to the "newer using" regions.[17]

Over most of the Corn Belt, the region which has moved into first place in total quantity of fertilizer purchased by farmers, soil fertility generally was not the limiting factor in yields until hybrid corn was

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[17] Another model estimated for the U.S., with the period and measurement as in Table 7.10 is

$$\log Y_f = .441 + \underset{(.066)}{.932} \log Y_{f,t-1} - \underset{(.176)}{.289} \log F_1 + \underset{(.038)}{.043} \log T$$

$$R^2 = .952$$

where F_1 is the first difference of the fertilizer/crop price ratio, Z_r. This equation can be transformed to predict fertilizer consumption and thus represents a semi-expectation model. The adjustment coefficient is 1 minus the coefficient of lagged quantity, or .068. The long-run coefficients, the short-run coefficients divided by .068, are -4.26 for F_1 and .63 for T.

adopted. Research on seedling rates and rotations has led to higher potential fertilization rates even since 1950. Farmers' decisions have been affected by these findings. In the Great Plains, the region with the greatest percentage increase in fertilizer use since 1940, fertilizer was seldom recommended for the main crop, wheat, in earlier periods because (a) the original soil supplies of phosphates and potash were high and nitrogen was released by soil bacteria as rapidly as it was needed and (b) moisture, not nutrients, was the limiting factor in production. But with the advent of summer fallow, new rust and pest resistant wheat varieties and other techniques such as changed planting dates and irrigation, and with the gradual depletion of the original nutrients, fertility has become a limiting factor in part of the area. Research eventually has shown some fertilizer response, information which has been passed to, and used by, farmers in the newer using areas. Technical change and knowledge, provided gradually over time to farmers, certainly has been important along with price ratios in causing an increase in demand for fertilizer. While technical knowledge has increased in the older using regions, this change probably has been relatively less important than the price ratio, institutional alterations affecting farm size and the level of managerial abilities for fertilizer in determining fertilizer demand quantities.

Two distributed lag models of regional fertilizer demand are included in Tables 7.12 and 7.13. The equations in Table 7.12 have separate variables for fertilizer and crop price. Those in Table 7.13 substitute a cash receipts variable for the crop price variable. The period analyzed for these and all subsequent data (except where noted otherwise) is 1926-60 with 1944-50 excluded. Similarly, all variables are measured as for the estimate in Table 7.3. All regional coefficients for lagged fertilizer consumption are significant at a probability level of .95 or higher for Table 7.12 and for all regions but the Southeast in Table 7.13. Few of the coefficients for time in either table are significant even at a .80 probability level because the T and $Y_{i,t-1}$ variables

Table 7.12. Statistics for Regional Demand (F_i) Functions for Total Commercial Fertilizer, Including Regression Coefficients (b), Standard Errors (s) and R^2, 1926-60 With 1944-50 Excluded

Region	R^2	Log of Constant	Log Z_c		Log Z_f		Log T		Log $Y_{i,t-1}$	
			b	s	b	s	b	s	b	s
1. Northeast	.965	3.75	.031	.205	-.553	.231	.0006	.0016	.552	.156
2. Corn Belt	.988	6.30	.0022	.107	-1.930	.481	.0007	.0030	.565	.095
3. Lake States	.987	4.07	.242	.143	-1.357	.458	.0037	.0034	.624	.096
4. Appalachian	.956	5.59	.189	.168	-1.149	.345	-.0019	.0022	.418	.124
5. Southeast	.973	6.28	.413	.094	-1.304	.269	-.0020	.0017	.306	.091
6. Delta	.923	6.68	.605	.281	-2.030	.763	-.0038	.0054	.338	.128
7. Southern Pl.	.974	5.47	.531	.211	-2.097	.855	-.0016	.0053	.538	.089
8. Northern Pl.	.990	7.74	.450	.204	-3.438	.892	.0121	.0059	.442	.103
9. Mountain	.994	1.15	.514	.231	-.442	.502	.0323	.0104	.445	.147
10. Pacific	.996	3.42	.0022	.157	-.914	.291	.0097	.0052	.635	.125

Table 7.13. Statistics for Regional Demand (F_i) Functions for Total Commercial Fertilizer With a Cash Receipts Variable, Including Regression Coefficients (b), Standard Errors (s) and R^2, 1926-60 With 1944-50 Excluded

Region	R^2	Log of Constant	Log R		Log Z_f		Log T		Log $Y_{i,t-1}$	
			b	s	b	s	b	s	b	s
1. Northeast	.968	3.48	.250	.164	-.682	.235	-.0004	.0015	.409	.168
2. Corn Belt	.988	5.06	.192	.223	-1.826	.480	.0003	.0028	.541	.097
3. Lake States	.987	2.87	.416	.297	-1.463	.452	.0027	.0033	.520	.116
4. Appalachian	.956	4.93	.189	.164	-1.123	.352	-.0026	.0020	.410	.125
5. Southeast	.960	6.04	.412	.173	-1.467	.327	-.0041	.0019	.166	.117
6. Delta	.938	3.12	.849	.249	-1.823	.666	-.0043	.0044	.283	.116
7. Southern Pl.	.969	5.76	.498	.379	-2.935	.822	-.0081	.0048	.472	.102
8. Northern Pl.	.988	10.29	.0028	.447	-4.215	1.000	.0069	.0084	.438	.142
9. Mountain	.993	.75	.414	.244	-.0757	.743	.0279	.0103	.473	.152
10. Pacific	.996	1.07	.305	.179	-.529	.354	.0099	.0037	.609	.103

are highly correlated and the influences generally reflected in the former are absorbed by the latter. The fertilizer price variable was significant at a probability level greater than .95 for all but the Mountain region in Table 7.12 and for all but the Mountain and Pacific regions in Table 7.13. In Table 7.12 the crop price variable had a significant regression coefficient at a .95 or higher probability level for regions 5, 6, 7, 8 and 9. The cash receipts variable was significant at this level for only regions 5 and 6.[18] For the estimates in Tables 7.12 and 7.13, the newer using regions of the Corn Belt, Lake States, Northern Plains, Mountain and Pacific regions tended to have the highest elasticities with respect to time, lagged value of fertilizer purchases and prices. The older using regions of the South tended to have the highest elasticity with respect to cash receipts, an expected outcome for this region where capital is more nearly a limiting resource in decisions. However, some lack of reality is reflected in estimates of these two tables by the negative coefficients for time where it tends to be dominated by the substitute variable, the lagged value of fertilizer purchases.

Given the high R^2 values of the equations in Tables 7.12 and 7.13, but the failure of regression coefficients for cash receipts and crop price generally to exceed standard errors, several other regional models were estimated for total fertilizer purchases. One, including cash receipts, fertilizer price, land price and time had a coefficient of determination of .923 or larger for all regions, and while regression coefficients for fertilizer price and cash receipts were generally accepted as probability levels of .95 or higher, few regions had coefficients for land price and time significant at a .80 probability level. A regional model with only crop price, fertilizer price and time variables had an R^2 of .90 or larger for all regions, but again it was mainly the fertilizer price variable which was significant at an acceptable probability level. Evidently, disaggregation of fertilizer purchases results

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[18] For crop prices, fertilizer prices and cash receipts, the regions not mentioned failed to have significant regression coefficients at even the .80 probability level.

in a change, as compared to a national aggregate demand function, in the relative importance of selected variables in explaining demand structure and farmer behavior in use of this resource.

Since the regional specifications above were somewhat unsatisfactory with more variables, three less complex and alternative models were estimated by regions. We look upon these as inadequate specifications of regional demand functions, but expect that they, while insufficient for predicting demand structure, will serve about as efficiently as those above for short-term predictions and projections of fertilizer use by regions. The estimated demand equations from these three alternative specifications are included in Table 7.14. The results encourage precaution in interpretation of fertilizer demand elasticity with respect to the price ratio. The elasticity with respect to the price ratio (Z_r) is much higher in the third equation in each region without the cash receipts variable than in the second equation with it. Similarly, the "short-run" elasticity with respect to the price ratio for the first or distributed lag model for each region is generally smaller than

Table 7.14. Alternative Regional Demand (F_i) Functions for Total Commercial Fertilizer, Including Regression Coefficients (b), Standard Errors (s) and R^2, 1926-60 With 1944-50 Excluded

		Log of	Log Z_r		Log T		Log R*		Log $Y_{i,t-1}$	
Region	R^2	Constant	b	s	b	s	b	s	b	s
1. Northeast	.960	2.68	-.252	.174	.003	.001	--	--	.633	.158
	.942	5.23	-.679	.149	.005	.001	.355	.181	--	--
	.933	7.45	-.763	.150	.006	.001	--	--	--	--
2. Corn Belt	.980	1.31	-.163	.122	.007	.003	--	--	.786	.092
	.935	1.67	-.356	.243	.020	.005	1.201	.516	--	--
	.920	6.09	-.716	.203	.031	.003	--	--	--	--
3. Lake States	.985	2.09	-.422	.124	.007	.003	--	--	.739	.085
	.967	-3.90	-.410	.192	.021	.003	1.591	.345	--	--
	.937	5.86	-.810	.230	.033	.003	--	--	--	--
4. Appalachian	.947	3.69	-.430	.137	.002	.001	--	--	.534	.122
	.910	5.64	-.652	.192	.005	.002	.311	.250	--	--
	.904	7.69	-.822	.136	.005	.002	--	--	--	--
5. Southeast	.964	4.59	-.583	.081	.002	.001	--	--	.461	.081
	.933	4.23	-.525	.148	.004	.001	.558	.225	--	--
	.915	7.86	-.799	.108	.006	.001	--	--	--	--
6. Delta	.915	5.13	-.903	.206	.004	.003	--	--	.397	.125
	.915	1.75	-.772	.234	.008	.002	.951	.300	--	--
	.880	8.05	-1.310	.190	.008	.003	--	--	--	--
7. Southern Pl.	.971	3.34	-.774	.146	.005	.003	--	--	.614	.077
	.928	-2.78	-.897	.243	.014	.004	1.570	.479	--	--
	.896	7.09	-1.361	.234	.021	.004	--	--	--	--
8. Northern Pl.	.986	2.48	-.788	.194	.019	.006	--	--	.635	.094
	.980	-5.57	-.876	.226	.050	.003	1.651	.323	--	--
	.958	5.04	-1.442	.280	.058	.004	--	--	--	--
9. Mountain	.994	2.29	-.497	.135	.038	.009	--	--	.446	.144
	.991	1.87	-.433	.229	.059	.002	.229	.219	--	--
	.991	3.40	-.615	.150	.061	.002	--	--	--	--
10. Pacific	.994	1.62	-.227	.152	.013	.006	--	--	.705	.136
	.991	1.78	-.495	.182	.036	.003	.587	.237	--	--
	.988	2.55	-.821	.158	.028	.001	--	--	--	--

*Cash receipts from farming (crops and livestock) in regions 1, 2, 3, 7 and 8 and from crops and government payments in regions 4, 5, 6, 9 and 10.

for the second equation with only a time variable. The crop receipts variable, as mentioned at previous times, is a result of (and quite highly correlated with) the price ratio variable. The cash receipts variable appeared strongest for the southeast or southern regions where level of income more clearly affects funds available for purchase of operating inputs in the following year. However, in a somewhat opposite effect, the price elasticity jumped above unity for the Plains regions when the cash receipts (R) variable was dropped from the second equation of each region to form the third equation. In a broad sense, and irrespective of the particular model, the elasticities with respect to the price ratio were highest in the southern regions and the northern Great Plains for all three models while the "time elasticity" was highest for newer using regions. On a purely probabilistic foundation, there is no basis for accepting the first or second equation of each region over the third (or in accepting the third in comparison with $Y_{i,t-1}$ substituted for T).

The long-run and short-run elasticities among regions for the distributed lag model of Table 7.14 are shown in Table 7.15. The long-run elasticities generally are at least two or three times the short-run elasticities, magnitudes similar to those mentioned for the U.S. Depending on the adjustment coefficient, a considerable difference exists among regions in the short- and long-run elasticities, and the relative differences tend to be greatest for the newer using regions. These results would suggest that the period required for adjustment to change in the price ratio is slower in the older using regions. We might expect a longer period of adjustment in those older regions where farm income is lower, credit is more restrained and the effect of increased revenue and savings would allow a more gradual acquisition of more resources as the price ratio decreases.[19] We believe, however, that

Table 7.15. Long-Run and Short-Run Elasticities of Fertilizer Quantity With Respect to Price for the Distributed Lag Model of Table 7.14

Region	Short-Run	Long-Run
1. Northeast	-.252	-.687
2. Corn Belt	-.163	-.762
3. Lake States	-.422	-1.621
4. Appalachian	-.430	-.923
5. Southeast	-.583	-1.080
6. Delta	-.903	-1.504
7. Southern Plains	-.774	-2.013
8. Northern Plains	-.788	-2.162
9. Mountain	-.497	-.897
10. Pacific	-.227	-.769

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[19] In contrast, an increase in the ratio of fertilizer to crop prices (an increase in Z'_r), might curtail purchases more rapidly, and to greater proportion in regions of lowest income per farm.

the greater long-run elasticity, relative to short-run elasticity suggested for the newer using regions, is partially a reflection of the strong upward (and nearly linear) trend in use due to greater technical knowledge of fertilizer response or productivity — especially over a major part (the 1940's and 1950's) of the full period when the price ratio was declining.

Regional Estimates for Individual Plant Nutrients

Several regional models were estimated for individual plant nutrients for the period 1926-60, 1944-50 excluded, and with variables measured as at the outset of this chapter. One model applied to regions which included variables for crop price, fertilizer price, cash receipts, and time with variables transformed to logarithms is included in Table 7.16. The value of R^2 was .83 or larger (exceeding .93 in most cases) for all regions and individual nutrients or resources. In general, the coefficients for time, the price of land and the price of fertilizer were significant at probability levels of .95 or greater. The same general model with the cash receipts variable deleted is included by regions for aggregate fertilizer and the three individual nutrients in Table 7.16. This function had greater "uniformity," among regions and individual nutrients than the models mentioned above in respect to regression coefficients consistent in sign with theory and of large magnitude relative to standard errors. Except for one nutrient in one region, all values of the coefficient of determination exceeded .88 (Table 7.16). However, this attainment is not especially noteworthy or unusual with the degree of intercorrelation among variables related to fertilizer demand. Functions estimated with time and a relevant price variable give an R^2 of this magnitude in most cases. A time or closely related variable alone also results in a high correlation coefficient with fertilizer purchases in the current year.

Except for K_2O in the Mountain and Pacific regions (Table 7.16) all coefficients for fertilizer price are negative. While these coefficients are unstable because of high intercorrelation among variables, it is possible that the effect of knowledge has dominated price in its effect on use of the particular resource in these two newer using regions.[20] Aside from these two exceptions and the four fertilizer price coefficients in the Mountain region, all coefficients for fertilizer price are significant at a .99 level of probability. The spread of irrigation in the Mountain region, thus greatly altering fertilizer productivity, as suggested by the large elasticities with respect to time, likely dominates trends in fertilizer use in the latter regions. In general, the elasticity

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[20] Also, the particular weighting method used in computing the price variable may have had some effect in biasing the results for these two regions. However, this result is likely small for crop prices alone since movement in prices was parallel from 1930 to 1960 (the Pacific region deviating more from this standard than other regions, given the weighted crop price index used for it).

Table 7.16. Regional Demand Function Estimates, 1926-60 With 1944-50 Excluded

Region and Demand Quantity	R^2	Log of Constant	Log Z_f b	s	Log Z_c b	s	Log Z_d b	s	Log T b	s
1. All fertilizer	.952	7.93	-1.123	.196	.318	.220	-.171	.105	.0028	.0018
N_1	.972	4.39	-.643	.201	.345	.226	.320	.107	.0109	.0018
P_1	.958	7.49	-1.534	.237	.373	.266	-.102	.126	.0028	.0022
K_1	.992	5.44	-1.541	.174	.776	.196	.210	.093	.0136	.0016
2. All fertilizer	.974	11.02	-3.667	.513	.274	.174	.628	.281	.0062	.0043
N_2	.977	5.88	-2.989	.597	.323	.203	1.614	.327	.0199	.0050
P_2	.975	10.11	-3.902	.567	.215	.192	.823	.311	.0090	.0048
K_2	.978	8.72	-4.065	.680	.372	.231	1.192	.373	.0192	.0057
3. All fertilizer	.970	8.90	-3.005	.563	.345	.239	.611	.299	.0137	.0048
N_3	.973	5.10	-2.369	.609	.176	.259	1.220	.324	.0244	.0053
P_3	.974	8.17	-3.603	.642	.390	.272	.953	.341	.0180	.0056
K_3	.985	7.03	-3.811	.606	.554	.257	1.259	.323	.0279	.0053
4. All fertilizer	.935	8.96	-1.793	.358	.357	.244	.088	.183	-.0021	.0028
N_4	.975	5.74	-1.383	.306	.385	.209	.460	.156	.0072	.0024
P_4	.907	8.87	-1.902	.444	.283	.303	-.202	.227	-.0024	.0034
K_4	.985	6.79	-1.923	.307	.466	.209	.344	.157	.0092	.0024
5. All fertilizer	.965	8.55	-1.795	.230	.515	.128	.247	.127	-.0027	.0019
N_5	.969	5.96	-1.617	.328	.453	.182	.623	.181	.0064	.0027
P_5	.885	8.07	-1.591	.350	.471	.194	-.184	.194	-.0038	.0029
K_5	.985	7.12	-1.934	.252	.464	.140	.324	.140	.0066	.0021
6. All fertilizer	.902	10.83	-3.023	.787	.701	.322	-.231	.329	-.0049	.0062
N_6	.967	7.36	-3.530	.826	.931	.338	.896	.345	.0115	.0065
P_6	.831	12.01	-3.256	.923	.387	.378	-.747	.386	-.0096	.0073
K_6	.937	9.85	-3.180	.813	.602	.333	-.295	.340	.0027	.0064
7. All fertilizer	.951	9.27	-4.160	1.000	.847	.328	1.220	.417	-.0013	.0075
N_7	.984	2.31	-3.524	.840	1.137	.276	2.845	.351	.0211	.0063
P_7	.959	8.13	-4.388	1.062	.909	.349	1.379	.443	.0035	.0079
K_7	.944	7.21	-3.235	.972	.782	.320	.606	.406	.0043	.0073
8. All fertilizer	.985	10.47	-5.455	.823	.771	.281	1.010	.419	.0260	.0066
N_8	.990	4.59	-5.624	.914	.951	.312	3.013	.466	.0481	.0073
P_8	.986	9.93	-6.168	.929	.712	.317	1.479	.473	.0308	.0074
K_8	.969	10.41	-4.000	.885	.232	.302	-.556	.451	.0212	.0071
9. All fertilizer	.991	2.55	-.601	.592	.593	.273	-.196	.252	.0608	.0048
N_9	.986	-5.49	-.0125	1.068	1.406	.492	1.367	.455	.0897	.0087
P_9	.984	-1.04	-.247	.930	.937	.428	.224	.396	.0727	.0075
K_9	.927	4.25	1.193	1.064	-.702	.490	-2.199	.454	.0496	.0086
10. All fertilizer	.992	6.85	-1.878	.336	.158	.211	.414	.188	.0311	.0032
N_{10}	.986	4.38	-2.155	.637	.768	.399	.397	.355	.0473	.0061
P_{10}	.992	5.60	-1.133	.254	.135	.159	-.119	.142	.0250	.0024
K_{10}	.974	4.32	.0033	.371	.076	.232	-.613	.207	.0275	.0036

of fertilizer purchases with respect to time is greatest for all nutrients in the newer using regions of the Corn Belt, Lake States, Northern Plains, Mountain and Pacific areas. In fact, the time variable tends to be negative and smaller than the standard error for the three southern regions 5, 6 and 7, suggesting that recent influences reflected in T have had little impact relative to other variables. It is noticeable that the crop price variable seems to have a stronger effect in these three regions than in the other regions.[21] Similarly for the parallel model

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[21] It is significant at the .99 level of probability for all four estimates in regions 5 and 7, for total fertilizer and nitrogen in region 6. The crop price variable for K_2O was significant at the .90 percent level of probability in region 6. A regression model, with logarithmic transformation, applied to all fertilizer purchases, 1926-56, for regions 1, 2, 3, 5, 6 and 10 with first differences taken between years (i.e., the observations for each variable computed as $Z_t - Z_{t-1}$) and including fertilizer/crop price ratio, crop prices, cash receipts, total cropland acreage and time, generally had significant regression coefficients only for cash receipts. For details, see Yeh, op. cit.

including a cash receipts variable, these three regions (especially 6 and 7) had significant regression coefficients for cash receipts. In these older using regions of small farms and limited capital, crop prices and cash income of the previous year more nearly may be expected to dominate fertilizer price and time. In these as in all other regions, the elasticity of fertilizer purchases with respect to fertilizer price is predicted to be much larger than the elasticity with respect to crop price. The result could occur because all related resource/commodity price ratios are not included.

Since crop price is highly related to land price and since the fertilizer/crop price ratio determines more directly the use of the resource, three additional specifications were used in estimating regional demand functions for nutrients. These functions have the same algebraic form and variables as the total regional fertilizer demand equations in Table 7.14, except that measurements are for the individual nutrients. The estimated equation, including cash receipts (R in Table 7.14), is not included. This variable generally had a regression coefficient 1.5 or more times greater than the standard error but was not significant at a .90 or greater level of probability for more than half of

Table 7.17. Estimated Demand Functions by Nutrients and Regions Including Regression Coefficients (b), Standard Errors (s) and R^2, a Distributed Lag Model

Region	Nutrient	R^2	Log of Constant	Log Z_r		Log T		Log $Y_{i,t-i}$	
				b	s	b	s	b	s
1. Northeast	N_1	.981	2.49	-.347	.115	.005	.0018	.596	.116
	P_1	.971	2.00	-.256	.196	.003	.0014	.694	.135
	K_1	.993	3.46	-.654	.160	.009	.0021	.494	.109
2. Corn Belt	N_2	.981	.78	-.128	.130	.010	.0040	.808	.092
	P_2	.982	.73	-.073	.129	.007	.0035	.825	.091
	K_2	.987	.71	-.134	.134	.009	.0042	.836	.084
3. Lake States	N_3	.990	1.31	-.399	.110	.006	.0035	.834	.076
	P_3	.988	1.66	-.440	.136	.009	.0036	.761	.077
	K_3	.993	1.68	-.535	.123	.010	.0038	.780	.065
4. Appalachian	N_4	.968	2.86	-.370	.125	.006	.0023	.527	.132
	P_4	.933	3.04	-.415	.165	.002	.0016	.565	.135
	K_4	.982	3.20	-.520	.133	.008	.0024	.501	.112
5. Southeast	N_5	.968	2.92	-.476	.105	.005	.0022	.586	.105
	P_5	.921	4.14	-.596	.103	.00002	.0011	.459	.104
	K_5	.984	3.55	-.594	.085	.007	.0018	.497	.081
6. Delta	N_6	.973	3.52	-.907	.202	.012	.0039	.525	.102
	P_6	.857	3.72	-.724	.225	.001	.0028	.508	.137
	K_6	.945	4.17	-.921	.200	.009	.0033	.402	.121
7. Southern Pl.	N_7	.981	2.05	-.671	.161	.009	.0042	.736	.078
	P_7	.975	2.84	-.772	.158	.008	.0032	.623	.078
	K_7	.962	3.21	-.810	.150	.008	.0032	.510	.097
8. Northern Pl.	N_8	.993	1.33	-.598	.165	.011	.0064	.847	.068
	P_8	.992	1.68	-.668	.158	.014	.0055	.759	.069
	K_8	.980	1.98	-.671	.159	.015	.0055	.606	.106
9. Mountain	N_9	.992	1.55	-.657	.208	.018	.0114	.738	.123
	P_9	.991	1.61	-.543	.184	.027	.0099	.565	.130
	K_9	.952	.98	-.308	.255	-.002	.0067	.923	.127
10. Pacific	N_{10}	.989	2.56	-.727	.268	.028	.0088	.493	.152
	P_{10}	.991	1.95	-.190	.122	.015	.0056	.516	.175
	K_{10}	.976	1.05	.142	.130	.012	.0044	.561	.150

Table 7.18. Regional Demand Functions for Nutrients With Time and Price Ratio Variables With Regression Coefficients (b), Standard Errors (s) and R^2

Region	Nutrient	R^2	Log of Constant	Log T		Log Z_r	
				b	s	b	s
1. Northeast	N_1	.960	5.36	.0127	.0012	-.500	.157
	P_1	.940	6.89	.0081	.0014	-1.01	.184
	K_1	.987	6.61	.0174	.0011	-1.19	.141
2. Corn Belt	N_2	.921	3.89	.0417	.0034	-.468	.248
	P_2	.920	4.79	.0358	.0031	-.670	.229
	K_2	.935	4.25	.0470	.0036	-.761	.263
3. Lake States	N_3	.937	3.42	.0415	.0029	-.431	.264
	P_3	.939	4.76	.0413	.0031	-.913	.283
	K_3	.955	4.32	.0521	.0033	-1.03	.299
4. Appalachian	N_4	.946	5.64	.0136	.0016	-.604	.139
	P_4	.883	6.82	.0047	.0018	-.886	.155
	K_4	.967	6.03	.0175	.0017	-.871	.143
5. Southeast	N_5	.925	5.79	.0151	.0017	-.608	.153
	P_5	.858	7.00	.0021	.0013	-.823	.117
	K_5	.960	6.12	.0162	.0014	-.780	.125
6. Delta	N_6	.944	6.45	.0277	.0032	-1.50	.235
	P_6	.774	6.84	.0053	.0032	-1.17	.234
	K_6	.920	6.34	.0167	.0027	-1.27	.200
7. Southern Pl.	N_7	.910	4.82	.0417	.0051	-1.25	.316
	P_7	.910	6.03	.0269	.0041	-1.43	.253
	K_7	.919	5.44	.0200	.0031	-1.20	.188
8. Northern Pl.	N_8	.949	2.46	.0855	.0061	-1.27	.415
	P_8	.954	3.68	.0691	.0050	-1.44	.338
	K_8	.952	3.28	.0437	.0033	-1.00	.222
9. Mountain	N_9	.980	1.81	.0841	.0039	-.889	.316
	P_9	.983	2.29	.0692	.0029	-.727	.235
	K_9	.846	-.0157	.0431	.0047	+.642	.385
10. Pacific	N_{10}	.984	4.72	.0562	.0020	-1.30	.235
	P_{10}	.988	4.02	.0316	.0009	-.409	.110
	K_{10}	.962	2.55	.0283	.0014	+.221	.158

the estimates. For regions 5, 6, 7 and 8, including the South and the Great Plains, the variable was significant at a .99 probability level for all individual nutrients, except for nitrogen in the Southern Plains, potash in the Pacific region and phosphate in the Southeast.

The results by regions and nutrients are presented in Table 7.17 for the distributed lag model, while those with only time and the price ratio variables are presented in Table 7.18. In general, these two sets of functions have estimates with the same implications as those in Table 7.14 for all fertilizer. In Table 7.18, most coefficients for time are significant at the .99 probability level, and those for the price ratio are significant at this same level except in four cases. (The coefficient for the fertilizer/crop price ratio is positive for K_9 and K_{10}. In Table 7.17, however, the lagged value of nutrient consumption withdraws much of the effect from the time variable, with the former variable being significant at the .99 probability level in all cases and the latter failing to be significant at the .90 level of probability for a fourth of the functions (but above the .99 level in three-fourths). For price variables measured as specified earlier, none of the coefficients for the price ratio were significant at the .80 level of probability in the Corn Belt and Pacific regions, except for potash in the latter. The distributed lag models explain a slightly larger portion of the variance (from mean) of nutrient purchases than do the parallel estimates of Table 7.16. However, the additional variance explained by models of Table 7.17 are not statistically significant. In terms of prediction errors or deviations from regression, errors for individual years are smallest for Table 7.17 estimates when the trend is continuously upward.

The differences between the long-run and short-run elasticities, computed from the equations in Table 7.17 (but not presented), again tend to be largest in the newer using regions and smallest in the older using regions. The coefficients for time are especially large in the two newer Mountain and Pacific regions (except K_2O which is negative in the Mountain region, perhaps because of an unstable coefficient caused by an extremely high linear correlation coefficient between T and $Y_{i,t-1}$).

ALTERNATIVE MODELS

Numerous alternative models can be used in specifying demand structure for fertilizer and individual nutrients; on a purely statistical basis all are about equally acceptable, and it appears that any equation containing two variables relating to time and price, over a large span of the period studied, explains a major portion of variance in fertilizer consumption. While all predict about equally well over the full period analyzed, some are more sensitive in predicting a downturn or a sudden spurt in demand. Numerous variables which seem theoretically and practically reasonable in explaining demand structure are highly correlated, and ability to isolate their separative effect is difficult. For example, the tendency of the fertilizer-crop price ratio to decline much since 1930, during a period or in relation to a time variable expressing increased knowledge of fertilizer productivity, perhaps quantitatively overemphasizes and biases the magnitude of long-run elasticity with respect to the price ratio. Aside from estimates of structure these simple models generally are quite adequate short-run predictors.

8.

Market Structure for Hired Farm Labor[1]

A PRINCIPAL orthodox means suggested for solving the farm income problem is adjustment or decrease in the size of the farm labor force. Greater knowledge of the factors which affect the demand and supply of farm labor is important in analysis of factors related to the supply of farm products and income of the industry.

Labor, of course, is not an inanimate resource that can be shunted abruptly out of agriculture in immediate response to relative price changes. Rather, labor represents a human resource with a consuming unit attached to it. It has many sociological attributes which relate to its mobility. This chapter, however, emphasizes the economic aspects of hired labor as a resource and examines responses by it in respect to farm income, wage rates, and other relevant variables.

Two categories of farm labor, hired and family, are considered in this and the next chapter. Most of the estimates are by single-equation, least-squares methods. However, some use is made of limited information and other simultaneous equation methods. The procedure in this chapter is to describe historic trends in employment of farm labor, to discuss the nature and basis of various estimates by government agencies of the number of workers in the farm labor force, and to present empirical estimates of coefficients and elasticities based on supply and demand functions for hired farm labor.

It is hoped that the analysis might lead to useful knowledge for such questions as: (a) How much time must elapse, given the specified differentials between farm and nonfarm wages, before a specified amount of labor leaves agriculture? (b) What is the effect of varying rates of unemployment in the national economy on the rate of migration from agriculture? (c) What is the elasticity of supply response for farm labor in respect to farm and nonfarm wage rates? (d) What are the important variables which affect the demand for farm labor and the

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[1] The study reported in this chapter was initiated in 1956. An important portion of the early work was conducted by Stanley S. Johnson, formerly a graduate student and research associate at Iowa State University (currently employed by the USDA). He is a co-author of this chapter. For earlier reports on this study, see Heady, Earl O., and Johnson, Stanley S. The labor resource; its demand in agriculture. Iowa State University Center for Agricultural and Economic Development. CAEA Report No. 13; and Johnson, Stanley S., and Heady, Earl O. Demand for labor in agriculture. Iowa Agr. Exp. Sta. Bul. (forthcoming).

amount of labor held on farms in the various geographic regions of the United States? (e) Is the supply of farm labor highly responsive to changes in the farm wage? The results of this study provide some initial answers to questions such as these, and to questions which are related in judging adjustment rates and potentials in agriculture.

TRENDS IN FARM LABOR AND RELATED INPUTS

Total labor employment in agriculture has undergone a large change, the general trend since 1910 being mainly downward. The total number of farm workers declined 47 percent between 1910 and 1960 (see Figure 8.1). Estimated requirements for man-hours in agriculture declined 50 percent during the same period (Figure 8.2). The rate of decrease was far from constant over the 50-year period. Total farm employment increased from 1910 to 1916 and dropped by only 8 percent from 1910 to 1930. Due to depression and lack of off-farm opportunities, farm employment increased 2 percent between 1930 and 1935. After 1935, however, the rate of net migration from farms increased. Farm employment declined 19 percent between 1935 and 1946, and by 31 percent between 1946 and 1960.

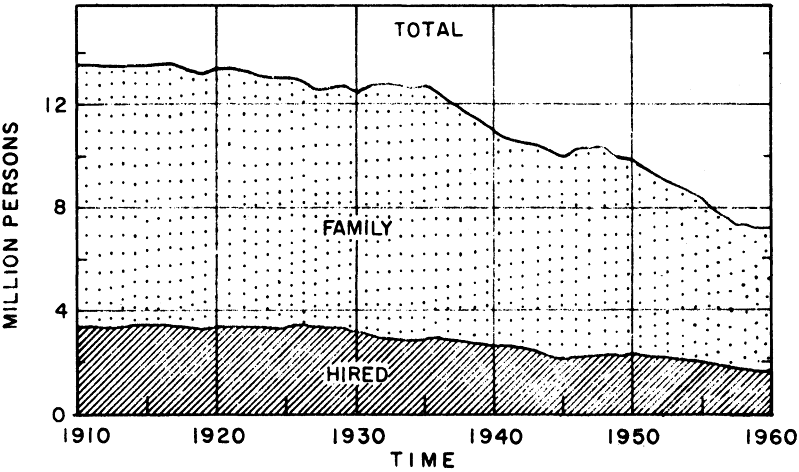

Figure 8.1. Total farm employment, 1910-60, with comparisons for hired and family labor.

The hired labor force has constituted about 25 percent of the national farm labor force since 1910. Hence, national or aggregative changes in the numbers of hired and family workers over time have been similar to changes in the total farm labor force. However, this relative stability in mix of hired and total family labor does not hold true on a regional basis. The changes in Table 8.1 for farm labor in

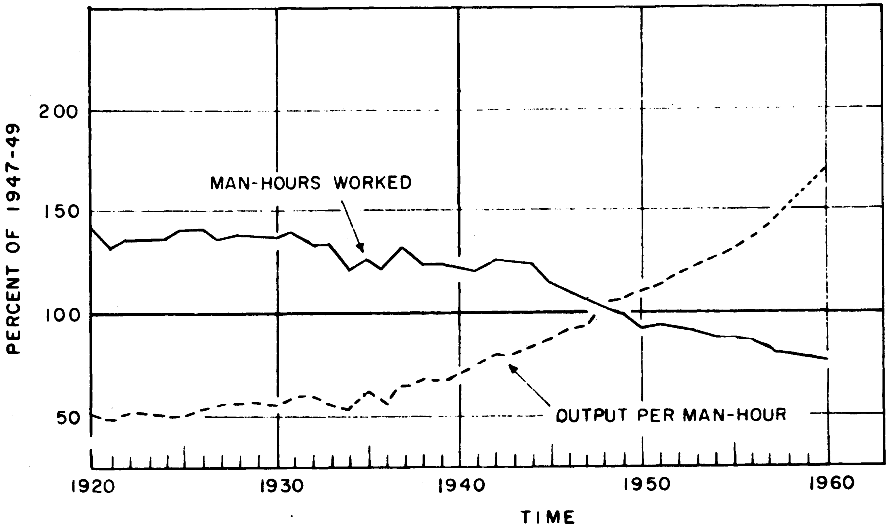

Figure 8.2. Man-hour requirements in agriculture and agricultural output per man-hour, 1920-60.

nine geographic regions indicate no consistency among areas. These differences likely are due to level of income, race of workers, employment opportunities and other variables analyzed in this chapter at the national level.

SOURCES AND NATURE OF DATA

The data used in this study are time series observations of employment, prices and other relevant variables. The data are taken from USDA sources for the nation, except as otherwise indicated on a regional basis. Several sources of farm employment data exist, and each has somewhat different implications for empirical analysis. Accordingly, these several sources are discussed as a basis for indicating limitations in the data and for explaining the logic in selecting particular measurements and variables.

Major Sources of Employment Data

The major sources of data on farm employment are: (a) employment estimates of the Agricultural Marketing Service of the USDA (hereafter indicated as the AMS series[2]); (b) estimates published by the Bureau of the Census, the Current Population Survey (hereafter

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[2] USDA. Agricultural Marketing Service. Farm employment. USDA Sta. Bul. 236. 1958.

Table 8.1. Size of the Farm Labor Force, by Regions, for 1957, and the Percentage Change in the Hired and Family Labor Force, by Regions, 1910-57 and 1929-57, as a Percentage of 1910*

Region	Size of Farm Labor Force, 1957	Percentage Change, 1910-57	Percentage Change, 1929-57		
		Total farm employment	Total farm employment	Hired workers	Family workers
	(Thousands)	(Percent)	(Percent)	(Percent)	(Percent)
New England	172	-53	-36	-33	-38
Middle Atlantic	444	-53	-36	-47	-30
East North Central	1,307	-36	-22	-54	-12
West North Central	1,398	-36	-35	-65	-24
South Atlantic	1,345	-49	-42	-36	-44
East South Central	969	-58	-56	-47	-58
West South Central	1,000	-54	-57	-46	-61
Mountain	354	-18	-35	-46	-27
Pacific	588	+14	+1	+2	+1
United States	7,577	-44	-40	-44	-39

*USDA. Agricultural Marketing Service. Farm employment. USDA Sta. Bul. 236. 1958; USDA. Agricultural Marketing Service. Farm labor. Oct. 1953.

indicated as CPS[3]); (c) man-hour requirements estimated by the Agricultural Research Service of the USDA (hereafter indicated as FERD[4]); (d) estimates of the hired farm working force of the Agricultural Marketing Service of the USDA, and based on a survey of the Bureau of the Census (hereafter indicated as HFWF[5]). Though the source is not described here, a rough estimate of the number of available farm workers also may be derived from farm population estimates.

Comparison of the Major Employment Series

The most important sets of farm employment estimates are the AMS and the CPS series. They are emphasized in the discussion below. The remaining series are accorded separate analysis later.

The CPS and AMS total farm employment series on an annual basis are presented in Table 8.2. The AMS series of average annual employment is higher than the CPS series in every year. The difference

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[3] U.S. Bureau of the Census. Current population reports: labor force. Series P-50, Nos. 72-89. March 1957-June 1959.

[4] USDA. Agricultural Research Service. Changes in farm production and efficiency. USDA Sta. Bul. 233. Revised September 1959.

[5] Maitland, Sheridan T., and Fisher, Dorothy Ann. The hired farm working force of 1957. USDA Info. Bul. 208. 1959.

Table 8.2. Annual Average of Farm Employment From CPS and AMS Series and Differences, 1940-57, Family and Hired Workers

Year	CPS*	AMS†	Excess of AMS Over CPS Series
		(Thousands of persons)	
1940	9,540	10,979	1,439
1941	9,100	10,669	1,569
1942	9,250	12,504	1,254
1943	9,080	10,446	1,366
1944	8,950	10,219	1,269
1945	8,580	10,000	1,420
1946	8,320	10,295	1,975
1947	8,266	10,382	2,116
1948	7,973	10,363	2,390
1949	8,026	9,964	1,938
1950	7,507	9,926	2,419
1951	7,054	9,546	2,492
1952	6,805	9,149	2,344
1953	6,562	8,864	2,302
1954	6,504	8,639	2,135
1955	6,504	8,639	2,135
1956	6,585	7,820	1,235
1957	6,222	7,577	1,355

*U.S. Bureau of the Census. Current population reports: labor force. Series P-50, Nos. 72-89. March 1957-June 1959.

†USDA. Agricultural Marketing Service. Farm employment. USDA Sta. Bul. 236. 1958.

between the two series gradually widened from 1940 to 1950, but narrowed from 1951 to 1957. The difference between the two series may have decreased after 1951 as the Bureau of the Census enlarged its samples in 1954 and in 1956.

Table 8.3 contains hired seasonal employment for the AMS, CPS and HFWF series for 1957. During this year the AMS estimates were higher than the CPS series for the summer months, but were lower during the winter months. The HFWF data are similar to the CPS estimates, since both sets of data are collected by the Census Bureau. However, the employment estimates for the HFWF are much below the CPS estimates for the earlier months of the year, but similar over the latter months. This bias in the HFWF series will be discussed later in this section.

While the three hired employment series in Table 8.3 agree on the months of minimum employment (December, January and February), they differ on periods of peak employment. The AMS series indicates July, August and September to be similar in the number employed,

Table 8.3. Average Employment of Hired Farm Workers by Months, United States, AMS, CPS, and HFWF Series, 1957

Month	AMS*	CPS†	HFWF Original	HFWF Adjusted‡
	(Thousands of persons)			
January	896	1,154	757	827
February	1,040	1,180	768	839
March	1,284	1,209	856	935
April	1,543	1,322	1,085	1,177
May	1,985	1,710	1,394	1,538
June	2,684	2,138	1,924	2,058
July	2,983	2,354	2,189	2,364
August	2,883	1,971	2,058	2,219
September	2,805	1,911	1,872	2,121
October	2,237	2,112	1,706	1,944
November	1,450	1,654	1,405	1,568
December	951	1,533	1,073	1,174
Average	1,895	1,687	1,424	1,564

*USDA. Agricultural Marketing Service. Farm employment. USDA Sta. Bul. 236. 1958.

†U.S. Bureau of the Census. Current population reports: labor force. Series P-50, Nos. 72-89. March 1957-June 1959.

‡Adjusted to include foreign workers. From Maitland, Sheridan T., and Fisher, Dorothy Ann. The hired farm working force of 1957. USDA Info. Bul. 208. 1959.

while the CPS series is bimodal. In previous years the AMS series also has been bimodal, with September being the month of greatest employment.[6]

Discrepancies between the CPS and AMS series exist because of differences in concept and method of enumeration. The AMS series essentially estimates the number of farm jobs, while the CPS series estimates the number of farm workers. Both series have relative advantages and disadvantages. There are five main differences between the AMS and CPS employment estimates. First, the data are compiled in the two series by means of different enumerative techniques. The AMS derives farm employment estimates from selected representative farmers who report on their own particular farm. This method of data collection is referred to as the "establishment" method, since the information is obtained about all workers on the establishment. On the other hand, the CPS series is derived from Bureau of Census data which are collected from households. The "household" method obtains information only on actual members of the household. Consequently, a worker employed on more than one farm during the survey period may be counted more than once under the establishment method, but only once

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[6] USDA. Agricultural Marketing Service. Farm employment, _op. cit._

under the household method. Double counting under the establishment method has been estimated to be at a minimum of a quarter of a million persons, and may be considerably larger seasonally.[7]

A second source of difference between the two series is in the counting method in relation to age limits. The AMS series sets no age limit while the CPS enumeration includes only persons 14 years of age or over. When unpaid members of the family who work 15 hours or more a week are included, the number of children under 14 years of age is estimated by the USDA to be as high as a million.[8] A private estimate by Johnson placed the maximum at 2 million during peak periods.[9]

A third difference arises over multiple job holding. The requirements for a worker to be included in the AMS enumeration are minimal for the survey week: 1 or more hours of farm work for a hired worker, any work at all for an operator and 15 or more hours for unpaid family workers. However, to be included in the CPS enumeration, the worker not only must be 14 years of age or over, but also must have earned a major share of his income in agriculture. Persons with multiple jobs who actually do some farm work, but who are not included in the CPS enumeration, number from 1/2 to 1 million seasonally.[10]

A further difference between the two series may arise because the CPS includes categories of farm workers who engage in nonfarm occupations, such as bookkeepers, typists and persons engaged in some processing activities.[11] It also includes some unemployed farm operators. A difference between the two series also may occur because of different dates of the surveys. While the dates of the surveys of the CPS relate to the week ending nearest the 15th of the month, AMS estimates relate to the last full calendar week of the month.

Besides these five differences between the two major series, other factors are important in the selection of a series to use in the analysis. The estimates of the CPS series are derived from a statistically selected sample, so that standard errors of the estimates can be computed. Standard errors of the estimates are not obtainable from the AMS series. A further and important consideration is the length of time covered by the two series. The AMS estimates cover the period 1910 to the present, include separate series for hired and family labor and include regional as well as national estimates. The CPS series, inaugurated in 1940, presents estimates of hired and family labor on a national basis only.

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[7] USDA. Major statistical series of the U.S. Department of Agriculture, how they are constructed and used. Vol. 7. USDA. Agr. Handbook 118. 1957.

[8] Ibid.

[9] Johnson, D. Gale, and Nottenburg, M. C. A critical analysis of farm employment estimates. Journal of the American Statistical Association 46:191-205. 1951.

[10] USDA. Major statistical series of the U.S. Department of Agriculture, Vol. 7, op. cit.

[11] An estimate of the number of nonfarm workers included in the CPS series may be obtained by subtracting the number of persons employed in agricultural occupations (farm operators and farm laborers) from the total number of persons employed in agriculture. For 1957 an annual average of 198,000 persons were estimated to be engaged in these nonfarm activities. (See Maitland and Fisher, op. cit.)

The Hired Farm Work Force (HFWF)

The HFWF series is relatively new, being started in 1945 for the purpose of providing more detailed information on work done by hired workers. It was derived from information obtained by the Agricultural Marketing Service from the Bureau of the Census through supplementary questions included in one of the regular Current Population Surveys. Employment data for the year are collected at the beginning of the following year, and questions are asked about any farm work done over the past year. Consequently, the HFWF estimates are subject to memory bias, and provide a relatively low estimate of employment in the earlier months of the year. Since the enumeration covers work for the whole month rather than for a survey week and is derived from the same sample as the CPS, the HFWF employment estimates are expected to be larger than the monthly CPS estimates. The HFWF series is not available by regions.

The Series of Man-Hour Requirements (FERD)

Another farm employment estimate not directly comparable to the three previously discussed sets of estimates is the FERD series of man-hour requirements. The purpose of the series is to estimate the number of man-hours required for annual farm output, rather than man-hours actually expended. Compiled by the Agricultural Research Service of the USDA, these estimates are "built up" by multiplying estimated average man-hours per acre of crops and per head or unit of livestock production by the official estimates of total acres and numbers of livestock reported by the Crop Reporting Board of the USDA.[12] A limitation of this series is that errors in the magnitude of the estimates of man-hours per acre or per head of livestock are greatly enlarged when these initial estimates of requirements are multiplied by the total number of acres and animals. Too, a test of statistical reliability cannot be applied to them. The series includes both national and regional estimates, and covers the period 1910 to the present.

Employment and Other Variables Used in Chapter 8

Each of the employment series has been derived for a particular purpose. Each estimate, because of its particular advantages and disadvantages, is unique and suitable only for specific analyses. The AMS series has been utilized more than the other series for labor analyses. It also is used in this study for the following reasons: (a) the series covers a relatively long period, from 1910 to the present; (b) the series

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[12] USDA. Major statistical series of the U.S. Department of Agriculture, how they are constructed and used. Vol. 2. USDA. Agr. Handbook 118. 1957.

encompasses both the hired and family components of farm labor; (c) since no age limits are imposed in the enumeration and all farm work is included, the series is a better measure of marginal changes in the farm labor force than is the CPS series.[13] The FERD series is used for one set of long-run predictions since it best reflects changes in labor productivity.

Except as otherwise specified, the variables used in this chapter and Chapter 9 are as follows. The variable is measured in the current year, except where noted otherwise (where t is used, it refers to measurement in the current year also, and t-1 is the same variable lagged one year).

Q = the annual quantity of labor employed on farms, with Q_H designating the quantity of hired labor, and Q_F the quantity of family labor.

Q' = the annual quantity of labor supplied by households, with Q'_H designating the quantity of hired labor, and Q'_F the quantity of family labor.

P_H = the index of the annual farm wage rate as an aggregate for the United States. The data were deflated principally by the index of prices paid by farmers for living expenses, not including wages, and the index of prices paid by farmers for production expenses. The wage rate was included because it is the price of hired labor and perhaps is the "going" price of family labor.

P_R = the index of annual prices received by farmers for all commodities as an average for the United States, deflated by the index of prices paid by farmers for production expenses and the index of farm machinery prices. The series thus deflated is the ratio of product price to factor price and is lagged by 1 year in all equations.

P_M = the annual aggregate index of farm machinery prices for the United States, deflated as for P_H. This variable is included to allow expression of the substitution relationships of farm machinery for farm labor. (Empirical labor demand functions which included the price of farm machinery had regression coefficients which were inconsistent in sign and nonsignificant. Hence, equations for labor demand containing the price of farm machinery as a variable are accorded a separate analysis later in Chapters 8 and 9.)

S_m = the index of the value of farm machinery on hand Jan. 1 for the United States, deflated by the prices paid by farmers for living expenses, to indicate the stock of resources which substitute for labor. The series was compiled commencing with a deflated value of farm machinery on farms from the 1930 census. For succeeding

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[13] Hathaway, Dale. Agriculture in an unstable economy revisited. Journal of Farm Economics 41:496. 1959.

years, the deflated increments to (or depreciation of) the nation's stock of machinery and equipment were added (or subtracted) from the prior year's total.

T = time as a variable. Time in linear form is used to represent technological and other changes which have occurred but are not readily quantified as separate and explicit variables.

P_N' = a nonfarm wage-rate variable. This variable is a "composite" of the annual index of hourly factory wages altered to reflect the percentage of unemployment in the total work force. It was assumed arbitrarily that when unemployment of the total work force reached 20 percent, no further off-farm opportunities would exist. Consequently, with unemployment equal to or greater than this level, changes in nonfarm wage rates are expected to have no effect in causing net migration from agriculture. To reflect conditions where nonfarm wage rates would not cause migration when unemployment is 20 percent or greater, this variable was constructed:

$$P_N' = P_N\ (1 - 5U)$$

where P_N is the hourly earnings of factory workers and U is the percent of unemployment in the national economy. When the unemployment rate reaches 20 percent or more, P_N' becomes zero; when the unemployment rate is zero, the variable reaches the average level of earnings by factory workers.

Variations in regression models are made for these purposes: (a) to examine the effect of the inclusion or noninclusion of variables assumed to have important effects on the use of farm labor; (b) to compare results from variables deflated by different price series; (c) to use different time periods for estimation; (d) to compare equations containing observations entered in linear and in logarithmic form; (e) to compare estimation techniques such as single equations (some taken with a distributed lag), simultaneous-equations estimation by the reduced-form, the limited information and Theil-Basmann methods, and autoregressive least-squares methods;[14] and (f) to include the quantity of farm labor, lagged one period (Q_{t-1}), as an additional independent variable (i.e., as a predictor of Q_t). The results of the empirical analysis are presented in a later section. Further variations in notation from that listed above will be defined in the appropriate section.

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[14] Theil, Henri. Estimation and simultaneous correlation in complete equation systems. Central Plan Bureau, The Hague, Netherlands. Mimeo. report. June 23, 1953. (Original not available for examination; cited in Wallace, T. D., and Judge, G. G. Discussion of the Theil-Basmann method for estimating equations in a simultaneous system. Oklahoma State University. Processed series P-301. Aug. 1958.); and Basmann, R. L. A generalized classical method of linear estimation of coefficients in a structural equation. Econometrica 25:77-83. 1957.

EMPIRICAL PROCEDURES

Since the models derived in this study are all "shock" models, the data are presumed to be measured without error. The results may be invalidated to some extent, since errors of observation in economic time series are usually present. A method of dealing with this problem is presented by Tintner,[15] and an example involving labor has been analyzed by Mosback.[16]

Equations taken with a distributed lag, as well as the more common form of equations, have been used in this study. For several of the national demand and supply functions for hired labor, distributed lag equations were used. Both conventional and autoregressive least-squares equations were estimated for national data.[17] Tests for residual correlation have typically been made by the Durbin-Watson test.[18] However, Fuller and Martin illustrate that this test is not always "effective." It is likely that the lagged dependent variable "extracts" some of the autocorrelation from the residuals, biasing the coefficient and use of the d statistic.

Koyck[19] proposed the model in equation (8.1) to obtain consistent estimators when the error term u_t is generated by an autoregressive scheme.

$$u_t = Bu_{t-1} + e_t \tag{8.1}$$

The assumptions are that e_t has a zero mean and a constant variance, is not correlated with u_{t-1} and is not autocorrelated with lagged values of e. Further, he assumes specific values of B, the autoregressive coefficient. Estimation by this technique is referred to in this study as autoregressive least squares or A.L.S.

In an equation such as in (8.2), assuming that a first-order autoregressive scheme applies, the cases in which a variable b′ is a consistent estimator of the real b has been outlined by Fuller.[20]

$$w_t = ap_t + bw_{t-1} + u_t \tag{8.2}$$

He shows that Koyck's basic equation combined with the autoregressive scheme of equation (8.1) leads to

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[15] Tintner, Gerhard. Econometrics. John Wiley & Sons. New York. 1952. Chap. 7.

[16] Mosback, Ernest J. Fitting a Static Supply and Demand Function for Labor. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1957.

[17] Fuller, W. A., and Martin, J. E. The effects of autocorrelated errors in the statistical estimation of distributed lag models. Journal of Farm Economics 43:71-82. 1961.

[18] Durbin, J., and Watson, G. S. Testing for serial correlation in least squares regression, II. Biometrika 38:159-78. 1951.

[19] Koyck, L. M. Distributed Lags and Investment Analysis. New Holland Publishing Co. Amsterdam, Netherlands. 1954.

[20] Fuller, Wayne. A Non-Static Model of the Beef and Pork Economy. Unpublished Ph.D. Thesis. Iowa State University Library. Ames. 1959. See also Fuller, Wayne A., and Ladd, George W. A quarterly model of the beef and pork economy. Journal of Farm Economics 43:797-812. 1961.

$$u_t = B(w_{t-1} - ap_{t-1} - bw_{t-1}) + e_t. \tag{8.3}$$

By substituting equation (8.3) into equation (8.2), he shows that the probability limit of b′ is given by

$$\text{plim } b' = b + \frac{B}{1 + Bb} \left\{ \frac{\left(1 - r^2_{p_t w_t}\right) - b^2}{\left(1 - r^2_{p_t w_{t-1}}\right)} \right\} \tag{8.4}$$

where w is labor quantity and p is labor price. Under these assumptions, b′ is a consistent estimator of b only when B = 0. These results indicate that a more accurate estimate of b could be obtained if the value of B were known. (Since there is usually autocorrelation among economic time series, it is likely that estimates of b have an upward bias, depending on the value of B.) Methods for estimating B have been presented by Klein and Orcutt and Cochrane.[21] A simplified method for estimating B by an iterative process has been developed by Fuller.[22] Basically the method is as follows, using the notation of equations (8.2) and (8.3). By substituting (8.3) into (8.2) the following equation is formed:

$$w_t = ap_t + (b + B)w_{t-1} - aBp_{t-1} - bBw_{t-2} + e_t. \tag{8.5}$$

A regression on these variables provides initial values of estimates of a, b and B. By a method of ~~nonlinear~~ regression,[23] a function containing the estimates of the coefficients is expanded in a first-order Taylor expansion about the point defined by the initial values above. The sums of squares and cross products from the Taylor expansion become linear combinations of those in equation (8.5). Retaining only the first-order terms, the results of the Taylor expansion yield:

$$w_t = w_0 + m_1 \Delta\hat{a} + m_2 \Delta\hat{b} + m_3 \Delta\hat{B} \tag{8.6}$$

where $w_0 = w_t - \hat{w}_t$, the residuals in equation (8.5),

$$m_1 = p_t - B\hat{p}_{t-1},$$

$$m_2 = w_{t-1} - B\hat{w}_{t-2},$$

$$m_3 = w_{t-1} - a\hat{p}_{t-1} - bw_{t-2},$$

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[21] Klein, op. cit.; and Cochrane, D., and Orcutt, G. H. Application of least squares regression to relationships containing autocorrelated error terms. Journal of the American Statistical Association 44:36-61. 1949.

[22] Fuller, Wayne. Autocorrelated errors and the estimation of distributed lag models. (Typewritten.) Statistical Laboratory, Iowa State University. Ames. 1960.

[23] Levenberg, Kenneth. A method for the solution of certain non-linear problems in least squares. Quarterly Journal of Applied Mathematics 2:114-68. 1944.

where $\hat{a}$, $\hat{b}$ and $\hat{B}$ are the initial estimates of the coefficients, and $\Delta \hat{a}$, $\Delta \hat{b}$ and $\Delta \hat{B}$ represent changes for each iteration. The least-squares method applied to equation (8.6) produces further changes in the estimates; the iterative method continues until the change becomes sufficiently small. The final estimates are consistent estimates of the coefficients.

EMPIRICAL ESTIMATES OF THE NATIONAL DEMAND FUNCTIONS FOR HIRED FARM LABOR

This section presents the empirical results testing the hypothesis that the demand for hired labor is a function of its own price (the farm wage rate); the prices of other inputs such as farm machinery, the scale of farming as exemplified by the value of farm machinery, and the return on or price of products sold.[24] In contrast to family labor, hired labor has an explicit wage or price which is reported nationally and regionally. The price of inputs such as the series of aggregate farm machinery prices, was originally included in the regression model. However, farm machinery price resulted in inconsistent results when this variable was included with other explanatory variables. Because of the importance of farm machinery to the demand for hired labor, it is accorded a separate analysis later in this chapter.

The demand functions for hired labor in Tables 8.4 and 8.5 have been estimated using a variety of algebraic forms and estimating methods and are from the earlier phase of this study. Results for hired labor demand using an alternative set of models will follow in a later section. The statistics in Table 8.4 are the results of the estimated equations, while Table 8.5 includes the elasticities of hired labor with respect to the variables indicated. Standard errors are included in parentheses under the regression coefficients in Table 8.4. The form of equations and variables and the estimating technique is that indicated in column 2. The periods for which the variables are measured are included in the middle of the table. The value of R^2 is included in the third column. The deflators of the farm wage rate and prices received variables are listed in Table 8.5. Wherever a space is blank, the

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[24] For other empirical studies of the demand for hired farm labor, see Griliches, Zvi. The demand for inputs in agriculture and a derived supply elasticity. Journal of Farm Economics 41:309-22. 1959; and Schuh, George E. The demand and supply relations for hired labor in agriculture. Paper presented at the Joint Meetings of the Econometric Society and the American Farm Economic Association, Washington, D.C., December 28-30, 1959. (Mimeo.) Department of Agricultural Economics, Purdue University, Lafayette, Indiana. 1959. Griliches specified a distributed lag model representing the demand for hired labor for the period 1912-56, containing one independent variable, the farm real-wage rate. Schuh estimated demand functions for hired labor over the period 1929-57 simultaneously with hired-labor supply functions. Schuh's time period and model specification are similar to equation (8.14) of Table 8.4 (to be presented further in this study). The demand functions in this study, other than the A.L.S. equations, were estimated simultaneously with Schuh's work and without knowledge of it.

Table 8.4. Regression Coefficients and Standard Errors (in Parentheses) for United States Hired-Labor Demand Functions*

Equation Number	Form and Method†	R^2	Constant	P_{Ht}	P_{Rt}	S_{mt}	T	Q_{Ht-1}
				1910-57 period				
(8.7)	O, least squares	.983	40.74	-.077 (.045)	--	--	-.297 (.141)	.777 (.082)
(8.8)	O, least squares	.981	15.23	-.091 (.044)	--	--	--	.931 (.047)
(8.9)	O, least squares	.983	27.89	-.098 (.055)	.054 (.033)	--	-.179 (.119)	.826 (.073)
(8.10)	O, least squares	.982	12.86	-.122 (.053)	.079 (.029)	--	--	.907 (.054)
(8.11)	L, least squares	.984	.35	-.095 (.034)	.057 (.022)	--	-.021 (.017)	.871 (.054)
(8.12)	O, least squares	.982	23.86	-.046 (.058)	.048 (.064)	--	-.240 (.114)	.851 (.073)
				1920-39 period				
(8.13)	O, least squares	.935	68.40	-.054 (.187)	.248 (.111)	--	-.686 (.262)	.478 (.271)
				1929-57 period				
(8.14)	O, reduced form	.970	52.47	-.168 (.108)	.099 (.069)	--	-.335 (.119)	.658 (.041)
(8.15)	O, Theil-Basmann	.988	116.32	-.341 (.122)	.243 (.112)	--	-.687 (.523)	.206 (.195)
(8.16)	O, Theil-Basmann	.980	94.49	-.287 (.091)	.245 (.081)	.00207 (.00085)	-1.635 (.674)	.237 (.265)
				1940-57 period				
(8.17)	O, least squares	.980	122.03	-.458 (.091)	.119 (.040)	--	-.311 (.244)	.236 (.159)
(8.18)	O, least squares	.936	98.22	-.232 (.081)	--	--	-.120 (.325)	.530 (.491)
(8.19)	O, least squares, not distributed lag	.979	153.23	-.475 (.178)	.127 (.031)	--	-.492 (.504)	--

*The price variables are deflated as indicated in Table 8.5. The variables, in index form, are:

P_{Ht} = the index of the average hired farm wage rate for the United States where t refers to measurement in the current year.

P_{Rt} = the index of average prices received by farmers for all commodities for the United States.

S_{mt} = the average value of farm machinery and equipment for the United States.

T = time as a linear variable.

Q_{Ht-1} = the number of hired workers lagged 1 year for the United States.

†O refers to original observations introduced in models in linear form; L refers to observation in logarithmic form; reduced forms and Theil-Basmann method refer to the technique used to solve simultaneous equations. Equations (8.7), (8.8), (8.15) and (8.16) were estimated using autoregressive least-square methods.

corresponding variable was omitted from the model. The forms and estimating methods include: (a) linear observations in all equations other than for equation (8.11), which is in logarithms; (b) least-squares method for equations (8.7) to (8.13) and (8.17) to (8.19), inclusive, and simultaneous-equation estimation by reduced forms for equation (8.14) and by the Theil-Basmann technique in equations (8.15) and (8.16);[25]

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[25] Theil, Henri, op. cit., and Basmann, R. L., op. cit.

Table 8.5. Elasticities of Demand Computed From the Demand Equations for Hired Labor (United States) Presented in Table 8.4

Equation Number	Form and Method	Deflator of the Farm Wage Rate	Elasticity of the Farm Wage-Rate Variable: Short run, Mean	Short run, 1957	Long run, Mean	Long run, 1957	Deflator of Prices Received	Elasticity of the Prices Received Variable: Short run, Mean	Short run, 1957	Long run, Mean	Long run, 1957	Adjustment Coefficient	Time Variable Included
					1910-57 period								
(8.7)	O, least squares	-- *	-.0529	-.1374	-.2376	-.6173	--	--	--	--	--	.223	Yes
(8.8)	O, least squares	-- *	-.0627	-.1646	-.9092	-2.387	--	--	--	--	--	.052	No
(8.9)	O, least squares	-- †	-.0576	-.1301	-.331	-.7747	-- ‡	.0347	.0394	.1995	.2265	.174	Yes
(8.10)	O, least squares	-- †	-.0718	-.1621	-.7754	-1.751	-- ‡	.0519	.0584	.5603	.6302	.039	No
(8.11)	L, least squares	-- †	-.0953	-.0953	-.7365	-.7365	-- ‡	.0574	.0574	.4434	.4434	.129	Yes
(8.12)	O, least squares	-- §	-.0276	-.0663	-.1737	-.4173	--	.0338	.0474	.2128	.2984	.159	Yes
					1920-39 period								
(8.13)	O, least squares	-- ¶	-.0245	--	-.0469	--	--	.1715	--	.3283	--	.523	Yes
					1929-57 period								
(8.14)	O, reduced form	-- †	-.1261	-.2229	-.3683	-.6510	--	.0826	.0982	.2412	.2868	.342	Yes
(8.15)	O, Theil-Basmann	-- †	-.256	-.552	-.32	-.57	--	.20	.241	.255	.303	.794	Yes
(8.16)	O, Theil-Basmann	-- †	-.215	--	-.28	--	-- #	.203	--	.266	--	.7635	Yes
					1940-57 period								
(8.17)	O, least squares	-- †	-.4595	-.608	-.6010	-.795	-- #	.1016	.0887	.1329	.1160	.7645	Yes
(8.18)	O, least squares	-- *	-.2517	-.4142	-.5351	-.8805	--	--	--	--	--	.4704	Yes
(8.19)	O, least squares, not distributed lag	-- §	-.4803	-.6813	--	--	--	.1238	--	--	--	--	Yes

*Index of average prices received by farmers.
† Index of prices paid by farmers for living expenses.
‡ Index of average farm machinery prices.
§ Index of prices paid by farmers for production expenses.
¶ Index of average farm machinery prices, lagged 1 year.
# Index of prices paid by farmers for production expenses, lagged 1 year.

(c) autoregressive least squares were employed for equations (8.7), (8.8), (8.15) and (8.16); and (d) equations (8.9) and (8.12) have variables deflated by different indices. All equations in Table 8.4 other than (8.19) include a distributed lag variable.

Inclusion of Additional Independent Variables

The price of hired labor, the farm wage rate, was the principal explanatory variable in each equation of Table 8.4. Inclusion of other variables in the specification of the model caused the values of the coefficients of the original variables to be altered substantially. The rationale for the inclusion of time as a variable was indicated earlier. Equations (8.7) through (8.10) were estimated to allow comparisons of estimates using various deflators with and without time. The major difference between the two sets of equations, equation (8.7) as compared to (8.8) and equation (8.9) as compared to (8.10), is in the size of the coefficient of the lagged dependent variable Q_{Ht-1}. The coefficients of Q_{Ht-1} in equations (8.8) and (8.10), not containing time, are larger than the coefficients of Q_{Ht-1} in equations (8.7) and (8.9). The coefficients are used to estimate the adjustment coefficient and long-run elasticities of demand for hired labor.[26] The estimated long-run elasticities of labor quantity with respect to the farm wage rate were high for equations (8.8) and (8.10), respectively, being -2.39 and -1.75 for 1957 (Table 8.5). The long-run elasticities of equations (8.7) and (8.9) were considerably less than one. The time variable materially reduced the estimate of the long-run elasticity of demand quantity with respect to the price of hired labor.

The effect of adding the index of the value of farm machinery and equipment is demonstrated by equations (8.15) and (8.16), both estimated by A.L.S. Specifications of the two were identical except for the farm machinery variable in the latter. The value of the regression coefficient for the time variable changed from -.687 to a significant -1.635 between the two equations. The coefficient of the farm machinery variable S_m is significant at the 90 percent level of probability. Otherwise, the values of the other regression coefficients were not changed substantially.

The Effect of Different Deflators and Forms of Equations

The effect of different deflators upon demand elasticities is illustrated in the first six equations, estimated with data from 1910 to 1957.

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[26] See Chapter 3 and Nerlove, Marc. Distributed lags and the estimation of long-run supply and demand elasticities: theoretical considerations. Journal of Farm Economics 40:301-11. 1958; and Koyck, L. M. Distributed Lags and Investment Analysis. North Holland Publishing Co. Amsterdam, Netherlands. 1954.

Only the long-run elasticities of hired-labor demand were substantially changed by the use of different deflators. However, the regression coefficient for the farm wage rate was not statistically significant in equation (8.12) where the deflator was the index of prices paid for all production items.

Observations for the time variable, along with other variables, were converted to logarithmic values in equation (8.11). Since the time variable in this equation is significant only at an extremely low level, as compared to the other equations, we suppose this function to be less appropriate than equations linear in original observations. Aside from the time variable, there was little difference between coefficients of comparable equations using variables in logarithms or in linear form.

The Effect of the Assumption of an Autoregressive Scheme

Four hired-labor demand functions taken with a distributed lag were estimated initially using autoregressive least squares (A.L.S.). Because of the time and expense involved in performing the necessary iterations, not all of the equations were estimated in this manner. The results of the A.L.S. equations are presented in Tables 8.4 and 8.5 as equations (8.7), (8.8), (8.15) and (8.16). Equations (8.7) and (8.8) are analyzed first. They cover the period 1910-57, and include the variables hired labor lagged 1 year and the farm wage rate. In addition, equation (8.7) contains time as a trend variable.

Equation (8.8), the A.L.S. equation which does not include time as a variable, may be compared with the ordinary least-squares equation using the same variables.[27]

$$(8.20) \qquad Q_{Ht} = 11.97 + \underset{(.039)}{.9480Q_{Ht-1}} - \underset{(.037)}{.0783P_{Ht}}$$

The simple least-squares equation (not A.L.S.) corresponding to equation (8.7) in Table 8.4 which included time as a variable was estimated as:

$$(8.21) \qquad Q_{Ht} = 29.02 - \underset{(.0643)}{.8397Q_{Ht-1}} - \underset{(.0383)}{.0530P_{Ht}} - \underset{(.1080)}{.2252T} .$$

The coefficients of the lagged dependent variables were highly significant in equations (8.20) and (8.21) as well as in equations (8.7) and (8.8). The coefficient of the lagged variable in equation (8.20), not including time as a variable, was .948, while the corresponding coefficient in A.L.S. equation (8.8), Table 8.4, was .931. For the equations including time, (8.21) and (8.7), the coefficients of the lagged endogenous

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[27] The variable P_{Ht} in equations (8.20) and (8.21) was deflated by the index of prices received by farmers for all commodities, United States.

variable were .840 and .777, respectively. In both comparisons the value of the lagged endogenous variable in the A.L.S. equation was slightly less than in the ordinary least-squares equations. But in the A.L.S. equations, the coefficients of the farm wage rate and time were larger than the comparable coefficients in the non-A.L.S. equations. The residual sums of squares is reduced by A.L.S. in both cases — from 461.4 to 441.9 for the equations containing time and from 507 to 490 for the other two equations.

In summary, the slight differences between the A.L.S. equations and the ordinary least-squares equations were: (a) the A.L.S. equations reduced the residual sum of squares, implying a better "fit"; (b) the regression coefficients of the lagged endogenous variables in the A.L.S. equations were lower with an accompanying shorter time period of adjustment; and (c) in the A.L.S. equations the regression coefficients of the other independent variables increased and became significant at higher probability levels. The long-run elasticities were less in the A.L.S. equations because of the decrease in the value of the lagged coefficients.

The estimate of B, the autoregression coefficient, is expected to decrease when a trend variable is included in the equation. However, in the case of equations (8.7) and (8.8) of Table 8.4, the results were indeterminate. The estimated values of B are the numerical coefficients in these two estimated equations — see equation (8.1):

$$u_t = \underset{(.1385)}{.2534} u_{t-1} \tag{8.22}$$

for equation (8.7), and

$$u_t = \underset{(.1338)}{.1710} u_{t-1} \tag{8.23}$$

for equation (8.8). Neither of the estimates of B were significant at high probability levels, although the estimate of B in equation (8.22) was significant at the 90 percent level. Since the initial value of the coefficient of the lagged dependent variable in equation (8.8) approached one, it is possible that the autoregressive structure of the equation could not be adequately ascertained. Though the results indicated that the B's are small, their statistical significance was such (along with the differences of the A.L.S. equations as described above) that the A.L.S. equations estimated for 1910-57 were preferred over the non-A.L.S. equations.

Further comparison of the autoregressive assumption is made for hired-labor demand functions over the period 1929-57. Equation (8.14) of Table 8.4 was estimated by reduced form with no autoregressive assumptions. Equations (8.15) and (8.16) were estimated by the Theil-Basmann technique under the assumption of an autoregressive scheme.[28]

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[28] See Theil, H., op. cit., and Basmann, R. L., op. cit.

In equation (8.14) the regression coefficients for the farm wage rate and prices received variables were nonsignificant. Both regression coefficients were significant in A.L.S. equations (8.15) and (8.16). The adjustment coefficient in equation (8.14) is .34, but .79 and .76 respectively for A.L.S. equations (8.15) and (8.16). Since the lagged endogenous coefficient "picks up" part of the residual term, the autoregressive assumption perhaps provides a better estimate of the adjustment coefficient. In this sense, equations (8.15) and (8.16) may serve most effectively in the analysis of demand for hired labor.

The estimated autoregressive coefficient, B, of equations (8.15) and (8.16), respectively, is the numerical quantity in the following two equations:

$$u_t = \underset{(.120)}{.753}u_{t-1} \tag{8.24}$$

$$u_t = \underset{(.326)}{.339}u_{t-1}\,. \tag{8.25}$$

The estimate of B for equation (8.15) was large and significant, while the value of B for equation (8.16) was small though larger than its standard error. Evidently the inclusion of the additional variable in equation (8.16) aided in the specification of the model, and reduced the value of B. We again conclude that the A.L.S. equations are preferable statistically to non-A.L.S. equations when distributed lags are used. However, because of the time and costs involved in the A.L.S. estimates, the autoregressive scheme was not assumed for other equations.

Analysis of Major Variables in the National Demand Functions for Hired Labor

Demand Relative to Farm Wage Rate

The values of the above single-equation regression coefficient for the farm wage rate estimated over the entire period, 1910-57, were low relative to their standard errors, the estimates in the six equations ranging in value from -.046 to -.122. For the linear equations (8.7), (8.9) and (8.12), including time as a variable, the regression coefficients of the farm wage rate were significant at the 90 percent level in the first two and nonsignificant in the third. The 48-year period, however, stretches over a span of time when the structure of agriculture and labor demand changed greatly. For this reason, equations have been estimated for subperiods of this span. For the period 1920-39 the value of the wage-rate regression coefficient was -.054 and was not significantly different from zero (equation (8.13), Table 8.4). This lack of significance may not have great importance, however, since the period included was one of agricultural recession. In the 1940-57 period, a period of relative prosperity in agriculture, single-equation regression coefficients for the price of farm labor in equations (8.17), (8.18) and (8.19), Table 8.4, ranged from -.232 to -.475 and were significant at a probability level of 95 percent or higher. Significant response of demand for labor in respect to the price is indicated in this period. Lack of significance of the wage-rate regression coefficient in equations estimated from 1910-57 data does not reflect accurately the response of labor quantity to wages for intervening periods. The years 1910-57 combine periods both of great depression and great prosperity, as well as periods varying greatly in the structure of technology.

This conclusion also tends to be substantiated for estimates over a shorter period, 1929-57, by simultaneous-equation methods. The "system" of demand functions for hired labor are equations (8.14), (8.15) and (8.16) in Table 8.4. The regression coefficient of the farm wage rate for equation (8.14) was -.168, but nonsignificant. The corresponding regression coefficients for the demand functions (8.15) and (8.16), estimated under the assumption of autocorrelated errors, were -.341 and -.287, respectively. The coefficients were significant at the 99 percent level. These results correspond with the findings of the demand functions for the shorter period 1940-57: that hired farm labor employment is responsive to changes in the farm wage rate.

Price Elasticities of Demand

For equations (8.7) through (8.12), estimated over the period 1910-57, the short-run price elasticities (labor demand with respect to farm wage rate) at the mean of the observations ranged from -.03 to -.10. Basically, the price elasticities for the over-all period were low.

The short-run price elasticities taken at the mean of observations for the 1929-57 period ranged from -.13 to -.26. For the 1940-57 period, the short-run elasticities at the mean ranged from -.25 to -.48. These statistics suggest that the short-run elasticity of labor demand with respect to farm wage rate has been increasing, although it has remained considerably smaller than unity.

Long-run price elasticities of demand also were derived and are included in Table 8.5. In a distributed lag equation, the long-run elasticity depends on the size of the adjustment coefficient. The adjustment coefficients for the six demand functions covering the 1910-57 period ranged from .05 to .22. Correspondingly, the long-run price elasticities (demand quantity relative to wage rate) at the mean ranged from -.17 to -.91 for the six equations. (In comparison, the short-run elasticities for the same period ranged from -.03 to -.10.) With the assumption that the errors in the equations follow an autoregressive scheme, the long-run demand elasticities for equations (8.7) and (8.8) were -.24 and -.91, respectively. The long-run price elasticities at the mean observation for the 1929-57 period ranged from -.28 to -.37.

For the 1940-57 period they ranged from -.53 to -.60. These results again suggest a higher level of response of labor demand relative to the farm wage rates, given time to adjust.

Demand Relative to Farm Product Prices

The cross elasticity of demand for hired farm labor with respect to the index of prices received indicates the responsiveness of labor employment to changes in agricultural product prices. The series, deflated by an index of prices paid for production items, relates product prices to factor prices and serves as an indicator of the relative profitability of farming. The deflator of the index of prices received for each equation is listed in Table 8.5. The index of prices received has been lagged 1 year in all of the hired-labor demand functions other than those for the period 1910-57. The assumption is that farmers react to product price changes in the previous year, since the present year's price is known relatively late in the year.

In general, the regression coefficients relating hired-labor demand to prices received were significant at acceptable levels of probability for the several time periods analyzed. Similarly, the signs of the regression coefficients were positive for all equations and all time periods. We conclude that the demand for hired farm labor has been responsive to farm product prices and the profitability of farming in all of the time periods analyzed.

The cross elasticities of labor demand with respect to farm product prices again were considerably higher for the long run as compared to the short run. This difference is, of course, consistent with the original hypothesis that time is required before farmers can change the organization of their farms and increase resource inputs in response to more favorable product prices. The long-run elasticity is much less than unity, however, for all time periods and equations or estimating techniques.

Demand in Relation to Farm Machinery Inventory

The stock of machinery and equipment on farms, January 1, was constructed and added to equation (8.16) of Table 8.4 for the period 1929-57. The equation was estimated using the A.L.S. method so that, except for S_m, the farm machinery variable, the specifications of equation (8.16) and equation (8.15) are the same. Theoretically, the variable should indicate the response of the demand for hired labor to changes in the scale of farming as exemplified by the value of the stock of farm machinery and equipment. The resultant coefficient of the farm machinery variable is positive and significant at the 95 percent level, and has a short-run elasticity at the mean of .13. The results suggest that as the scale of farming (investment in machinery) has increased, the number of hired workers has increased. This result could bear closer examination on a less aggregated level.

Trends and Predictions of Hired Labor Employment

Figure 8.3 indicates both actual numbers and predicted numbers of hired farm workers from 1910 to 1957 based on equation (8.9), Table 8.4. From 1935 to 1945 and from 1950 to 1957 the decline in employment was quite uniform and, as expected, equation (8.9) predicts well.

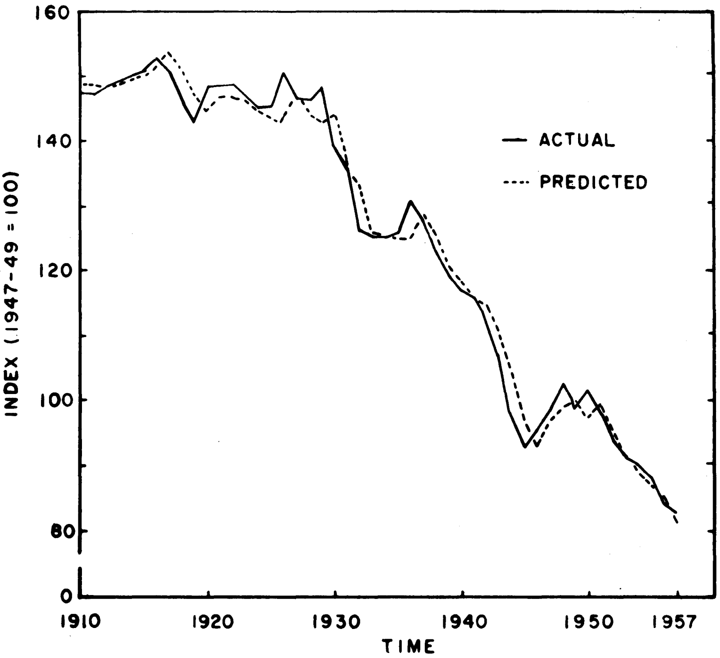

Figure 8.3. Actual and predicted number of hired farm workers in the United States, 1910-57 (demand equation (8.9), Table 8.4).

In other periods of less stability in labor trends, the equation predicts less accurately. The total period is heterogeneous, and a high degree of precision in predicting year-to-year changes is not expected. The high R^2, .983, indicates, however, that the actual values are predicted with some accuracy by equation (8.9). Projections beyond 1957 are not attempted from the equation.

Table 8.6. Regression Coefficients, Standard Errors (in Parentheses) and Elasticities of the Demand Functions for Hired Labor for the Nine Geographic Regions, United States*

									Elasticities (Mean)			
									Farm wage rate		Parity ratio	
Equation Number	Time Period	R^2	Region†	Q_{Ht-1}	P_{Ht}	P_{Rt}	T	Adjustment Coefficient	Short-run	Long-run	Short-run	Long-run
(8.26)	1929-57	.945	NE	.721 (.126)	-.031 (.056)	--	-.457 (.241)	.28	-.05	-.17	--	--
(8.27)	1929-57	.967	MA	.750 (.122)	-.343 (.122)	32.2 (9.98)	-.201 (.467)	.25	-.19	-.75	.16	.64
(8.28)	1929-57	.980	ENC	.830 (.107)	-.440 (.200)	.101 (.148)	.162 (.939)	.17	-.15	-.90	--	--
(8.29)	1940-57	.986	WNC	.278 (.110)	-1.06 (.167)	101.0 (16.8)	-.659 (.731)	.72	-.51	-.71	.36	.50
(8.30)	1929-57	.933	SA	.615 (.172)	-.862 (.608)	-2.25 (34.8)	-.921 (1.21)	.39	-.12	-.32	--	--
(8.31)	1929-57	.955	ESC	.573 (.110)	-1.71 (.413)	83.7 (19.9)	-.251 (.656)	.43	-.35	-.82	.29	.68
(8.32)	1929-57	.930	WSC	.612 (.123)	-1.59 (.477)	94.0 (34.9)	-.127 (1.46)	.39	-.26	-.67	.19	.50
(8.33)	1940-57	.906	MTN	.351 (.273)	-.133 (.132)	2.34 (13.2)	-2.12 (1.17)	.65	-.11	-.18	--	--
(8.34)	1947-57	.839	PAC	.299 (.053)	-.356 (.395)	--	-2.16 (.802)	.70	-.19	-.27	--	--

*The regional variables are:

Q_{Ht-1} = the number of hired workers for each region, lagged 1 year.

P_{Ht} = the average hired farm wage rate for each region, deflated by the index of prices paid by farmers for living expenses.

P_{Rt} = the regional "parity ratio," the ratio of the index of prices received by farmers for all commodities for each region to the index of prices paid by farmers for production items, interest, taxes and wages (as computed for a "typical" state within each region).

T = time (linear).

†The identifying letters under the "Region" heading stand for the nine regions, as follows: NE, New England; MA, Middle Atlantic; ENC, East North Central; WNC, West North Central; SA, South Atlantic; ESC, East South Central; WSC, West South Central; MTN, Mountain; PAC, Pacific.

EMPIRICAL ESTIMATES OF THE REGIONAL DEMAND FOR HIRED LABOR

In addition to the demand functions for hired labor derived for the United States, demand functions for hired labor were estimated for each of nine geographic regions. Although the data are highly aggregated, they do present the response to the important variables on a less aggregated scale than the national analysis. We wish to examine differential response in labor demand among regions.

Methodology Used for the Regional Analysis

Demand functions using the general approaches outlined above, derived for hired labor in each of nine geographic regions, are presented in Table 8.6. Given the hypothesis that the variables affecting the regional demand for hired labor are the same as those affecting national demand, the specification of the regional equations essentially is the same as the national equations explained above. The principal independent variables are the farm wage rate, the parity ratio, time as a trend variable and the hired-labor force lagged 1 year.

All of the regional demand functions for hired labor were estimated by single-equation least-squares methods. Equations were estimated in original observations covering the period 1929-57, except for the Mountain, Pacific and West North Central regions which were made for the more recent time periods listed in Table 8.6. For these regions the regression coefficients for the whole period were either inconsistent in sign or nonsignificant.

All relevant regional data are included in Table 8.6. The coefficient of determination, R^2, is high for each region. It ranges from .839 in the Pacific region to .986 in the West North Central region. Tests for serial correlation in the residuals were not made.

Analysis of the Results of the Regional Demand Functions for Hired Labor

The order of presentation for the regional demand functions for hired labor is: First, the significance of the farm wage regression coefficients will be analyzed. Second, the short-run and long-run elasticities will be compared. Third, the parity ratio will be examined as it relates to the demand for hired labor. Finally, the time trend will be evaluated.

The Farm Wage Rate

Paralleling the demand functions for the United States, the important independent variable in the regional functions is the farm wage rate. The regression coefficients for the farm wage rate were significant at the 95 percent level or better in five of the nine regions. Regression coefficients for the farm wage rate were consistently negative in sign. The short-run elasticities of labor quantity in respect to wage rate varied from -.05 in New England to -.51 in the West North Central region. Disregarding the elasticities derived from regression coefficients at low significance levels, the range was from -.15 to -.51.

The regions in which regression coefficients of the wage-rate variable were significant at low levels included New England, South Atlantic, Mountain and Pacific. The South Atlantic and Pacific regions use a large number of seasonal hired workers commonly paid by piece rates, which are not included in the reported farm wage rate. Hence, the reported regional wage rates may not have been as appropriate in these two regions as for other regions.

Long-run elasticities of the price variable also were estimated for each region. Excluding estimates for regression coefficients at low levels of significance, the long-run elasticities of demand in respect to wages ranged from -.67 to -.90. Similar to the long-run price elasticities for the national demand functions, the long-run price elasticities were less than unity but much larger than the short-run elasticities.

The Parity Ratio Variable

The ratio of the index of prices received by farmers for all commodities to the index of prices paid by farmers for production items, interest, taxes and wages, was used as the indicator of farming profitability for the regions. The "parity ratio" is not computed by federal sources on a regional basis. As a consequence, the index of the parity ratio for each region was computed for a typical state in each region. The ratio could not be computed for a state of the New England or Pacific regions because data were not available for the desired years.

The regression coefficients for the parity ratio variable were significant at the 95 percent level of probability in four of the regions, only beyond the 60 percent level in three, while the data were not available in two regions. The regions with regression coefficients significant at low probability levels were East North Central, South Atlantic and Mountain. For regions with regression coefficients significant at the 95 percent level of probability, the short-run cross elasticities estimated at the mean observation ranged from .16 to .36. The long-run cross elasticities for these four regions ranged in value from .50 to .68. While the cross elasticities for the parity ratio variable were less than 1.0 in the long run, they again were much larger than the short-run elasticities.

The Trend Variable As an Indicator of Technological Change

Time as a variable was included in each of the regional hired-labor demand functions as a technology variable and to complete the specification. This variable was significant at a probability level of 95 percent in only one region, the Pacific region. Consequently, the time variable is not considered to be a reasonable indicator of changes in technology by region.

The adjustment coefficients, which differentiate the magnitude of short-run and long-run elasticities, ranged in value from .17 in the East North Central to .72 in the West North Central. The higher the value of the adjustment coefficient, the more rapid is the rate of adjustment to the equilibrium or desired level of employment. The results suggest that the New England, Middle Atlantic and East North Central regions have been slower than other regions in adjusting to sustained price changes.

As a note of caution it is well to remember that hired as well as family workers are not a homogeneous group. Family workers include old persons "on the way out," young persons temporarily on the farm but ready to leave the agricultural labor force, low-income farmers being squeezed by economic pressure, well-established operators "well fixed" in farming and others. To be qualified as a family worker, a person must be (a) a member of the operator's family and (b) spend 15 or more hours at farm work during the survey week. Part of these same problems of enumeration show up in the hired work force, and the heterogeneity is easily represented in the overly simplified functions of this and the next chapter.

FURTHER ANALYSIS OF THE HIRED LABOR MARKET

After the year's plans have been initiated on farms, ability to contract labor is somewhat limited. Hence, the lagged rather than current wage and price variables may better explain changes in the numbers of hired laborers on farms in the current year. The subsequent analysis also differs from the foregoing analysis by excluding observations for 1942 to 1945. The market structure for hired labor was not considered normal during World War II because of the drafting of farm workers into the armed forces. After presentation of the results of the following functions, all estimates for the period 1926-59, interpretation of policy implications will be made.

Specification of the Demand Function

Estimates of hired-labor demand functions are made by means of a conventional least-squares equation and by a limited information simultaneous-equation system. All single equations have only linear

Table 8.7. Demand Functions for Hired Labor, Q_H, Estimated by Least Squares With Annual Data From 1926 to 1959, Excluding 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation and Transformation †	R^2	d ‡	Constant	P_H/P_R t	P_H/P_R t-1	P_H/P'_P t	P_H/P'_P t-1	S_P t	G t	T	Q_H t-1
(8.35-O)	.982	1.08	345.13	-.0043 (.2260)	-.69 (.22)		.30 (.19)	1.99 (.70)	-.56 (.24)	-5.19 (.38)	
(8.36-O)	.978	1.06	335.58		-.45 (.16)		-.027 (.137)	2.24 (.62)		-5.49 (.37)	
(8.36-L)	.985	1.34	2.18		-.199 (.051)		-.0011 (.0350)	.49 (.19)		-.00800 (.00054)	
(8.37-O)	.973	.78	339.78	-.33 (.20)		-.0079 (.1670)		2.10 (.85)		-5.59 (.43)	
(8.37-L)	.979	1.83	2.21	-.157 (.066)		.012 (.043)		.42 (.26)		-.00820 (.00065)	
(8.38-O)	.978	1.06	337.56		-.46 (.15)			2.21 (.59)		-5.50 (.37)	
(8.38-L)	.985	1.34	2.18		-.200 (.046)			.49 (.18)		-.00800 (.0053)	
(8.39-O)	.982	1.56	196.42		-.056 (.097)					-1.88 (.61)	.56 (.12)
(8.39-L)	.987	1.75	1.66		-.072 (.033)					-.00390 (.00086)	.44 (.11)

*Sources and composition of the dependent variable Q_H and of the indicated independent variables are discussed in the text.

† Equations designated O are estimated linear in original values, those specified L are estimated linear in logarithms. The time variable T is untransformed in the L equations. The annual percent shift in demand through time in the L equations is computed from the coefficient c of T as: 100(antilog c - 1).

‡ The Durbin-Watson autocorrelation statistic d.

terms, and observations are expressed both in original values and in logarithms. (See Table 8.7 for indication of each.) In the interdependent system, the market for hired farm labor is estimated jointly with demand and supply functions for other inputs and farm output. The number of hired workers in the single-demand equations is specified as a function of the wage of hired labor, prices received by farmers for operating inputs and machinery, the stock of all productive assets, a variable representing government policies and slowly changing influences represented by a time variable. These variables are defined explicitly as follows:

Q_{Ht} = the number of hired workers employed in agriculture during the current year, measured in 10 thousands.

$(P_H/P_R)_t$ = the current year index of the ratio of the farm wage rate to prices received by farmers for feed and livestock, expressed as a percent of the 1947-49 average. In addition, the past year ratio is also included.

$(P_H/P_P')_t$ = the current year index of the ratio of the farm wage rate to prices paid by farmers for operating inputs and machinery, expressed as a percent of the 1947-49 average. The past year ratio is also specified.

S_{pt} = the total stock of productive farm assets on January 1 of the current calendar year. The variable is in billions of 1947-49 dollars.

G_t = an index of government agricultural policies.

T = time, an index composed of the last two digits of the current year.

All variables are national aggregates for the calendar year from 1926 to 1959, excluding 1942 to 1945. A t is added to the subscript to note the current year observation, and t-1 is added to note a one-year lag of the same variable.

The Least-Squares Demand Equations

The coefficient of $(P_H/P_R)_{t-1}$ is the only significant coefficient of the three price variables in equation (8.35), Table 8.7. The coefficient of the government program variable is negative and statistically significant in the equation where it occurs. This result is consistent with the hypothesis that government programs have served unimportantly as an obstacle to farm labor mobility. No strong inferences can be made about this relationship, however, because of the crude formulation of the variable. The variable is not included in subsequent equations.

Equations (8.36) and (8.37) are included to evaluate the role of current and past prices in the hired-labor demand function. The magnitude and significance of the coefficients of lagged price tend to be greater than of current price. If the price of operating inputs and farm machinery influences the demand for hired labor, it is not apparent because of the nonsignificant coefficients for P_H/P'_P in equations (8.35), (8.36) and (8.37). Sound a priori basis exists for supposing these variables to be important in explaining demand for labor. Some possible reasons why their coefficients are not significant include: (a) the variables may have an important influence, but only in the long run; (b) the level of aggregation is too great, the individual effects offsetting each other and leaving the coefficient not significantly different from zero; (c) the correlation between P_H/P'_P and P_H/P_R is high ($r = 0.88$) and causes the former variable to be overshadowed; and (d) the short-run influence of machinery and operating inputs on demand for hired labor largely arises from technological and other nonprice influences.

Since the price of related inputs is not significant, an attempt is made to let this resource category have an influence on labor demand. The expected effect is allowed by including the predetermined stock of related inputs in the demand function. This is a principal reason for including S_p in the demand function. The coefficient of S_p is positive and significant in the demand equations. The coefficient of S_p in the logarithm equations L indicates that a 1 percent increase in the stock of productive assets increases the demand for hired labor .5 percent. The sign of the coefficient likely is consistent with the short-run influence of investment in machinery and other stock on labor demand: an increase in the stock of machinery might raise the marginal product of labor. A stronger hypothesis for the long run, however, is that machinery and other assets substitute for labor, with a negative coefficient expected.

The coefficients of the three explanatory variables $(P_H/P_R)_{t-1}$, S_p and T are highly significant in equation (8.38). Together the variables explain 98 percent of the variance in the number of hired laborers over the period. The slightly higher R^2 and the smaller degree of autocorrelation in the residuals indicated by $d = 1.34$ in equation (8.38-L) suggest a small advantage of the logarithm form for expressing hired labor demand.

The distributed lag or adjustment model (not presented), formed by including a lagged employment variable in equation (8.39), had a coefficient for Q_{Ht-1} which is not significant when S_p, the asset stock, is included. This condition would suggest that there is no long-run adjustment given the size of the agricultural plant (stock of productive assets). The stock variable is omitted in equation (8.39), and the coefficient of lagged employment then is significant. The significant coefficient indicates an adjustment coefficient of approximately .5. The coefficients of price and time are lower in adjustment equation (8.39) than in the conventional equation (8.38). It is difficult to ascertain the structural validity of adjustment equation (8.39), but its high R^2 indicates that it might have somewhat greater short-run predictive value than the other equations presented in Table 8.7.

Demand for Hired Labor Estimated by Limited Information

Numerous bases exist for supposing that the interdependence between supply and demand may be stronger for hired farm labor than for any other major agricultural input. The assumption of the simultaneous-equation model for hired labor is that current agricultural employment and wage rates are determined simultaneously by farm variables, as well as by nonfarm variables including factory wages and unemployment. Hence, a limited information model has been estimated from variables specified for the single-equation plus a farm numbers variable, N. Prices are deflated by the implicit price deflator of the Gross National Product. The limited information simultaneous-equation demand relationship estimated with annual data from 1926 to 1959, excluding 1942 to 1945, is:

$$Q_{Ht} = 1566 - \underset{[1.69]}{4.30P_{Ot}} + \underset{[.81]}{2.06P_{Mt}} - \underset{[-.46]}{1.55P_{Ht}} + \underset{[.68]}{2.28P_{Rt}} - \underset{[-2.12]}{9.16N} - \underset{[-.15]}{.44(P_H/P_R)_{t-1}} - \underset{[-.14]}{.38S_{pt}} - 1.18T \tag{8.40}$$

where P_O is the price of operating inputs, P_M is the price of farm machinery, P_H is the current hired wage rate and P_R is the current index of prices received for feed and livestock. Standard errors were not estimated; elasticities are included in brackets below the coefficients. The last three variables in (8.40) are predetermined, the remainder being endogenous. The signs of the coefficients in the equation again would indicate that operating inputs (through the price variable P_{Ot}) are complements but that machinery inputs are substitutes for hired labor in the market. Based on equation (8.40) and inputs at the mean of the period, a 1 percent fall in the price of machinery is predicted to be associated with a .8 percent decrease in demand quantity of hired labor. The negative coefficient of N indicates that a decrease in the number of farms (expansion in farm size) is associated with an increasing demand for hired labor. It is reasonable that as farms expand in size, family labor must be supplemented with hired labor.

The coefficients of P_H and P_R possess the expected signs, but the magnitudes of the coefficients and dominance of current variables conflict with the single-equation estimates. The least-squares estimates appear to be more reasonable, however. The results in equation (8.40) conform with those of other limited information estimates of input demand in this study; namely, the magnitudes of the coefficients appear unusually large. The cause is difficult to pinpoint, but may arise from multicollinearity and underidentification. Because the signs of the coefficients generally are consistent with logic and because there is no exact test of the structural reliability of equation (8.40), it is considered to be one of the more logical estimates of the demand function for hired labor. However, structural inferences in the following pages are based primarily on single-equation results because of inability to estimate the structural reliability of equation (8.40).

Price Elasticity of Demand

The demand elasticities estimated from the single equations in Table 8.7 are relevant only for "average" national employment conditions from 1926 to 1959. The heroic assumption of the single equations in Table 8.7, as well as in Table 8.4, is that a shift in the farm wage or price variable will shift the demand quantity, irrespective of the level of unemployment in the nonfarm sector. The estimated coefficients actually would be much lower for periods of high unemployment, as suggested later by the demand functions for family labor.

The logarithm equations displayed some slight advantages for expressing demand for hired labor. Hence, the elasticity estimates are based on equations (8.38-L) and (8.39-L). Equation (8.38-L) indicates that the "point estimate" and 95 percent confidence interval of the demand elasticity with respect to P_H or - P_R is -.20 ±.095. The adjustment equation (8.39) estimates the short-run demand elasticity with respect to P_H or - P_R to be -.072 ± .068. The long-run elasticity, found by dividing the short-run elasticity by the adjustment coefficient .56, is estimated to be -.14. Approximately 90 percent of the long-run adjustment is predicted to be completed in five years. These findings generally are consistent with results from equations fitted to 1929-57 data and with specification in Tables 8.4 and 8.5. The combined results from equations (8.14), (8.15), (8.16) and (8.38-L) and (8.39-L) suggest that the short-run elasticity of hired-labor demand with respect to P_H or - P_R approximately is -.2 in the short run and is no more than -.4 in the long run. The results indicate that a 10 percent drop in farm product prices (or 10 percent increase in farm wage rates) would decrease the number of hired farm laborers by 2 percent in one or two years and by 4 percent in approximately five years. These results are most applicable during periods of "average" national unemployment. The elasticity of demand for labor is nearly zero when national unemployment is high and may be considerably greater than the above estimates when national unemployment is low. Equations fitted to 1940-57 data and presented in Table 8.4 indicate that the short-run elasticity of labor demand with respect to farm wages may be as high as -.5. Some possible reasons for the high estimate are: (a) inclusion of data for the war years when the draft of workers from agriculture correlated with increasing wage rates, (b) estimation of the demand function from a period with an unusually high rate of national employment, and (c) a secular increase over time in the labor demand elasticity. The responsiveness of laborers to a change in wages may be rising because of increased education and skills, improved communications and transportation and because of other factors influencing mobility. The <u>elasticity</u> of labor demand may be increasing since a given change in the <u>absolute</u>

number of workers causes a greater percentage change in employment because the base or total number of hired laborers in farming is less. But while the elasticity of labor demand appears to be increasing over time, it evidently remains highly inelastic.

EMPIRICAL ESTIMATE OF NATIONAL SUPPLY FUNCTIONS FOR HIRED FARM LABOR

Nonfarm variables such as national unemployment influence employment and wage rates in agriculture. The influence of these and other variables on the labor structure in agriculture is analyzed in the following supply functions for hired labor estimated by limited information and Theil-Basmann methods.

The Limited Information Supply Equation

The supply equation for hired farm labor estimated by limited information with annual time series from 1926 to 1959, excluding 1942 to 1945, is:

$$(8.41) \qquad P_{Ht} = -36 + \underset{(.056)}{.183Q_{Ht}} + \underset{(.10)}{.43P_{Nt}} + \underset{(.051)}{.147P'_{Nt-1}} + \underset{(.056)}{.374C}$$

where C is a shift variable with values of zero from 1926 to 1941, and values of 100 from 1946 to 1959, P_N is the wage rate of factory workers and P'_N is $P_N(1 - 5U)$ where U, as explained earlier, is the proportion of the national labor force unemployed. P_H and Q_H are endogenous in the equation, and the limited information estimate is independent of the direction of normalization. (Price or quantity can be to the left of the equal sign and the computed supply elasticity is the same.) The price variables are deflated by the implicit price deflator of the Gross National Product. Standard errors, indicated in parentheses below the coefficients, are less than one-half the coefficients. All coefficients display signs expected from theory. The elasticity of supply of hired farm labor with respect to the own-price, computed from equation (8.41), is 1.63.

The result from equation (8.41) indicates that a sustained 1 percent rise in P_N tends, as an average of the period, to increase P_H by approximately .62 percent when U is at the 1926-59 average level. The coefficient of C would indicate that there has been a significant upward shift in supply during the postwar period.

A Just-Identified (Reduced-Form) Supply Function for Hired Labor

A two-equation just-identified system of equations also was utilized to estimate a supply function for hired labor for the period 1929-57 and, in variables specified, parallels regression equations in Table 8.5. The just-identified demand function of this system for hired labor was presented as equation (8.14) of Table 8.4. The corresponding supply function of the system is equation (8.42) where the coefficient of adjustment is .1855:[29]

$$(8.42)\quad Q'_{Ht} = 22.869 + .8145Q'_{Ht-1} + .1757P_{Ht} - .3654T - .1036P'_{Nt}.$$

The composite nonfarm wage variable, P'_N, was described previously where P_N is the average hourly earnings of the factory workers, and U is the percentage total unemployment. As mentioned above, this model supposes that when unemployment rises to 20 percent, the nonfarm wage rate has zero effect in pulling labor from farms. The standard errors of the regression coefficients were not estimated because the Theil-Basmann estimates presented elsewhere contain standard errors and because of the added cost of computing them.

The signs of the regression coefficients appeared to be consistent with theory and the hypotheses underlying the estimates. The elasticity of supply quantity with respect to the farm wage rate is estimated to be low, .13, in the short run. It is estimated to be .71 in the long run, a magnitude lower than that for equation (8.41). In the past, as the farm wage rate has increased by 10 percent, ceteris paribus, there has been a corresponding rise of 1.3 percent in the supply of hired labor in the short-run period and 7.1 percent in the long-run period. On the basis of this function, the long-run elasticity is predicted to be more than five times the short-run elasticity.

The cross elasticity of supply quantity with respect to the nonfarm wage-rate variable is predicted to be -.06 in the short run and -.31 in the long run. Based on equation (8.42), an increase of 10 percent in the nonfarm wage-rate variable has been accompanied by a decrease in the supply of hired labor of .6 percent in the short run and 3.1 percent in the long run. Again, from this equation, the long-run elasticity is predicted to be more than five times the short-run elasticity.

A Supply Function for Hired Labor Estimated by Autoregressive Least Squares From a System of Equations

A two-equation system also was used in estimating a supply function for hired labor by autoregressive least-squares methods for the period 1929-57. The variables included in the system of equations are the same as those used in the just-identified system of Table 8.4, except that the nonfarm variable was lagged 1 year for the former. The demand function estimated from this equation system was presented in Table 8.4 as equation (8.15).

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[29] The variable, P_{Ht}, is deflated by the index of prices paid by farmers for living expenses.

When the estimation of the supply function for hired labor was initially attempted using the autoregressive system, difficulty was encountered in the iteration procedure. All of the coefficients of the supply function increased in absolute value with successive iterations, rather than following a converging sequence. The source of difficulty evidently was the failure of the demand shifter — the prices received variable — to provide sufficient identification of the supply function.[30] Hence, use of another demand shifter was deemed necessary to derive a satisfactory supply function for hired labor. The system of equations was enlarged by the addition of another demand shifter — the value of farm machinery and equipment — lagged 1 year. With the inclusion of this variable in the system, a supply function for hired labor was identified and is presented as equation (8.43), where standard errors are included in parentheses:

$$(8.43) \qquad Q'_{Ht} = 140.95 + \underset{(.357)}{.4862Q'_{Ht-1}} + \underset{(.237)}{.1667P_{Ht}} - \underset{(.574)}{.8548T} - \underset{(.095)}{.1411P'_{Nt-1}}.$$

The value of R^2 for this equation is .974, while the adjustment coefficient is .51. The signs of the regression coefficients are consistent with theory and expected effect of variables. The coefficients of the wage rate, P_{Ht}, and the composite nonfarm wage rate and employment variable, P'_N, are of magnitudes somewhat similar to those in equation (8.42). The coefficient of the farm wage-rate variable is smaller than the corresponding standard error. The remaining coefficients are significant at the 80 percent level. Autoregressive least-squares equations were used, and the estimate of B, the autoregressive coefficient, is .5155. The standard error of B is .3305, and B is significant at the 80 percent level.[31]

From equation (8.43) the corresponding elasticity of supply quantity with respect to the farm wage rate is still estimated to be low, at .13 in the short run. It is estimated at .24 in the long run. The supply response (elasticity) to an increase in the farm wage rate is estimated to be twice as great in the long run as in the short run, if we accepted the regression coefficients of equation (8.43), which are small relative to their standard errors.

The supply elasticity of the composite nonfarm wage-rate and employment variable, $P_N(1 - 5U)$, is estimated to be -.078 in the short run and -.15 in the long run, magnitudes much lower than for equation (8.41). Again, however, the regression coefficient is significant only at an 80 percent level of probability.

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[30] An equation specified like the supply function in equation (8.42) is insufficiently identified when the autoregressive assumption is applied.

[31] See equation (8.1).

In general, the signs of the coefficients in the supply functions for hired labor are consistent with theory and expected "real world" effects of relevant variables. Although emphasis in this chapter was on labor demand, it is hoped that the supply equations provide information useful in analysis of hired labor employed in agriculture. Because of the relatively large standard errors and inconsistencies among supply models in magnitudes of coefficients and elasticities, the results are regarded as tentative. Additional work is needed.

GENERAL IMPLICATIONS

Our analysis of demand for hired labor in agriculture indicates that its elasticity has been extremely low in the short run. The elasticity with respect to the hired-labor wage rate is much larger in the long run, however. This result is consistent with actual observations of the structure of the farm organization. Farms have a stock of machinery, buildings and other capital items with which they operate. A rise or decline in the farm wage rate relative to product price, or the prices of other factors, does not allow an immediate change in the fixed organization of the plant. Where machinery is substituted for labor, time is required either to depreciate out machines on hand, or to allow time for decision and acquiring capital for new machine purchases. Too, machinery substituted for labor often has capacity beyond that of the farm's original acreage. Hence, decisions to lessen labor input, through substitution of machinery, also may await the farm operator's ability to buy or rent additional land. Furthermore, adjustment to a higher relative farm wage rate and use of less hired labor may require reorganization of farming systems. Enterprises with lower labor requirements may be substituted for those on hand, but only after enough time has elapsed to allow for the necessary farm reorganization. Major farm reorganization requires time for the manager to acquire additional information and, in some cases, new buildings. Within a year, of course, some labor is under contract, and crop production has already been initiated. Short-run response is necessarily small under these conditions.

Our analysis leads us to believe that the demand elasticity for hired labor in respect to its own price has been increasing with time. Some of the reasons for the increased elasticity such as improved education and communication were discussed earlier. Another reason arises from the interrelationship of hired and family markets in agriculture. While it is not analyzed in the models of this study, changes in the supply elasticity of family labor are inseparable from changes in the demand elasticity for hired labor. The reason revolves around the element of long-run adjustment mentioned above; namely, substituting machinery for hired labor, in response to increasing wage rates. Where the machinery is costly and can be best added if the operator has a larger acreage, a more complete adjustment must await abandonment of farming by other farm families. Hence, to the extent that the mobility of family labor (the elasticity of family labor numbers with respect to the relative earnings in agriculture) is increasing over the long run, we would expect that the elasticity of demand for hired labor similarly would increase in the long run.

We believe the estimates of supply elasticity for hired labor are "less firm" than those of demand for this resource. With some greater degree of uncertainty granted, the estimates generally suggest a much higher supply elasticity in the long run than in the short run. Too, they suggest that the supply elasticity is increasing with time. The estimates on supply indicate an important link between the supply of hired labor to agriculture and the rate of unemployment in the national economy. Again, a smaller short-run elasticity is indicated.

Given the direction of relative factor prices and of technology under economic development, a further decline in the hired-labor work force in agriculture is predicted. The rate of decline may remain relatively close to the average compound rate of 1.75 percent per year over the period 1926-59. An increase in farm size tends to increase the demand for hired labor, partly as a substitute for family labor, but a rise in hired wage rates relative to machinery and product prices decreases the demand for hired labor. The relative price of hired labor is expected to increase, along with a higher nonfarm wage rate under further national economic development and perhaps some further increase in the supply elasticity of hired labor to agriculture. The demand for hired labor also will depend on the extent of new technologies which increase the marginal rate of substitution of capital for labor. This has been an extremely important force, probably dominating the relative increase in price of hired labor — although both are theoretically important as outlined in Chapter 3. The relative price of farm labor, P_H/P_R, increased 43 percent in the 33 years 1926-59. Using equation (8.38-L), we would predict, as an example, that 10 percent of the decline in hired workers during this period resulted from the increase in the relative wage rate. After allowing for errors in measurement, specification biases and failure to include other relevant prices, and adjustment for unemployment in the national economy, a large proportion of the total decrease in hired-labor employment remains to be explained by variables other than short-run relative prices in hired labor. The statistics for time in equation (8.38-L) suggest that hired-labor employment declined 1.8 percent per year, due alone to the technological and other forces which are aggregated under the time variable.

Not only is technology expressed in the time variable, but also other institutional and "over-all social capital" variables are related to time. A greater amount of education to a larger proportion of the farm population, employment services, much greater communication through improved transportation, radio and television and similar developments affect both the supply and demand for labor in agriculture. We should expect the effect of these forces to increase with time and the response of labor in agriculture to be more closely interrelated with nonfarm income or wage levels. Need exists to extend the public investment in education and employment services for the hired-labor force, to allow it to be better skilled and to allow more flexibility and opportunity to take advantage of favorable nonfarm employment opportunities. The above equations indicate that an increase in the supply price of hired labor would lower the demand quantity for it. But in so doing, the marginal productivity of hired labor should increase and its return in agriculture should be brought much closer to the nonfarm level of real wage return.

9.

Market Structure for Family Labor in Agriculture[1]

THIS CHAPTER continues the analysis of labor markets in agriculture. The emphasis is on family labor. Family labor influences farm income in two fundamental ways: (a) as a resource it may influence total output and total income in agriculture, and (b) as an income unit it determines the number of ways total farm income must be divided. The focus and end-in-view of most agricultural policies has been to raise family farm income. Whether these policies are effective depends on the answers to several basic questions.

Whether or how soon a "free price" or another policy will raise farm income per worker to the nonfarm level depends on the responsiveness of farm family workers to a fall in relative income. Whether a government policy to raise farm income perpetuates the farm problem by retarding needed labor adjustments also depends on the nature of labor functions in agriculture. How farm labor mobility is influenced by nonfarm variables such as national unemployment and the nonfarm wage rate is one of the basic questions asked by individuals concerned with agricultural adjustment. The interrelationships of policies affecting national employment and farm labor mobility cannot be judged empirically without estimates of coefficients relating to the major economic variables in functions explaining family labor employment.

TRENDS IN LABOR USE RELATIVE TO PRICES, MECHANIZATION AND OTHER SUBSTITUTIONS

Persons employed in agriculture have been responding to relative prices of resources in about the manner expected from economic theory. Figures 9.1 through 9.4 illustrate the parallel decrease in total labor employment with the increase in price of labor relative to selected other inputs of agriculture. However, as explained in Chapter 8, several forces or variables relating to national and agricultural development are intercorrelated, and it is unreasonable to impute all, or perhaps even the major part, of a decline in the farm labor force to its rising price relative to other farm resources. These price relatives

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[1] Stanley S. Johnson also is co-author of this chapter.

are obviously important, but also technological developments have shifted the capital-labor isoquants and have increased the marginal rate of substitution of capital for labor over time. Either change taken alone (increases in the relative price of labor or in the marginal rate of substitution of capital for labor) leads to substitution of capital for labor.

Figure 9.1 illustrates trends in ratios of (a) total family and hired labor to operating inputs in agriculture and (b) farm labor price to operating input price. (The wage of hired farm labor is used here as an indication of labor price, although it does not serve perfectly for family labor.) Operating inputs include fertilizer, protein feed, seed, repairs and other nondurables. Both the relative quantity of labor and the price ratio remained somewhat stable from 1910 into World War I. After 1921, and except during the depression and immediately following World War II, the price of labor rose relative to the price of operating inputs and employment of labor in agriculture declined. Operating inputs and resources related to them were substituted for labor as a result of relative changes in these resource prices, and as a result of developments in technology.

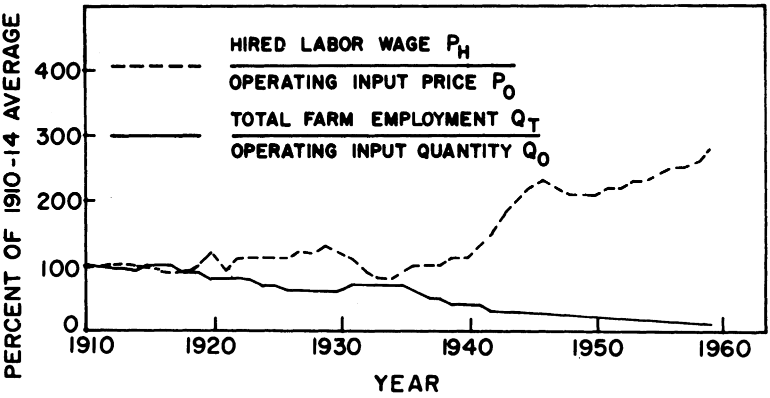

Figure 9.1. Ratios of farm labor and operating input prices and quantities from 1910 to 1959 (1910-14=100).

Figure 9.2 compares the ratios of (a) total employment in agriculture to the quantity of machinery inputs and (b) the price of labor (hired farm wage rate) relative to farm machinery prices. (Machinery inputs are measured as the services necessary to maintain them at current levels.) The proportion of labor employed relative to machine inputs has declined rapidly, paralleling an increase in ratio of the price of farm labor relative to the price of farm machinery. While the price of farm labor has risen less relative to the price of farm machinery than for other farm inputs (i.e. the price of machinery has risen relative to the price of inputs such as chemicals, seed and feed), substitution of machinery for labor has been large over much of the period because of

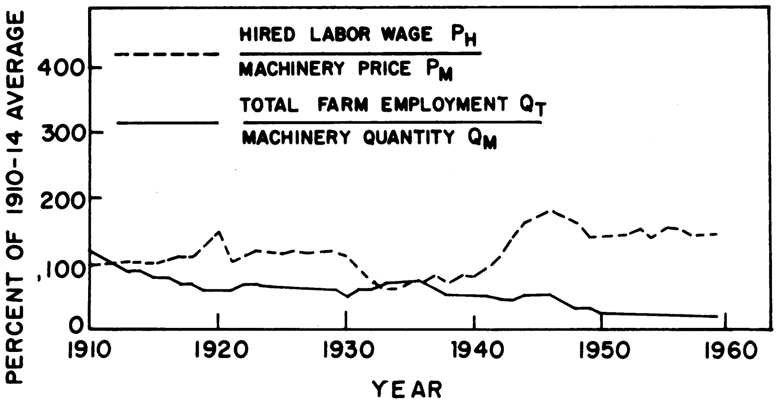

Figure 9.2. Ratios of farm labor and machinery prices and quantities from 1910 to 1959 (1910-14=100).

both the relative change in substitution rates and prices for machine inputs and labor. The continued substitution of machinery for labor during short periods when machinery price rose relative to labor price is a reflection of changes in substitution rates, perhaps as well as continued adjustments to previous price changes.

Figure 9.3 shows trends in the ratios of (a) labor used relative to land and (b) labor price relative to land price. Capital items have tended to substitute for both of these resources over time. Some substitution of land for labor, however, is indicated. (To an extent land also serves as a complement with machinery and other inputs in replacing labor. Farmers often buy higher capacity machinery, then add land to utilize it more fully.) The substitution of land for labor is not clearly indicated in response to the ratio of labor and land prices, perhaps partly because land return or price becomes a residual in the profitability of farming.

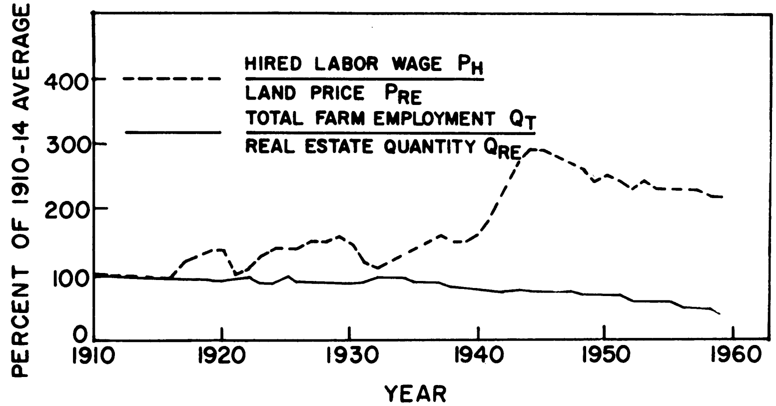

Figure 9.3. Ratios of farm labor and real estate prices and quantities from 1910 to 1959 (1910-14=100).

Figure 9.4 compares the ratios of (a) labor input to farm output and (b) labor price to prices received for crops and livestock. Labor input relative to crop output has declined as the labor/product price ratio has increased. The decline in input relative to output has been rapid especially since the 1930's. The decline in labor is expected theoretically, as an adjustment to increase marginal labor productivity following an increase in factor price relative to product price. Again, however, changes in technology increasing the rate at which labor is transformed into products, the low supply and demand elasticities of farm products and a decline in farm income accompanying a rapid increase in farm output, help to push labor out of agriculture.

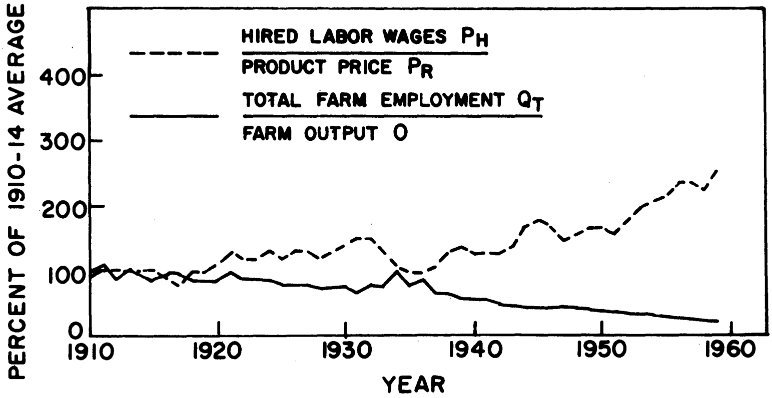

Figure 9.4. Ratios of farm labor and farm output prices and quantities from 1910 to 1959 (1910-14=100).

The data in Figures 9.1 through 9.4 suggest both direct and indirect relationships between employment of farm labor and relative prices of resources. Later sections include more detailed quantitative analysis of these and other interrelationships, with emphasis on family labor since it constitutes the major portion — 75 percent — of the farm labor force.

RELATIVE LABOR RETURNS

The number of family workers in agriculture decreased from 10.2 million in 1910 to 5.2 million in 1960. Since 1926 the number of family workers has declined at an average compound rate of 1.7 percent per year. Despite the rapid outmovement of workers, the per capita ratio of farm to nonfarm income remains low. The ratio was .43 in 1926, and was .47 in 1961.

Numerous hypotheses and propositions have been made to explain the continuous lag of labor returns in agriculture below returns in nonfarm employment. Some of the propositions are: (a) The existing ratio of farm and nonfarm incomes represents an equilibrium; real incomes being equal because of the psychic income in "farming as a way of life." (b) The ratio of returns as it exists represents an equilibrium, with equal returns for equal skills, because worker skills in agriculture are low. (c) Unionization of urban workers has reduced the mobility of farm workers and has perpetuated the disequilibrium income problem. (d) Mobility between regions is low and no serious disequilibrium exists between farm and nonfarm earnings in a given region. (e) Farmers are unaware of higher earning potential in alternative employments. (f) Farmers are responsive to wage differentials but unemployment in the urban sector has hindered farm labor mobility. (g) Farmers are responsive to wage (income) differentials but their responsiveness (elasticity) has not been great enough to cope with changes in farm structure. These changes in farm structure include output increasing (income decreasing) farm investment and technology.

Studies by Johnson provide some basis for rejecting hypotheses (a) to (d).[2] He states that it is necessary for per capita income of the farm population to be about 60 to 70 percent of the per capita income of the nonfarm population to have comparable real incomes. While it is reasonable to expect that in equilibrium some difference would exist between farm and nonfarm incomes due to psychic returns in the farm sector, the current discrepancy is too great to be explained by hypothesis (a). Johnson and Bishop[3] provide some data to reject the second hypothesis; namely, that skill capacities of rural workers are low. Based on actual earnings of farm migrants to urban areas and of urban nonmigrants, they conclude that average labor employed in agriculture has a labor capacity of approximately 90 percent of the labor capacity of urban and rural nonfarm populations for similar age and sex distributions. Differences in skills and earning capacities between farm migrants and nonfarm workers in urban areas tend to diminish with additional experience of farm workers on nonfarm jobs. These comparisons are, however, for farm workers who obtain positions comparable to laborers of nonfarm sources and do not entirely account for the fact that a greater proportion of unskilled farm laborers may be siphoned into the

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[2] Johnson, D. Gale. Comparability of labor capacities of farm and nonfarm labor. American Economic Review 43:296-313. 1953; Farm prices, resource use and farm income. In U.S. Senate. Joint Economic Committee. Policy for commercial agriculture. pp. 448-58. Washington. 1957; Functioning of the labor market. Journal of Farm Economics 33:75-87. 1951; Labor mobility and agricultural adjustment. In Heady, Earl O., Diesslin, Howard G., Jensen, Harald R., and Johnson, Glenn L. Agricultural Adjustment Problems in a Growing Economy. Ch. 10. Iowa State University Press. Ames. 1958; The nature of the supply function for agricultural products. American Economic Review 40:539-64. 1950; Policies to improve the labor transfer process. American Economic Review 50:403-12. 1960; and Policies and procedures to facilitate desirable shifts of manpower. Journal of Farm Economics 33:722-29. 1951.

[3] Bishop, C. E. Economic aspects of changes in farm labor force. In Iowa State Center for Agricultural and Economic Development. Labor Mobility and Population in Agriculture. pp. 36-49. Iowa State University Press. Ames. 1961; The mobility of farm labor. In U.S. Senate. Joint Economic Committee. Policy for commercial agriculture. pp. 436-448. Washington. 1957; and Underemployment of labor in agriculture. Journal of Farm Economics 36:258-72. 1954.

lower end of the skill hierarchy. Johnson's work[4] also indicates that hypotheses (c) and (d) do not explain the full differential in incomes between agriculture and other industries. Unions have not been a serious obstacle to farm labor mobility in periods of low national unemployment. However, they may force a greater proportion of farm people, during periods of high unemployment, to have "little access" to the employment opportunities requiring seniority. Also differentials in income between farm and nonfarm sectors are found throughout the country. Sizeable gaps exist between returns from farm and urban employment in all low-income farming areas of the country. Also some mobility exists between sectors, and hypothesis (d) does not explain the failure of the gap between per capita incomes in agriculture and other industries to narrow.

EMPIRICAL ESTIMATES OF DEMAND FUNCTIONS FOR FAMILY LABOR

In this chapter two approaches are used to determine the market structure for family labor. One approach, to be considered later, is based on the hypothesis that net farm income is the relevant family labor "price" or decision variable.

The underlying hypothesis of this section, consistent with the demand functions previously estimated for hired labor, is that the demand for family labor is responsive to (a) the hired farm wage rate as an indicator of the price of family labor, (b) the index of prices received by farmers for all commodities as an indicator of the relative profitability of farming and (c) the price and/or quantity of farm machinery as a main substitute for labor. To complete the specification and as an indicator of farm technology, time has been included as a variable, along with the two price variables. In the model specification, the question arises as to the type of variable which adequately represents the "price" of family labor. The net return to the labor of a farm operator and his family is difficult to ascertain.[5] Some economists argue that the hired farm wage rate is an indication of the wage accruing to family labor.[6] For lack of a better indication of the return to family labor and to preserve comparability between hired and family labor estimates, the hired farm wage rate is used as the "price" of family labor in this section.

A demand function for total farm labor also was specified and estimated, as a means for comparison with the family labor demand functions. The model contains the following variables: the ratio of the

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[4] Johnson, D. Gale. Policies and procedures to facilitate desirable shifts of manpower. op. cit.

[5] Ladd, George W. Farm income and the supply of agricultural products. Journal of Farm Economics 39:865-80. 1957.

[6] See: Douglas, Paul H. The Theory of Wages. The Macmillan Company. New York. 1934; and Fulmer, John L. Measurement of agricultural income of counties. National Bureau of Economic Research. Studies in Income and Wealth 21:343-57. 1957.

farm wage rate to the index of prices received, indicated as P_H; the index of the value of farm machinery deflated by the index of prices paid for living expenses by farmers, indicated as S_m; the index of prices received by farmers deflated by the index of prices paid (the parity ratio), indicated as P_R; and time T.

The family labor demand functions for the United States are included in Table 9.1 as equations (9.1) through (9.4). The periods for which the functions are fitted, the standard errors (in parentheses under regression coefficients) and the values of R^2 are included in Table 9.1, along with demand elasticities for P_H and P_R. (The subscript t indicates measurement of the variable for the current period and t-1 for the measurement lagged one year. See details on notation for labor in Chapter 8.) The predicted quantities for two of the family labor demand functions were plotted (figures not shown) against the actual numbers of family workers, and as expected, the functions for the more recent period, 1940-57, fitted the data better than those for the over-all period, 1910-57.

All regression equations presented are general single-equation least-squares estimates with original observations and are similar in specification for the different time periods. The sole difference between the equations is: the farm wage rate is lagged one year in equations (9.1) through (9.3). Since the number of family workers changes slowly over time, and because of estimation problems, the residuals may be autocorrelated. As an indication of autocorrelation, the d statistic for the Durbin-Watson test was computed for each of the four equations. The Durbin-Watson test for two of the equations (9.1 and 9.3) showed positive serial correlation, while test results in the other two (9.2 and 9.4) were indeterminate although time was included as a trend variable and was significant in all of the equations. The use of more refined techniques to help in eliminating autocorrelation was held to be unfeasible for this study.

Family Labor Demand in Relation to the Wage Rate and Farm Product Prices

Three of the four coefficients relating U.S. family labor employment to the farm wage rate were significant at a probability level of 95 percent with coefficients ranging in value from -.30 to -.93. There is some theoretical basis for lagging the wage rate in general least-squares equations. However, no advantage is indicated for such regression equations over the period 1940-57. For this period, equation (9.3) contained the wage rate lagged one year, while it was not lagged in equation (9.4). The regression coefficient in equation (9.4) was larger relative to its standard error than that of equation (9.3).

The demand for family labor is indicated to be responsive to changes in the farm wage rate. While all were inelastic, the price elasticities for the first three farm wage-rate variables were similar

Table 9.1. Regression Coefficients, Standard Errors (in Parentheses) and Elasticities of the Demand Functions for Family Labor, United States and Nine Geographic Regions*

Equation Number and Time Period	Region†	R^2	Code‡	Q_F t-1	P_N t	P_R t-1	S_m t	T
(9.1)	U.S.	.91	C	--	-.300	.040	--	-.629
1910-57			S		(.06)	(.04)		(.10)
			E		-.20	.03		
(9.2)	U.S.	.81	C	--	-.932	-.168	--	-.315
1920-39			S		(.12)	(.06)		(.07)
			E		-.16	-.11		
(9.3)	U.S.	.89	C	--	-.139	.313	--	-1.22
1940-57			S		(.11)	(.11)		(.33)
			E		-.14	.30		
(9.4)	U.S.	.95	C	--	-.878	.409	--	-.302
1940-57			S		(.20)	(.07)		(.07)
			E		-.32	.39		
(9.5)	NE	.87	C	.971	-.167	--	--	--
1940-57			S	(.12)	(.142)			
(9.6)	MA	.98	C	.908	-.303	.318	--	-.413
1929-57			S	(.12)	(.246)	(.23)		(.38)
			E		-.07	.07		
(9.7)	ENC	.87	C	.263	-2.71	1.93	--	4.08
1929-57			S	(.16)	(.71)	(.38)		(1.9)
			E		-.21	.02		
(9.8)	WNC	.75	C	--	-.155	--	-12.2	--
1929-57			S		(.51)		(2.0)	
(9.9)	SA	.98	C	.859	.605	.426	--	-8.08
1929-57			S	(.13)	(1.5)	(.962)		(3.41)
(9.10)	ESC	.94	C	--	-1.32	--	--	-39.1
1929-57			S		(2.3)			(4.4)
(9.11)	WSC	.92	C	--	-1.51	--	--	-35.7
1929-57			S		(1.85)			(5.43)
(9.12)	MTN	.96	C	.974	-.096	--	--	--
1929-57			S	(.08)	(.065)			
(9.13)	PAC	.98	C	.110	-.085	--	--	-5.94
1947-57			S	(.28)	(.26)			(1.52)

*The untransformed variables are:

Q_{Ft-1} = the number of family farm workers for the United States or by region as indicated, lagged 1 year.

P_{Ht} = the average hired farm wage rate for the United States or by region indicated, (lagged 1 year in equations (9.1) to (9.3).

P_{Rt-1} = the index of prices received by farmers for all commodities, United States for the national estimates, and the parity ratio for each region as explained under Table 8.6, lagged 1 year.

S_{mt} = the value of the stock of farm machinery and equipment, United States and regionally, as indicated.

T = time entered in linear form.

For the national estimates, P_H, P_R and S_m were deflated by the index of prices paid by farmers for production items, United States; for the regional estimates, P_H and P_R were deflated by the regional index of prices paid by farmers for living expenses.

†The identifying letters under the "Region" heading stand for the nine regions explained under Table 8.6, page 216.

‡C is the coefficient, S is the standard error and E is the elasticity, computed at the mean for the entire period.

in magnitude. The elasticity for (9.4) was somewhat larger. For the over-all period, 1910-57, given a 10 percent increase in the farm wage rate, ceteris paribus, the equations indicate an accompanying decrease in family labor employment ranging from 1.4 to 3.2 percent. There is no clear indication that the coefficients and elasticities have increased with time.

The response of family labor demand to prices received differed considerably for the time periods analyzed. For the period 1910-57, the regression coefficient and cross elasticity of demand approached zero. For two intervening periods the signs of the regression coefficients were different. The coefficient for the prices received variable was negative for the 1920-39 period and positive for the 1940-57 period. Further, both coefficients were statistically significant. The negative coefficient of P_R in equation (9.2) may result from some increase in the number of family workers over the 1920-39 period, along with a 10 percent decrease in the index of prices received. The depression, with a consequent lack of nonfarm opportunities, led to this situation during the 1930's. For the period 1940-57, as the index of prices received rose 10 percent, other things being equal, the demand for family workers decreased 3.5 percent. Since this period was one in which considerable off-farm work could be secured, the sign of the elasticity was also consistent.

Comparison of the Demand for Total Farm Labor With the Demand for Family Labor

A demand function for total farm employment was specified and estimated for the entire period, 1910-57, for comparison with the demand functions for family labor alone. The estimated total farm employment demand function is:

$$(9.14) \qquad Q_t = 156.14 - \underset{(.041)}{.013}(P_H/P_M)_{t-1} - \underset{(.103)}{.700}S_{mt-1} - \underset{(.039)}{.142}T - \underset{(.053)}{.205}(P_H/P_R)_{t-1}$$

The coefficient of determination for this equation is .95. In equation (9.14), the demand quantity of all farm labor is formulated as a function of the index of farm wage rates deflated by the index of farm machinery prices and lagged one year $(P_H/P_M)_{t-1}$, the value of the stock of machinery deflated by the price paid by farmers and lagged one year S_{mt-1}, time T and the farm wage rate deflated by the prices received by farmers for all commodities lagged one year $(P_H/P_R)_{t-1}$. In order to compare the results of the demand for total farm employment with a demand function for family labor, a demand equation for family labor was similarly estimated for the 1910-57 period. The resulting equation is:

$$(9.15)\quad Q_{Ft} = \underset{}{153.89} - \underset{(.065)}{.0821(P_H/P_M)_{t-1}} - \underset{(.162)}{.4338S_{mt-1}} - \underset{(.062)}{.1716T}$$

$$- \underset{(.084)}{.1974(P_H/P_R)_{t-1}}$$

with a coefficient of determination of .86.

Equations (9.14) and (9.15) suggest that demand equations for family labor and hired labor may be similar. While differences do exist between the two equations, the coefficients lead to similar elasticity estimates. As the farm wage rate relative to prices received rose by 10 percent, there were corresponding average decreases in the total farm working force of 1.6 percent and in the family labor force of 1.5 percent. (Both of the corresponding regression coefficients were significant at the 95 percent level.) Response in demand for total and family labor to changes in the price of farm labor relative to farm output price was similar for the two functions.

The farm machinery variable, S_m, suggests the response of farm labor to additions in farm machinery in the previous year. As the investment in farm machinery rose by 10 percent in the past, there was a concurrent decrease of 3.1 percent in the total farm labor force, and 1.9 percent decrease in the family labor force. (Both of the corresponding regression coefficients were significant at a probability level of 95 percent or greater.)

The demand for total and family labor responded somewhat differently to changes in the variable, P_H/P_M, relating farm wage rates to farm machinery prices. The regression coefficients in both equations were nonsignificant at the 80 percent probability level. Both regression coefficients for the time variable, T, were significant and similar in size. Evidently, factors that could be explained by a linear trend were of similar importance to the two labor groups.

Regional Demand Functions for Family Labor

Regional demand functions for family labor are presented in Table 9.1 as equations (9.5) through (9.13). The demand functions for family labor for the regions were initially estimated by general least-squares methods. Because of inconclusive results in these first equations, distributed lag models were then applied for some regions. Since the distributed lag equations generally failed to improve the level of significance of the regression coefficients, demand equations using this model were not estimated for the remaining regions.

The regression coefficients for the farm wage rate variable ranged from -2.71 to .605 among regions. Only one of the regression coefficients was significant at the 95 percent level, however, and only in the distributed lag equations were the coefficients significant even at the 70 percent level. (Three regions had regression coefficients larger than their standard errors.) On the basis of this model formulation, the regional demand functions would indicate that the family labor force by region has not been particularly responsive to changes in the hired farm wage rate. Only in the East North Central region was the family labor force significantly responsive to the farm wage rate, the price elasticity being -.207. Since the other regression coefficients were not statistically significant, price elasticities were not derived for them.

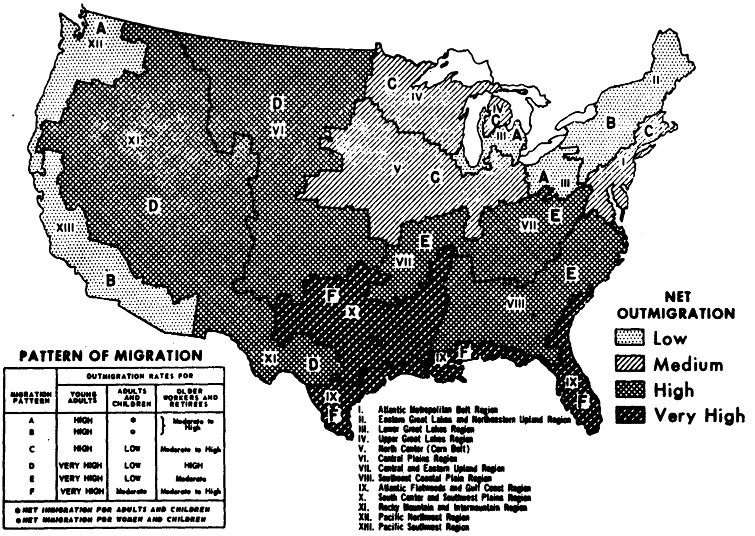
The parity ratio was included as a variable in three of tne regional demand functions. Of the three regions, its regression coefficient was significant at the 95 percent level in the East North Central, 60 to 80 percent probability level in the Middle Atlantic, and significant only beyond the 60 percent level in the South Atlantic region. Because the parity ratio was included in only three of the nine regional demand functions for family labor, particular analysis is not made for this variable in the Northeastern region.

The third variable included in the regional demand functions for family labor was time in linear form. The time variable was significant at the 95 percent level in five of the six regional demand functions in which it was included. Of the regional demand functions in which time as a variable was either not included or was nonsignificant, three of the equations were estimated by a distributed lag model, the lagged variable being significant at the 95 percent level of probability.

Why are the coefficients for the United States demand functions for family labor significant while the corresponding regional coefficients generally are not significant? A possible answer may lie in the dominance of the trend variable in the regional demand functions and specification of a model which does not measure labor income of agriculture relative to nonfarm returns — since households which stay in agriculture and supply labor also demand this resource. If the data collected for each region does not reflect year-to-year marginal changes in the family labor force, then a trend variable would explain the smooth variations quite well. When the data are aggregated on a national scale, the accumulation of data may bring the year-to-year changes into greater prominence. (The time periods covered by the regional and national demand functions are different.) Also, we believe that the dominant force explaining the magnitude of family labor employment is the availability of nonfarm jobs relative to labor income in agriculture. In general, rapid migration of family workers has taken place in periods of ample nonfarm employment opportunities, even though the return to labor in agriculture has been high, or has temporarily increased relative to nonfarm wage returns. In contrast, migration has been low during periods of high national unemployment, even though relative returns in agriculture declined. Finally, both technological change and family labor migration have been rather continuous and "smooth" functions of time, causing complexities in relating demand for family labor to the price magnitudes mentioned in the previous section.

In the following section we attempt to improve the specification by (a) using residual farm income rather than hired wage rates as the "price" of family labor and (b) allowing for interdependence among farm and nonfarm variables. That is, a model is constructed that permits the response of family labor to income differentials to be conditioned by the rate of national unemployment in what essentially is a single reduced form function incorporating both supply and demand concepts.

Changes in demand and supply of farm labor have resulted in divergent migration patterns among regions according to Figure 9.5. Since 1940, net migration from agriculture has been greatest in low-income areas and smallest in some of the high-income and production areas of agriculture. Migration also has been high in areas of surplus products, e.g. the wheat areas of the Central Great Plains. The movement of people from farms has been highly selective among age groups. In general, out-migration has tended to be highest among young adults.



PATTERN OF MIGRATION

MIGRATION PATTERN	OUTMIGRATION RATES FOR YOUNG ADULTS	ADULTS AND CHILDREN	OLDER WORKERS AND RETIREES
A	HIGH	●	Moderate to High
B	HIGH	○	
C	HIGH	LOW	Moderate to High
D	VERY HIGH	LOW	HIGH
E	VERY HIGH	LOW	Moderate
F	VERY HIGH	Moderate	Moderate to High

● NET IMMIGRATION FOR ADULTS AND CHILDREN
○ NET IMMIGRATION FOR WOMEN AND CHILDREN

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Figure 9.5. Net migration of the rural farm population by regions, 1940-60.

FARM EMPLOYMENT FUNCTIONS

We now turn to estimates which we prefer to call farm employment functions for family labor. One reason for doing so is because structural differentiation between the supply of and demand for family labor is difficult. We also use this distinction, from the functions estimated and certain ones to follow, because the specification of the demand structure is somewhat different.

Specification of the Family Labor Function

In this section we attempt to develop a flexible model of labor mobility to accommodate a fluctuating income and employment structure. The purpose is to obtain, from a function fitted to data extending over periods of heterogeneous employment and wage structures, reliable estimates of the influence of unemployment and other factors on labor mobility.

A single equation expressing the number of family workers as a function of earnings, unemployment and other variables appears logical for these purposes. Some justification for the single function is provided by the fact that the decisions to supply more manual labor or management, to migrate or not, in response to a favorable derived demand are made by the same individual. Too, the single endogenous variable, family employment in agriculture, is assumed to be a function of predetermined past income, financial position, machinery investment and of certain exogenous unemployment and nonfarm income variables.

In the previous section, in a manner similar to other studies, the hypothesis is examined that the hired farm wage rate, prices paid and prices received by farmers are the relevant family labor decision variables. In this section, residual farm income is used as the measure of the "price" of family labor. Family workers provide manual labor and entrepreneural (management and risk-taking) skills. The return or price for these services is implicit-not explicit. Because it is not possible to impute the amount of labor or return to each function of family labor, it is convenient to use residual net income as a combined measure of returns to family labor. The hypothesis is that family labor is not an out-of-pocket cost and, hence, market prices are not necessarily relevant. Whether the family worker stays on the farm is assumed to be, especially in the short run, a function of the residual income which remains to pay living expenses after production costs are paid. Although prices are unfavorable, this residual still may be sizeable because of improved farming efficiency, management or good weather. To consider the decision of a family worker to remain in agriculture as a function of farm prices received relative to the price of hired labor ignores the increased residual to family labor growing out of increased farming efficiency and other structural changes associated with improved entrepreneural skills. There also are definite statistical advantages, as well as limitations, in summarizing the many price and efficiency aspects into the single variable.

We first specify the number of family workers employed in agriculture, Q_F, as a function of the ratio of income per factory worker to income per farm worker, Y_R, the national unemployment rate, U, the farm equity ratio, E, forced farm sales, F, government programs, G, machinery investment, S_M, and slowly changing influences or time, T. The form and logic of the specification is given additional explanation below.

A "conventional" statistical model which might be employed is a simple linear function,

$$Q_{Ft} = a - bY_{Rt-1} + c\,U_{t-1} + d\,X \tag{9.16}$$

where X represents variables other than income and unemployment influencing Q_F. The negative coefficient of Y_R would indicate that as nonfarm income rises relative to farm income, Q_F will decrease as family workers take urban employment. An important aspect of labor mobility which creates unstable coefficients in linear equations such as above is the interaction between U and Y_{Rt-1}. The rate, b, at which a given income ratio moves workers off farms is subject to the rate of national unemployment. To account for this structure, an interaction variable $Y_R\,(1-U)$ is added to equation (9.16) to form equation (9.17).

$$Q_{Ft} = a - b\,Y_{Rt-1} + c\,U_{t-1} + d\,X - e\,[Y_R\,(1-U)]_{t-1} \tag{9.17}$$

Combining the two terms containing income, the coefficient of Y_R is $-b - e\,(1-U)$ and obviously is a function of the level of unemployment.

Equation (9.17) is modified slightly to conform to certain a priori considerations. There is some doubt whether unemployment U shifts the level of family labor of itself, irrespective of income and other ininfluences. To correct for this, the variable U_{t-1} is omitted. Second, it is likely that if U reaches some level, the coefficient of relative income becomes zero. The implication is that when national employment reaches some critical level, V, a low relative income in agriculture no longer is effective in adjusting employment to equilibrium levels. Under these circumstances, average incomes are not a useful economic indicator. At the margin, Y_R is zero because the marginal nonfarm income is zero for the unemployed factory worker (assuming no unemployment compensation). If the signs of the coefficients are as indicated in equation (9.17), the coefficient of Y_R approaches -b as U approaches one. This critical value is too high, and equation (9.17) is modified in two ways to accommodate a lower value. The first is to assign different values of V in the interaction term. The equation then is

$$Q_{Ft} = a - b\,[Y_R\,(1-U/V)]_{t-1} + d\,X. \tag{9.18}$$

It is apparent that when U equals V, b equals zero. The variable within brackets may be constructed for several values of V until one is found by trial and error giving the highest R^2. The variable is constructed to equal zero when U is greater than the assigned value of V, the assumption being that b may be zero but not positive.

If we allow b to be positive or negative, the trial and error method for finding V in equation (9.18) may be replaced by a noniterative scheme. The case for a positive coefficient b when U is larger than V is supported by the growth in numbers of agricultural workers during the depression. If the necessary statistical assumptions also are met, the following model will also give the best linear unbiased estimate of

V. The model is formed by multiplying the terms within the brackets of equation (9.18) by b. The result is

$$Q_{Ft} = a - b\, Y_{Rt-1} + \frac{b}{V}\,(UY_R)_{t-1} + d\, X. \tag{9.19}$$

It is apparent that the critical unemployment level V at which relative income no longer is effective in drawing workers from agriculture is readily computed from the coefficient of UY_R. Equation (9.19) does not restrict the value of b; the coefficient becomes positive when U is greater than V. This conforms with historical experience since during the depression of the 1930's there was a net migration into agriculture. The greatest potential influence of Y_R on Q_F is indicated by b. That is, the coefficient of Y_R is the maximum negative value b only when unemployment is zero. The logic of the model of income and unemployment depicted in equation (9.19) is appealing and is the foundation for several fitted equations which follow.[7]

The Variables

The "X" variables in equation (9.19) need further explanation. These variables are investment stock of farm machinery, S_M, the equity ratio, E, percentage of forced (bankruptcy) sales, F, government programs, G, and slowly changing influences, T. If farmers are in a favorable financial position because of inflated land or other values or because past income has been greater than expenses, it is reflected in the ratio of proprietors' equity to liability. E is a measure of long-term financial success and ability to withstand the vicissitudes of short-run income fluctuations. If E is high, farmers may be able to withstand short-run income reverses by utilizing financial reserves obtained in the past.

Investment in machinery is somewhat both output increasing and cost increasing for a given number of workers. Due to the inelastic demand for farm products, these influences of machinery are reflected in residual farm income. It might be argued that machinery investment need not be specified separately in the labor function because the

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[7] Other, nonlinear assumptions about the relationship between unemployment and relative incomes may be appropriate. One is to assume a model of the form

$$Q_F = a\, Y_R^{-b(1-U/V)}\, X^c. \tag{a}$$

It may be estimated by least squares as a linear function

$$\log Q_F = \log a - b \log Y_R + \frac{b}{V}\,(U \log Y_R) + c \log X. \tag{b}$$

Another suggested model is

$$Q_F = a - b\, Y_R\, (1 - U^2/V) + c\, X \tag{c}$$

and would be estimated by ordinary least squares as

$$Q_F = a - b\, Y_R + \frac{b}{V}\,(U^2\, Y_R) + c\, X. \tag{d}$$

laborsaving feature does not of itself reduce family employment. (Workers need only work fewer hours and receive the same income.) There exists an important indirect reason for specifying an investment effect other than that reflected in farm income. Although farm income is favorable, some workers will migrate because of high capital requirements, or because they are not needed on highly mechanized farms.

The following variables, undoubtedly, have influenced family labor mobility, but cannot be specified separately in the labor function. The slowly changing trend variable, T, reflects, although imperfectly, some of these factors such as education, transportation and communication. The influence of economies of scale and consequent pressures for larger and fewer farms also may be embodied in the time variable.

When farm incomes become very low, the "smoothly" functioning labor market breaks down as farmers become bankrupt. To accommodate this changing structure, a variable indicating the percent of forced sales is included in the labor function. The family farm operator who has lost his farm may become a hired farm laborer if he cannot find employment in a depressed urban economy, and the other variables in the function may not adequately represent these effects.

The influence on labor mobility of government policies shifting farm income is measured to some extent by Y_R. But other indirect influences of legislation may be specified separately. For example, land retirement policies may have a direct effect not reflected in Y_R, and are indicated by a separate institutional variable, G.

Finally, if adjustments to relative income, machinery investment and other explanatory variables are made slowly, the lagged employment variable Q_{Ft-1} can be specified in the labor function to estimate the adjustment coefficient.

It might be contended that an improved farm financial position indicated by a low value of Y_R or a high value of E facilitates labor mobility by providing capital for moving. The fact that outmovement of family laborers has been more rapid from low-income farm areas than from high-income farm areas provides a sufficient basis for rejecting this hypothesis. This does not preclude the hypothesis, however, that favorable agricultural earnings reduce the number of agricultural workers in the long run by providing funds for laborsaving farm mechanization.

The variables in the family labor or employment function are defined specifically as follows:

Q_{Ft} = the dependent variable which is the number of family workers employed in agriculture during the current year, measured in 10 thousands.

Y_{Rt-1} = an index of the ratio of the average annual wage per employed factory worker to the residual farm income per family worker in agriculture in the past year. Residual farm income is gross farm income, including government payments and nonmoney income, less production expenses including hired labor. The index is expressed as a percent of the 1947-49 period.

U_{t-1} = the percentage of the national labor force unemployed during the past year, unadjusted for seasonal variation. When specified with income as UY_R, the unemployment variable is expressed as a proportion rather than a percent.

E_{t-1} = the past year ratio of proprietors' equity to liabilities in agriculture.

F_t = the percentage of farm sales forced through bankruptcy in the current year.

G_t = an index of government policies. Years when acreage allotments or production controls are in force are given the value -1. Years when farm prices are supported are assigned values of +1. If supports are fixed, an additional +1 is added. The values are summed to form the index G.

S_{Mt} = the stock of all productive farm machinery on farms January 1 of the current year.

T = time, an index composed of the last two digits of the current year.

All the above variables are annual data for the U.S. from 1926 to 1959, omitting 1942 to 1945. Some of the variables were not recorded prior to this period. While there would be obvious advantages in analyzing the labor function for various segments of the 1926-59 period, the data are not considered adequate for such refinements.

Family Labor Equations Estimated by Least Squares

The six explanatory variables in equation (9.20) of Table 9.2 explain a large proportion of the annual variation in the quantity of family labor employed on farms. Two variables, F and G, contribute little to the explanation, however. The results indicate that there has been a nonsignificant direct effect of government programs, G, and forced (bankruptcy) sales, F, on labor mobility not reflected by other variables such as Y_R and E. In equation (9.21) the beginning year stock of machinery, S_M, is substituted for these variables. The standard error is twice the coefficient of the machinery variable, however. For this reason, S_M is excluded in equation (9.22). The four independent variables in equation (9.22) explain 98 percent of the variation about the mean of Q_F. The coefficient of Y_R is significant at the 95 percent probability level; the other coefficients are significant at the 99 percent level. All coefficients display the expected signs, and the test for autocorrelation in the equation is inconclusive.

If E is omitted and F and G are included as in equation (9.23), the

Table 9.2. Functions for Family Labor Q_F Estimated by Least Squares With Annual Data From 1926 to 1959, Excluding 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation	R^2	d†	Constant	Y_R t	UY_R t	Y_R t-1	UY_R t-1	E t-1	S_M t	F t	G t	T	Q_F t-1
(9.20)	.979	1.16	1344			-.50	3.32	19.31		.71	-.47	-15.27	
						(.25)	(.67)	(5.03)		(.99)	(.94)	(1.08)	
(9.21)	.979	1.10	1367			-.40	3.30	16.01	-.0022			-14.97	
						(.31)	(.83)	(2.75)	(.0046)			(1.34)	
(9.22)	.978	1.14	1385			-.50	3.60	16.07				-15.52	
						(.24)	(.54)	(2.70)				(.70)	
(9.23)	.966	.86	1469			-.75	4.33			-1.19	2.13	-14.04	
						(.30)	(.77)			(1.08)	(.82)	(1.30)	
(9.24)	.983	1.10	1455	-1.16	4.69			11.74				-14.63	
				(.19)	(.47)			(2.12)				(.60)	
(9.25)‡	.990	-‡	-‡	-.56	2.22			1.79				-1.41	
				(.18)	(.60)			(2.66)				(1.19)	
(9.26)	.989	1.40	324			.25	.30	7.90				-5.13	.74
						(.23)	(.78)	(2.58)				(2.19)	(.15)
(9.27)	.993	1.68	671	-.48	2.29			7.43				-7.43	.54
				(.18)	(.52)			(1.61)				(1.33)	(.10)

*The dependent variable Q_F and the indicated independent variables are defined in the text. All equations are linear in original values. For exact sources of each variable, and for values of the R^2 adjusted for degrees of freedom see: Tweeten, Luther G. An economic analysis of the resource structure of U.S. agriculture. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962.

†The Durbin-Watson autocorrelation statistic d.

‡Estimated by least squares with a first-order autoregressive transformation. The first-order autoregressive coefficient was estimated to be .92, the standard error .09. The Durbin-Watson autocorrelation statistic and constant terms were not computed for the autoregressive equation. All results in the table are based on the model presented in text equation (9.19).

coefficient of G is positive and significant. If taken seriously, the inference is that government programs have significantly influenced family labor mobility. The inconsistency of the results in equations (9.20) and (9.23), and the crude formulation of the variable G, suggests that the extent of the direct influence of government programs on labor mobility cannot be determined from the equations in Table 9.2.

When current rather than past income and employment variables are included in the labor function, the magnitude and significance of the coefficients of Y_R and UY_R are increased. The R^2 also is greater in equation (9.24) than in equation (9.22). Statistically, equation (9.24) is preferable, but logically equation (9.22) with lagged variables is desirable. It is expected that at least a 1-year lag is required for farmers to adjust to a change in relative incomes.

The relatively low values of d cast doubt about the randomness of the residuals in equation (9.24) and previous equations. For this reason equation (9.24) is estimated assuming the residuals follow a first order autoregressive scheme.[8] Autoregressive equation (9.25) is estimated

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[8] The assumption is that the residuals are formed by a Markov process, i.e.

$$\text{(a)} \qquad u_t = B\, u_{t-1} + e_t$$

where u_t is the current residual and e_t is randomly distributed. In equation (9.25) the residual is found by an iterative process described in Chapter 8, and is

$$\text{(b)} \qquad u_t = \underset{(.09)}{.92}\; u_{t-1} + e_t.$$

with the assumption that the current residuals are a linear function of the residuals in the past year plus a random element. The transformation resulted in a first order autoregressive coefficient of .92 with a standard error of .09. The highly significant coefficient obviously has absorbed the time trend in equation (9.25). The autoregressive transformation (and time, T) essentially is a substitute for other variables which cannot be specified individually in the equation. Whether the time trend is reflected in the autoregressive scheme or by the time variable itself does not necessarily lead to a different interpretation. Either result is an indication of our inability to specify more exact variables, and we can only postulate what influences either represents. Analysis of employment numbers suggests a strong basis for a time trend not adequately explained by the independent variables. Equation (9.25) adds little to our knowledge of labor mobility, and the following discussion of equations (9.26) and (9.27) indicates that the autoregressive transformation may not be appropriate. Thus, inferences of the nature of family labor mobility in subsequent pages are based on other equations in Table 9.2.

Equations (9.26) and (9.27) are estimated with a distributed lag to allow a gradual adjustment to equilibrium. The results using the current rather than past income and employment variables are more acceptable. Certain considerations suggest that inclusion of the lagged employment variable completes the specification. First the coefficient of the variable is significant and the R^2 is increased. Second, the autoregressive transformation applied to equation (9.27) (the equation is not included) resulted in a nonsignificant first order coefficient of .58 with a standard error of .33. The R^2 was not increased by the transformation. A highly nonsignificant F test for the contribution of the autoregressive transformation to the explanation of employment suggests that introducing the autoregressive scheme only realigned coefficients and did not improve the explanation. The coefficients of income, employment and Q_{Ft-1} remained nearly the same, but the coefficients of E and T were reduced substantially by the autoregressive form of equation (9.27). A third reason for supposing that addition of Q_{Ft-1} completed the specification is the similarity of the coefficients of Y_R and UY_R in equations (9.26) and (9.27). The implication is that the autoregressive scheme "substituted" for Q_{Ft-1} in equation (9.25). It is not possible, of course, to infer from this that the autoregressive transformation always will substitute for an incomplete specification. The short-run coefficients of Y_R and UY_R may be more consistent after the autoregressive transformation in equation (9.25), but without knowledge of the correct structure, inferences about the long-run coefficients would be incorrect. The long-run labor function is found by dividing the coefficients in equation (9.27) by the adjustment coefficient 1 - .54 = .46. If this division is made, it is interesting to observe that the long-run coefficients are very similar to the coefficients of equation (9.24), estimated without the lagged employment variable.

The R^2 is .99, the coefficients meaningful and significant; thus equation (9.27) appears to be a useful expression of the family labor function. Some instability is introduced by the high simple correlation ($r = .94$) between T and Q_{Ft-1}. Other simple correlations among explanatory variables are less than .90 in equation (9.27).

To help resolve the question of the importance of current and past price and employment variables posed in Table 9.2, the specification of the family labor function is modified slightly. Assume that decisions to seek alternative employment are based on expected relative income. The expected income is likely to be based primarily on *past* income, because current income is not known until late in the year. If expected income is favorable, the ultimate and final decision to change jobs may depend on *current* unemployment. This reasoning leads to specification of variables Y_{Rt-1} and U_tY_{Rt-1} in the family labor function. The resulting least-squares equation is:

$$(9.28)\quad Q_{Ft} = 1407 - \underset{(.29)}{.86Y_{Rt-1}} + \underset{(.64)}{4.27(U_tY_{Rt-1})} + \underset{(2.82)}{12.70E_{t-1}} - \underset{(.73)}{14.57T}$$

$$R^2 = .979 \qquad d = 1.19.$$

In some respects this equation is an improvement over equation (9.22). The R^2 is slightly higher and the magnitude and significance of the coefficient of Y_{Rt-1} is greater. Also, the degree of autocorrelation, indicated by d, is somewhat less in equation (9.28). The importance of current and price variables is not completely resolved, however. To avoid misinterpretation, coefficients of either current or past income and employment variables are labeled "short run."

Table 9.2 was comprised entirely of equations patterned after the model in (9.19). Table 9.3 illustrates alternative specifications of the family labor function based on the variables found most useful in Table 9.2. The important impact of national unemployment on labor mobility is illustrated more clearly in equation (9.29). The number of family laborers is specified as a conventional simple linear function of Y_R, U, E and T. (Cf. equation (9.16)). The coefficient of Y_R is nonsignificant and the sign is opposite that expected. Yet the coefficient of determination is larger than for several equations in Table 9.2. Addition of the interaction term in equation (9.30) reverses the sign on the coefficient of Y_F, but neither the coefficient of Y_F nor of $Y_F(1-U)$ is significant. (Cf. equation (9.17)). It is probable that an F test for the joint influence of the two variables containing Y_R would be significant. Thus, equation (9.30) does not necessarily lead us to accept the hypothesis that relative incomes are unimportant in determining the level of family employment.

Equations (9.31) to (9.34) are included to illustrate the results of using several critical unemployment values V. (Cf. equation (9.18)). The income-employment variable $Y_F(1-U/V)$ is constructed to equal zero when U is greater than V. For convenience the critical value is given as a reciprocal in Table 9.3. That is, for $Y_R(1-3U)$, $V = .33$; for

Table 9.3. Alternative Functions for Family Labor Q_F Estimated by Least Squares With Annual Data From 1926 to 1959, Excluding 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation	R^2	d†	Constant	Y_R t	U t-1	$Y_R(1-U)$ t-1	$Y_R(1-3U)$ t-1	$Y_R(1-5U)$ t-1	$Y_R(1-5U)$ t	$Y_R(1-7U)$ t-1	E t-1	T	Q_F t-1
(9.29)	.984	1.07	1285	.19	6.40						22.43	-16.52	
				(.14)	(.76)						(2.31)	(.60)	
(9.30)	.986	1.04	1212	-1.83	10.49	2.56					16.69	-17.19	
				(1.45)	(3.01)	(1.82)					(3.79)	(.76)	
(9.31)	.916	.24	1295			.68					13.99	-15.56	
						(.38)					(5.20)	(1.36)	
(9.32)	.954	.78	1517				-1.34				6.84	-14.47	
							(.26)				(2.95)	(.97)	
(9.33)	.975	.79	1443					-.95			13.35	-15.24	
								(.11)			(2.27)	(.71)	
(9.34)	.970	.58	1430							-.90	14.50	-15.47	
										(.12)	(2.55)	(.79)	
(9.35)	.993	1.36	750						-.59		8.19	-8.20	.49
									(.11)		(1.65)	(1.38)	(.10)

*Sources and composition of the dependent variable Q_F and of the indicated independent variables are discussed in the text. All equations are linear in original values.

†The Durbin-Watson autocorrelation statistic d.

$Y_R(1-5U)$, V = .20; and for $Y_R(1-7U)$, V = .14. When V = 1.00 in equation (9.31), the coefficient of the income-employment variable has the wrong sign and is not significant, the R^2 is relatively low and autocorrelation in the residuals is highly significant. As V is decreased to .20, the R^2 increases, the degree of autocorrelation in the residuals declines and the significance of the coefficient of the income-employment variable increases appreciably. The results indicate that V approximately is 20 percent unemployment, a quantity corresponding to the arbitrary value selected for similar equations for hired labor in Chapter 8.

Equation (9.35), estimated with a distributed lag, and assuming V equals .20, explains 99 percent of the annual variation about the mean of Q_F. All coefficients have the expected signs and are highly significant. The estimated adjustment coefficient, .5, is the same as that estimated in equation (9.27), Table 9.2. The distributed lag model appears to be a useful formulation of the family labor function. It may be noted that the long-run coefficients of E and T, found by dividing the short-run coefficients by the adjustment rate .5 in equations (9.27) and (9.35), are nearly equal to the coefficients of E and T in equations (9.20) to (9.24) and (9.29) to (9.34).

Income Elasticities

The elasticities of family labor movements with respect to relative incomes are illustrated in Table 9.4 for selected equations from Tables 9.2 and 9.3. The results indicate that the short-run (one or two years) response to relative incomes is low and is sensitive to the level of unemployment. The maximum short-run elasticity (zero unemployment) probably is no greater than -.1 according to the data of Table 9.4. The implication is that a 10 percent decline in farm income relative to income of factory workers could decrease the number of family workers up to 1 percent in the short run. But if unemployment were 15 to 20 percent, a 10 percent decline in relative farm income would have no effect on the number of family workers in agriculture. Thus, the short-run response of Q_F to relative incomes is low when national unemployment is low and is negligible when unemployment reaches 15 to 20 percent according to Table 9.4.

The long-run response of family workers to changes in relative incomes is considerably greater than the short-run response. In the long run the farmers' financial situation, indicated by the equity ratio E, deteriorates with a low farm income. The result is that the long-run elasticity with respect to farm income may be as high as .36 according to equation (9.35).[9] Because the interrelationship between labor

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[9] The elasticities computed from equation (9.28) are not included in Table 9.4 although the equation has certain logical and statistical advantages. The short-run elasticities computed from equation (9.28) are slightly greater than those computed from equations (9.22), (9.27) and (9.35). The long-run elasticities computed from equation (9.28) are less; the maximum long-run elasticity for U = .05 is .27 compared with .34 and .35 based on equations (9.27) and (9.35).

Table 9.4. Elasticities of Family Labor Q_F With Respect to Farm Income per Family Worker Y_F' and Factory Income per Worker Y_N Estimated at the Mean From Equations in Tables 9.2 and 9.3

Unemployment (Percent)	Equation (9.22)		Equation (9.27)			Equation (9.35)		
	Short run (1-2 years) Y_R *	Long run (4-6 years) Y_F'†	Short run (1-2 years) Y_R *	Long run (4-6 years) Y_N‡	Y_F'§	Short run (1-2 years) Y_R *	Long run (4-6 years) Y_N‡	Y_F'§
0	-.089	-	-.087	-.189	-	-.107	-.208	-
5	-.057	.25	-.067	-.144	.34	-.080	-.156	.35
10	-.024	.22	-.046	-.099	.30	-.054	-.104	.30
15	.008	-	-.025	-.054	-	-.027	-.052	-
20	.041	-	.004	.008	-	.000	.000	-
25	.073	-	.017	.037	-	.000	.000	-
1926-59 average (9 percent)	-.031	.23	-.050	-.108	.31	-.059	-.114	.31
1946-59 average (4 percent)	-.063	.26	-.071	-.153	.35	-.086	-.166	.36

*The short-run elasticities with respect to Y_R. Since $Y_R = Y_N/Y_F'$, the short-run elasticities with respect to Y_R, Y_N and $-Y_F'$ are equal.

†The long-run elasticity with respect to farm income, Y_F, is the short-run elasticity .057 (for U = 5 percent) plus the elasticity with respect to E. The elasticity of Q_F with respect to E is .126. A sustained 1 percent increase in Y_F' is expected to raise E approximately 1.57 percent. The total long-run elasticity with respect to Y_F' roughly is .057 + (.126)(1.57) = .25 when unemployment is 5 percent. Because the elasticity with respect to E is not adjusted adequately for U, it is only estimated well within the range of the average U from historical experience.

‡The short-run elasticity with respect to Y_R divided by the adjustment coefficients .46 in equation (9.27) and .52 in equation (9.35). The long-run elasticity with respect to Y_N is much less than with respect to Y_F' because Y_N does not influence E.

§The long-run elasticity with respect to Y_F' is the short-run elasticity .067 (for U = 5, equation (9.27)) plus the long-run Y_F' component of E, or .091, divided by the adjustment coefficient .46. The total elasticity is, therefore, (.067 + .091)/.46 = .35. Similar computations are made for equation (9.35). The long-run elasticity with respect to Y_F' is much greater than with respect to Y_N because a reduction in the former affects farm equity. The magnitude of the adjustment coefficient .5 indicates that slightly over three years are required to make 90 percent of the total adjustment after the explanatory variables have changed. Because the explanatory variables do not change immediately, one to three years are added to the three-year adjustment indicated in the equation.

mobility, unemployment and a change in equity E was not stressed in the empirical analysis, it is not feasible to estimate the response to a change in E for values of U other than 5 and 10 percent. That these unemployment rates are quite realistic and well within the range of historical experience is indicated by the average unemployment in the 1926-59 and 1946-59 periods in Table (9.4). It seems reasonable that the long-run response to a given income differential is less conditioned by the level of unemployment than is the short-run response. Given time, family workers can filter into scattered nonfarm jobs despite high general unemployment.

The long-run elasticity of Q_F with respect to a change in the nonfarm income Y_N may be as high as -.21 according to equation (9.35). The long-run elasticity with respect to Y_N is lower than with respect to Y_F' because a sustained drop in farm income leads to a weakening of the farm financial position. Eventually the farmer may not be able to meet fixed financial obligations, and loan foreclosure or other difficulties may result. To summarize, a 10 percent fall in farm income is predicted to decrease the number of family workers up to 3.5 percent in the long run. A 10 percent rise in nonfarm incomes may decrease the number of farm family workers as much as 2 percent. But if unemployment is high, the response of workers to a change in income may be much lower than these estimates according to Table 9.4.

The elasticity estimates are from data covering a period of falling family employment and relative farm income. The results, therefore, are relevant for such conditions, and it is hazardous to gauge the impact of large <u>increases</u> of farm income on employment from the data of Table 9.4.

Table 9.4 emphasizes the important interaction between the rate of unemployment and the income elasticities. The critical level, V, at which elasticities reach zero for equation (9.22) is .14, equation (9.25) is .25, equation (9.27) is .21, equation (9.28) is .20 and for the trial and error equations (9.31) to (9.34) is .20. In several depression years, national unemployment equaled or exceeded the critical value indicated by the above equations. Unemployment of 3 percent of the national labor force is consistent with seasonal and frictional labor adjustments. Equation (9.22) indicates that the short-run effectiveness of relative incomes in bringing adjustments in the farm labor force is decreased 25 percent when unemployment increases from 3 percent to 6 percent (unemployment in some years has been 6 percent or slightly greater). The results emphasize the close economic relationship between the farm and nonfarm sectors. They also emphasize that a government policy encouraging high national employment also facilitates adjustments in agriculture.

Shifts in the Family Labor Function

The number of family workers in agriculture declined 43 percent from 1926 to 1959, or at an average compound rate of 1.7 percent per year. Some of the forces responsible for this change may be evaluated from the foregoing labor functions. A measure of the relative influence of income, equity and time on the number of workers may be judged by the standard partial regression coefficients. If U equals zero, the standard partial regression coefficients of equation (9.22) are -.16 for Y_R, .39 for E and -1.15 for T.[10] If U equals 14 percent, the standard partial

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[10] The standard partial regression coefficient b_i' is computed as

(a) $$b_i' = b_i\sqrt{\frac{\sum x_i^2}{\sum y^2}}$$

where b_i is the multiple correlation coefficient, $\sum x_i^2$ is the corrected sum of squares for independent variable X_i and $\sum y^2$ is the corrected sum of squares for the dependent variable. The standard partial regression coefficients are corrected for the estimated differences in variances and are intended to reflect the relative influence of the independent variables on Y. They are somewhat comparable to the usual estimates of elasticities E_i of Y with respect to X_i computed at the means, i.e.,

(b) $$E_i = b_i\frac{\bar{X}_i}{\bar{Y}.}$$

The elasticities are corrected by the ratio of the means; standard partial regressions by the square root of the ratio of estimated variances.

regression coefficient of Y_R is zero. The results indicate that the relative influence of Y_R on Q_F tends to be small and is overshadowed by E and T even with high national employment. If U equals zero, the actual coefficient of Y_R is -.86 and of T is -14.57 in equation (9.22). The index of relative incomes Y_R would have to fall 17 points in one year to decrease Q_F in the short run as much as forces associated with the time variable. This result and the foregoing elasticity estimates provide support for the hypothesis that the responsiveness of farm employment to a change in relative earnings is not great enough to cope with the large adjustments necessary to equate earnings in the farm and nonfarm sectors.

The actual change in Q_F for a given period of time depends on the trend in the variables as well as on the relative impact of a given variable on Q_F. Equation (9.22) predicts a total decline, over the period analyzed, of 42 percent in the family labor force; the actual decline was 43 percent. The value of Y_R was nearly the same in 1926 as in 1959. Even if the coefficient of income were large, it would not explain the decline in Q_F from 1926 to 1959. Ceteris paribus, the improvement in equity E from 1926 to 1959 would have increased Q_F by 8 percent according to equation (9.22). It is apparent that nearly the entire decline in Q_F is associated with the time variable T. The results suggest that the family labor force has decreased approximately 150,000 per year due to factors associated with this variable. The result is based on the coefficients of T in equations (9.20) to (9.25), (9.28) and (9.29) to (9.34). (This result also agrees with the long-run coefficients of equations (9.22) and (9.35).)

EMPIRICAL ESTIMATES OF NATIONAL SUPPLY FUNCTIONS FOR FAMILY LABOR

This section includes direct empirical estimates of supply functions for family labor in the United States. Paralleling equations (9.1) through (9.15), the hypothesis is tested that the supply of farm labor is responsive largely to changes in the farm wage rate and the nonfarm wage rate. The foregoing analysis of the equations (9.16) through (9.36) pull the hypotheses in the direction of selected other variables. However, the latter variables have not been included in the analysis of farm labor supply (since the supply analysis was made prior to that of the previous employment section). However, the first of the equations presented in this section might also be "looked upon" as farm labor employment equations, while later equations of the section are "migration" equations. This hypothesis is related to quantification of the "push-pull" migration theory: the assumption that the rate of off-farm migration, which directly affects the supply of farm labor, is subject more to the "pull" of nonfarm wage rates and employment opportunities than to the "push" of the introduction of laborsaving machinery and techniques.[11]

The analysis of the supply functions for hired labor in Chapter 8 does not necessarily reflect the relationship of the variables specified to the supply quantity of all farm labor. Hence, a supply function for family labor for the United States also was estimated. With no previous quantitative analysis for family labor, the hypotheses adopted were the same as those for hired labor. Thus, the supply function for family labor was specified with the same variables as for hired labor, except that the nonfarm wage-rate variable was included for the present year and lagged one year. Estimates again were based on the Theil-Basmann technique, using autoregressive least-squares equations. To assist further in the determination of the dominant factors affecting the supply of family labor, an analysis was made of the variables affecting the net migration from farms.

The Supply Function for Family Labor in the United States

In the estimation of autoregressive least-squares equations, several iterations are "run" until negligible changes occur among the estimated coefficients. The results of the second iteration estimating the supply function for family labor indicated large and inconsistent changes from the previous iteration among the lagged variable, time, and the estimate of B — the autoregressive coefficient. However, the regression coefficients of the farm wage rate and nonfarm wage rate changed little. Evidently, without highly significant independent variables other than time and the lagged dependent variable, problems of multicollinearity arose. On the initial iteration, however, as the iteration was beginning to "settle down," the estimated family labor supply function for 1929-57 is:

$$(9.36) \qquad Q_{Ft} = .17P_{Ht} - \underset{(.74)}{1.08T} - \underset{(.05)}{.013P'_{Nt}} - \underset{(.07)}{.079P'_{Nt-1}} + \underset{(.36)}{.52Q_{Ft-1}} \,.$$

The variables in (9.36) are measured as deviations from the mean. The variables are Q_{Ft}, the supply quantity of farm labor; P_{Ht}, the index of farm wage rates deflated by the index of prices paid by farmers for production expenses; T, time; P'_{Nt}, the nonfarm composite wage variable explained in Chapter 8; and P'_{Nt-1}, the same variable lagged 1 year. The regression coefficients of equation (9.36) were "consistent" in sign, and had significance levels as follows: The variables for the composite nonfarm wage rate lagged one year, time, and the family

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[11] See Fuguitt, Glenn V. Part-time farming and the push-pull hypothesis. American Journal of Sociology 44:375-79. 1959; Hagood, Margaret J., and Sharp, Emmit F. Rural-urban migration in Wisconsin, 1940-1950. Wis. Agr. Exp. Sta. Res. Bul. 176. 1951; and McDonald, Stephen L. Farm out-migration as an integrative adjustment of economic growth. Social Forces 34:119-28. 1955.

labor force lagged one year were significant at the 60 to 80 percent probability level, but the farm wage rate and nonfarm wage rate (for the present year) were significant only below the 60 percent level. The autoregression coefficient, B = .65, was not significant at the 80 percent level. Upon the completion of the next iteration, the coefficients of the remaining variables changed erratically. Consequently, because of the unfinished estimation of the supply function for family labor, elasticities were not derived. However, the size and significance of the primary explanatory variables are of interest. Nonsignificant results (i.e., not significant at the 60 percent probability level) were obtained both for the farm wage rate and for the nonfarm wage-rate variables. The results are similar to those obtained in the estimate of the supply function for hired labor.

The supply of family labor was also estimated for the same period, 1929-57, by ordinary least-squares methods. In these equations, coefficients for the nonfarm wage rate and the percentage of unemployment were estimated separately. The resulting supply functions are presented below, with the observations measured as deviations from the mean:

$$(9.37)\quad Q_{Ft} = \underset{(.101)}{.136P_{Ht}} - \underset{(.176)}{.408T} - \underset{(.096)}{.152P_{Nt}} + \underset{(.137)}{.139U_t} + \underset{(.145)}{.773Q_{Ft-1}}$$

$$(9.38)\quad Q_{Ft} = \underset{(.059)}{.132P_{Ht}} - \underset{(.153)}{.405T} - \underset{(.078)}{.149P_{Nt}} + \underset{(.103)}{.135U_t} + \underset{(.136)}{.774Q_{Ft-1}}$$

where U_t is percent of unemployment in the national economy, P_{Nt} is the nonfarm wage rate deflated by the index of prices paid by farmers for living expenses and other variables are as indicated for equation (9.36). Equation (9.37) was estimated from a system of equations, and equation (9.38) was estimated singly. The farm wage-rate coefficients of these equations were similar to those of (9.36). The significance levels were higher in equations (9.37) and (9.38), however, reaching the 95 percent level in equation (9.38). The nonfarm wage-rate coefficients were also significant at a higher probability level though not directly comparable. (Had the iterative procedure "settled down," all the coefficients of equation (9.36) may have been significant at the 80 percent level or greater.)

Based on the tentative results of equation (9.37), the supply of family labor appears to respond only slightly to the farm wage rate and the nonfarm wage rate. Again, we believe the availability of nonfarm employment to have dominated the farm labor supply function over the last several years of rapid mechanization of agriculture as suggested in the analysis of the previous section and the equations to follow.

Analysis of Net Farm Migration

Our hypothesis is that the migration from farms is mainly and directly in response to off-farm employment opportunities. The estimated supply functions presented above provide one test of this hypothesis, the results indicating a relative lack of response of the farm labor supply to both wage-rate variables. Hence, we now analyze farm labor from the standpoint of net changes in the farm population Q_L. An autoregressive transformation was not used in these estimates. The time period covered again was 1929-57. The resultant equation with the observations measured as deviations from the mean was:[12]

$$(9.39)\quad Q_{Lt} = \underset{(.184)}{.255P_{Ht}} - \underset{(.053)}{.099P_{Rt-1}} - \underset{(.210)}{.492T} - \underset{(.071)}{.069P'_{Nt-1}} - \underset{(.022)}{.023Q_{Lt-1}}.$$

The value of R^2 for equation (9.39) is .36. The sign of the farm wage-rate coefficient, taken alone, would indicate that as the wage rate has risen, there has been an accompanying net return of labor to farms. Similarly, the coefficient of the composite nonfarm wage rate and employment variable indicates that as this variable increased in the previous year, there was an accompanying net migration from farms. The signs of the regression coefficients were as expected for all but one of the variables. The sign of the parity ratio, P_R, was negative, indicating that as the parity ratio increased in the previous year, there was an accompanying net departure from the farm. The time periods in which the parity ratio increased were similarly periods when nonfarm employment opportunities increased most rapidly. The anomalous coefficient may be explained from the findings of the previous section. That is, coefficients indicating the influence of farm variables (e.g., income or parity ratio) on farm labor mobility only have meaning in relation to the rate of national unemployment. Failure to account adequately for the influence of national unemployment on labor mobility may result in wrong signs of coefficients.

SHORT-RUN PROJECTIONS OF FARM EMPLOYMENT

The short-run projections of family employment for 1965 in this section supplement the long-run projections of farm labor employment and requirements for 1980 made in Chapter 18. The short-run projections are based on the single least-squares equation (9.22) presented earlier. The structure postulated by the single linear equation is somewhat rigid for long-run projections. Hence, the projections to 1980 in Chapter 18 are based on a less formal "nonstructural" algebraic form.

Figure 9.6 illustrates that the number of family workers in

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[12] The regression variables are as defined previously, except Q_{Lt-1} which is the annual net migration from farms, United States.

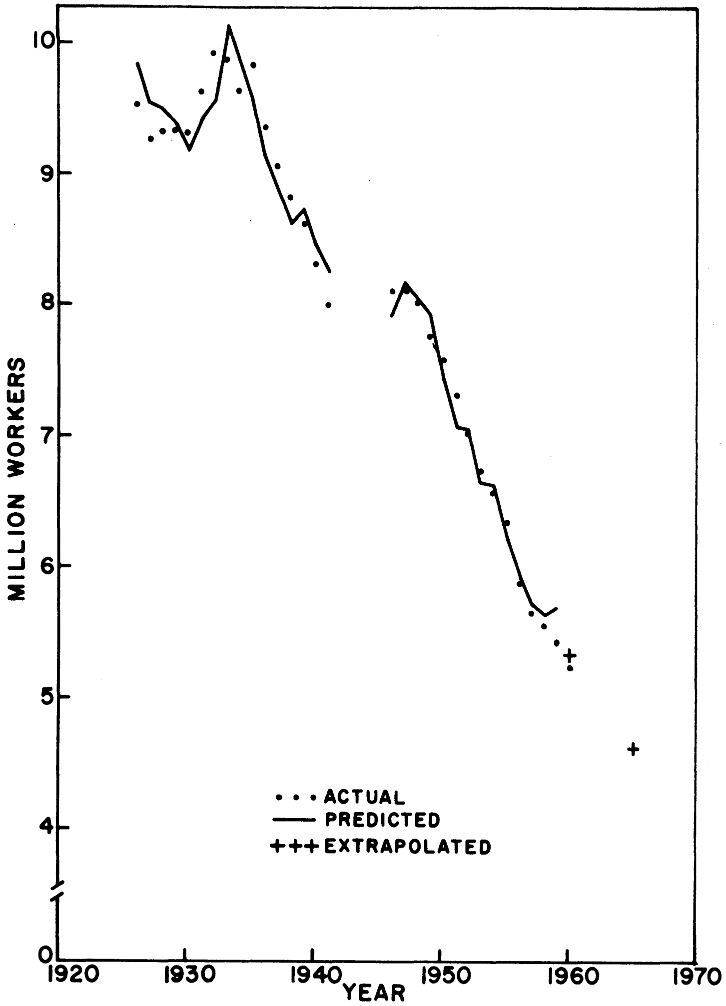

Figure 9.6. Trends in numbers of family workers in farming from 1926 to 1960 (predicted and projected estimates from equation 9.22).

agriculture dropped sharply from the mid-1930's to the present. The increase in labor numbers during the depression years of the 1930's indicates labor mobility is related to economic conditions, as do equations (9.18) through (9.36) of the text. The out-migration was interrupted by World War II but continued at nearly the same linear rate during the postwar years that was established in the late 1930's. There is some evidence that the rate is slowing. Out-migration remains large, however.

The actual values of the farm labor force are predicted by equation (9.22) in Figure 9.6. In general, the predictions are quite accurate.

The number of workers is estimated for 1960 by extrapolating from 1959 values of explanatory variables. The actual number of workers is overestimated slightly, but the error is small. The number of family workers is projected to 1965 from equation (9.22), assuming relative income and equity will remain at 1955-59 levels. The projected number of family workers for 1965 is slightly over 4.6 million. The number approximately is 14 percent below the predicted 1960 number. The results suggest that the number of workers in agriculture will be considerably less in 1965. Whether this reduction will increase per worker income in agriculture depends on movements in total net farm income.

IMPLICATIONS OF RESULTS

The several sets of family labor functions of this chapter have established links among returns to labor in agriculture relative to nonfarm wage rates and level of farm employment. The labor functions also provide an empirical link between labor employment in agriculture and the degree of unemployment in the nonfarm economy. Approximately a 20 percent rate of unemployment has reduced net farm migration to zero in past decades. Even in more recent times, national unemployment, though at a much smaller rate than in the 1930's, has greatly lessened the rate of net out-migration from agriculture.

Income per family worker did not improve relative to nonfarm income from 1926 to 1959 because the outmovement of farm workers was just rapid enough to compensate for the reduction in total residual income resulting from farm adoption of output increasing (income decreasing) farm technology. That is, the reduction in number of family workers was offset by the decrease in residual farm income, leaving relative income per worker unimproved. If institutional or other barriers to off-farm migration had been great, income per worker in agriculture would have decreased. Perhaps it is notable that farm technology and capital investment were sufficiently labor saving and off-farm opportunities sufficiently large to prevent an even greater deterioration of the relative income per farm worker.

After adjusting for differences in skills and nonmonetary returns, a reduction of approximately 25 percent in family labor numbers would bring comparable returns in farming and industry, other things being equal. A free market economy is one of several alternatives which might be proposed to bring the needed adjustment. The results of Table 9.4 suggest that the elasticity of family employment with respect to relative income is no greater than .35, even in the long run. The inelastic response indicates that a given percentage drop in farm income is associated with a smaller percentage drop in employment. The result is that a fall in farm income reduces rather than increases income per farm worker, even in the long run. If narrowing the differential between farm and nonfarm incomes is a goal of farm policy, active programs may be necessary to increase farm labor mobility. Structures and elasticities for the past period are not necessarily those desired for the future.

The mobility of farm people was large in the 1950's because of the cumulative effects of such forces as education, transportation and communication media generally. For the benefit of farm people, particularly youth, there is necessity of a growing number of nonfarm employment opportunities and for public services which increase still further the elasticities in response of farm labor to relative differences in labor returns in agriculture.and nonfarm wage rates. In general, farm people have been at both a geographic and educational disadvantage in migration opportunities. Education, employment and monetary assistance which can help overcome these disadvantages will increase the elasticity of response of farm labor. As Table 9.5 indicates, this aid will be needed. Not only are farm labor opportunities highly negative relative to the rest of the economy, but also the agricultural population has tended to average lowest in educational attainment.

Increasing numbers of farm persons will turn to nonfarm employment at a time when an excess occurs in the labor force because of the jump in the birth rates during the 1940's. The number of new entrants in the national labor force will average upwards of 2,600,000 per year during the 1960's, an increase of 40 percent over the 1950's. (The number of young persons reaching 18 years of age is predicted to increase from 2.6 million annually in 1960 to 3.8 million in 1965.) The number of new jobs created during the 1950's averaged about 2.3 million annually. Hence, without stepped up growth rate, competition for employment will be keen, disadvantage lying mostly with those having least preparation and knowledge of opportunities. Employment opportunity is predicted to increase in professional, technical, clerical,

Table 9.5. Projected Change 1960 to 1970 in Job Opportunities in Selected Employment Categories and Average Education of Persons Employed in Category in 1959*

Type of Worker	Change in Opportunities, 1960 to 1970	Average Schooling, 1959
	(percent)	(years)
Professional and technical	+42	16.2
Proprietors and managers	+23	12.4
Clerical and sales	+25	12.5
Skilled craftsmen	+23	11.0
Semiskilled operatives	+18	9.9
Service workers	+24	9.7
Unskilled laborers	0	8.6
Farmers and farm workers	-17	8.6

*U.S. Department of Labor. Manpower — challenge of the 1960's. Washington. 1960.

Table 9.6. Percentage Allocation of Vocational Education Funds Among Categories, Census Regions and Selected States, 1955-59*

Region or State	Percentage Allocation Within Region or State for: Agriculture	Home ec.	Trades and industry†	Percentage Allocation of Region or State of U.S. for: Agriculture	Home ec.	Trades and industry‡
U.S.	31	30	39	100	100	100
New England	11	18	71	2.3	3.8	12.8
Mid. Atlantic	16	13	71	6.5	5.6	24.4
E. North Central	31	31	38	16.3	17.2	16.3
W. North Central	41	31	28	12.3	9.8	5.9
S. Atlantic	36	34	30	19.9	20.0	12.8
E. South Central	42	36	22	11.2	10.1	4.7
W. South Central	42	38	20	20.9	20.1	7.0
Mountain	32	32	36	4.3	4.5	3.6
Pacific	21	28	51	6.4	8.9	12.4
New York	13	9	78	2.3	1.7	12.0
Minnesota	38	28	34	3.1	2.4	2.1
Iowa	49	33	18	2.7	1.9	.8
S. Carolina	44	36	20	2.8	2.4	.9
Georgia	44	40	16	4.8	4.6	1.2
Tennessee	37	38	25	2.8	3.0	1.6
Alabama	42	33	25	3.1	2.6	1.5
Mississippi	48	37	15	3.0	2.4	.7
California	19	26	55	3.8	5.7	9.1

*Digest of Annual Reports of State Boards for Vocational Education to the Office of Education, Division of Vocational Education. U.S. Dept. of Health, Education and Welfare. Office of Education. Fiscal years ending in 1955-59.

†Includes distributive occupations, nursing, area programs and other minor allocative categories.

‡Trades and industries only.

skilled, service and sales jobs, but to remain constant in unskilled jobs.[13] Hence, some unemployment is likely to prevail in unskilled jobs while shortages exist in professional and skilled positions favored by economic growth. Typically, a majority of migrants from farms first have had to seek or remain in unskilled employment, with approximately half the expansion in urban-industrial labor force between 1930 and 1955 coming through migration from the farm population.[14] Educational

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[13] U.S. Department of Labor. Manpower - challenge of the 1960's. Washington. 1960.

[14] Ducoff, L. J. Trends and characteristics of farm populations in low income farming areas. Journal of Farm Economics 37:1399-1407. Over the single decade 1940-50, 8.6 million persons, alive in both 1940 and 1950, were added to the urban labor force through net migration from agriculture.

and vocational training deficiencies of rural areas (see Table 9.6) cause farm migrants to be at a disadvantage in migration and nonfarm employment. This is importantly true for farm youth, but particularly true for persons of 35 years and up who have spent their entire lives in farming and have had but little education oriented towards modern industrial employment requirements.

Increasing the mobility of farm workers through improved skills, subsidies or loans to migrants and through national employment agencies to disseminate job information is desirable from the standpoint of economic efficiency and societal welfare. It is even more desirable for farm persons who otherwise would be crowded "forever" into agriculture at low return. If the annual marginal value product (contribution to the real income of society) is much higher in nonfarm employment, the gains to society are large indeed from movement of 150,000 family workers per year from farm to urban employment. National income is increased a great deal by the migration of farm people to jobs paying $2000 per year more than their former employment. Even if this is only a crude indication of the real gains to the individual (salary) and to society (marginal value product), it does emphasize some of the actual and potential benefits of a more mobile population. There are few gains in increasing the mobility of the farm population, however, if national unemployment is high. In fact, the national income may be reduced by migration if unemployment is high. The marginal product of the unemployed in agriculture essentially is zero, but in urban areas is negative because of unemployment compensation and other social costs. It follows that policies to encourage full national employment and a vigorous economy have important ramifications for farm people as well as for nonfarm people.

10.

Farm Investment Behavior

A CHARACTERISTIC of economic growth is an increase in the proportion of capital used relative to labor. In agriculture, economic development has been accompanied by an absolute increase in capital and an absolute decrease in labor. The relative increase in price of labor, especially as influenced by nonfarm sectors and by economic growth, and the development of technologies increasing the marginal rate of substitution of capital items for labor have made this trend possible. However, even within the category of capital, with this resource coming to dominate the input structure of agriculture as illustrated in Chapter 2, substitutions also have taken place. One of the major substitutions has been capital produced in the nonfarm sector for that previously produced in the farm industry. This trend was illustrated in Chapter 2 by the large increase in all purchased inputs and the quite rapid decline in nonpurchased inputs.

This substitution, both within the capital category and between capital and labor, has brought about a large increase in the capital investment of agriculture. Not only has aggregate investment increased, but also the investment per farm has risen even faster as farms have decreased in numbers and increased in size. In physical volume the amount of durable assets (including real estate) in agriculture increased by 60 percent between 1920 and 1959. The rise was even greater — 200 percent — for operating inputs. These investments which substitute for labor increase capital stock greatly, just as they increase labor productivity. Labor productivity increased 280 percent over the period 1926-59 while labor and horse inputs dropped 43 and 85 percent respectively in the same period.

In this and following chapters we analyze investment in several categories of durable resources including (a) all motor vehicles, and individual analyses for autos, trucks and tractors, (b) machinery other than motor vehicles, (c) building improvements and (d) some aggregates of all productive assets. A later chapter relates to farm buildings and real estate. This chapter is designed to: (a) illustrate graphically some of the major input substitutions taking place, (b) examine a theoretic framework for analysis of the investment process and (c) present several statistical investment models used for later empirical analysis. Details of the logic are presented in this chapter since the general framework is employed in the estimates of several chapters to follow. For convenience our discussion of the theoretical framework is couched in terms of farm machinery investment. However, it also applies to the other investment categories analyzed subsequently.

MACHINERY PRICE AND QUANTITY TRENDS

To summarize further some substitutions occurring in agriculture and to suggest the role of prices in them, Figures 10.1 to 10.4 present important trends for farm machinery, other major farm inputs and farm outputs from 1910 to 1959. Previous quantitative or econometric studies, this study included, have not adequately isolated the influence of labor price and other input costs on capital investment and demand. The graphic analysis which follows is subject to the limitations of a two-dimensional analysis, but does provide some insight into price-quantity relationships not reflected by more sophisticated econometric approaches.

As the price of machinery falls relative to other prices, especially labor wages, machinery input is expected to increase in relative importance as it is substituted for other resources. Machinery inputs, Q'_M, in the figures are measured as the services required to maintain farm machinery and motor vehicles (40 percent of auto) for productive purposes. Q'_M includes depreciation, license fees, insurance and interest on inventory.

While the general trend in ratio of machinery prices to operating input prices has been upward, it has been relatively stable (Figure 10.1). This stability, as compared to prices of inputs from sectors outside agriculture relative to those from within agriculture, arises from the high correlation of labor prices among nonfarm sectors supplying operating inputs and machinery to farmers. As Figure 10.1 also indicates, the ratio of farm machinery inputs to operating inputs also

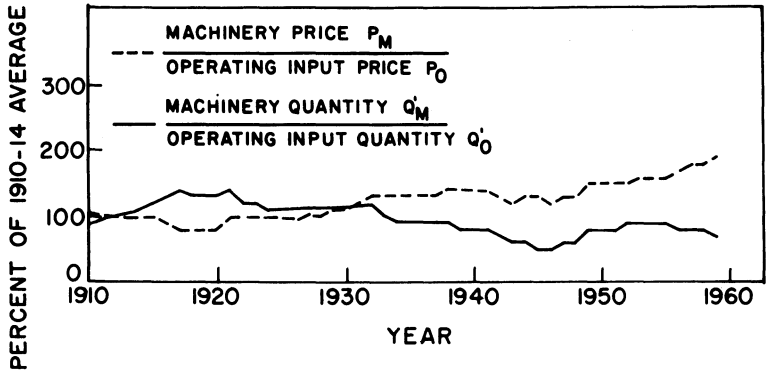

Figure 10.1. Ratios of farm machinery and operating input prices and quantities from 1910 to 1959 (1910-14=100).

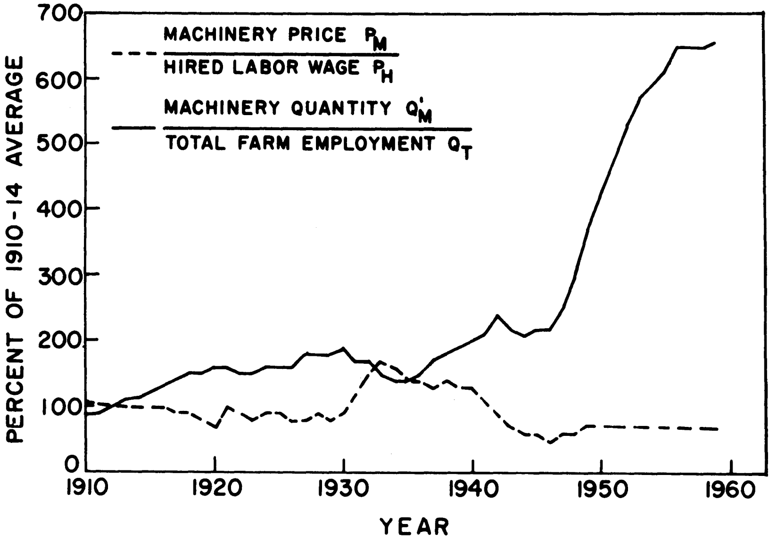

Figure 10.2. Ratios of farm machinery and labor prices and quantities from 1910 to 1959 (1910-14=100).

has been relatively stable over the period 1910-59. Stability in the quantity ratio is expected because machinery inputs such as tractors are technical complements with operating inputs such as fuel. Also, the same price and technical considerations of economic growth favoring improved machines also favored improved operating inputs over the period. In contrast to the degree of stability for machinery and operating inputs, Figure 10.2 indicates opposite trends in ratios of prices and quantities for machinery and all labor. Major substitutions have occurred particularly since 1946. The substitutions certainly cannot be explained by relative prices alone. The technological influences emphasized in Chapter 3 undoubtedly have been important. From 1910 to 1930, relative prices remained highly constant but machinery inputs increased relative to labor. New tractors, combines, etc., and improvement of existing models, increased the marginal productivity of machines relative to labor. Although price ratios remained almost unchanged from 1946 to 1959, the ratio of machinery to labor inputs grew rapidly. For the latter period, the relative decline in machinery price and increase in farmer capital position from 1940 to 1946 created a latent demand which could not be filled until the postwar period. Depreciation also depleted machinery stock in the war years, and machinery could not be replaced until the postwar era. Undoubtedly, improvements in existing machinery, introduction of new models and other nonprice influences also have encouraged substitution of machinery for labor inputs during the postwar period.

Figure 10.3 indicates the indices of the ratios: Q'_M to real estate inputs, Q_{RE}, and P_M relative to land price, P_{RE}. Despite the tendency

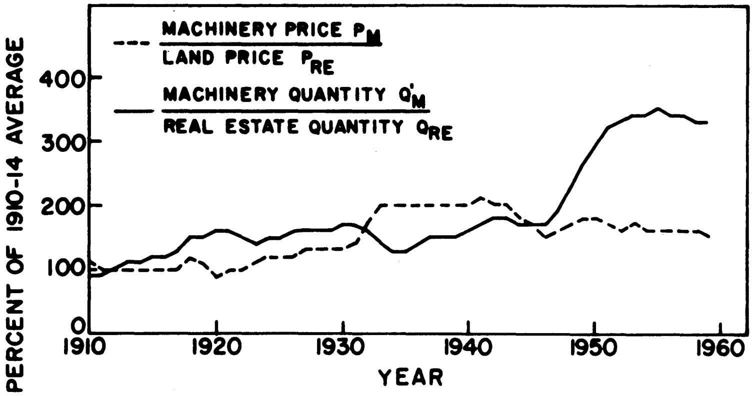

Figure 10.3. Ratios of farm machinery and real estate prices and quantities from 1910 to 1959 (1910-14=100).

for machinery prices to rise relative to land prices, the ratio Q'_M/Q_{RE} increased from 1910 to 1940. After 1940, machinery prices declined relative to land prices, and the relative importance of machinery inputs increased sharply. In the period 1955-59, however, the input ratio stabilized. The lack of correspondence between price and quantity ratio may arise because land price is not directly a decision variable in machinery purchases. Cash expenses such as hired labor and operating inputs, and the expected returns from sales of farm output, are examples of decision variables that may be of greater direct importance. However, since the marginal value productivity of land is affected by the magnitude of machinery inputs for the individual farmer, the price of land does have some importance in determining whether acreage can be profitably purchased or rented to complement added machine investment.

The two graphs in Figure 10.4 express: the ratio of P_M to prices received by farmers for crops and livestock, P_R, and the ratio of Q'_M

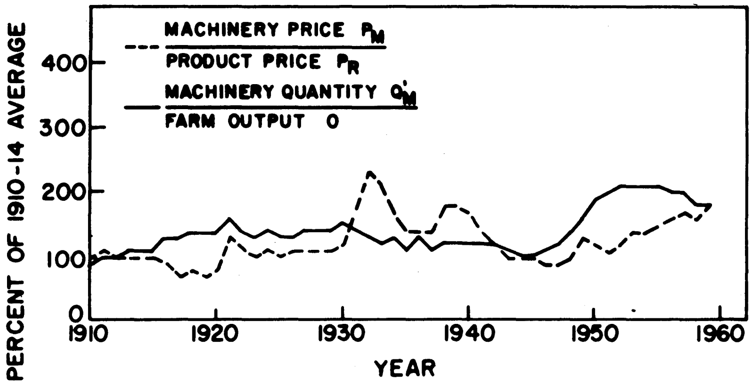

Figure 10.4. Ratios of farm machinery and farm output prices and quantities from 1910 to 1959 (1910-14=100).

to agricultural output O from 1910 to 1959. The quantity ratio was quite stable until 1940. During the decade of the 1940's, inputs of machinery declined in relative importance although prices were favorable because of conditions mentioned previously. In the late 1940's as machinery became available, the input began to substitute for other inputs in the production process. In the period when the backlog of demand was being filled, the quantity ratios ran counter to what might be expected on the basis of price ratios. After 1952, however, price-quantity interrelationships followed a pattern expected from theory.

PREVIOUS FARM INVESTMENT STUDIES

Previous econometric studies of demand for durable goods in agriculture, though few, provide useful insights into forces influencing the investment process. A study by Kendrick and Jones published in 1953 specified the outlay for farm plant and equipment (machinery and building improvement) as a simple function of net farm income.[1] Their least-squares analyses for the period 1910-41 indicated a significant relationship between income and investment. They estimated the income elasticity of demand for plant and equipment to be 1.08. Their data also suggested farm capital outlay was a relatively constant proportion — 20 percent — of net cash income. Griliches specified two principle demand functions for farm tractors: (a) the stock of tractors as a function of the past price of tractors relative to prices received by farmers for crops, the rate of interest and lagged stock and (b) the annual investment in tractors as a function of current price, the rate of interest and beginning year stock.[2] His estimates of price elasticities of the tractor stocks was -.25 for the short run and -1.50 for the long run. The adjustment coefficient was .17, indicating the long run is "far away." Elasticity with respect to the interest rate was approximately -1.0 in the short run and from -4.5 to -10.3 in the long run, quantities considerably higher than for the price elasticity. Specification of the price of labor, the price of motor supplies, a time trend, a capital gains variable, the stock of horses and mules on farms and alternative measures of the stock of tractors on farms did not improve the results.

Cromarty specified the demand quantity of farm machinery (value of manufacturers' sales of machinery deflated by the wholesale price index of machinery) as a function of: (a) machinery price, (b) the index of prices received by farmers for crops and livestock, (c) the index of prices paid by farmers for items used in production, (d) the value of farm machinery at the beginning of the year, (e) asset or equity position of farmers, (f) realized net farm income in the previous year,

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[1] Kendrick, John W., and Jones, Carl E. Farm capital outlays and stock. In Survey of Current Business. 33, No. 8:16-23. U.S. Dept. of Commerce. Washington. 1953.

[2] Griliches, Zvi. The demand for a durable input: Farm tractors in the United States, 1921-57. In Harberger, Arnold C. (ed.). The Demand for Durable Goods. pp. 181-207. The University of Chicago Press. Chicago. 1960.

(g) cropland acres per farm and (h) an index of labor costs.[3] A least-squares demand equation fitted to annual data from 1923 to 1954 explained 95 percent (adjusted R^2) of the variation about the mean of the dependent variable. Only variables (c), (e) and (h) were significant in the equation. The sign of the labor cost variable (h) was negative and does not support the hypothesis that machinery is substituted for labor as farm wages rise. In an alternative specification, he considered the machinery market as an interdependent system. The (a) deflated value of shipments of farm machinery, (b) retail price index of farm machinery and (c) value of machinery produced were determined interdependently in a system of three equations. The two predetermined variables that most significantly explained the three endogenous variables were (a) the wholesale price index of farm machinery and (b) industrial wage rates. Predetermined variables such as the parity ratio, beginning year assets, a quantified measure of farm price programs, changes in manufacturers' inventories, steel price and a measure of plant capacity had little influence on the endogenous variables — using the ratio of the coefficient to the standard error as the criterion.

SPECIFICATION OF THE INVESTMENT FUNCTION

Complex investment functions, providing for the macro-economic influences of multipliers and accelerators to explain cyclical fluctuations in investment, have been formulated by Samuelson, Hicks and others.[4] Refined models allowing for the macro influence of aggregate demand seem inappropriate for agriculture since: (a) agricultural investment is a sufficiently small portion of total investment and the macro effects may be ignored as a reasonable approximation and (b) it is necessary to construct less refined models compatible with statistical procedures and data limitations. The procedure in this study is to develop simple models consistent with the desired information of parameters in the investment process.

Durable asset theoretically should be purchased if the present value of discounted future earnings exceeds the cost of the asset. If uncertainty were absent, the rate of discount might be the bank rate of interest. But in agriculture a liberal discount for risk and uncertainty and capital limitations must be made. Future earnings are determined by the sales price of the product and the flow of services from the durable stock in the production function. Because the flow of services from a durable good tends to be proportional to stock, the annual investment essentially is derived from the desire by farmers for a given level of stock. For a durable input, the flow of services from stock rather than annual purchases is the relevant input in the production

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[3] Cromarty, William A. The demand for farm machinery and tractors. Michigan Agr. Exp. Sta. Bul. 275. East Lansing. 1959.

[4] Cf. Allen, R. G. D. Mathematical Economics. Macmillan and Company. London. 1959. Chaps. 7 and 8.

function. It does not necessarily follow that the stock of assets rather than annual investment should be the dependent variable in the investment function. Although the objective may be an optimum inventory, the variable manipulated by farmers to achieve the proper level of stock is annual purchases (gross investment). In this study, annual investment, rather than stock, is chosen as the dependent variable. The former is a more volatile quantity and sensitive measure of investment behavior. Furthermore, by proper structuring of the investment equations, it is possible to infer results about stock levels from knowledge of annual investment. In the following pages a number of other variables are specified as relevant in the investment function.

Under certain rigid assumptions of classical economics, the volume of investment is determined by the cost of capital and the market rate of interest.[5] Growing awareness of the role of expectation in business cycles has caused more attention to be focused on investment behavior in recent years. The trend has been to relax the somewhat unrealistic classical assumptions resting so heavily on the rate of interest and to allow assumptions more nearly approaching real world conditions. Interest rates have been given a less prominent role in investment theory, and greater emphasis has been given to the nature of expectations. Profit maximization is less often assumed to be the sole motivator in the decision process, allowances being made for utility maximization, the desire for security (e.g., game theory minimax criterion), convenience, stability, etc.[6]

Lagged Stocks

The demand for gross annual investment normally is derived from two sources: (a) desire to increase stock to levels suggested by new values of decision variables and (b) need to replenish existing stock because of depreciation. The level of past stock exerts an opposite influence on these two sources of demand. The greater the level of beginning year stock, the greater the depreciation and demand for replacement stocks. But ceteris paribus, greater stock levels decrease the marginal product of investment goods and reduce the demand from the first source above. If we consider a declining balance depreciation method (depreciation a linear proportion of stock) to be realistic, beginning year stocks can be included in the linear investment function to represent the second source, the coefficient of lagged stock being the rate of depreciation. In some instances the rate of depreciation changes or the same level of stock at two points in time does not indicate comparable replacement demands because the total stock is newer at one point in time. Refinements such as these can be introduced into

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[5] For further discussion, see Meyer, John R., and Kuh, Edwin. The Investment Decision. Harvard University Press. Cambridge, Mass. 1957.

[6] A brief discussion of several decision criteria is given in Walker, Odell, Heady, Earl O., Tweeten, Luther G., and Pesek, John T. Iowa Agr. Exp. Sta. Res. Bul. 488. Ames. 1960.

the demand function if necessary. The greatest challenge, however, is to select variables to express the first source of investment, the desire to increase or decrease stock levels. Several variables can be suggested for this purpose and are discussed below.

Net Farm Income

The variable most often suggested in empirical analysis of investment in nonfarm industries as the source of investment is net income or corporate profits. Studies by Meyer and Kuh,[7] Tinbergen[8] and several other studies cited by Kuh[9] show profit to be an important variable determining the actual rate of investment. Grunfeld states, however, that while profit may be a useful indicator of investment behavior, better indicators might be found.[10] He finds that the market value of the firm predicts investment better than profit. The studies of investment in agriculture by Cromarty[11] and Griliches[12] indicated no significant importance of net income in explaining demand for farm durables. But the study by Kendrick and Jones does indicate that net farm income is useful in explaining aggregate investment behavior.[13]

The argument for inclusion of net income in the investment function is strong. Net farm income (gross receipts less production expenses), Y_F, is an important expectation variable for two reasons. First, it is an indication of the returns from the durable resource. After subtracting production costs from gross returns, the remainder may be interpreted as the return to family labor and durable resources. Farmers subjectively and directly have imputed little return to their own labor. Hence, a tendency may exist to attribute a major part of the return to fixed capital. Theoretically, the decision to purchase a durable resource is made if the present value of discounted future earnings from the asset is greater than the purchase price. Because expected future earnings from durable resources probably tend to be based on past earnings, lagged values of Y_F in the demand function may be important.

A second reason exists for including Y_F in the investment function. The variable is an important indication of the future financial capabilities and ability to pay for the asset. Investment in a durable asset such as machinery entails considerable financial encumbrance in many

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[7] Meyer and Kuh, op. cit.; and Meyer, John R., and Kuh, Edwin. Acceleration and related theories of investment: An empirical inquiry. The Review of Economics and Statistics. 37:217-30. 1955.

[8] Tinbergen, J. Statistical evidence on the acceleration principle. Economica. 5:164-76. 1938.

[9] Kuh, Edwin. The validity of cross-sectionally estimated behavior equations in time series applications. Econometrica. 27:197-214. 1959.

[10] Grunfeld, Yehuda. The determinants of corporate investment. In Harberger, Arnold C. (ed.) The Demand for Durable Goods. pp. 211-66. The University of Chicago Press. Chicago. 1960.

[11] Cromarty, op. cit.

[12] Griliches, op. cit.

[13] Kendrick and Jones, op. cit.

instances. Although the current price of machinery may be low relative to prices received, a farmer may hesitate to invest unless he feels assured of future earning potential, and the degree of assurance often depends on past income, and equity which he has built up out of it. Financial institutions employ similar decision variables to determine the feasibility of a loan. External credit availability is often determined to a greater extent by the ability to repay the loan than by the profitability of the specific investment. Equity, as a facet of past net income, again is important in this respect. Even though the marginal efficiency of a particular investment is high relative to the interest rate, financing or supplying firms often are reluctant to make loans if the capital return is highly variable or is likely to be consumed by the household sector. Hence, net income reflects both the internal and external financing restraints of the farm firm.

Consideration of some machinery as a "household" expenditure provides another basis for including net income in the investment equations. Farmers occasionally purchase additional machinery because of greater convenience or prestige, even though marginal returns are low. These purchases emphasize the complex interaction between the farm firm and household in the investment processes. The marginal efficiency of capital and the interest rate may have little influence on such purchases. Ability to pay for assets purchased mainly for "household" reasons depends heavily on net income. Again, past values of Y_F are likely to be an important decision variable for both the farmer and the external credit source.

Income is determined by prices, weather, technology and other influences which can be specified individually in the demand function. Ideally, it is desirable to include each component of Y_F separately in the demand function to determine the relative impact of each on the demand quantity. Because the least-squares model tends to degenerate with the resulting large numbers of variables and because the several series often are highly intercorrelated, it perhaps is desirable or acceptable to sacrifice some information on individual components of Y_F to gain a more accurate estimate of the total impact of Y_F on the demand quantity. Furthermore, the hypothesis that farmers focus attention on a few decision variables including net income rather than attempt to digest the implications of the myriad components of Y_F appears reasonable.

Equity

Assets, other than that represented by the particular resource, should be important in the resource investment function. Assets held in liquid forms, as cash reserves and government bonds, provide flexibility of input purchases. Also different assets are technically related; a "stock" of large power units may stimulate demand for four- or six-row planting, cultivating and harvesting machinery. Different types of assets also may be economically related, the farmer with a herd of cattle being better able to borrow funds for buildings and equipment.

The ratio of proprietors' equity to total liabilities has several impacts on resource demand in a dynamic agriculture. It is one measure of the farm firm's ability to withstand unfavorable outcomes. According to Kalecki's principle of increasing risk, the impact of an uncertain event is an increasing function of the firm's equity position.[14] A given financial loss may cause little concern if equity is high. But if equity is low, the same loss may increase liabilities above owned assets and cause bankruptcy. The equity ratio is a measure of this influence both psychologically for the farmer and actually for outside credit sources.

The equity ratio also reflects income represented by capital gains accrued on durable assets during periods of inflation. The equity ratio tends to increase in an inflationary period since liabilities ordinarily are fixed financial obligations not directly influenced by inflation. Capital gains serve as a source of equity and funds for investment, and it seems appropriate to include this influence in the investment function. Finally, the equity ratio also is a measure of all income-generating processes. Periods of high income provide an opportunity for farmers to pay debts and build equity. Hence, the equity ratio serves as a proxy variable for past income. Favorable income over several years tends to be reflected in the equity ratio because of the lagged adjustment of consumption and durable purchases to higher income.

Monetary Variables

Theoretically, the interest rate is a fundamental variable in demand functions for durable inputs. Yet, Meyer and Kuh state that "empirical findings...indicate that the interest rate is not important whether statistical inference, interviews, or questionnaires have been the method of investigation."[15] Logic and introspection suggest that the interest rate probably is overshadowed by other variables as a determiner of investment. It also is likely that many individual farmers have not invested to levels where the marginal efficiency of capital approaches the interest rate. More often the restraints imposed by "internal and external" capital rationing have provided the typical "upper bounds" on capital employment. Fluctuating weather and other stochastic elements cause the marginal efficiency of capital to vary widely, a consideration which may be of greater concern to farmers than is the interest rate. Empirical studies by Kendrick and Jones[16] and by Cromarty[17] suggest a

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[14] Kalecki, M. The principle of increasing risk. Economica (New series). 4:440-47. 1937.

[15] Meyer and Kuh. The investment decision, op. cit., p. 8. For earlier comments on the role of interest rates in investment see Henderson, H. D. The significance of the rate of interest. Oxford Economic Papers. 1:1-13. 1938.

[16] Kendrick and Jones, op. cit., p. 18.

[17] Cromarty, op. cit.; and Cromarty, William A. The farm demand for tractors, machinery and trucks. Journal of Farm Economics. 41:323-31. 1959.

secondary role for the interest rate in farm investment decisions. The study by Griliches,[18] however, indicates that tractor purchases are highly sensitive to changes in the interest rate. More research is needed to determine if this result arises because other trend variables (such as farm size, labor price, asset structure, the real prices of material capital items and technological changes) are correlated with trends in interest rates, causing difficulties of specification, or whether interest as the price of investment funds is singularly important.

Institutional restraints of lending agencies may be of greater significance than the interest rate in restraining loans to farmers. Tostlebe's study indicates that farmers have supplied the major share of the funds financing capital acquisitions.[19] But there is evidence that the externally financed portion of capital acquisitions is increasing.[20] Moreover, it may be argued that external capital sources have a significant marginal impact on investment. Because the external capital agencies of "marginal importance" are few, and because studies indicate that internal rather than external capital rationing is the greatest investment restriction,[21] the institutional restraints are not explicitly included in this study. Institutional restraints on credit are defined as factors other than the interest rate affecting the availability of funds from credit institutions. We believe, to a large extent, that influences affecting institutional credit restraints are reflected implicitly in the investment function through the income and equity variables discussed earlier.

Price Variables

As indicated previously, some price variables are implicitly included in net farm income. Prominent price variables which might be singled out for their hypothesized unique and prominent influence on investment are the own price of the durable item and the farm wage rate. The price of the durable item is likely to be particularly important in the short run. Even if equity, earning power and other financial variables are favorable, the final decision to purchase may be based on the

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[18] Griliches, Zvi. The demand for a durable input, op. cit.; and The demand for inputs in agriculture, op. cit. Another quantitative study, which indicates a significant response of farm mortgage credit to changes in the interest rate, is by Hesser, Leon F. The Market for Farm Mortgage Credit. Unpublished Ph.D. Thesis. Library, Purdue University, Lafayette, Indiana. 1962.

[19] Tostlebe, Alvin S. Capital in Agriculture: Its Formation and Financing Since 1870. Princeton University Press. Princeton, N. J. 1957. p. 21.

[20] Hathaway, Dale E. Trends in credit and capital. In Baum, E. L., Diesslin, Howard G., and Heady, Earl O. Capital and Credit Needs in a Changing Agriculture. pp. 81-96. Iowa State University Press. Ames. 1961; Hopkins, John A. Adequacy of credit for commercial agriculture in a growing economy. In Baum, E. L., Diesslin, Howard G., and Heady, Earl O. Capital and Credit Needs in a Changing Agriculture. pp. 247-54. Iowa State University Press. Ames. 1961.

[21] Heitz, Glenn E. Determinants of capital formation: Discussion. In Baum, E. L., Diesslin, Howard, and Heady, Earl O. Capital and Credit Needs in a Changing Agriculture. pp. 37-38. Iowa State University Press. Ames. 1961.

input price based on the farmer's belief that it is relatively high or low in terms of his experience. Once the input is purchased, the price is of historic interest only. Farmers need not be greatly concerned with expectations and future trends since ability to pay for the input does not depend on what happens to the price, once the durable is purchased. But the ability to pay for the input does depend on wage rates, operating input prices and farm output prices. These latter prices are more likely candidates for expectation variables. The farm wage rate might be singled out as a separate variable in the investment process because of the large substitution of capital for labor indicated in Figure 10.2. Past efforts to measure the influence of wage rates on farm investment demand largely have been unrewarding, however.[22]

The Accelerator

One argument for including a variable to represent an accelerator effect is based on an assumed fixed or "prescribed" ratio of output to durable capital. The decision by farmers to increase output could be realized in the short run by greater use of operating inputs. Given time to adjust durable capital, the previous prescribed ratio of durable capital to output would be restored according to the argument. Inclusion of an output variable in the investment function would accommodate this accelerator effect. Obviously, however, the causal relationship may be clouded, with greater output arising because of increased durable capital inputs, or durable capital extended to maintain the prescribed capital/output ratio.

The need for an accelerator variable depends on the resource investment structure being investigated. For farm machinery and buildings, the range of substitution with labor and operating inputs is large because of the technical characteristics of the inputs. Also, because many farmers tend to be overinvested in machinery in many instances and, as explained in Chapter 2, decrease in farm numbers allows the same or more output from a given stock of capital, a considerable increase in output could occur without increasing machinery inventories. Thus there appears to be no strong basis for inclusion of an accelerator variable for farm machinery demand.

The basis for the accelerator may be stronger for investment in livestock and feed inventories. The nature of these resources suggests there are few substitutes. In the short run, however, animals fed to heavier weights cause feed to be a substitute for animals. Farmers can increase output by selling breeding stock in the short run, but if output is to be sustained at the old level or at higher levels, the inventory level must be raised. A certain number of breeding stock and feed inventories are needed for a sustained output, and this ratio of

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[22] Cromarty, The demand for farm machinery and tractors, op. cit.; Griliches, The demand for inputs in agriculture, op. cit.; Kendrick and Jones, op. cit.

inventories to output is quite constant in the long run. The ratio, of course, has changed secularly somewhat as outlined in Chapter 4.

As mentioned previously, this logic may appear to be anachronistic, since it is expected that greater investment causes greater output. Undoubtedly, some elements of simultaneity are present and, in the absence of more sophisticated techniques, least-squares bias may be present in single-equation investment functions including an accelerator. Attempt to reduce the bias can be made by using lagged rather than current output as an explanatory variable in least-squares investment functions.

The relevance of first differences or original values to represent the accelerator influence has been debated. Kaldor has summarized several positions by different economists.[23] Our approach is pragmatic; we use the form giving most realistic empirical results. In several preliminary regressions, output and income variables were included both in first differences and original values. Without exception, the equations linear in untransformed, original data were more realistic and acceptable from a statistical and economic standpoint.

Other Variables

Additional variables that might be specified in the investment function include farm size, government programs and technological and other changes reflected in a time trend. A farmer acquiring additional land may work the added acres with the same capital equipment but with longer hours of labor and more operating inputs such as fertilizer, fuel, oil and repairs. But, given time, he may increase his capital stock of machinery, livestock and feed. Whether, as a result of farm consolidation, the final investment in assets is greater than the combined assets of different owners has not been finally established.[24]

Government programs may have contrasting elements of influence on investment demand. Acreage restrictions and marketing quotas would be expected to reduce demand for machinery. However, price supports also may improve the farmer's financial position and encourage investment. The net influence is not clear, although the short-run effect may be to reduce machinery demand.

Machine capital has indeed had its marginal productivity, and the marginal substitutability, raised by technical knowledge. A major portion of the basic farm machines, including the row-crop machinery and tractors, was in existence in the 1920's. But continual refinements of the basic machinery to provide greater versatility, convenience and productivity have increased the demand for durable assets. Knowledge of the productivity and profitability of improved investment items came

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[23] Kaldor, N. Mr. Hicks on the trade cycle. Economic Journal. 61:833-47. 1951.

[24] Hoffman, Randall A., and Heady, Earl O. Production, income and resource changes from farm consolidation. Iowa Agr. Exp. Sta. Res. Bul. 502. Ames. 1962.

as a gradual process to farmers. These and other gradual influences can best be represented, although somewhat imperfectly, by a time trend variable in investment equations.

Single-Equation Estimates

Single-equation investment functions are generally used in the analysis which follows, although a few estimates are made by means of limited information techniques. We believe that the supply price of farm machinery and similar resources is determined primarily by variables in the nonfarm economy, and the resource price may be treated as exogenous in the farm investment function. If the supply of farm machinery and other durable assets is highly elastic as implied, the supply function need not be estimated simultaneously with the demand function. Specification of income and output variables in the demand function, as discussed earlier, may violate the monocausal structure. That is, income and output may be a function of investment and vice versa. Because some studies indicate the marginal product of machinery is low, and because services of durables are spread over the long run, additional investment is expected to influence output and gross income little in the short run. If this is true, least-squares bias may be small and the monocausal structure implied by a single-equation estimate may serve as a reasonable approximation of demand or investment functions. However, because of the contrary argument above, some demand functions are estimated by limited information. (The models examined in this chapter refer to single equations only.)

While a large number of variables could be specified in the investment function, the number must be reduced to a few important influences consistent with the estimational "capacity" of existing statistical models and available data. The judgment of what variables to include is based to some extent on the judgment of the researcher since selection cannot be based entirely on objective statistical tests: Several quite different specifications may give equally acceptable statistical results, and statistical inference may not allow differentiation among them. The investment function for machinery, for example, is specified as

$$(10.1)\quad Q_M = f(P_M/P_R,\ P_M/P_H,\ Y_F,\ E,\ S_p,\ S_M,\ A,\ r_S,\ G,\ T)\ .$$

The demand quantity (annual purchases or gross investment) is specified to be a function of the price of machinery, P_M, relative to prices received, P_R, and to wages of hired farm labor, P_H, net farm income, Y_F, the equity ratio, E, stocks of productive assets, S_p, stocks of machinery, S_M, farm size, A, short-term interest rate, r_S, government programs, G, and time, T. Not all of these variables, because of limitations from the data and methods used, can have a statistically significant effect on demand. Alternative equations then prove to be about equally efficient in predicting demand, and we are faced with making a selection.

EXPECTATION AND ADJUSTMENT MODELS OF INVESTMENT

The use of distributed lag models to express investment behavior appears appropriate for several reasons: First, expectations are important in determining the profitability and ability to pay for a durable asset. The principal expectation variable discussed earlier is net income, reflecting especially output prices and weather since they are least predictable. A somewhat different form of distributed lag model may arise if farmers are subjectively certain of the favorable price and financial conditions. A "psychologically" lagged adjustment to an equilibrium or desired quantity may result if farmers adopt a wait-and-see attitude, postpone purchase because of inertia of past decisions, etc. Other influences causing lagged adjustments are institutional restraints posed by laws and customs. External restraints arising from inadequate repair facilities in earlier days, or from waiting until neighboring farms can be purchased to obtain an economic unit for use of larger machinery, also result in adjustment lags.

One of the prominent features of modern econometric research is the emphasis on simple, structural equations providing information about long-run and short-run coefficients, adjustments, expectations and other information. Various types of statistical distributed lag models may be devised to approximate the actual farm investment function. Each has unique advantages, depending on the nature of the "true" function, but none of the models possesses all the properties desired in a general model. It is useful to consider several of these models and base the final choice on the basis of empirical results in later chapters as well as on a priori considerations.

Model A

The most general demand model is formed by allowing the parameter estimates of lagged variables to be unrestricted. It is useful to assume that the true model is linear in the parameters, but the estimated parameters of the lagged variables need not be forced to decline at a linear or geometric rate. Model A, used later in this study, is of that form. Expected income, Y_F^*, is a function of past income:

$$(10.2) \qquad Y_{Ft}^* = a + b_1 Y_{Ft-1} + b_2 Y_{Ft-2} + \dots + b_n Y_{Ft-n}.$$

To form model A, the demand quantity or stock is considered a function of expected income, the ratio of machinery price, P_M, to prices received by farmers, P_R, time, T, and error, u. The least-squares estimate of model A is formed by substituting the right side of (10.2) for Y_F^* in the demand equation (10.3).

$$(10.3) \qquad Q_{Mt} = a + bY_{Ft}^* + c(P_M/P_R)_t + dT + u_t.$$

The advantage of model A is that no assumption is made of the magnitudes of the coefficients of lagged income, but practical statistical considerations such as loss of degrees of freedom and multicollinearity limit the number of coefficients which may be estimated with reliability. We can continue to add lagged variables until the coefficients of the additional variables are nonsignificant, or the adjusted R^2 falls, and/or the regression coefficients become unstable. While it is impossible to determine if an additional variable fails to improve the equation, because of statistical problems or because the true farm decision function does not include the variable, we do estimate some forms of model A in subsequent chapters.

If model A is the appropriate demand function, an autocorrelated error structure arises if the distributed lag is not accommodated in the estimation process. If model A is correct and a model is estimated by least squares with income lagged only 1 year, the effect of Y_F on purchases for the remaining n-2 years becomes part of the unexplained residual. The error would not be distributed randomly, but would display positive autocorrelation since the lagged values of Y_F are autocorrelated and exert a consistent positive influence on Q_M.

Model B

A second and somewhat similar distributed lag model of machinery demand is formed by selecting a dependent variable resulting from the income generating process. The variable E, the ratio of farm proprietor's equity (owned assets) to liabilities on January 1 of the current year, is assumed to be a function of farm income in the past n years:

$$(10.4) \qquad E_t = a + b_1 Y_{Ft-1} + b_2 Y_{Ft-2} + \dots + b_n Y_{Ft-n}.$$

As mentioned previously, E may be used as a proxy variable for Y_F^*. The demand model B, formed by substituting E_t for the expected income in equation (10.3), is:

$$(10.5) \qquad Q_{Mt} = a + bE_t + c(P_M/P_R)_t + dT + u_t.$$

If E_t is a realistic indication of expected income, as purely under capital gains, models A and B are equivalent. The advantage of model B is that only the single variable E_t needs to be included in the least-squares regression to represent the lagged income and other effects discussed earlier. But this equation has a type of leakage since information on the b_1 values in equation (10.2) is lost. An estimate of these can be provided from a least-squares estimate of equation (10.4). While the equity ratio is an indicator of current financial position to farmers and credit institutions, as a measure of ability to finance a durable asset and to reflect capital gains from inflation, E is not a realistic indication of past net income if current income is wholly spent for consumption goods.

Model C

If the number of lagged income variables in model A is large and a useful proxy variable is not available, expected income may be represented by making assumptions about the values and distribution of the b_1's in equation (10.2). Expectations may be most heavily influenced by recent variables, the influence of past variables declining at a linear rate. Using this condition, and assuming current income expectations are formed from income of only the past n years, expected income is

$$(10.6) \qquad Y^*_{Ft} = a + b\left[\frac{nY_{Ft-1} + (n-1)Y_{Ft-2} + \dots + Y_{Ft-n}}{\sum\limits_{i=0}^{n}(n-i)}\right].$$

If n = 3, we may write equation (10.6) as

$$Y^*_{Ft} = a + b\left[\frac{3Y_{Ft-1} + 2Y_{Ft-2} + Y_{Ft-3}}{6}\right].$$

Model C is formed by substituting the variable in brackets for expected income in equation (10.3). We can experiment with several values of n and choose the appropriate value on the basis of the R^2 or other criteria. The distribution need not, of course, be restricted to the linear form illustrated in (10.6). More imaginative forms, such as a distribution forcing the b_1's to decline at a geometric rate, might be employed. A distribution declining by equal decrements as in equation (10.6) has intuitive appeal since data imperfections may prohibit isolation of a more realistic form.

Model D

The generalized Working method, a linear long-run equilibrium model proposed by Ladd and Tedford, which we slightly modify as a machinery investment function, can be expressed as

$$(10.7) \quad Y^*_F = a + b_1 Y_{Ft-1} + (b_1 - k)Y_{Ft-2} + \dots + [b_1 - (n-1)k]Y_{Ft-n}$$

where k is the annual decline of the income coefficients.[25] When $b_1 - (n-1)k=0$, no additional terms need be added. Simplifying terms, (10.7) becomes

$$(10.8) \qquad Y^*_F = a' + b_1 Y_{AFt-1} + kY_{WFt-1}$$

where Y_{AF} and Y_{WF} respectively are simple and weighted averages of

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[25] Ladd, George W., and Tedford, John R. A generalization of the Working method for estimating long-run elasticities. Journal of Farm Economics. 41:221-33. 1959.

past income. Substituting the right side of equation (10.8) for expected income in equation (10.3), model D is formed.

Model D has this chief disadvantage: the year t-n, when income no longer influences current expectations, is not determined explicitly by the model. In application, model D can be estimated with average and weighted income variables with increasingly greater lags, and the magnitude of the adjusted R^2 might be used as the criterion for final selection of the appropriate n.

An advantage of model D is that only two variables need be used to represent expected income, hence the model is suitable for least-squares estimation. If b_1 and k are positive and significant, the coefficients of lagged income decrease by equal decrements k, and models C and D essentially are equivalent. Model D allows more flexibility in determining the nature of the income lag, however. If k is zero and b_1 is greater than zero, the model implies that income expectations are influenced equally by n past incomes and not at all by income beyond n. The income expectation can be represented by a simple average of n past incomes, Y_{AF}.

Model E

If the expected change in income is proportional to the error made in estimating income last year (the difference between actual income and expected income last year), another type of expectation model is generated.[26] (See Chapter 3.) The model, expressed mathematically, is

$$(10.9) \qquad Y^*_{Ft} - Y^*_{Ft-1} = e(Y_{Ft-1} - Y^*_{Ft-1})$$

where e is the expectation coefficient. If we solve for current expected income, Y^*_{Ft}, then for Y^*_{Ft-1} in the basic demand equation (10.3) and substitute these values into the expectation equation (10.9), the following model E is formed:

$$(10.10) \quad Q_{Mt} = a' + beY_{t-1} + c(P_M/P_R)_t - c(1-e)(P_M/P_R)_{t-1} + deT + (1-e)Q_{Mt-1} + u_t - (1-e)u_{t-1}.$$

The error structure in equation (10.3) must be quite complicated if autocorrelation is to be absent in (10.10). Two estimates of 1-e are available — from the lagged quantity and lagged price. Model E is sometimes approximated in least-squares analysis by omitting the lagged price variable. The value of e is assumed to lie between zero

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[26] Nerlove, Marc. Distributed lags and demand analysis for agricultural and other commodities. USDA Handbook 141. 1958; Nerlove, Marc. The Dynamics of Supply. The Johns Hopkins Press. Baltimore. 1958.

and one, and implies that the influence of successively distant prices declines at a geometric rate but never reaches zero.

Income may not be the only expectation variable in the demand function. The extent of modification of model E to accommodate other expectation variables depends on the nature of the respective expectation coefficients. If the expectation coefficient is the same magnitude for all variables, the model becomes comparable to the following adjustment model F. This situation is very unlikely, however.

Model F

The previous demand models basically have been expectation models whereby farmers are assumed to base purchases on expected net income. Model F is an adjustment model, the basic assumption being that farmers are subjectively certain of the current explanatory variables in demand equation (10.1), but adjust purchases slowly to desired levels because of the psychological, institutional or other reasons. For numerous resources, it is reasonable to assume that the greatest adjustment is made towards the desired or equilibrium level of purchases in the early years. As the equilibrium level is approached, annual adjustments become very small. A model of demand proposed by Nerlove is based essentially on these conditions.[27] The actual adjustment in purchases in year t is a constant proportion, g, of the difference between the desired or equilibrium level of purchases in the current year, Q^*_{Mt}, and the actual purchases during the past year:

$$Q_{Mt} - Q_{Mt-1} = g(Q^*_{Mt} - Q_{Mt-1}) \tag{10.11}$$

or

$$Q_{Mt} = gQ^*_{Mt} + (1-g)Q_{Mt-1}.$$

The equilibrium quantity is a function of income, prices and time, or

$$Q^*_{Mt} = a + bY_{Ft-1} + c(P_M/P_R)_t + dT + u_t. \tag{10.12}$$

The term u_t is the residual in year t. Substituting the right side of (10.12) for Q^*_{Mt} in (10.11), model F is

$$\begin{aligned} Q_{Mt} = ag + bgY_{Ft-1} &+ cg(P_M/P_R)_t \\ &+ dgT + (1-g)Q_{Mt-1} + gu_t. \end{aligned} \tag{10.13}$$

Coefficients in the model may be estimated by least squares. The single estimated coefficient of Q_{Mt-1} is 1-g, from which the adjustment

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[27] Nerlove, Distributed lags and demand analysis, op. cit.

coefficient g may be found. The coefficients of the price and income variables are short-run coefficients. The long-run coefficients b and c in equation (10.12) are found by dividing the coefficients estimated in equation (10.13) by g. Variables included in model F are similar to those in model E, but the error structure in model F is somewhat less complicated. Thus, single-equation least squares is a more satisfactory estimational procedure if the adjustment model F rather than the expectation model E is appropriate. It is possible to combine expectation and adjustment models E and F into a single equation, but the necessary modifications tend to reduce the reliability of the coefficients estimated by least squares from time series.[28] If expectations and adjustments are both essential in the investment function, any one of several expressions from equations (10.2), (10.4), (10.6) or (10.8) might be substituted for Y_{Ft-1} in model F.

If a desired level of annual investment rather than stock is the goal of investment behavior, equation (10.13) is appropriate in the given form. But if a desired level of stock is the goal of investment behavior, then machinery stock S_M might be substituted for Q_M in the model F, or the following adjustment models might be used.

Model G

Conceptually, a principal basis for input purchases in agriculture is a subjective farm production function. Machinery inputs are an important resource in the production function, and the equilibrium or desired level of machinery input may be more nearly identified as the total stock of machinery than as annual gross investment. Investment in machinery during the current year then may be a function of the desired level of machinery inventory since machine services are distributed over several years, not only the year of purchase. Griliches proposes an adjustment model based essentially on this argument.[29] The actual adjustment in machinery inventories during year t is some proportion, g, of the desired or equilibrium change in inventories. The adjustment to the desired machinery stock is made gradually. Mathematically, the adjustment model is

$$(10.14) \qquad S_{Mt+1} - S_{Mt} = g(S^*_{Mt+1} - S_{Mt})$$

where S_{Mt+1} and S_{Mt} are machinery stocks on January 1 of year t+1 and t respectively. S^*_{Mt+1} is the desired or long-run equilibrium stock of machinery on January 1 of year t+1. Depreciation is assumed to be a constant proportion, h, of beginning year stocks. Equation (10.15) is an identity, indicating that

$$(10.15) \qquad S_{Mt+1} = Q_{Mt} + (1-h)S_{Mt}$$

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[28] Ibid., pp. 59-60.

[29] Griliches, The demand for inputs in agriculture, op. cit., p. 314.

stocks at the end of the year equal investment plus undepreciated carryover from last year. Rearranging terms, we may write (10.15) as

$$Q_{Mt} = (S_{Mt+1} - S_{Mt}) + hS_{Mt} . \tag{10.16}$$

Assuming the desired level of stocks, S^*_{Mt+1}, is

$$S^*_{Mt+1} = a + bY_{Ft-1} + c(P_M/P_R)_t + dT + u_t \tag{10.17}$$

and substituting the right side of (10.14) for the term in parentheses in equation (10.16), an investment model, G, is formed.

$$\begin{aligned} Q_{Mt} &= ag + bgY_{Ft-1} + cg(P_M/P_R)_t \\ &\quad + dgT + (h-g)S_{Mt} + gu_t \end{aligned} \tag{10.18}$$

The long-run coefficients b, c and d cannot be determined directly from model G because the values of h and g are not known. Although the values of g in (10.13) and (10.18) are not strictly comparable, the estimate from (10.13) (with S_M rather than Q_M the dependent variable) might be used to determine the long-run coefficients in equation (10.17). Also, a previous estimate of the rate of depreciation, h, is sometimes available. If so, g can be found from the least-squares coefficient (h-g) of beginning year stocks in equation (10.18).

Model G has several advantages. It explicitly recognizes machinery stock as an important variable in the investment process. The dependent variable, however, is annual investment Q_{Mt}, a more volatile and sensitive quantity. We are "explaining" considerably more if the annual investment, rather than total stock, is selected as the dependent variable. Furthermore, the error structure is not particularly complicated. A disadvantage of the model is the failure to identify separate values of h and g.

Model H

It is possible to formulate an investment function using the assumptions underlying model G, but which provides estimates of g and h.[30] A slight modification is made in equation (10.17), though it is not necessary in the formulation. Since current income may influence investment, equation (10.17) is modified to form equation (10.19).

$$S^*_{Mt+1} = a + bY_{Ft} + c(P_M/P_R)_t + dT + u_t \tag{10.19}$$

Using the assumptions embodied in equations (10.14), (10.15) and (10.19), the following investment model, H, is derived where B = bg,

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[30] Nerlove, Distributed lags and demand analysis, op. cit., pp. 86-93.

$C = -bg(1-h)$, $D = cg$, $E = -cg(1-h)$ and $F = dgh$. The residual V_t is $gu_t - g(1-h)u_{t-1}$, implying that equation (10.19) must follow a very complicated autoregressive pattern for V_t to be distributed randomly.

$$(10.20)\quad Q_{Mt} = A + BY_{Ft} + CY_{Ft-1} + D(P_M/P_R)_t + E(P_M/P_R)_{t-1} + FT + (1-g)Q_{Mt-1} + V_t$$

Assuming equation (10.20) is estimated by least squares from data transformed into logarithms, the following price elasticities of demand may be computed: for the short run (first year), D; for the intermediate run (two year), D + E; and for the long run, $D/g = c$. Similar estimates can be made of the elasticity with respect to Y_F. The value of the adjustment coefficient g can be readily estimated from the coefficient of lagged Q_M. Model H is overidentified and provides two estimates of the depreciation rate: $h = (C + B)/B$ and $h = (E + D)/D$. Nerlove suggests that the coefficients of the variable measured most accurately be used to estimate g. Given the value of h and g, the value of d may also be computed.

Model H is potentially useful because of the extended information provided by the coefficients. Its chief disadvantage is the frequent occurrence of lagged variables which tend to be highly correlated with current values in economic time series. Also the error structure is somewhat foreboding. Model H may be revised to conform with the investment specification of equation (10.17), rather than of equation (10.19), merely by lagging Y_F one year in each of the income variables in equation (10.20).

Model I

The investment model G may be modified slightly to allow determination of the adjustment coefficient g. Defining ΔS_{Mt} as $S_{Mt+1} - S_{Mt}$, equation (10.14) may be written as $\Delta S_{Mt} = gS^*_{Mt+1} - gS_{Mt}$. By substituting the expression for desired stocks from (10.17) into (10.14), model I (10.21) is formed.

$$(10.21)\quad \Delta S_{Mt} = ag + bgY_{Ft-1} + cg(P_M/P_R)_t + dgT - gS_{Mt} + gu_t$$

Model I, essentially a Koyck model, is model G with an adjustment of the dependent variable for depreciation.[31] This is obvious if we rewrite equation (10.15) as $\Delta S_{Mt} = Q_{Mt} - hS_{Mt}$ where net investment is equal to gross investment less depreciation. The advantage of model H is that it can be easily estimated, all coefficients are identifiable and the error structure is relatively uncomplicated. Model I is advantageous when estimates of investment stock S_M are available and annual investment

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[31] Koyck, L. M. Distributed Lags and Investment Analysis. Contributions to Economic Analysis. North-Holland Publishing Company. Amsterdam. 1954.

Q_M are unavailable. The dependent variable in model I is computed by taking first differences of S_M. After estimating the coefficients in model H by least squares, the short-run and long-run coefficients may be computed. It is possible, of course, to predict ending year stocks from the predicted change in stocks, $\Delta S'_{Mt}$, i.e.

$$S'_{Mt+1} = \Delta S'_{Mt} + S_{Mt} \, . \tag{10.22}$$

If the rate of depreciation h is known from other sources, gross annual investment Q'_{Mt} can be predicted as

$$Q'_{Mt} = \Delta S'_{Mt} - hS_{Mt} \tag{10.23}$$

and may be a useful approximation if h tends to be relatively constant.

An approximate description of the investment process depicted by models G and I aids in evaluating the coefficients of the models. Assume that product prices P_R increase 1 percent and that Y_F consequently increases 2 percent. According to the models, the first short-run effect is to reduce the real price of machinery, P_M/P_R, thereby encouraging some investment. Since expected income is based on past income variables, the farmer waits a year or more until he believes the income rise is "permanent." He then raises Q_M to the desired amount. In the intermediate run, after he has become subjectively certain of a favorable future income, he raises annual investment Q_M to the level necessary to reach the desired level of stock at the rate specified by the adjustment coefficient g.

The complete adjustment of annual investment is made long before the desired level of stock is reached in most instances. When the maximum response or long-run elasticity of annual investment to P_R is achieved, the response of stock to P_R is only partially complete and is called the "intermediate-run" elasticity. Three phases of stock elasticity with respect to P_R are apparent: (a) the short-run response with respect to $-P_M/P_R$, (b) the intermediate response with respect to (a) plus the P_R component of expected net income completed when Q_M reaches the desired level and finally (c) the long-run response completed when the adjustment to the desired level of stock is achieved. The desired level of stock is reached when the inventories no longer grow, i.e. when $Q_{Mt} = hS_{Mt}$. Depreciation has reached a sufficient level to consume annual gross investment.

Model J

Under different assumptions, structural models such as I may be identically specified but with alternative interpretations of the coefficients. Assume that farmers are unconcerned about stock levels but only derive satisfaction from the purchase of new machinery. Further assume that they adjust immediately to this satisfactory level of purchases when they become subjectively certain on the basis of past year income that earnings will be favorable for purchasing the input. The demand equation is correctly specified as

$$(10.24) \qquad Q_{Mt} = a + bY_{Ft-1} + c(P_M/P_R)_t + dT + u_t .$$

Suppose that the right side of identity equation (10.15) is substituted for Q_{Mt}

$$(10.15) \qquad Q_{Mt} = \Delta S_{Mt} + hS_{Mt}$$

in equation (10.24). The resulting equation, after rearranging terms is

$$(10.25) \; \Delta S_{Mt} = a + bY_{Ft-1} + c(P_M/P_R)_t + dT - hS_{Mt} + u_t .$$

The phenotypes (variables included in the least-squares equations) of models I and J are exactly alike. But the genotypes (true structure) of the two models are quite different. Without a priori knowledge of the investment structure, it is difficult to interpret the coefficients correctly. The model dramatizes the need for caution in interpreting the results of structured equations. Interpretation of the coefficient of lagged stock as the depreciation rate h (model J) when it actually is the adjustment rate g (model I) ~~would~~ be disconcerting indeed. Surprisingly, this does not necessarily lead to ambiguity in interpreting the short- and long-run price and income elasticities. The short-run coefficient of stock with respect to $(P_M/P_R)_t$ in model I is the least-squares coefficient of the price variable in equation (10.21). The long-run coefficient is the short-run coefficient divided by the adjustment rate g.

For model J, the short-run coefficient of stock with respect to $(P_M/P_R)_t$ again is the least-squares coefficient of the price variable in equation (10.25). Determination of the long-run coefficient is more subtle, however. In the long run, the equilibrium level of stock S^*_{Mt+1} is reached when

$$(10.26) \qquad S^*_{Mt+1} + S_{Mt} ,$$

that is, when net additions to stock become zero, or

$$(10.27) \qquad \Delta S_{Mt} = 0 .$$

On the basis of equation (10.27), the right side of equation (10.25) is equated to zero, and the long-run equilibrium level of stock occurs when

$$(10.28) \qquad a + bY_{Ft-1} + c(P_M/P_R)_t + dT = hS_{Mt} .$$

Substituting the equilibrium stock relationship from equation (10.26), and dividing through by h, the expression for equilibrium stock is

$$S^*_{Mt+1} = \frac{a}{h} + \frac{b}{h} Y_{Ft-1} + \frac{c}{h} (P_M/P_R)_t + \frac{d}{h} T . \tag{10.29}$$

It follows that for model J, the long-run coefficient of stock with respect to price is the least-squares coefficient of the price variable divided by the least-squares coefficient of the lagged stock variable. This is exactly the same coefficient and procedure as used for computing short- and long-run price responses from model I. Despite the different form of the equations, the estimates of price and income responses are the same. Less emphasis, therefore, need be given to determining whether model I or J is appropriate.

Numerous other models of value in explaining investment behavior could be presented. For example, adjustment and expectation models might be formulated with ending year stock as the dependent variable. In most of the analysis which follows, however, we select to explain net or gross annual investment. This approach better relates to farmer decision processes and variables important to them in defining the structure of agriculture. We are, of course, interested in eventual explanation of the resource structure of agriculture. If we have information about the parameters determining quantities in annual investment equations, inferences can be made about total stock by use of models such as G, H and I.

Most of the models explained above are modified in the process of estimation in the quantitative analysis of later chapters. Perhaps the most successful models are those resulting from relatively simple expectation models, such as those in equation (10.2), (10.4), (10.6) and (10.8) combined with adjustment models G and I. The terminology used in subsequent chapters generally refers to the models outlined in this chapter.

11.

Machinery and Equipment

AS CHAPTERS 2 and 4 indicate, some of the major structural changes in agriculture have revolved around farm machinery. Machine capital not only has been a direct substitute for labor, but also the fixed costs associated with it provide cost advantages for larger units and create pressures for increased acreage per farm. Certainly a major portion of the decline in the agricultural labor force and in farm numbers must be attributed to mechanization. The process of mechanization is quantified as the demand for farm machinery.

On the surface it would appear that demand functions for machinery and farm labor might be easily and simultaneously specified through relative prices of the factors and change in technical coefficients. Quantification of labor and machinery demand relative to each other is difficult from time series data, however, because of multicollinearity in the several sets of relevant observations. Relative prices of labor and machinery, labor inputs of agriculture and mechanization are all highly intercorrelated through time.

In an aggregate sense, machinery also is a substitute for certain biological forms of capital. For example, more timely cultivation which controls weeds and increases yields is a substitute for weedicides. On an individual farm basis, mechanization is an economic complement with land inputs, due to the cost economies mentioned earlier. It is a technical complement with fuel and similar operating inputs. Again, however, because of the nature of the time series data, the exact relationships are not easily quantified.

The demand functions in the first part of this chapter largely represent an application of the investment concepts and models outlined in Chapter 10. The models outlined in the latter chapter are applied to all farm machinery, motor vehicles and machinery other than motor vehicles. Demand functions, following alternative models, then are presented for some specific categories of machines. The investment functions outlined in Chapter 10 are extended to include even broader aggregates of capital in Chapter 12.

THE DEMAND FOR ALL FARM MACHINERY

In this section the demand for all farm machinery is estimated by least-squares and limited information techniques, the function being specified in some detail in Chapter 10.

The Variables

The variables included in the least-squares demand equation are as follows:[1]

Q_{Mt} = the dependent variable and a weighted national aggregate of motor vehicle and other machinery purchases for the current calendar year. Quantities are weighted by 1935-39 prices prior to 1940 and by 1947-49 prices after 1940. Observations are in millions of 1947-49 dollars. Because the dependent variable roughly is a first difference of stocks, the statistical equations are estimated only in original values and logarithms of original values. The productive portion of machinery purchases (40 percent of automobiles) is included.

$(P_M/P_R)_t$ = the current year index of the ratio of the price of all farm machinery to prices received by farmers for crops and livestock.

$(P_M/P_H)_t$ = the current year index of the ratio of the price of all farm machinery to the hired labor wage rate.

S_{Mt} = the stock of productive farm machinery on January 1 of the current year in millions of 1947-49 dollars.

S_{Pt} = the total stock of productive assets in billions of 1947-49 dollars on January 1 of the current year including: real estate, machinery, livestock, feed, and cash held for productive purposes.

E_{t-1} = the past year ratio of proprietors' equities to total liabilities in agriculture.

Y_{Ft-1} = the net income of farm operators from farming during the past year, deflated by the index of prices paid by farmers for items used in production, including interest, taxes and wage rate. Net income includes cash receipts, government payments and nonmoney income less production expenses.

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[1] Sources of these and other time series variables in this study are in Tweeten, Luther G. An Economic Analysis of the Resource Structure of U.S. Agriculture. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962.

Y_{DFt-1} = the declining three year arithmetic average of Y_F.

$$Y_{DFt-1} = \frac{3\ Y_{Ft-1} + 2\ Y_{Ft-2} + Y_{Ft-3}}{6}.$$

G_t = an index of government agricultural policies. Years when acreage allotments or production controls are in force are given the value -1. Years when farm prices are supported are assigned values of +1. If supports are fixed, an additional +1 is added. The values are summed to form the index G.

T = time, an index of the last two digits of the current year.

The price indices are expressed as a percent of the 1947-49 base, i.e. 1947-49 = 100. Variables are annual data for the United States from 1926 to 1959, excluding 1942 to 1947. The period is chosen to be long enough to allow variation in the variables and reasonably precise estimates of structural parameters. Since the variables are measured less accurately in earlier years, and since structural changes over extended periods cannot be accommodated in the models, observations prior to 1926 are not used. The years 1942 to 1947 are omitted because of farm machinery rationing during the period. During these years, explanatory variables in "true" demand structures would predict a higher demand quantity that it was possible to fill. Hence inclusion of data for these years when estimating structural relationships would result in biased parameter estimates. It can be argued that the demand structure had not returned to normal for several years following 1948. However, estimation of a function for years following (say) 1954 would not be possible.

Agricultural machinery has a low reservation price and marginal value productivity outside agriculture. Few opportunities exist to sell machinery during periods of farm depression to more prosperous sectors because the machinery is specialized to agriculture. Furthermore, severe income cycles in other sectors tend to be correlated with those of agriculture, further limiting the sale of surplus machinery. The maximum rate of decline in machinery stocks during an economic downswing largely is governed by the depreciation rates.[2] The limit on stock expansion is quite different, thus the optimum approach might include estimation of separate demand functions for expansion and depression periods. This procedure is not followed in this study because mechanization was only "well started" during the last major depression and sufficient time series observations are not available.

Structural changes which relate to farm machinery demand have been especially important since 1926. The quality and size of many

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[2] The USDA estimate of average annual depreciation on all farm machinery is approximately 20 percent. This suggests potential for a comparatively rapid decline in machinery inputs with unfavorable prices. The above depreciation rate essentially is for accounting purposes, however, and machinery services as a farm resource decline less rapidly.

farm machines themselves have changed. A 1926 unit of machinery (e.g. tractor) is not strictly comparable to a 1959 unit, and it is not possible to compensate completely for quality change. Weighting quantities by prices partially compensates for this difference, because the improved unit of machinery is weighted by a higher price. The total number of machines may be the same, but the "quantity" weighted by prices may be greater if the improvement is reflected in the price.

The structure and magnitude of gross farm income have also changed greatly since 1926. Gross receipts are much greater because resources previously used to provide farm power (seed, feed, breeding stock, etc.) have been freed for sale. Substitution of nonfarm inputs has permitted greater farm product sales but also has added to cash costs. This structural change in income can be handled partly by use of net income rather than gross income as a variable relating to farmer capital position. Net income is included as a variable in the demand equations which follow to indicate the earning expectations and financial capabilities of farmers, measure farmers' expected return on durable resources and to correct for structural changes in farm income.

Least-Squares Demand Equations for All Machinery

Table 11.1 includes relevant statistics for machinery demand equations estimated by least squares. Some variables from the economic model presented in Chapter 10 are excluded either because they are insignificant (e.g., short-term interest rate) or because they are highly correlated with other variables (e.g., cropland per farm).

Only the coefficients of the variables $(P_M/P_R)_t$, E_{t-1} and T are significant in equation (11.1). The equation appears to indicate that lagged prices, S_p, G and the ratio of machinery and labor prices do not influence Q_M significantly. It should be remembered, however, that statistical complications (e.g., correlation among variables, observational errors, lack of variation in the data, etc.) may be important for the data under analysis. The relative prices of labor and machinery undoubtedly are influential in determining demand quantity of either resource.

To determine if both income and equity are important variables in the demand function, equation (11.2) includes both E and Y_F. The results indicate that either variable may be used. The inconsistent signs for E in the two expressions are caused by either the correlation between the income and equity variables or the inappropriateness of the

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[3] Regressions were run including farm size (cropland per farm) and the short-term interest rate. The farm size variable was significant, the interest rate variable was not. The equations predicted about as well as those in Table 12.1 because the farm size variable is highly correlated with other explanatory variables.

logarithm transformation.[4] Hence, either income or equity (never both variables) is included in later equations. Since the logarithm transformation does not reflect the influence of E, equations involving this variable are estimated only in original values.

Equations (11.3) and (11.4) are estimated to determine the importance of wages in the demand for machinery without complications caused by other variables. Again the coefficients of wages are not significant, perhaps because machinery prices and wage rates have been highly correlated over time. The two equations also provide some basis for evaluating the relevance of current or past prices in the demand function. The magnitude and significance of the coefficient of the current variable P_M/P_R are greater, the R^2 is higher and the tendency for autocorrelation, indicated by d, is somewhat less evident in equation (11.4). While past prices are important, the influence of past values of P_R and resource prices tend to enter through the current price and income or equity variables. Equation (11.3) with only lagged values of the predetermined variables is useful, however, for predicting machinery purchases in the coming year since $(P_M/P_R)_t$ is unknown. Still, the prediction may be biased if, as equation (11.4) indicates, the current price is important. As a possible improvement over the results suggested by the above two equations, the ratio of current machinery price and lagged prices received by farmers, P_{Mt}/P_{Rt-1}, was included in a least-squares equation (not shown) with other explanatory variables, E and T. The magnitude and significance of the coefficient of the price variable P_{Mt}/P_{Rt-1} were lower than similar quantities in equation (11.5), and the modified price was rejected in favor of current price. (The current price ratio also represents some influence of past prices.)

The three variables in equation (11.5) explain 97 percent of the variation about the mean of Q_M, and the coefficients of each are highly significant. The test of the null hypothesis that the residuals are

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[4] The simple correlation between Y_{Ft-1} and E_{t-1} in original values is -.87. The matrix of simple correlations between other specified variables in original values O and logarithms L is as follows:

		$(P_M/P_R)_t$	E_{t-1}	T	S_{Mt}
Q_{Mt}	O	-.48	.95	.80	.77
	L	-.54	.86	.75	.74
$(P_M/P_R)_t$	O	--	-.30	.05	-.08
	L	--	-.23	.10	-.09
E_{t-1}	O	--	--	.83	.81
	L	--	--	.89	.89
T	O	--	--	--	.91
	L	--	--	--	.89

The simple correlation between E and Q_M falls substantially when the variables are transformed to logarithms; thus the relationship between Q_M and E appears to be linear in original values. The insignificance of the coefficient of E in the logarithm equations is ascribed to a situation where the logarithm transformation is not appropriate. It should be noted that the time variable, T, is always in original values.

Table 11.1. Demand (Annual Gross Investment) for All Farm Machinery, Q_M, Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1947; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Transformation and Model†	R^2	d‡	Constant	P_M/P_R t	P_M/P_R t-1	P_M/P_H t	P_M/P_H t-1	S_P t	E t-1	Y_F t	Y_F t-1	Y_F t-2	Y_{DF} t-1	G t	T	Q_M t-1	S_M t
(11.1-O) B	.97	1.86	1954.30	-8.99	.83		-.70	-16.37	98.85					5.45	40.52		
				(1.59)	(2.36)		(1.63)	(11.73)	(33.02)					(6.64)	(11.97)		
(11.2-O) AB	.97	1.47	535.75	-7.66					100.99		.030				27.00		
				(1.32)					(27.62)		(.024)				(5.87)		
(11.2-L) AB	.97	1.77	2.27	-1.42					-.41		.81				.0218		
				(.17)					(.15)		(.17)				(.0028)		
(11.3-O) B	.92	1.23	188.94		-6.91		1.51		145.20						26.63		
					(2.90)		(1.96)		(36.83)						(12.60)		
(11.4-O) B	.97	1.38	766.78	-8.82		.41			126.01						27.45		
				(1.77)		(1.30)			(20.87)						(7.56)		
(11.5-O) B	.97	1.37	852.25	-8.41					124.60						25.99		
				(1.18)					(20.00)						(5.87)		
(11.6-O) A	.95	1.27	-111.99	-7.98							.092				42.63		
				(1.63)							(.022)				(4.94)		
(11.6-L) A	.96	1.22	2.94	-1.29							.57				.0156		
				(.18)							(.16)				(.0017)		
(11.7-O) A	.96	1.28	-191.26	-7.46							.056	.048			39.61		
				(1.46)							(.023)	(.018)			(4.54)		
(11.7-L) A	.96	1.26	3.01	-1.30							.59	-.034			.0157		
				(.19)							(.19)	(.144)			(.0018)		
(11.8-O) C	.97	1.29	-168.19	-7.57									.107		38.62		
				(1.26)									(.017)		(4.14)		
(11.8-L) C	.95	.98	3.87	-1.47									.42		.0167		
				(.19)									(.19)		(.0019)		
(11.9-O) BF	.97	1.43	771.38	-7.63					99.83						23.33	.15	
				(1.33)					(27.95)						(6.17)	(.12)	
(11.10-O) F	.96	1.41	109.92	-6.69							.056				31.39	.30	
				(1.58)							(.025)				(6.53)	(.12)	
(11.10-L) F	.96	1.19	2.98	-1.28							.53				.0153	.030	
				(.19)							(.23)				(.0021)	(.127)	
(11.11-O) BG	.97	1.57	760.25	-8.83					126.01						35.20		-.038
				(1.17)					(19.35)						(7.98)		(.023)

(11.12-O) G	.95	1.26	-122.34	-8.17			.091	45.36	-.0099
				(1.75)			(.022)	(9.69)	(.0300)
(11.12-L) G	.97	1.43	4.06	-1.41			.56	.0202	-.28
				(.18)			(.15)	(.0027)	(.13)
(11.13-O) H	.97	1.86	-648.85	-5.65	4.35	.045	.063	13.24	.46
				(2.10)	(2.22)	(.024)	(.025)	(7.72)	(.12)
(11.13-L) H	.98	2.04	-.61	-1.36	.85	.21	.70	.0072	.29
				(.29)	(.32)	(.20)	(.20)	(.0027)	(.13)

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*Composition of the dependent variable, Q_M, and the indicated independent variables are discussed in the text.

† Equations estimated in original observations are designated by O; in logarithms of original observations by L. The time variable, T, is in original values in the L equations. Also $Y_{DF_{t-1}}$ in the logarithm equations is the logarithms of the simple declining arithmetic average. Expectation and adjustment models are presented in Chapter 10.

‡ The Durbin-Watson autocorrelation statistic d. Values near 2.0 indicate a random distribution of residuals, values less than 2 and approaching 0 indicate increasing positive autocorrelation, and values greater than 2 and approaching 4 indicate increasing negative autocorrelation. For probabilities see Friedman, Joan, and Foote, Richard J. Computational methods for handling systems of simultaneous equations. USDA Agr. Handbook 94. 1957.

uncorrelated is inconclusive. Model B, employing variable E which is a measure of farmers' financial position (and a proxy variable representing income expectations), apparently is one useful equation for expressing demand for farm machinery.

The remaining equations in Table 11.1 are included to evaluate the relevance of other distributed lag models. Equations (11.6) and (11.7) are model A (Chapter 10) with income lagged one and two years, respectively. While the logarithm transformation in (11.7) would indicate that income before the past year is not important in determining demand for machinery, the coefficient of Y_{Ft-2} in (11.7-O) is highly significant. The magnitudes of the lagged coefficients thus might indicate that incomes prior to the year t-2 also influence current demand. It seems appropriate to assume some structure of the coefficients permitting estimation of the lag with fewer variables. Equation (11.8), model C, is used where Y_{DFt-1} is a declining three year average of farm income. The coefficient of the variable is highly significant and is slightly larger than the combined coefficients of the two income variables in equation (11.7-O). The R^2 is increased by each additional income variable in equations (11.6-O), (11.7-O) and (11.8-O), and we select the last equation as "best" for prediction purposes.

Equations (11.1) to (11.8) essentially are expectation models. The appropriateness of the adjustment models F, G and H may be judged from equations (11.9) to (11.13). Equation (11.9) combines expectation model B and adjustment model F. The low significance of the coefficient of Q_{Mt-1} would suggest that farmers adjust purchases to the desired or equilibrium level in the short run if they are subjectively certain of favorable prices, income and other explanatory variables; and that the adjustment model is inappropriate for annual gross investment. Equation (11.10), however, indicates that if expectations are not adequately represented in the model, the adjustment coefficient may be significantly different from unity.

While annual machinery investment may be adjusted to the desired level in the short run, a long time may be required to reach the desired stock level. Thus, models B and G are combined to estimate the adjustment to the desired level of stocks (11.11). The coefficient of the lagged stock variable is not significant, suggesting that the adjustment coefficient, g, and depreciation rate, h, (see Chapter 10) are equal to each other. Since the depreciation rate is expected to lie somewhere between .14 and .25, the adjustment coefficient, g, is also expected to be within that range. Equation (11.12-L), however, indicates that the adjustment coefficient is somewhat larger.[5]

The R^2 is large and autocorrelation is not significant in the adjustment model H (equation 11.13). The positive sign of the past year price variable, $(P_M/P_R)_{t-1}$, does not appear reasonable, and the

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[5] It is interesting to note that if g=h as indicated by (11.11) and (11.12-0), omission of lagged stock from the investment function causes few statistical complications (see model G, Chapter 10). Equations such as (11.5) and (11.8) then may serve as satisfactory expressions of machinery demand.

adjustment coefficient .54 in (11.13-O) is inconsistent with estimates of g in other equations.

The machinery demand models in Table 11.1 which assume net farm income to be an expectational variable appear appropriate in the equations estimated in original data. The logarithm equations, based on the R^2, d and a priori knowledge, give less acceptable coefficients. The more acceptable linear demand function is consistent with a quadratic production function (a linear marginal value productivity as in Chapter 6) for expressing physical relationships in agriculture.[6]

Limited Information Demand Equation for All Farm Machinery

Demand for all farm machinery, as part of an interdependent market structure with other farm resources and farm output, is now estimated by limited information. The result is:

$$(11.14)\quad Q_{Mt} = 11907 - \underset{[-5.7]}{90.1\, P_{Ot}} - \underset{[-.3]}{5.0\, P_{Mt}} - \underset{[-2.9]}{59.2\, P_{Ht}} + \underset{[3.4]}{70.8\, P_{Rt}}$$

$$- \underset{[-4.3]}{113.9\, N_t} - \underset{[-.15]}{1.7\, (P_M/P_R)_{t-1}} + \underset{[.8]}{197.0\, E_{t-1}}$$

$$+ \underset{[2.8]}{66.3\, r_{S_{t-1}}} - 6.6\, T\ .$$

The demand quantity, Q_M, the number of farms, N, operating input price, P_O, machinery price, P_M, hired labor price, P_H, and farm output price, P_R, are endogenous variables. The equity ratio, E, short-term interest rate, r_S, time, T, and $(P_M/P_R)_{t-1}$ are predetermined variables. The variable, r_S, is coded as 100 times the short-term interest rate. Price variables are adjusted to a 1947-49 base and are deflated by the implicit deflator of the Gross National Product. The data extend from 1926 to 1959, omitting 1942 to 1945.[7] Standard errors were not computed. Elasticities, computed at the arithmetic mean of original observations for the 1926-59 period, are included in brackets below the coefficients of all variables except time, T, to aid in interpretation of the results.

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[6] Some error may be introduced because the expectation variables are logarithms of simple arithmetic aggregates rather than the sum of logarithms in the "L" equations. Other specification and aggregation procedures might improve the comparability of the estimates from different transformations. The more favorable estimates from equations estimated from original data might result since the linear form may best approximate demand relationships in the particular period studied. Selection of a different period might reveal advantages of other transformations.

[7] Rather than sacrifice the data for 1946 and 1947 in the entire model because the backlog of demand for machinery had not been filled, the data for machinery are "corrected" for the condition by using predicted values of Q_M for 1946 and 1947 from a single-equation least-squares demand function estimated from data not including these years.

Table 11.2. Elasticities of Demand for Annual Investment in Machinery, Q_M, and for Machinery Stocks, S_M, With Respect to Price and Net Farm Income Computed From Selected Equations in Table 11.1[*]

Equation, Transformation and Model[†]	Elasticity of Q_M With Respect to:				Elasticity of S_M With Respect to:					
	P_M[‡]		P_R		P_M			P_R		
	Short run (1-2 years)	Y_F[§]	Short run[‡] (1-2 years)	Long run[#] (3-4 years)	Short run[**] (1-2 years)	Long run[††] (many years)	Y_F	Short run[**] (1-2 years)	Intermediate run[‡‡] (3-4 years)	Long run[§§] (many years)
(11.5-O) B	-.79	.79	.79	2.37	-.18	-.90	.18	.18	.54	2.70
(11.8-O) C	-.71	.74	.71	2.19	-.16	-.80	.17	.16	.49	2.45
(11.8-L) C	-1.47	.42	1.47	2.31	-.33	-1.65	.10	.33	.52	2.60
(11.11-O) BG	-.83	.80	.83	2.43	-.19	-.95	.18	.19	.55	2.75

[*] See the text and Table 11.1 for discussion of data, methodology, coefficients, standard errors and related statistics.

[†] Elasticities for data in original values are computed at the full-period means.

[‡] Computed from the coefficient of current price, $(P_M/P_R)_t$.

[§] Computed from the sum of lagged income coefficients. The equity ratio, E, rather than income was included in equations (11.5) and (11.11). The coefficient of E was translated into elasticities with respect to Y_F by the least-squares regression

$$(a) \quad E_{t+1} = -5.57 + \underset{(.24)}{.71}\ Y_{Ft} + \underset{(.24)}{.86}\ Y_{DFt-1}, \qquad R^2 = .80$$

where E_{t+1} is the January 1 equity ratio, Y_F is net farm income and Y_{DF} is a declining three year average of Y_F. The variables are annual data in logarithms from 1926 to 1941 and 1946 to 1959.

[#] The sum of the short-run elasticity plus the component P_R of Y_F, assumed to be twice the income elasticity based on the equation in text, footnote 9. For equation (11.8-O), the elasticity is .71 + (2.0)(.74) = 2.19.

[**] Found by multiplying the elasticity of Q_M with respect to $(P_M/P_R)_t$ by the ratio of mean of Q_M to S_M.

[††] The short-run elasticity divided by the adjustment coefficient .20. The adjustment coefficient approximately is equal to the depreciation rate according to (11.11-O). The USDA estimated the machinery depreciation to be .19 percent of beginning year stocks for each of the six years from 1955 to 1960.

[‡‡] Found by multiplying the ratio of means by the long-run elasticity of Q_M with respect to P_R. This is the approximate response in total stock after Q_M has been increased to the desired level.

[§§] The intermediate-run elasticity divided by the assumed adjustment coefficient, as indicated in footnote ††. The long-run elasticity is the maximum level of stock achieved after an increase in P_R, and may not be reached for several years. If the adjustment coefficient is .20, approximately 90 percent of the total adjustment will be completed in 10 years.

The equation conforms with the least-squares functions in suggesting that the quantity demanded is more responsive to current price of machinery than to lagged price. The elasticity of machinery demand with respect to farm numbers, N, is -4, indicating that a 1 percent decrease in farm numbers tends to be associated with a 4 percent increase in machinery sales. We again run into difficulty with labor price, the P_H coefficient being negative and indicating labor and machinery to be short-run complements. The signs of the P_O and P_R coefficients are as expected, but the coefficients are unusually large.

Of predetermined variables, the coefficient of the equity ratio is larger than in the least-squares equation (11.5). The sum of P_M coefficients (-6.7) is slightly less in absolute value than the coefficient of price -8.4 in (11.5). The r_S and T coefficients in (11.14) conflict with a priori considerations possibly because the gradually changing r_S variable absorbed the influence of the time trend and vice versa. We conclude that the limited information equation, as we have specified it, is less acceptable than selected ones of our least-squares equations for expressing machinery demand.[8]

Price and Income Elasticities of Demand for All Machinery

Table 11.2 includes elasticities of demand for annual purchases, Q_M, and stock, S_M, with respect to prices and expected income for selected equations in Table 11.1. The elasticity of annual investment with respect to P_M or P_R approximately is unitary in the short run. The percentage increase in stock is less than one-fourth this amount because of the greater initial quantity. P_M essentially is a short-run variable and is not assumed to be a part of expectations, hence the elasticity of Q_M with respect to P_M is the same in the short and long run.

Because of the importance of P_R in Y_F, the long-run elasticity of Q_M with respect to P_R is greater than the short-run elasticity. Two equations are needed to translate E in equations (11.5) and (11.8) into P_R. The equations containing E but not Y_F can be translated by assuming that E is generated from past income. To determine the relationship between income and equity, the following least-squares equation (11.15) was computed from logarithms of annual data extending from 1926 to 1941 and 1946 to 1959.

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[8] The limited information equation may be less satisfactory than selected least-squares equations because of the nature of the identification process. Those equations in the simultaneous model which are of greatest interest tend to be specified in detail. Equations of least interest tend to be specified less fully. But the conditions for identification indicate that the tendency for underidentification is most likely to be found in the equations including the greatest number of variables (most adequately specified). Unwittingly, the researcher gets less satisfactory results from the equations in which he has greatest interest because of a tendency for underidentification. Also, some difficulties undoubtedly arise because of multicollinearity when many variables are specified in the equation. Some variables were omitted, of course, to reduce collinearities in the matrix of predetermined variables of the reduced-form equations.

$$(11.15) \qquad E_{t+1} = -5.57 + \underset{(.24)}{.71Y_{Ft}} + \underset{(.24)}{.86Y_{DFt-1}}, \qquad R^2 = .80$$

Equity is estimated as a function of net income Y_F and a declining average of net income Y_{DF}. The equation indicates that a sustained rise of 1 percent in net income will increase the equity ratio 1.57 percent. Since the elasticity of Q_M with respect to E in (11.5) is .50, the elasticity with respect to Y_F is approximately (.50) (1.57) = .79. The result is similar to the results of (11.8-O) in which income was directly included. The implication is that model B provides a relevant proxy variable for net income in the investment function.

A definitional equation used to relate net income to P_R/P_P provided a basis for translating net income into prices. The estimated elasticity of net income with respect to P_R/P_P is 2.0.[9] Therefore the elasticity of Q_M with respect to P_R computed from the income component of (11.5) is approximately (2.0) (.79) = 1.58. The total long-run elasticity of Q_M with respect to P_R is therefore .79 (due to P_M/P_R) plus 1.58 (due to E), or 2.37. The result agrees favorably with the estimates of other equations and indicates that a 1 percent increase in P_R tends to raise annual investment slightly more than 2 percent in the long run. Some disparity exists between the original value and logarithm equations in allocating the influence of P_R in P_M/P_R and Y_F. Since the logarithm equation tends to allocate more influence to P_M/P_R and less to Y_F, the short-run elasticity is greater in equation (11.8-L), but the long-run elasticities are surprisingly similar between transformations.

Once the desired level of annual purchases is reached, the stock of machinery continues to grow until gross investment equals depreciation. The maximum (long-run) level of stocks is reached much later than the maximum (long-run) level of annual investment. The estimates of stock elasticities in Table 11.2 are computed basically from the annual investment elasticities. The ratio of the investment mean to the stock mean was multiplied by the annual investment elasticities to form the short-run and intermediate-run stock elasticities. The long-run elasticity is based on equations (11.11-O) and (11.12-O), which indicate that the adjustment and depreciation rates are approximately

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[9] The definitional equation relating net income, Y_F, to prices paid, P_P, and prices received, P_R, by farmers for the specified period is

$$Y_{Ft} = K + \underset{\underset{[1.66]}{(13)}}{174(P_R/P_P)_{1910-25}} + \underset{\underset{[1.68]}{(15)}}{192(P_R/P_P)_{1926-41}} + \underset{\underset{[1.99]}{(12)}}{211(P_R/P_P)_{1946-59}}$$

$$d = 1.91 \qquad R^2 = .94$$

where K refers to the constant and other variables such as technology in the equation. Based on the equation, estimated from 1910-59 untransformed observations (excluding 1942-45), the marginal response of net income to a given price change is increasing over time. The average elasticity, in brackets, was 1.66 for 1910-25 and 1.99 for 1946-59. For further details see Tweeten, op. cit., Appendix B.

equal. From prior knowledge of the depreciation rate, the adjustment rate is assumed to be .20. Results in Table 11.2 suggest that stock is relatively unresponsive to changes in price in the short and intermediate run, a 1 percent rise in prices received, P_R, tending to raise stock only by one-fifth of 1 percent in the first one or two years. However, in several years stock may be increased between 2 and 3 percent.[10] The length of time required to reach this percentage depends on the adjustment rate. Because prices received by farmers fluctuate more extremely than machinery prices, a major portion of the past variation in investment activity is associated with farm output price, P_R.

Cromarty's least-squares estimates of short-run demand elasticities for machinery purchases with respect to P_M is -1.0, P_R is .7.[11] His results agree quite closely with those of this study. Cromarty makes no estimate of long-run elasticities, but if we use the above estimate to translate income elasticity to price elasticity, the long-run elasticity of annual purchases with respect to P_R is .7 plus (2.0) (.5) = 1.7. His study also includes farm assets as an explanatory variable, and if the P_R influence on assets is included, the total elasticity might be very near the estimates of this study.

Trends and Projections in All Machinery Purchases

Figure 11.1, showing actual and predicted values of annual farm machinery purchases, illustrates the wide variations which have taken place in purchases. The pattern reflects especially the importance of relative machinery and farm product prices and net farm income. Machinery purchases are much more sensitive than operating input purchases (see Chapter 13) to changes in prices received by farmers. Machinery purchases fell sharply in the depression years and again in 1938 when farm output prices dropped appreciably and farm machinery prices remained highly constant. Improved machinery, new models, favorable prices and other factors undoubtedly contributed to the large amount of purchases in the late 1940's. As the backlog of machinery orders was filled and farm income declined, demand for machinery fell rapidly in the 1950's. Based on actual observations, the downward

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[10] The number of years, N, required for a specified proportion, A, of total adjustment, given the adjustment rate, g, is

$$N = \frac{\log (1-A)}{\log (1-g)} .$$

If A = .9, g = .2, then N = 10. That is, 10 years are required to make 90 percent of the adjustment to the equilibrium level of machinery stock. The number of years required for the adjustment of stock is conservative because the formula assumes the annual investment is at the equilibrium level. Because three or four years are required for annual investment to reach this level, an adjustment may be made in the time required to reach the equilibrium level of stock by adding two or three years to N above.

[11] Cromarty, William A. The demand for farm machinery and tractors. Michigan Agr. Exp. Sta. Bul. 275. East Lansing. 1959. p. 40.

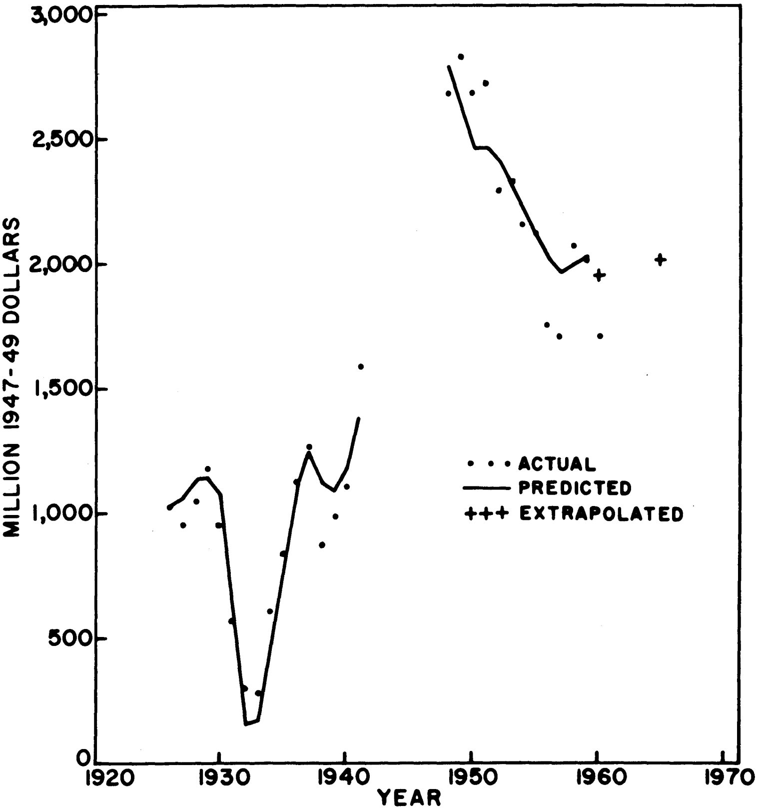

Figure 11.1. Trends in purchases of all farm machinery Q_M from 1926 to 1960 (predicted and projected estimates from equation 11.8-O).

trend in machinery demand, during the postwar era analyzed, showed few signs of reversal.

Although (11.8-O) appears, statistically, to be one of the better predicting models, our ex post comparisons show that it errs quite extremely in periods of rapid downturn in demand. As an example, the extrapolated value for 1960 considerably overestimates the actual quantity (a preliminary estimate).

Machinery purchases, projected for 1965 from (11.8-O), depend on the assumed future values of the major independent variables, prices and net farm income. The projected estimate is based on net income at the 1955-59 average value. Relative price P_M/P_R has increased 10 percent in the five years preceding 1960, and also is assumed to increase the same percentage from 1960 to 1965. The projected purchases, approximately 2 billion 1947-49 dollars, are slightly greater than the predicted 1960 value. At current depreciation rates, nearly 2 billion 1947-49 dollars gross investment is required to maintain existing stock. Thus, the projected gross investment is consistent with a projection of no appreciable change in stock level for 1965.

The projections imply (based mainly on technological and other influences reflected in the time variable) that the downward postwar trend in purchases will not continue. The extent to which the projections are realized depends on the structural validity of the equation and also on the prices received by farmers, the most volatile element in the price and income variables.

Limited Information Supply Estimate for All Farm Machinery

The decoded supply equation for all farm machinery paralleling (11.14) is

$$(11.16) \qquad P_{Mt} = -18.75 + \underset{(.0084)}{.0218\ Q_{Mt}} + \underset{(.27)}{.93\ P_{ISt}} - \underset{(.17)}{.32\ C_t}$$

where P_M is defined previously, P_{IS} is the wholesale price of iron and steel and C is a structural variable with a value of zero in each prewar year and 100 in each postwar year. Prices are deflated by the general price deflator of the Gross National Product, with the base 1947-49 = 100. The period analyzed again is 1926-59 with 1942-45 excluded.[12]

The computed price elasticity of machinery supply is 2.92. The coefficient of Q_M is more than twice the standard error (in parentheses) and probably is not equal to zero. The coefficient indicates the price flexibility, and if it is near zero the supply elasticity is very large. The approximate confidence limits for price elasticity, computed from the inverse of two standard deviations on each side of the price flexibility coefficient, are 1.8 to 4.1. The estimate indicates that the short-run elasticity of machinery supply is high, but not infinite. In an earlier, slightly modified and less acceptable structural model containing the same variables as in equation (11.16) but with actual rather than predicted values of Q_M for 1946 and 1947, the coefficient of Q_M was smaller than the standard error, a result consistent with the hypothesis that machinery supply is perfectly elastic. Although equation (11.16) indicates supply is not infinitely elastic, price is suggested to be relatively unresponsive to quantity changes in the short run.

The quantitative estimates are consistent with the discussion in Chapter 3; that is, the low supply elasticity for labor (Chapters 8 and 9) and high supply elasticity for machinery are a basis for low labor returns in agriculture.

The conclusion that farmers are price takers (quantity a function of price) and manufacturers are price setters (price a function of quantity)

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[12] To adjust for the latent demand in 1946 and 1947, values of Q_M predicted by a least-squares equation, estimated without the two years, were used as observations in the simultaneous model for 1946 and 1947.

Table 11.3. Demand (Annual Gross Investment) Functions for Motor Vehicles, Q_{MV}, Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1947; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Transformation and Model †	R^2	d‡	Constant	P_{MV}/P_R t	P_{MV}/P_R t-1	P_{MV}/P_H t	P_{MV}/P_H t-1	S_P t	E t-1	Y_F t	Y_F t-1	Y_F t-2	Y_{DF} t-1	G t	T	Q_{MV} t-1
(11.17-O) B	.95	2.16	1332.91	-5.77	.95		-.04	-14.39	60.17					2.82	27.38	
				(1.21)	(1.78)		(1.28)	(8.71)	(23.43)					(4.71)	(8.96)	
(11.18-O) AB	.93	1.57	335.94	-4.33					56.36		.015				15.31	
				(1.09)					(21.48)		(.19)				(4.73)	
(11.18-L) AB	.93	1.52	2.33	-1.15					-.23		.59				.0189	
				(.21)					(.19)		(.22)				(.0037)	
(11.19-O) B	.88	1.39	-27.09		-3.97		1.68		91.21						14.40	
					(2.03)		(1.33)		(23.41)						(8.43)	
(11.20-O) B	.94	1.64	235.61	-6.11		1.35			72.62						19.39	
				(1.40)		(1.00)			(15.20)						(5.68)	
(11.21-O) B	.93	1.51	490.84	-4.72					68.66						14.87	
				(.97)					(15.17)						(4.67)	
(11.22-O) A	.91	1.43	-24.51	-4.55							.050				24.15	
				(1.21)							(.015)				(3.71)	
(11.22-L) A	.92	1.43	2.77	-1.08							.44				.0153	
				(.21)							(.18)				(.0021)	
(11.23-O) A	.93	1.46	-63.32	-4.25							.030	.026			22.40	
				(1.16)							(.017)	(.013)			(3.61)	
(11.23-L) A	.93	1.47	2.88	-1.09							.48	.059			.0155	
				(.22)							(.21)	(.165)			(.0022)	
(11.24-O) C	.93	1.47	-51.38	-4.31									.058		21.90	
				(1.04)									(.013)		(3.40)	
(11.24-L) C	.92	1.28	3.51	-1.22									.32		.0164	
				(.21)									(.20)		(.0023)	
(11.25-O) BF	.93	1.61	458.87	-4.41					61.18						13.70	.095
				(1.11)					(19.79)						(5.12)	(.159)
(11.26-O) F	.92	1.64	37.46	-3.92							.037				19.31	.22
				(1.26)							(.018)				(5.12)	(.16)
(11.26-L) F	.93	1.41	2.72	-1.12							.54				.0163	-.098
				(.22)							(.25)				(.0027)	(.167)
(11.27-L) H	.95	2.30	-.64	-1.17	.73					.25	.71				.0085	.11
				(.35)	(.38)					(.24)	(.24)				(.0033)	(.17)

*Composition of the dependent variable, Q_{MV}, and the indicated independent variables are discussed in the text.

†Equations estimated in original observations are designated by O; in logarithms of original observations by L. The time variable, T, is in original values in the L equations. Also, $Y_{DF_{t-1}}$ in the logarithm equations is the logarithm of the simple declining arithmetic average. Expectation and adjustment models are presented in Chapter 10.

‡The Durbin-Watson autocorrelation statistic d (see Table 11.1).

should not necessarily be inferred because we normalize on quantity in (11.14) and on price in (11.16). The limited information coefficients are independent of the direction of normalization, and the results would have been the same for the equations normalized on other endogenous variables.

The coefficient of P_{IS} indicates that a 1 percent increase in iron and steel price is predicted to raise machinery price 1 percent (11.16). The variable reflects the price of iron and steel, but also includes the effects of wage rates correlated with P_{IS}.

DEMAND FOR MOTOR VEHICLES ESTIMATED BY LEAST SQUARES

The specification of the demand function for motor vehicles is similar to the previous model for all farm machinery. The logic of the specification is similar to that discussed previously in this chapter and in Chapter 10. Variables included in demand functions for motor vehicles are:

Q_{MVt} = the dependent variable, a weighted two-price aggregate of motor vehicle purchases during the current calendar year expressed in millions of 1947-49 dollars. The variable, including tractors, trucks and the productive portion of automobile purchases (assumed to be 40 percent), is weighted as discussed in the previous section on all farm machinery.

$(P_{MV}/P_R)_t$ = the current year index of the ratio of prices paid by farmers for motor vehicles to prices received by farmers for crops and livestock.

$(P_{MV}/P_H)_t$ = the current year index of the ratio of prices paid by farmers for motor vehicles to the hired labor wage rate on farms.

The remaining variables specified in the demand function (S_p, E, Y_F, Y_{DF}, G and T) are discussed in the previous section on all farm machinery. Variables are annual data for the period 1926-59, with 1942-47 excluded and 1947-49 = 100 for price indices.

The Estimated Demand Equations

Coefficients, standard errors and related statistics for motor vehicle demand equations presented in Table 11.3 are similar to the results in Table 11.1. The price of motor vehicles relative to prices received in the current year, equity or income, and time appear to be the uniformly significant variables in the numerous equations estimated.

Equation (11.18) indicates that either income or equity, but not both variables, needs to be specified in a given demand equation. The three coefficients in equation (11.21-O) are all highly significant. The coefficients of G and P_{MV}/P_H in equations (11.17), (11.19) and (11.20) do not suggest that farm wage rates and government programs, as measured here, have played significant roles in the rising demand for farm machinery.

The additional lagged values of net income, in equations (11.22-O), (11.23-O) and (11.24-O), show the sum of income coefficients to increase from .050 to .056 to .058 as successive income variables are included in the respective equations. Increments in the magnitude of the coefficients and R^2 suggest that additional lags beyond t-3 might improve the equation very little.

One conclusion from Table 11.3 is that gross annual investment in productive motor vehicles might be expressed simply by the current price, $(P_{MV}/P_R)_t$, time, T, and by one or more variables such as E or Y_F expressing financial or income structure in the demand function. However, inconsistencies exist between equations estimated in original values and in logarithms. While each is an acceptable form and the degree of autocorrelation is not high in either, those estimated in original values more clearly reflect the influence of past income on motor vehicle purchases.

A demand equation, not included, was estimated with Q_{MV} a function of current price, past year income, cropland per farm, the short-term interest rate and time. The coefficient of the short-term interest rate was highly insignificant; the coefficient of the farm size variable was significant and negative. Because farm size is highly correlated with other variables, did not improve the R^2 appreciably and raises questions about the direction of causality, the variable was not retained in the equation. Current year machinery prices may be known and current year prices received unknown when machines are purchased. Accordingly, the ratio of current machinery price to past year prices received was included in the demand equation with other explanatory variables, E and T. This price variable was considered inferior to current price and was not retained in subsequent equations.

Price and Income Elasticities of Demand for Motor Vehicles

Demand elasticities for motor vehicles, Q_{MV}, are slightly lower but similar to those for all machinery in Table 11.2. Based on equations (11.23-O) and (11.24-O), the price elasticity of demand computed at the means for the entire period with respect to $(P_{MV}/P_R)_t$ is -.64. The demand elasticity with respect to Y_F computed from the same equations is .66. Using a definitional equation (see footnote 9) to translate income to price elasticity, the elasticity of Q_{MV} with respect to P_P is -(2.0) (.66) = -1.32, and with respect to P_R is .64 plus 1.32, or 2.0 in the long run. Similarly, the respective total elasticities of Q_{MV}

with respect to P_{MV} , P_P and P_R from equation (11.23-L) are -1.1, -.84 and 1.9. It appears that the instability in relative magnitudes of the price and income elasticities between the original value and logarithm equations may arise from the importance of P_R in the variables. The logarithm equation indicates a heavier weight for current price, the original value equations a heavier weight for income (past price). But the total long-run elasticity of Q_{MV} with respect to P_R is approximately 2.0 for both forms.

Because mean annual purchases are approximately one-fourth of the mean stock of motor vehicles, the percent increase in stock from a 1 percent increase in P_{MV}/P_R is (.25) (-.64) = -.16 based on equations (11.23-O) and (11.24-O). The elasticity of stock at the time (three or four years) when annual purchases have reached the desired level is referred to as the intermediate elasticity of stock. It is approximately (.25) (2.0) = .5 with respect to P_R according to the above equations. If we assume the adjustment coefficient is .2, the long-run elasticity of stock with respect to P_R is .5/.2 = 2.5. If .2 is the correct adjustment rate, approximately 10 years are required to make 90 percent of the adjustment to the long-run level of stock. The 1 percent increase in P_R is assumed to be sustained at the same value throughout the entire period, of course.

Trends and Projections of Motor Vehicle Purchases

The purchases of motor vehicles fell appreciably in the depression years, in 1938, and after the postwar high (Figure 11.2). In the immediate postwar years, farmers spent more than twice as much for motor vehicles as in 1940. The demand quantity in the postwar years began a downward trend that continued through the period analyzed. In some recent years, annual investment has been below the 1941 level.

Equation (11.24-O) is used for the "ex post predictions" in Figure 11.2. The extrapolated quantity for 1960 overestimates demand by a sizeable amount. The prediction error, larger than expected from normal sampling variation, may stem from failure to account for recent structural changes in the demand function.

Motor vehicle prices increased approximately 10 percent in the five years preceding 1960. Using a price ratio, P_{MV}/P_R , 10 percent above the 1960 price and net income at the 1955-59 average, the 1965 projected quantity is slightly greater than the predicted 1960 quantity. The 1965 projection is approximately the level of purchases required to maintain the 1960 stock of machinery, assuming the past 21 percent depreciation rate. Again the projections depend heavily on the underlying price and income assumptions. The projection quantity for 1965 is nearly the same as the predicted 1960 quantity because increasing relative price, depressing Q_{MV}, tends to compensate for increases in demand through improvements in vehicle quality and other factors embodied in the positive coefficient of T. Other values of prices and

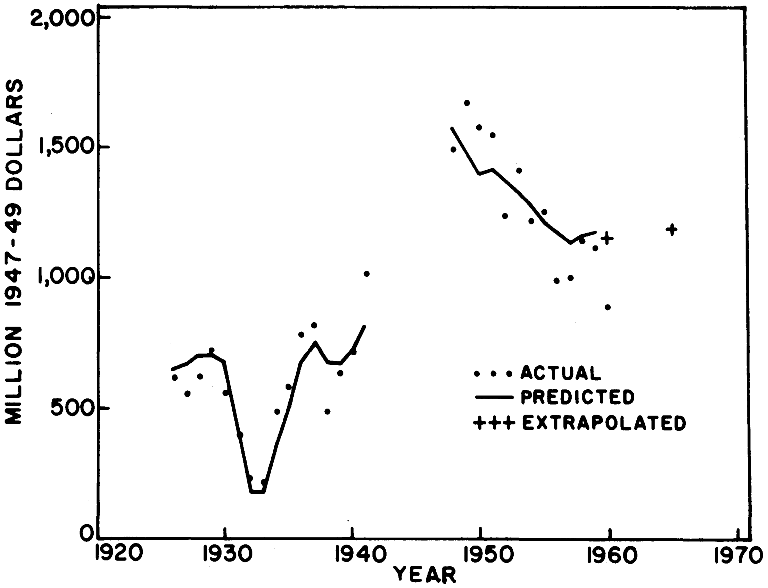

Figure 11.2. Trends in purchases of motor vehicles Q_{MV} from 1926 to 1960 (predicted and projected estimates from equation 11.24-O).

income would provide different projections. No estimate is made of the standard error for 1965 projections, but it is expected to be large for extrapolations several years in advance.

MACHINERY AND EQUIPMENT DEMAND FUNCTIONS ESTIMATED BY LEAST SQUARES

Using parallel models to those above, we now estimate demand functions for machinery and equipment. Machinery and equipment, as defined here, includes all farm machinery other than motor vehicles. Items ranging from milking machines to combines are included in the category. Variables included in the functions are:

Q_{MEt} = the dependent variable, a weighted two-price aggregate of farm machinery and equipment purchases during the current calendar year for productive purposes, expressed in millions of 1947-49 dollars. The variable includes planting, harvesting and tillage machines, farm wagons, sprayers, gas and electric engines, dairy machines and haying equipment; it excludes motor vehicles.

$(P_{ME}/P_R)_t$ = the current year index of the ratio of prices paid by farmers for machinery and equipment to prices received by farmers for crops and livestock.

$(P_{ME}/P_H)_t$ = the current year index of the ratio of machinery and equipment prices to the composite farm wage rate.

National aggregate data for the years 1926 to 1959, with 1942-47 excluded, are used with 1947-49 = 100 for price indices. Other variables (stock of productive assets, S_p, the equity ratio, E, net farm income, Y_F, government programs, G, and time, T) specified in the demand functions are defined in previous sections.

Estimated Demand Equations

Results of the estimated demand equations for machinery and equipment presented in Table 11.4 are similar to those in Tables 11.1 and 11.3. R^2's in Table 11.4 generally are greater than those in Table 11.3, and the adjustment coefficients in equations (11.36) and (11.37) suggest that about 70 percent of the shift to the equilibrium position for machinery and equipment purchases is made in the short run. The results in Table 11.4 thus support the same adjustment conclusions as Table 11.1 and Table 11.3: If farmers are subjectively certain that prices and financial circumstances are favorable, they are not severely restrained by institutional, psychological or technological barriers in making a rapid adjustment to desired annual investment levels. The adjustment to the desired level of stock may require considerable time despite the rapid adjustment of annual purchases, however.

Price and Income Elasticities of Demand for Farm Machinery and Equipment

Equations (11.34-O) and (11.35-O) indicate that the elasticity of demand for farm machinery other than motor vehicles with respect to $(P_{ME}/P_R)_t$ is -.75. The total elasticity with respect to income computed from the same equations is approximately .86. Assuming that a 1 percent rise in $(P_R/P_P)_t$ increases net income by 2 percent (see footnote 9), the long-run elasticity of Q_{ME} is -1.50 with respect to P_P, and .75 plus 1.50, or 2.25, with respect to P_R. Similar computations with equation (11.34-L) indicate an elasticity of Q_{ME} is -1.55 with respect to the price variable P_{ME}, -(2.0)(.86) = -1.72 with respect to P_P, and 1.55 plus 1.72, or 3.3, with respect to P_R (long run). (The elasticities from equations estimated in original observations are calculated at the means of the variables.) Using the average of these estimates, a sustained 1 percent increase in prices received by farmers is expected to increase machinery and equipment purchases slightly more than 1 percent in the short run, and nearly 3 percent in the long run.

The elasticities of machinery and equipment stock may be approximated from the above elasticities. Since, on the average, annual purchases are one-fifth of machinery and equipment stock, the short-run

Table 11.4. Demand (Annual Gross Investment) Functions for Farm Machinery and Equipment Other Than Motor Vehicles, Q_{ME}, Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1947; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Transformation and Model†	R^2	d‡	Constant	P_{ME}/P_R t	P_{ME}/P_R t-1	P_{ME}/P_H t	P_{ME}/P_H t-1	S_P t	E t-1	Y_F t	Y_F t-1	Y_F t-2	Y_{DF} t-1	G t	T	Q_{ME} t-1
(11.28-O) B	.97	1.25	692.73	-3.32 (.68)	.14 (1.10)		-.77 (.97)	-3.67 (7.57)	38.82 (15.10)					2.95 (2.86)	14.61 (5.92)	
(11.29-O) AB	.97	1.25	191.64	-3.11 (.54)					47.59 (12.16)		.014 (.011)				10.96 (2.46)	
(11.29-L) AB	.96	1.90	.91	-1.81 (.25)					-.69 (.22)		1.28 (.24)				.0254 (.0038)	
(11.30-O) B	.94	1.29	173.26		-3.22 (1.02)		.38 (.71)		55.82 (14.97)						12.18 (4.34)	
(11.31-O) B	.97	1.23	433.73	-2.94 (.63)		-.58 (.49)			56.12 (8.94)						9.04 (2.68)	
(11.32-O) B	.97	1.18	346.25	-3.45 (.47)					58.17 (8.84)						10.37 (2.45)	
(11.33-O) A	.95	1.10	-121.88	-3.19 (.68)							.044 (.010)				18.18 (2.07)	
(11.33-L) A	.95	.90	1.87	-1.56 (.28)							.29 (.25)				.0151 (.0022)	
(11.34-O) A	.96	1.02	-161.47	-2.98 (.61)							.027 (.011)	.0224 (.0080)			16.91 (1.88)	
(11.34-L) A	.95	.83	1.75	-1.55 (.29)							.86 (.28)	.060 (.212)			.0149 (.0024)	
(11.35-O) C	.97	1.04	-147.18	-3.04 (.52)									.0504 (.0077)		16.43 (1.71)	
(11.35-L) C	.93	.58	3.15	-1.81 (.29)									.69 (.28)		.0161 (.0026)	
(11.36-O) BF	.97	1.35	305.48	-3.01 (.48)					36.91 (12.50)						9.13 (2.33)	.26 (.11)
(11.37-O) F	.97	1.37	79.16	-2.69 (.57)							.019 (.011)				12.04 (2.38)	.39 (.11)
(11.37-L) F	.96	.65	3.26	-1.52 (.25)							.36 (.31)				.0127 (.0023)	.28 (.12)
(11.38-L) H	.98	1.14	-2.20	-1.46 (.37)	1.06 (.37)					.47 (.25)	.60 (.27)				.0038 (.0028)	.51 (.11)

*Composition of the dependent variable, Q_{ME}, and of the indicated independent variables are discussed in the text.

† Equations estimated in original observations are designated by O; in logarithms of original observations by L. The time variable, T, is in original values in the L equations. Also, Y_{DFt-1} in the logarithm equations is the logarithm of the simple declining arithmetic average net farm income. Expectation and adjustment models are presented in Chapter 10.

‡ The Durbin-Watson autocorrelation statistic d (see Table 11.1).

estimated elasticity of stock with respect to P_{ME}/P_R is (.2) (-.75) = -.15 based on equations (11.34-O) and (11.35-O). Since the adjustment rate and ratio between annual purchases and stock are assumed to be nearly equal for machinery and equipment, the long-run elasticity for stock and annual investment with respect to P_R are the same magnitude, or 2.25. But the "long run" for Q_{ME} is three or four years, whereas only about 90 percent of the adjustment to the "long run" of stock is made in 10 years (assuming the adjustment coefficient is .2). The adjustment coefficient .2 is based on the equations in Table 11.1. The long-run elasticity of stock is particularly sensitive to the magnitude of the adjustment coefficient.[13]

Trends and Projections of Farm Machinery and Equipment Purchases

The trend in machinery and equipment purchases, shown in Figure 11.3, is similar to the trend in motor vehicle purchases. The quantities appear to follow a somewhat more uniform trend in Figure 11.3, and there appear to be stronger signs of a reversal of the postwar decline in purchases. Equation (11.35-O) estimates the actual quantities somewhat better than those used for illustrations in previous sections.

Assuming prices 10 percent above the 1960 level and net farm

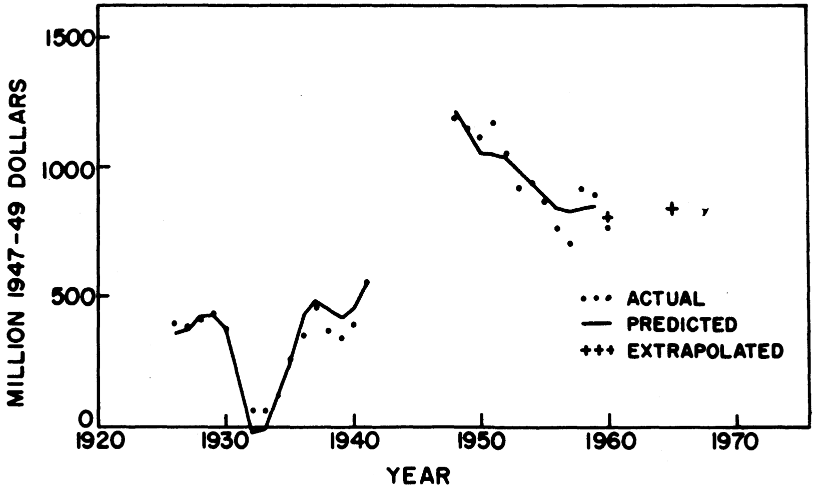

Figure 11.3. Trends in purchases of farm machinery other than motor vehicles from 1926 to 1960 (predicted and projected estimates from equation 11.35-O).

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[13] We again emphasize that difficulty exists in obtaining an accurate estimate of the coefficient. The influence of other variables correlated with stock is confounded in the coefficient of the lagged stock variable. The reader may wish to consider the magnitude of the elasticity under alternative assumptions about the value of the adjustment coefficient.

income at the 1955-59 value, 1965 purchases of machinery and equipment are projected to be slightly above the predicted 1960 level.

The assumption that net income will remain at the 1955-59 level may be overly optimistic. It essentially is based on the assumption that demand for farm products will expand uniformly with farm output, and leave P_R unchanged. Gross receipts, however, are expected to be greater because more units of output will be marketed. Furthermore, farms will become more efficient, producing more output with the same or fewer resources. These tendencies to increase income may be offset by increased input prices and greater reliance on purchased inputs.

SHIFTS IN MACHINERY DEMAND

Shifts in demand for all machinery, Q_M, motor vehicles, Q_{MV}, and machinery other than motor vehicles, Q_{ME}, are similar. Hence, only the results for Q_M are discussed in detail in this section. Changes which have occurred in demand for machinery depend on the parameters of the demand functions as well as on the relative shifts in prices, income and other relevant variables. The standard partial regression coefficients indicate the relative impact that variables can have on the demand quantity, Q_M. These respective coefficients for the price, farm income and time variables computed from equation (11.8-O) are -1.4, 1.5 and 2.2. These coefficients indicate that the "slowly changing influences" represented by the time variable are potentially important in determining the demand quantity. The magnitudes of the other influences are sizeable also, and if historic trends in the price or income variables are large, either one could be responsible for a greater portion of the change in Q_M than the time variable.

Actual purchases (constant 1947-49 dollars) of all farm machinery increased 109 percent since 1926, or at an average compound rate of 2.25 percent per year. Equation (11.5-O) provides a basis for investigating the sources of the increase. Real machinery price (P_M/P_R) was over 60 percent greater in 1959 than in 1926. (More important, perhaps, machinery price declined relative to labor price over this period.) If other variables had been at 1926 values but P_M/P_R had been at the 1959 value in 1926, the demand quantity would have been 54 percent below the actual 1926 purchases according to equation (11.5-O). The more than 100 percent increase in demand for machinery during the 33-year period can hardly be attributed to a falling price of machinery relative to prices received.

Equation (11.5-O) suggests that machinery purchases would have been 60 percent greater in 1926 if farmers had experienced the financial or equity position present in 1959, <u>ceteris paribus</u>. More efficient methods of production, substitution of cheap operating inputs for farm labor and horsepower, improved management and inflation permitted a slight increase in net farm income and a considerable improvement in the equity of farmers from 1926 to 1959 despite the rise in the ratio

P_M/P_R. An "accelerator" influence may be evident, since adoption of machinery in early years partially was responsible for farmers' increased efficiency and improved financial position that permitted greater machinery purchases in later years.

A major source of the increased machinery demand evidently has been structural changes represented by the time variable. The two "economic" categories (a) price and (b) earnings or equity, nearly offset one another, leaving "structure" to explain almost the entire shift in machinery demand since 1926. Perhaps most important of the structural changes embodied in the time variable is the continuous improvement in the quality and adaptability of machinery. (This is less true, however, for shorter periods.) Concurrent with these improvements has been the increased awareness by farmers of the returns and convenience from using improved machinery. Of course, it is well to remember that the structural and financial categories are not entirely independent.

If the supply of farm machinery were not highly elastic and if a small increase in farm demand had brought sharp machinery price increases, farm mechanization undoubtedly would have progressed less rapidly. The fact that manufacturers have made farm machines available in quantities, and of the quality desired by farmers, has been an important element helping to explain the rapid growth of farm machinery stock. In turn, the rising stock of farm machinery and substitution of machinery for farm produced power has been a significant element in the rising farm labor efficiency.

DEMAND FOR INDIVIDUAL FARM MACHINES

We now estimate demand equations for individual farm machines by single-equation least squares. This analysis is made for specific machinery categories to circumvent some of the aggregation and technical considerations involved in the preceding classes. Estimates for individual machines also involve difficulties such as imperfect price series for each item, changes in quality of machine resources and special problems in intercorrelation among the price and quantity series being analyzed. The data are not adequate for estimating separate demand functions for large numbers of machines; only the functions for farm trucks, tractors and automobiles are presented.

Least-Squares Demand Equations for Farm Trucks

Variables included in the demand equations for farm trucks are the following:

Q_{Tkt} = the dependent variable, a price-weighted aggregate of farm truck purchases during the current calendar year in million 1947-49 dollars.

Table 11.5. Demand Functions for Farm Trucks Estimated by Least Squares With U.S. Data From 1926 to 1960, Excluding 1942 to 1948; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Dependent Variable and Model†	R^2	d‡	Constant	P_{Tk}/P_R t	Y_{DF} t-1	E t-1	T (1926-41)	T (1949-60)	T (1926-60)	S_{Tk} t
(11.39) Q_{Tk} C	.92	.910	-87	-1.60	.0196				7.93	
				(.42)	(.0045)				(1.21)	
(11.40) Q_{Tk} C	.94	1.072	86	-1.42	.0156		3.01	5.36		
				(.38)	(.0043)		(2.12)	(1.44)		
(11.41) Q_{Tk} B	.96	1.441	103	-1.55		29.91			3.92	
				(.28)		(3.92)			(1.19)	
(11.42) Q_{Tk} B	.96	1.433	136	-1.53		27.81	3.05	3.64		
				(.29)		(4.99)	(1.73)	(1.27)		
(11.43) ΔS_{Tk} CI	.63	.842	-192	-1.33	.0184				9.50	-.245
				(.42)	(.0049)				(2.73)	(.058)
(11.44) ΔS_{Tk} CI	.79	1.120	-87	-1.39	.0191		9.32	14.35		-.490
				(.33)	(.0038)		(2.12)	(2.44)		(.076)
(11.45) ΔS_{Tk} BI	.82	1.611	-74	-1.45		32.74			8.72	-.330
				(.28)		(4.47)			(1.88)	(.044)
(11.46) ΔS_{Tk} BI	.86	1.841	-79	-1.54		29.70	8.59	11.09		-.433
				(.26)		(4.30)	(1.73)	(2.01)		(.060)

*Variables are defined in the text.

†Expectation and adjustment models are presented in Chapter 10.

‡The Durbin-Watson d statistic (see Table 11.1).

S_{Tkt} = the stock of farm trucks on January 1 of the current year, in million 1947-49 dollars.

ΔS_{Tk} = a second dependent variable, $S_{Tkt+1} - S_{Tkt}$.

$(P_{Tk}/P_R)_t$ = an index of the current year ratio of prices paid by farmers for new trucks to prices received by farmers for crops and livestock (1947-49 = 100).

Other variables in the demand function are defined previously. All data are original (untransformed) observations for the United States from 1926 to 1960, excluding 1942 to 1948.

The highly significant coefficients of all variables in (11.39) and (11.41), Table 11.5, suggest that models B and C are structurally relevant for truck demand as well as for all motor vehicles (Table 11.3). The value of R^2 and the autocorrelation statistic d indicate certain advantages for including the equity ratio E rather than past net income in the demand functions for farm trucks.

Equations (11.43) to (11.46) are estimated with first differences of stock rather than gross investment as the dependent variable to obtain more accurate estimates of the influence of explanatory variables on truck stock. Based on the magnitudes of the R^2's, the independent variables predict net investment, ΔS_{Tk}, less accurately than gross investment, Q_{Tk}. Again, (11.45) and (11.46) with E display advantages based on the R^2 and d over (11.43) and (11.44) with Y_{DF}. The average adjustment rate (coefficient of S_{Tk}) is approximately .3, indicating that 6 to 7 years are required to make 90 percent of the adjustment to the desired level of stock after a change in price, income or equity.

The failure of previous equations to predict accurately in recent years implies that structural changes in demand may have occurred. To accommodate this possible structural change, (11.40) and (11.42) are estimated with separate time variables for the prewar and postwar periods, allowing a test of the null hypothesis that the trends in the two periods are equal. The similarity of the coefficients of the two trend variables in (11.42) provides little basis for rejecting the null hypothesis. The differences in trend coefficients in (11.40), (11.44) and (11.46) were not tested statistically, but the results suggest an increase in the coefficients in the postwar years. These results are surprising because of the decline in truck purchases in recent years (see Figure 11.4) and are consistent with the hypothesis that the postwar trend in truck purchases is explained by price, income and equity variables rather than by technological and other influences embodied in the time variable.

Inclusion of variables representing farm size, liquid assets and the short-term interest rate in the demand functions did not improve the results. Also estimates using truck numbers rather than a value aggregate as the dependent variable were less satisfactory.

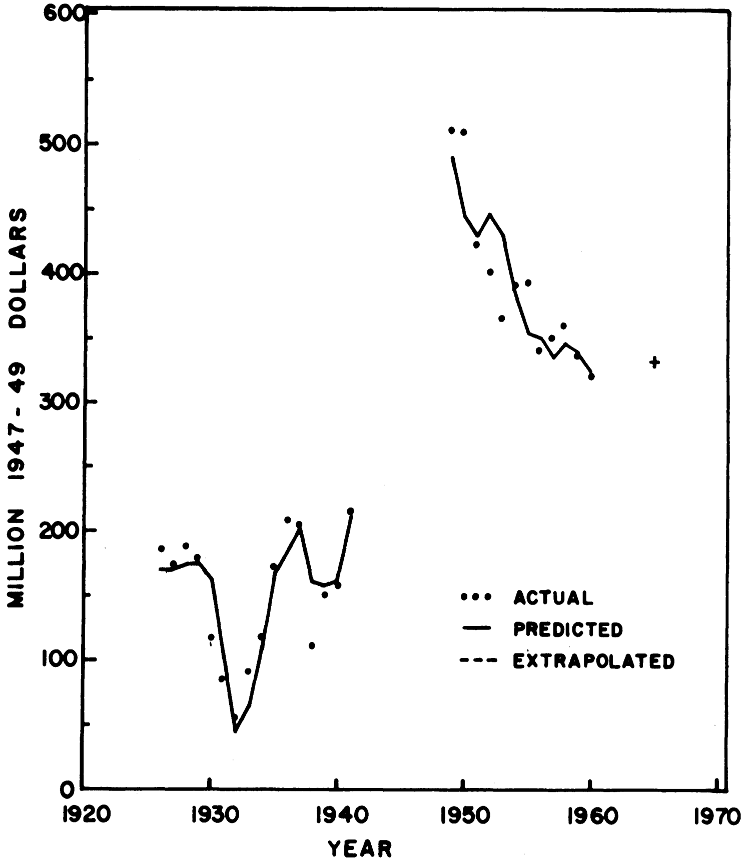

Figure 11.4. Trends in purchases of farm trucks from 1926 to 1960 (predicted and extrapolated estimates from equation 11.41).

Price and Income Elasticity of Demand for Farm Trucks

Computed at the 1926-60 mean from equation (11.39), the elasticity of Q_{Tk} is -.77 with respect to P_{Tk}/P_R, and .79 with respect to Y_{DF}. The long-run elasticity with respect to P_R is approximately -.77 + (2.0)(.79) or 2.3. A sustained 1 percent increase in P_R is predicted to raise annual truck purchases about 1 percent in one or two years and some over 2 percent in three or four years based on (11.39).

The elasticity of S_{Tk} with respect to P_{Tk}/P_R is -.19 and with respect to Y_{DF} is .22, according to (11.43). Based on the estimated adjustment coefficient .245 and the component of P_R in Y_{DF}, a once-for-all rise of 1 percent in prices received by farmers is expected to increase S_{Tk} .2 percent in one or two years, .6 percent in three or four years and 2.5 percent in eight years. These estimates, computed from (11.43) at the mean for the entire period, would differ if 1960 means were used.

Cromarty estimated the number of new truck shipments as a function of price P_{Tk}/P_R, net income and other variables.[14] Based on a least-squares equation estimated with data from 1920 to 1955, omitting 1942-50, he predicted the short-run elasticity of truck demand with respect to price to be -.3; with respect to net income to be .6. These estimates are for demand at the wholesale level, those of this study for demand at the retail level, and hence are not strictly comparable.

Trends and Projections

Purchases of trucks were at a considerably higher level in the postwar than in the prewar period. The downward postwar trend showed signs of reversal from 1956 to 1958, but 1959 and 1960 purchases were again in line with the postwar decline (Figure 11.4). Unlike the earlier predictions for all farm machinery, equation (11.41) accurately predicts the actual 1959 and 1960 observations. Based on 1955-59 average net income and a 10 percent increase in P_{Tk}/P_R over the 1960 value (the price increased 11 percent in the five years preceding 1960), the 1965 projected purchase of farm trucks is 337 million 1947-49 dollars. Since approximately 350 million dollars gross investment is required to meet replacement demand at the current 24 percent depreciation rate, the projection suggests that truck stock may decline somewhat from the current level.

Least-Squares Demand Equations for Farm Tractors

The following variables are specified in the demand function for tractors:

Q_{Trt} = the dependent variable, a price-weighted aggregate of tractor purchases during the current calendar year, in million 1947-49 dollars.

S_{Trt} = the stock of all tractors on farms on January 1 of the current year, in million 1947-49 dollars.

ΔS_{Trt} = a second dependent variable, $S_{Trt+1} - S_{Trt}$.

$(P_{Tr}/P_R)_t$ = an index of the current year ratio of prices paid by farmers for new tractors (30-39 horsepower) to prices received for crops and livestock.

$(P'_{Tr}/P_R)_t$ = an index of the current year ratio of wholesale prices for

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[14] Cromarty, William A. The market for farm trucks. Michigan Agr. Exp. Sta. Tech. Bul. 271. East Lansing. 1959.

Table 11.6. Demand Functions for Farm Tractors Estimated by Least Squares With U.S. Data From 1935 to 1960, Omitting 1942 to 1947; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Dependent Variable and Model†	R^2	d‡	Constant	P'_{Tr}/P_R t	P_{Tr}/P_R t	Y_{DF} t-1	E t-1	A t-1	T (1935-41)	T (1948-60)	T (1935-60)	S_{Tr} t
(11.47) Q_{Tr} C	.89	1.70	316		-3.26	.0255					6.63	
					(.81)	(.0074)					(1.96)	
(11.48) Q_{Tr} C	.89	2.09	868	-1.67		.0258					-8.32	
				(.42)		(.0075)					(3.48)	
(11.49) Q_{Tr} C	.92	1.81	1020		-3.17	.0177		-32.47			37.86	
					(.70)	(.0071)		(12.48)			(12.12)	
(11.50) Q_{Tr} B	.91	1.68	1288		-2.86		19.30	-38.94			41.48	
					(.90)		(9.80)	(12.47)			(12.59)	
(11.51) Q_{Tr} C	.93	1.87	771		-3.49	.0207		-27.89	38.23	36.54		
					(1.01)	(.0099)		(16.35)	(12.48)	(12.80)		
(11.52) Q_{Tr} B	.92	1.73	1001		-3.09		25.40	-33.81	41.73	39.54		
					(1.05)		(16.73)	(17.04)	(12.95)	(13.61)		
(11.53) ΔS_{Tr} CI	.91	2.47	789		-2.95	.0183		-26.42	30.70	28.08		-.089
					(.90)	(.0090)		(14.77)	(11.17)	(11.48)		(.051)
(11.54) ΔS_{Tr} BI	.91	2.36	813		-2.57		28.07	-28.08	32.44	27.97		-.081
					(.89)		(14.18)	(14.51)	(11.05)	(11.66)		(.050)

*Variables are defined in the text.

†Expectation and adjustment models are presented in Chapter 10.

‡The Durbin-Watson d statistic (see Table 11.1).

tractors per horsepower unit to prices received by farmers.[15]

A_{t-1} = cropland acres per farm in the past year.

The equity ratio, E, time, T, and net income, Y_{DF}, variables are defined previously. The variables are U.S. data from 1935 to 1960, omitting 1942 to 1947. Adequate price data were not available prior to 1935, and the war and immediate postwar period was excluded because of a different structure of demand.

The coefficients of the variables in (11.47), Table 11.6, are highly significant and display the signs theoretically anticipated. The price variable in (11.48), the wholesale price per unit of horsepower, is also corrected for improvements such as rubber tires; electric and hydraulic systems. The coefficient is highly significant but the magnitude is somewhat less than that of the more "hybrid" price variable in the foregoing equation. It would also be desirable to correct the quantity Q_{Tr} for changes in quality, but data are not adequate for this refinement.

Inclusion of farm size A in (11.49) improves the fit of the equation and increases the coefficient of T. Farm size and other variables correlated with T influence Q_{Tr} in opposite ways, and the net influence moved the coefficient of the trend variable toward zero in (11.47) and (11.48).

Similar coefficients of the separate time variables in (11.51) and (11.52) support the hypothesis that structural influences represented by T have shifted tractor demand at the same rate in the prewar and postwar years.

Equations (11.53) and (11.54), with net investment ΔS_{Tr} the dependent variable, display slightly higher d values and slightly smaller (absolute value) coefficients than comparable equations (11.51) and (11.52). The adjustment coefficient is .09 according to (11.53); however, additional equations (not included) estimated without A and with a single T variable indicated the adjustment coefficient is approximately .13.

The results in Table 11.6 consistently indicate a negative relationship between farm size and tractor purchases. Of the categories of machinery examined, only the tractor demand function is considered to be "improved" by inclusion of A when price, income or equity, and time variables are adequately specified. This result is consistent with theory since tractors represent major discrete input units, and farmers often are able to profitably expand machinery investment only by expanding acreage. Greater output has been possible in recent years despite declining gross investment in tractors (see Figure 11.5) because larger farms allow existing tractors to be used more efficiently. According to Table 11.6, tractor purchases Q_{Tr} may decline up to 4

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[15] Based on the John Deere B, 50, 520, 530, 3010 series. See: Facts about John Deere tractor wholesale prices in the United States, 1935-1961. Deere and Company. Moline, Illinois. 1961.

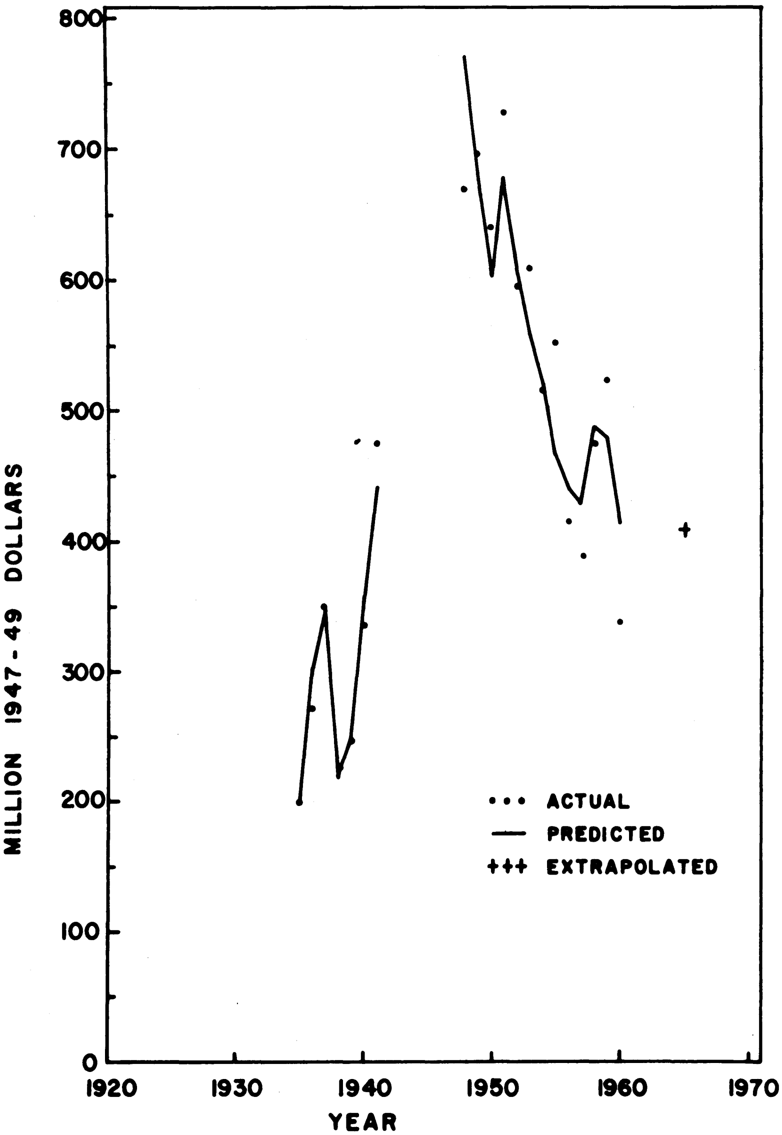

Figure 11.5. Trends in purchases of farm tractors from 1935 to 1960 (predicted and projected estimates from equation 11.51).

percent and stock, S_{Tr}, 1 percent by expanding farm size 1 percent. The results apply primarily to a short period; in the long run, machinery can be substituted for labor on larger farms and the net influence of farm size on tractor demand is less clear. Inclusion of the farm size variable introduces the question: Does an increase in farm size decrease machinery demand or does a decrease in machinery demand increase farm size? A joint causal structure dictates a simultaneous system such as (11.14) and suggests that the monocausal relationships including A in Table 11.6 be interpreted cautiously.

Price and Income Elasticity of Demand for Farm Tractors

The elasticity of Q_{Tr} with respect to P_{Tr}/P_R is -1.1, based on (11.51) and using means for the 1935-60 period. With respect to Y_{DF}, the elasticity is .52. The results indicate that if P_R increases 10 percent and remains at that level, tractor purchases will increase 10 percent in one or two years, and 21 percent in about four years.

The predicted elasticity of stock from (11.53) is -.25 with respect to P_{Tr}/P_R and .12 with respect to Y_{DF}. The results suggest that a 1 percent once-for-all rise in P_R tends to increase S_{Tr} .25 percent in one or two years, .5 percent in four years and up to 5 percent in roughly 20 years. Twenty-eight and 16 years respectively are required to make 90 percent of the equilibrium adjustment, with adjustment coefficients of .08 to .13.

Cromarty estimated the elasticity of tractor shipments to be -.5 to -.7 with respect to P_{Tr}/P_R and .2 to .4 with respect to net cash receipts.[16] Some reasons his estimates are lower than those in this study are: (a) he included an asset variable which contains elements of P_R not included in elasticity estimates, and (b) his estimates are for wholesale shipments of tractors rather than for farm purchases.

Trends and Projections

Purchases of farm tractors dropped markedly in 1938, then increased sharply to 1941 (Figure 11.5). The high demand quantity, 700 million dollars in 1951, was followed by a general decline to 340 million 1947-49 dollars in 1960. Because equation (11.51) predicted more accurately than others over the entire period, it is selected to depict the actual observations. However, it is apparent that inclusion of farm size A and separate time variables to account for recent structure changes did not prevent a sizeable prediction error in 1960.

For the 1965 projection, we assume farm size will continue to increase at the current rate and be 6 percent greater in 1965 than in 1960. Using a price, P_{Tr}/P_R, 10 percent above the 1960 level, and 1955-59 average net farm income, the 1965 demand quantity is projected from (11.51) to be 417 million 1947-49 dollars. This is less than the estimated 485 million dollars required to maintain the 1960 tractor stock, assuming a 21 percent depreciation rate.

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[16] Cromarty, William A. The demand for farm machinery and tractors. Michigan Agr. Exp. Sta. Bul. 275. East Lansing. 1959.

Table 11.7. Demand Functions for Farm Autos (as Production Durables) Estimated by Least Squares With U.S. Data From 1926 to 1960, Excluding 1942 to 1948; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, Dependent Variable and Model†	R^2	d‡	Constant	P_A/P_R t	Y_{DF} t-1	E t-1	S_L t	T (1926-41)	T (1949-60)	T (1926-60)	S_A t
(11.55) Q_A C	.61	2.25	222	-2.11	.061					1.08	
				(1.62)	(.016)					(4.52)	
(11.56) Q_A C	.66	2.28	607	-2.68	.030		56.3			-13.32	
				(1.58)	(.023)		(31.3)			(9.10)	
(11.57) Q_A B	.60	2.15	788	-3.01		71.82				-5.28	
				(1.54)		(19.09)				(5.98)	
(11.58) Q_A B	.65	2.20	888	-3.20		31.50	59.41			-16.50	
				(1.48)		(29.16)	(33.48)			(8.53)	
(11.59) ΔS_A CI	.68	2.28	328	-3.39	.039			17.26	22.22		-.434
				(1.87)	(.021)			(9.66)	(7.95)		(.100)
(11.60) ΔS BI	.70	2.69	417	-3.50		71.57		14.28	14.23		-.380
				(1.72)		(31.40)		(9.40)	(9.10)		(.102)

*Variables are defined in the text.

†For expectation and adjustment models, see Chapter 10.

‡The Durbin-Watson d statistic (see Table 11.1).

Least-Squares Demand Equations for Farm Autos

Automobiles, more than other durables discussed above, embody characteristics of a consumption good. The USDA estimates that 60 percent of automobile purchases are identified with the farm consumption rather than production sector. It is not possible to determine the actual, or even the intended, purpose of auto purchases and therefore the classification necessarily must be arbitrary. Yet the specification of demand depends on the sector with which car sales and use is identified. The procedure in this section is first to specify the demand for autos as a production good, using substantially the same specification as above for other farm machinery. In a second formulation treating cars as consumption goods, we estimate a per capita demand equation with the demand quantity a function of prices and income deflated by prices paid by farmers for items used in living (consumption).

Variables not defined previously are as follows:

Q_{At} = a price-weighted aggregate of automobile purchases for all purposes by farmers during the current year, in million 1947-49 dollars. (Q'_A denotes purchases per capita where the farm population is the unrevised, higher estimate discussed in Chapter 18.)

S_{At} = the stock of farm autos on January 1 of the current year, in million 1947-49 dollars (S'_A is per capita stock).

ΔS_{At} = $S_{At+1} - S_{At}$.

$(P_A / P_c)_t$ = a current year index of the ratio of auto price to prices paid by farmers for items used in living (consumption).

Y'_{DFt-1} = a declining three year average of past net farm income per capita, deflated by P_c (constructed similarly to Y_{DF} discussed previously).

S_{Lt} = January 1 stock of liquid farm assets, including bank deposits and currency, savings bonds and investment in cooperatives, deflated by prices paid by farmers for items used in production, including interest, taxes and wage rates. S'_{Lt} is liquid assets per capita, deflated by P_c .

The above variables and equity, E, and time, T, discussed earlier are national aggregates for 1926 to 1960, omitting 1941 to 1948. The "prime" notation refers to quantities or income per capita, and all equations are linear in original observations.

Demand Equations for Autos as Production Durables

As expected, the adjustment and expectation models depict demand for automobiles (Table 11.7) less successfully than for other durables discussed earlier. The coefficient of Y_{DF} is highly significant;

Table 11.8. Per Capita Demand Functions for Farm Autos (as Consumption Durables) Estimated by Least Squares With U.S. Data From 1926 to 1960, Omitting 1942 to 1948, 1952, 1953; Including Coefficients, Standard Errors (in Parentheses), etc.*

Equation, Dependent Variable and Model †	R^2	Constant	P_A/P_c t	Y'_{DF} t-1	E t-1	S'_L t	T (1926-41)	T (1949-60)	T (1926-60)	S'_A t
(11.61) Q'_A C	.82	7.23	-.13	.079					-.0072	
			(.12)	(.012)					(.1956)	
(11.62) Q'_A C	.85	15.49	-.14	.053		.41			-.11	-.103
			(.14)	(.021)		(.27)			(.28)	(.065)
(11.63) $\Delta S'_A$ CI	.82	-.98	-.23	.036		.60			.76	-.462
			(.15)	(.023)		(.29)			(.30)	(.070)
(11.64) $\Delta S'_A$ CI	.83	3.23	-.20	.046			.83	1.20		-.431
			(.15)	(.019)			(.28)	(.26)		(.062)
(11.65) $\Delta S'_A$ BI	.82	8.21	-.20		2.74		.60	.84		-.341
			(.15)		(1.21)		(.30)	(.37)		(.084)

*The variables are discussed in the text.

†See Chapter 10 for expectation and adjustment models.

however, the coefficient of time is nonsignificant and that of price is significant only at the 80 percent (90 percent with one-tailed test) probability level in (11.55). Inclusion of liquid assets, S_L, in (11.56) raises the R^2 and significance of the T coefficient. The variable "competes" with other financial variables, E and Y_{DF}, and lowers the magnitude and significance of these variables according to the first four equations.

The R^2's, though still low, are enhanced slightly in regressions (11.59) and (11.60) on net investment. The divided time variables give no basis for rejecting the hypothesis that the time trends have been equal in the prewar and postwar periods. According to (11.59) and (11.60), the adjustment coefficient is .4 for autos, somewhat greater than for other machines.

Demand Equations for Autos as Consumption Durables

Comparing production equation (11.55), Table 11.7, with consumption equation (11.61), Table 11.8, the latter registers a higher R^2 but less significant price coefficient. The R^2 of equation (11.61), estimated in total rather than per capita and including 1952 and 1953 observations, was .61, the same as (11.55). The R^2 was increased from .61 to .76 by converting quantities and income to a per capita basis and from .76 to .82 by dropping the 1952 and 1953 observations. These observations were omitted because they deviated markedly from other estimates due to the unusual demand structure connected with the Korean War.

The coefficient of P_A/P_c is significant at the 80 percent level (one-tailed), other variables at the 90 percent level in (11.64) and (11.65). The coefficients generally display the expected signs, and the five independent variables in each equation together explain slightly over 80 percent of the variation in net auto investment. Some evidence points to an increase in the trend, T, after the war, a surprising tendency based on the downward trend in annual purchases (see Figure 11.6). The rate of increase in gross or net investment is low, however, increasing one dollar per person per year if the time coefficient is 1 in Table 11.7. The adjustment rate again is estimated to be approximately .4, indicating that the time required to make 90 percent of the total desired adjustment is five years.

Price and Income Elasticities of Demand

The elasticity of demand for Q_A with respect to P_A, computed at the 1926-60 mean from production equation (11.55), is -.33; from consumption equation (11.61) it is -.41. Both are lower than previous results for other durables. Based on the P_R component in income, the elasticity of Q_A with respect to P_R is .33 in the short run and 2.2 in about four years according to (11.55). The long-run demand elasticity thus appears similar to that for previous durables.

With respect to P_A, the short-run demand elasticity for stock, S_A, is -.14 and -.16 computed respectively from (11.59) and (11.64). The

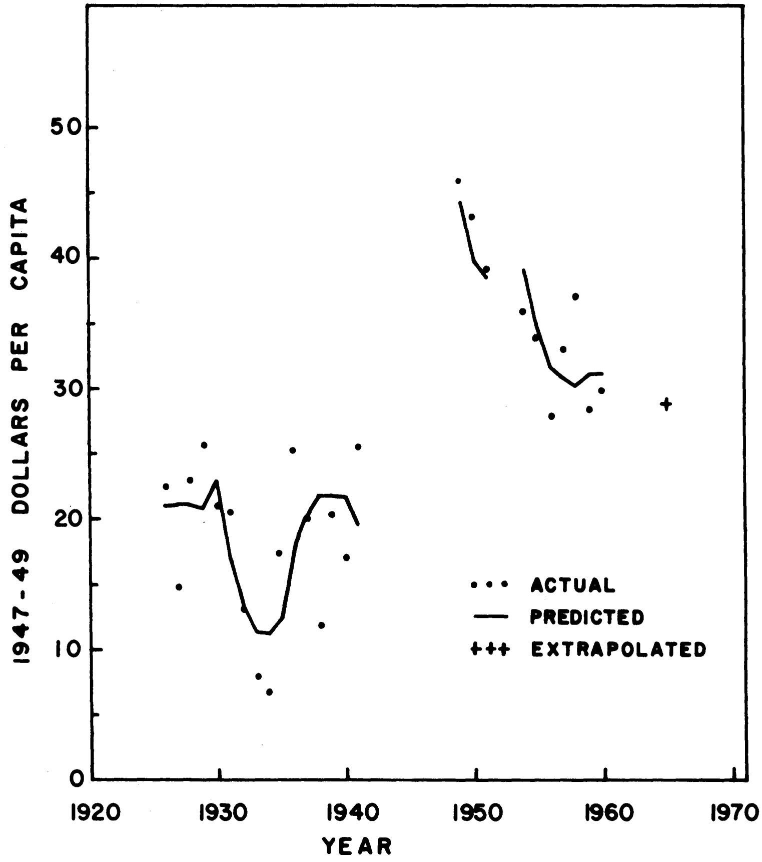

Figure 11.6. Trends in per capita purchases of automobiles by farmers from 1926 to 1960 (predicted and projected estimates from equation 11.61).

long-run elasticity with respect to P_A is the short-run estimate divided by the adjustment coefficient .4, or two and one-half times larger than the short-run elasticity. If production demand equation (11.59) is appropriate, the elasticity of S_A with respect to P_R is .14 in one or two years, .44 in approximately four years and 1.2 in roughly seven years.[17]

In 1957 Chow published U.S. demand equations for automobiles estimated from national time series for 1931 through 1953, with 1942 to 1946 excluded.[18] Variables specified in the per capita demand functions

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[17] The adjustment rate .4 indicates that five years are required to make 90 percent of the adjustment after farmers are subjectively certain of price and income variables. It is especially important to adjust for expectations when the adjustment rate is large (say more than .2). Since about two or three years are required to form income expectations, we add two years to the indicated five year adjustment rate.

[18] Chow, Gregory C. Demand for Automobiles in the United States, a Study in Consumer Durables. North-Holland Publishing Company. Amsterdam, Netherlands. 1957. See also: Chow, Gregory C. Statistical demand functions for automobiles and their use for forecasting. In Harberger, Arnold C., (ed.) The Demand for Durable Goods. pp. 149-78. The University of Chicago Press. Chicago. 1960.

were prices and quantities of autos, disposable and expected income, money stock and time. He found the long-run stock elasticities with respect to own-price and income respectively to be -1 and 2. Equivalent elasticities -.4 and .4 computed from equation (11.64) are somewhat less than Chow's results. Because of differences in models, data and concepts, the estimates provide no basic inferences about the relative magnitude of price and income elasticities in the farm and nonfarm sectors.

The trend in auto purchases, characterized by a "trough" in the 1930's and a high and declining trend after the war, is similar to that for other machinery (Figure 11.6). The observations display considerable scatter due to measurement errors and other reasons, and (11.61) does not accurately predict the actual data. Because of unusually large deviations from the trend in 1952 and 1953 stemming from the Korean War, these observations are omitted.

The price variable P_A / P_c increased 9 percent from 1956 to 1960. Net income did not fall accordingly, as this and other machinery prices increased, because of increased farming efficiency and because many input prices remained quite stable. Adding 10 percent to the 1960 price and averaging 1955-59 net income, the projected 1965 per capita demand quantity is 29 1947-49 dollars. This estimate is slightly below the actual 1960 demand quantity, 31 1947-49 dollars, and is consistent with the tendency of the 1950's for auto purchases to decrease at a decreasing rate.

SUMMARY OF RESULTS

Considerable uniformity exists among productive machinery (other than autos) in the models, variables and elasticities which can express demand. Except for autos, a simple linear function of three variables, the machinery/commodity price ratio, income or equity, and time explain a major portion of the variation in machinery purchases. The variables predict less accurately in recent years in some instances, possibly because the actual data are preliminary and need revision, or because structural changes have occurred which cannot be isolated in the models because of few time series. Although the models are intended to be structural rather than simply predictive, statistical complications precluded obtaining estimates of the market interaction between labor and machinery. Undoubtedly, some of these and other influences are reflected by the significant and positive time coefficients.

Computed from the equations estimated in original observations at the full-period means, in round numbers a 1 percent increase in the price of either trucks, tractors or the equipment aggregate Q_{ME} is predicted to increase respective annual purchases 1 percent; stock .2 percent in one or two years. In four years the elasticity of machinery purchases Q_i with respect to P_i remains about unity, but with respect to P_R is 2 or more. A sustained 1 percent rise in prices received by farmers is expected to increase stock for these same items .2 percent in one or two years, .5 percent in four years and more than 2 percent in the long run. The "long run" is reflected in the adjustment rate and differs markedly by items. As expected, the lowest adjustment and depreciation rates (highest long-run elasticities) are for farm tractors and the highest rates are for autos.

Purchases of each machinery category are projected to be nearly the same level in 1965 as in 1960. The reason is that influences such as a decline in the machinery/labor price ratio and improvements in machine quality and versatility, tending to increase demand, are offset by rising machinery/commodity price ratios. Since projected annual investment roughly equals replacement rates, stocks are projected also to remain at or near 1960 levels. Future trends for some items not separately examined, e.g. feed handling equipment, are expected to deviate significantly from above trends.

12.

Investment in Plant and Equipment

THIS CHAPTER is an extension of the methodology in Chapter 10 and parallels the empirical applications in Chapter 11. It is an analysis of aggregate capital categories. In this monograph, capital is divided into two broad categories: (1) operating or working capital, and (2) durable or fixed capital. Both include heterogeneous types of resources. While the individual types of resources often are quite "unlike" in respect to their function in the production process and the products for which they are used, we wish to examine whether some "over-all" aspects of capital investment behavior can be explained for the U.S. farm industry. One purpose in analyzing aggregate investment is to explain the stock of productive assets in relation to: (a) the demand for other resources such as operating inputs and (b) the supply of agricultural output. We also wish to evaluate the response of investment in the agricultural plant to price changes and technical trends.

From a broad policy standpoint, problems of underemployment, low returns and pressures for labor movements from rural areas are associated with the laborsaving and output-increasing investment process in agriculture. Policies to deal with these problems cannot be devised intelligently without knowledge of the effect of programs on the agricultural investment process. Some policies to raise labor income may increase investment and output sufficiently to reduce product prices and thus mitigate the intended benefits in the long run. The problems are quite different in underdeveloped areas where investment does not occur rapidly enough, but the same type of information about the investment parameters can be useful in devising strategies to stimulate capital formation.

Least-squares estimates are used for estimating demand functions for two aggregate categories of farm investment. The first major category of aggregate investment examined in this chapter includes farm buildings and improvements and all farm machinery. This investment aggregate is analyzed separately because it often is referred to as "investment in agricultural plant and equipment." However, as a separate category, it preserves some properties of homogeneity by excluding human, livestock and feed components of investment. The analysis also is of methodological interest for the analyses of all productive assets to follow and contributes some useful hypotheses on the elasticities, depreciation rates and other empirical quantities of building improvements and farm machinery. The second aggregate category of agricultural investment to be examined includes all farm machinery, real estate, livestock, feed and cash held for productive purposes. While there would be advantages in excluding land and including only real estate improvements, difficulties in separating the two components prompted inclusion of the total stock of real estate.

INVESTMENT IN BUILDING IMPROVEMENTS AND ALL FARM MACHINERY

The general logic of the model employed was discussed in detail in the previous chapters. Annual net or gross investment is considered to be a function of prices, technology, weather, government programs, external and internal financing capabilities, the interest rate, capital gains and weather. Expectations are undoubtedly important in explaining year-to-year investment in the farm plant. The profitability and ability to pay for a durable asset depends on future prices, technology, weather, and other quantities which change with time. Risk and uncertainty theory suggests that farmers base future expectations on past realities. Hence it appears desirable to include past values of prices and other variables in the investment function. Even if the data were available, it is necessary to reduce the number of expectation and other explanatory variables in the model because of multicollinearity and the limitations of least-squares statistical techniques. The analysis is restricted to those few variables previously found most significant in explaining investment behavior for farm assets, and such additional variables as deemed appropriate for specific investment functions.

Past net farm income concisely represents several expectation influences that are essential elements of the investment function. Since net income may be either invested in productive assets or spent for household items, the variable introduces concepts associated with the firm-household complex. The marginal propensity to invest and to consume may be regarded as a manifestation of the preference or indifference function of the farmer, and perhaps as important, of his wife. At times the distinction between the firm or production sector and the household or consumption sector is not clear. This is especially apparent for farm autos, but is more subtle for farm tractors. Undoubtedly, many tractors add more to farm costs than returns even in the long run. These uneconomic purchases of a "productive" asset might very well be classified as consumption expenditures because the purchase is similar to expenditures for household appliances providing comfort and convenience. These considerations do not necessarily lead to a different specification of the investment function, but suggest caution in interpretation of the coefficients as "marginal propensities to invest in productive assets."

Since expectations and adjustments are important features of the investment process in agriculture, it is desirable to combine adjustment models such as G, I and J with the expectation models B or C from Chapter 10. A more accurate estimate of stock than of annual gross investment is available for all productive assets; hence, models I and J are useful. These models are based on the assumption that farmers adjust gradually to the equilibrium level of stock on the basis of expected income, prices and other variables. The dependent variable is net investment (first differences of total stock) and is a sensitive measure of investment behavior. In addition, models I and J are more amenable to estimation of the elasticities of stock with respect to income and prices than are models with gross annual purchases as the dependent variable.

Time series of both gross and net investment in building improvements and machinery are available. Hence, functions are derived using each as the dependent variable. This procedure provides a test of the comparability of two models and preliminary knowledge on net investment in all productive assets. Equations are estimated in original value only because net investment is sometimes negative and not suited for logarithm transformation. Net investment is a first difference; consequently, an additional first difference transformation is not appropriate.

The Variables

The variables specified in the investment function are defined as follows:

Q_{It} = a dependent variable, national aggregate expenditure on building improvements (including fences, windmills, wells and dwellings not occupied by the farm operator), motor vehicles (40 percent of automobile purchases) and other farm machinery and equipment. The variable is intended to measure the productive portion of purchases in millions of 1947-49 dollars. Components of the series are weighted by 1935-39 prices prior to 1940 and 1947-49 prices after 1940.

S_{It} = the stock of farm buildings and all farm machinery on farms on January 1 of the current year in millions of 1947-49 dollars.

ΔS_{It} = a dependent variable to represent the change in investment stock during the current year, i.e. $S_{It+1} - S_{It}$, measured in millions of 1947-49 dollars.

$(P_I/P_R)_t$ = the current year index of the ratio of the price of all farm machinery and building materials to prices received by farmers for crops and livestock; 1947-49 = 100.

Table 12.1. Annual Gross Investment in All Farm Machinery and Building Improvements Q_I Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1947; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation and Model †	R^2	d‡	Constant	P_I/P_R t	Y_F t-1	Y_F t-2	Y_{DF} t-1	Y_{AF} t-1	E t-1	T	Q_I t-1	S_I t
(12.1) B	.984	1.55	888	-11.65 (1.19)					1.74 (.19)	38.00 (5.62)		
(12.2) A	.959	1.09	-348	-11.54 (2.15)	.117 (.027)					63.10 (6.27)		
(12.3) A	.973	1.04	-455	-10.79 (1.78)	.063 (.027)	.072 (.020)				58.62 (5.31)		
(12.4) C	.977	1.06	-467	-10.74 (1.50)			.142 (.019)			56.91 (4.72)		
(12.5) D	.983	1.24	-227	-11.78 (1.19)				.135 (.015)		55.07 (4.09)		
(12.6) BF	.986	1.60	786	-10.23 (1.33)					1.33 (.27)	33.05 (5.87)	.188 (.095)	
(12.7) F	.976	1.39	93	-8.66 (1.82)	.054 (.026)					39.92 (7.55)	.41 (.10)	
(12.8) G	.960	1.17	-492	-10.94 (2.28)	.123 (.028)					55.88 (10.73)		.017 (.021)

*Sources and composition of the dependent variable Q_I and the indicated independent variables are discussed in the text.

†Estimated only from original observations. Adjustment and expectation models are presented in Chapter 10.

‡The Durbin-Watson autocorrelation statistic d.

E_{t-1} = the past year ratio of proprietors' equities to total liabilities in agriculture.

Y_{Ft} = the net income of farm operators from farming during the current year, deflated by the index of prices paid by farmers for items used in production, including interest, taxes and wage rates. Net income includes cash receipts, government payments and nonmoney income less production expenses in millions of 1947-49 dollars. Lagged values of income are also specified in the investment function.

Y_{DFt-1} = the declining three year arithmetic average of Y_F. Past year income t-1 is weighted by .50, the previous year t-2 by .33 and the year t-3 by .17.

Y_{AFt-1} = the simple past four year arithmetic average of Y_F.

Y_{WFt-1} = the increasing arithmetic average of Y_F. Y_{Ft-2} is weighted by .16, Y_{Ft-3} by .33 and Y_{Ft-4} by .50.

T = time, an index composed of the last two digits of the current year.

All variables in Tables 12.1 and 12.2 are annual data for the United States from 1926 to 1941 and 1948 to 1959. In Table 12.3, variables extend from 1913 to 1959, omitting 1942 to 1947 in selected equations for comparison with the results of equations fitted to data for 1926 and later years.

In addition to the variables indicated, the price of operating inputs, P_O, the hired farm wage rate, P_H, and the price of all farm inputs, P_P, individually were initially specified in the investment function. However, since the coefficients of the variables were not significantly different from zero, they were dropped from equations presented. The influence of operating input and other related input prices perhaps is best expressed in the net farm income variable. Equations were specified including farm size, the short-term interest rate and a measure of return on investment in common industrial stock, but the coefficient of each of these variables also was not significant and the corresponding equations are not included.

Gross Annual Investment

Current price, net income, the equity ratio and time explain a large proportion of the annual variation in gross annual investment according to the results in Table 12.1. The coefficients of P_I/P_R, E and T are highly significant in equation (12.1), and the coefficient of determination between Q_I and the three variables is .98. The Durbin-Watson statistic ($d = 1.55$) does not lead to rejecting the hypothesis that the residuals are uncorrelated at the 95 percent probability level. Interpreting E as representing the combined effects on investment of farm income, capital

Table 12.2. Annual Net Investment in All Farm Machinery and Building Improvements ΔS_I Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1947; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation and Model †	R^2	d‡	Constant	P_I/P_R t	Y_F t-1	Y_F t-2	Y_{DF} t-1	Y_{AF} t-1	E t-1	T	S_I t
(12.10) BI	.944	1.35	1297	-10.28 (1.35)					1.34 (.21)	37.85 (8.20)	-.113 (.014)
(12.11) AI	.924	1.10	189	-9.36 (1.90)	.049 (.028)	.056 (.021)				48.98 (8.97)	-.100 (.017)
(12.12) CI	.932	1.16	196	-9.38 (1.63)			.110 (.020)			48.52 (8.05)	-.102 (.016)
(12.13) DI	.944	1.30	429	-10.35 (1.34)				.107 (.017)		50.46 (6.97)	-.111 (.014)

*Sources and composition of the dependent variable ΔS_I and the indicated independent variables are discussed in the text.

†Estimated only in original observations. Adjustment and expectation models are presented in Chapter 10.

‡The Durbin-Watson autocorrelation statistic d.

gains and financial position (reflecting both the willingness of farmers to invest and also the willingness of external sources to lend funds), equation (12.1) might be taken as a simple but meaningful expression of the investment process.

Equations (12.2) to (12.5) are included to express more clearly the role of net income in investment. As additional lags are introduced, the value of R^2 increases. The sum of the income coefficients in equations (12.2), (12.3) and (12.4) increases from .117 to .135 to .142 as additional lags are added. It appears that the marginal propensity to invest (income coefficient) would be increased very little by additional income lags. The four year simple arithmetic average income in equation (12.5) increases the R^2 slightly, but the marginal propensity to invest is slightly less. Originally, the equation was estimated with the Ladd-Tedford model D (see Chapter 10), but the coefficient of the weighted income variable Y_{WFt-1} was not significant and it was dropped from the equation.

The coefficient (1-g) of the lagged annual gross investment Q_{It-1} is significantly greater than zero in equation (12.7) and would indicate that the adjustment coefficient may be less than 1. However, equation (12.6) provides a different result, indicating an adjustment coefficient near unity. If we accept (12.6), it appears that if farmers and external credit sources are satisfied with the current financial and price structure and expectation of future earnings, little time is required to adjust to the equilibrium level of annual purchases. However, while little time might be required to adjust to the desired level of annual investment, the time required to adjust to the equilibrium level of capital stock may be long. Model G (equation 12.8), included to determine the nature of the long-run adjustment to equilibrium stock, indicates that the adjustment and depreciation coefficients are of equal magnitude. Since the coefficient of lagged stock, h-g, does not differ statistically from zero, the implication is that the adjustment and depreciation rates are equal. If the depreciation rate is .10, the adjustment rate also is approximately .10.

Table 12.3. Annual Net Investment in All Farm Machinery and Building Improvements ΔS_I With Current Net Income Substituted for the Current Price Variable Used in Table 12.2; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included for Least-Squares Estimates From Annual Data*

Equation, Time Period and Model†	R^2	d‡	Constant	Y_F t	Y_F t-1	Y_F t-2	Y_{DF} t-1	Y_{AF} t-1	Y_{WF} t-1	E t-1	T	S_I t
(12.14) (1926-59)	.909	1.70	-686	.130						1.30	-4.53	-.054
BI				(.025)						(.29)	(8.82)	(.019)
(12.15) (1926-59)	.912	1.34	-1635	.116	.082	.032					8.88	-.046
AI				(.027)	(.027)	(.024)					(8.45)	(.018)
(1913-59)	.756	1.98	-1474	.122	.057	.030					6.54	-.038
				(.029)	(.032)	(.027)					(5.35)	(.020)
(12.16) (1926-59)	.917	1.42	-1607	.119			.113				8.25	-.048
CI				(.025)			(.023)				(8.05)	(.018)
(1913-59)	.775	2.06	-1474	.119			.097				6.68	-.043
				(.026)			(.027)				(5.06)	(.019)
(12.17) (1926-59)	.918	1.51	-1582	.120				.188	-.074		7.81	-.050
DI				(.025)				(.072)	(.061)		(8.17)	(.018)
(1913-59)	.801	2.35	-1454	.131				.065	.035		6.96	-.055
				(.026)				(.079)	(.067)		(4.82)	(.019)
(12.18) (1926-59)	.913	1.71	-1546	.131				.104			7.01	-.052
DI				(.024)				(.022)			(8.24)	(.018)
(1913-59)	.800	2.29	-1458	.125				.105			6.97	-.053
				(.022)				(.024)			(4.78)	(.019)

*Sources and composition of the dependent variable ΔS_I and the indicated independent variables are discussed in the text.

†Estimated only from original observations. Adjustment and expectation models are presented in Chapter 10. Observations for 1942 to 1947 are omitted in both periods.

‡The Durbin-Watson autocorrelation statistic d.

On the basis of the equations in Table 12.1 it appears that annual investment Q_I can be expressed adequately without lagged annual investment or stock. It is interesting to note that the long-run coefficients in equation (12.6), found by dividing the short-run coefficients by the adjustment coefficient .81, is -12.6 for $(P_I/P_R)_t$ and is 1.64 for E_{t-1}. The similarity of these coefficients to the respective estimates -11.65 and 1.74 in equation (12.1) implies that the error introduced into estimates of short-run or long-run elasticities from ignoring the adjustment (through Q_{It-1}) of gross annual investment to equilibrium is small.

Net Annual Investment

Net investment is the dependent variable for the equations in Table 12.2. The relationship between net investment ΔS_{It} and gross investment Q_{It} is expressed in the identity (12.9), where h is the annual rate of depreciation. Gross investment necessarily is positive, but if $Q_{It} < hS_{It}$, net investment is negative.

$$\Delta S_{It} = Q_{It} - hS_{It} \tag{12.9}$$

If the annual depreciation allowance were nearly constant and small, use of either gross or net investment as the dependent variable would result in similar coefficients. Q_{It} and S_{It} both are increasing functions of time, and subtraction of the replacement or depreciation allowance from Q_{It} tends to reduce the absolute magnitudes of the coefficients as compared to those estimated for Q_{It} alone.[1] The coefficients are smaller in Table 12.2 than in Table 12.1 for this reason. (An adjustment is made in the coefficients to insure comparability of elasticity estimates in subsequent analysis.)

Aside from the fact that the R^2's are lower in Table 12.2 than in Table 12.1, the coefficients are quite similar, as they are expected to be, given the relationship between ΔS_{It} and Q_{It} in (12.9). This similarity is preserved although the dependent variable ΔS_I is the first difference of a stock variable based on somewhat dubious data. Because of initial errors and additional errors introduced in construction of the stock data, changes in the depreciation rate h, etc., the identity in (12.9) is not entirely satisfied by available data. Despite this and the fact that the dependent variable is the first difference of stock, the R^2's in Table 12.2 are relatively high.

The coefficients of lagged stock are negative and significant in all equations. The coefficient might be interpreted to mean: (a) the adjustment rate (model I), (b) the depreciation rate (model J), (c) an expression of farmers' desire to reduce annual purchases when stocks are high, or (d) the cumulative influence of variables correlated with

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[1] Subtraction of a quantity essentially proportional ($o < h < 1$) to the dependent variable is similar to dividing the dependent variable by a constant and, of course, moves the coefficients of the independent variables toward zero.

stock but not included in the equation (such as farm size, amount of liquid assets, technological advances and improved knowledge of the profitability and convenience of greater investment). These interpretations are not mutually exclusive, of course. Fortunately, model G, Chapter 11 (Table 11.1), indicates that the adjustment and depreciation rates approximately are equal. Since the estimates of elasticities and long-run equilibrium are not influenced by the interpretation, it is not necessary to specify whether the equations in Table 12.2 represent model I or J. A depreciation rate of .10, indicated by equations (12.11) and (12.12), is considerably lower than the rate ordinarily expected (and the one used in this study) for machinery. On the other hand, it is higher than the rate expected and used for building improvements. As an aggregate for the two categories, there is no basis for rejecting the estimate as unrealistic. However, if there is a positive net influence on investment of variables correlated with lagged stock but excluded from the equation, the coefficient of lagged stock is expected to be biased toward zero. Because the long-run coefficients are found by dividing the price and income coefficients by an adjustment coefficient biased toward zero, the estimated coefficients probably represent the upper boundary of long-run response to price and income.

Prices of investment items are not always available, and it sometimes may be useful and meaningful to substitute income for the price variable $(P_I/P_R)_t$. This step is taken for the equations in Table 12.3. Advantages of this step include: (a) adequate measures of P_I/P_R and E are not available for earlier years, substitution of Y_F permits estimation of the equations back to 1913; (b) the use of income rather than price permits a measure of the total marginal propensity to invest out of net income; and (c) use of current net income rather than P_I/P_R may reduce the ambiguity in interpreting results. Price and income variables are, of course, related. The variable P_R is common in each and P_I is correlated with some of the prices paid P_P by farmers for items used in production and which implicitly are included in net farm income. Because of the collinearity among input prices, interpretation of the influence of P_I on investment is difficult. The elasticity of investment with respect to P_I might, in fact, be the elasticity with respect to P_P. Of course, if the price of investment durables is the relevant short-run decision variable as implied in Tables 12.1 and 12.2, substitution of Y_F for P_I/P_R is not appropriate. The results in Table 12.3 are presented in order to allow comparisons of this type.

The level of significance of the income coefficient, the multiple coefficient of determination and magnitude of the coefficient of lagged stock S_{It} are generally at lower levels when Y_{Ft} is substituted for $(P_I/P_R)_t$. The results in Table 12.2, in comparison with those in Table 12.3, would support the hypothesis that the price of durable investment items is important in the investment decision function. (Equations computed but not shown indicate, however, that a <u>lagged</u> price variable, P_I/P_R, is overshadowed by adequately specified income variables.) Or perhaps a more realistic statement is that the results support the

Table 12.4. Elasticities of Investment Demand for the Aggregate Stock of Farm Machinery and Buildings S_I With Respect to Price and Net Farm Income Computed From the Equations in Tables 12.1, 12.2 and 12.3*

Equation	Model	Dependent Variable	Short run† (1-2 years) P_I	Short run† (1-2 years) P_R	Intermediate run‡ (3-4 years) P_I	Intermediate run‡ (3-4 years) P_P	Intermediate run‡ (3-4 years) P_R	Long run§ (many years) P_I	Long run§ (many years) P_P	Long run§ (many years) P_R	Adjustment or depreciation coefficient
(12.1)	B	Q_{It}	-.080	.080	-.080	-.16	.24	-.73	-1.45	2.18	.11#
(12.4)	C	Q_{It}	-.074	.074	-.074	-.15	.22	-.67	-1.36	2.00	.11#
(12.10)	BI	ΔS_{It}	-.078	.078	-.078	-.14	.22	-.71	-1.27	2.00	.11
(12.12)	CI	ΔS_{It}	-.071	.071	-.071	-.13	.20	-.71	-1.30	2.00	.10
(12.14)	BI	ΔS_{It}	Y_F		Y_F			Y_F			.054
			.073		.18			3.34			
(12.16) (1926-59)	CI	ΔS_{It}	.067		.13			2.73			.048
(1913-59)			.069		.13			2.98			.043

*See the text and Tables 12.1, 12.2 and 12.3 for discussion of data, methodology, coefficients, standard errors and related statistics. Elasticities are computed at the means.

†Price elasticities are computed from the coefficient of current price $(P_I/P_R)_t$; income elasticities from current income Y_{Ft}.

‡A 1 percent change in the parity ratio P_R/P_P is assumed to be associated on the average with a 2 percent change in net farm income. Translation of intermediate-run elasticities of E and Y_F to prices by multiplication of elasticities is done for convenience, but may impart some upward bias to the results. The price elasticities from the model B equations including equity E are computed on the assumption that a sustained increase of 1 percent in net income will in three or four years cause the equity ratio to increase 1.57 percent (cf. equation (11.15), chapter 11). The intermediate-run elasticity with respect to P_R is the price P_R component of income or equity plus the short-run price elasticity. Since P_I is not an important component of equity or income, the short-run and intermediate-run elasticities are identical.

§The intermediate-run elasticities divided by the adjustment coefficient g.

The elasticity estimates are "corrected" for the noncomparability of the dependent variables by adding h S_{It} to the mean of $\bar{S}_{It+1}$ in equations (12.1) and (12.4), because the dependent variable is $S_{It+1} - S_{It} + h\,S_{It}$ rather than $S_{It+1} - S_{It}$.

#Assumed adjustment coefficients, based on Table 12.2. The number of years N required to make T proportion of the adjustment to equilibrium at the annual adjustment rate g is $N = \frac{\log(1-T)}{\log(1-g)}$. If the adjustment rate is .11, approximately 20 years are required to make 90 percent of the total adjustment.

hypothesis that the price of durable investment items, taken alone, is important in the decision framework, but only in the short run. The important concern of the farmer is ability to pay for the newly acquired asset out of future earnings. Hence, expected earnings, reflected by past net farm income, is an important element in the investment function.

The coefficients of income in equation (12.15) decline with "remoteness" of time, and the results suggest that additional lags would add little to the explanation of investment. Coefficients for the income variable lagged two years were significant only at a low probability level. The similarity of the results in (12.15) and (12.16) also suggests that further income lags are unnecessary. In equation (12.17), with a four year income lag, the coefficient of Y_{WFt-1} is not significant and the variable is deleted to form equation (12.18). The hypothesis is that income of each of the past four years (e.g. the arithmetic average of four years) exerts an equal influence on current investment. Equation (12.16), which depicts a declining income effect, gives a larger R^2 and coefficient of past income and is a more reasonable expression of the investment function than equation (12.18). Model DI was also estimated with a three year income lag. The results were very similar to those in equations (12.17) and (12.18) and are not presented.

Equations for both time periods are consistent in indicating a marginal propensity to invest of .2 (Table 12.3). A sustained rise of one million dollars in net income is predicted to increase annual net investment in agricultural plant and equipment by 200 thousand dollars.

Price and Income Elasticities

Equations in Table 12.1 ideally are best suited for estimating the elasticity of gross annual investment or purchases; those in Tables 12.2 and 12.3 for estimating the elasticity of demand for investment stock. As anticipated, the price elasticities of demand for Q_I are similar to those computed for machinery in Chapter 11 and need little further discussion. The elasticity of Q_I with respect to P_I computed from equation (12.4) is -.76. The elasticity of annual purchases with respect to P_R computed from the same equation is .76 in the short run (current and past year) and 2.3 in the long run (three or four years). Equation (12.6) indicates that the adjustment of annual purchases to the desired level substantially is complete in four years.

From estimates in Table 12.4, the demand for stock of machinery and building improvements is highly inelastic in the short run. Stock is responsive to price changes in the long run, but if the adjustment coefficient is .11, only 90 percent of the total adjustment is completed in 20 years. Equations (12.1), (12.4), (12.10) and (12.12) indicate that the elasticity of investment stock S_I with respect to P_I approximates -.1 in the short run and -.7 in the long run. From the same equations, the elasticity of S_I with respect to P_R approximates .1 in the short run,

.2 in the intermediate run and 2.0 in the long run. With an elasticity of -1.3, the results also show stock to be quite responsive in the long run to changes in prices paid by farmers P_P. Equity and net income in equations (12.1), (12.4), (12.10) and (12.12) are translated to prices by the definitional equation (11.15). Since price ratios are used throughout, the investment functions are homogeneous of degree zero in prices.

Due to the similarity of response of annual investment to price changes, inferences about the aggregate may be extended to the components of Q_I. But because of the lack of uniformity in depreciation rates, adjustment rates and ratios of annual purchases to stock, it is inadvisable to generalize results of the aggregate functions in Table 12.4 for machinery stock S_M and building stock S_B. The equations in Table 12.2 indicate that the depreciation or adjustment rate for the aggregate investment function is .11. The rate for machinery is considerably greater than this figure and for building improvements is considerably less than this estimate based on the results in Chapters 11 and 15.

Equations (12.14) and (12.16) provide the basis for estimating the income elasticity of demand for investment stock. Because current net income does not appear to be an adequate substitute for prices, and because the equations in Table 12.3 are inferior in other respects to those in Table 12.2, the derived income elasticities should be regarded as tentative estimates. The income elasticity of stock demand is .07 in the short run, .1 or .2 in the intermediate run and approximately 3.0 in the long run according to equations (12.14) and (12.16). These estimates, particularly the long-run estimates, appear to be unusually large. The adjustment coefficients are low and, since the intermediate-run elasticities are divided by the adjustment coefficient to form the long-run elasticities, the latter are inversely related to the size of the adjustment coefficient. The adjustment coefficients are expected to be biased toward zero because of correlations with variables exerting a positive influence on net investment. Thus, the elasticity estimates may be taken to represent the upper boundary in response.

Shifts in Investment

Equation (12.1) is used for estimating sources of shifts in annual investment Q_I from 1926 to 1959. The actual increase in annual investment between 1926 and 1959 was 105 percent. Equation (12.1) estimates 108 percent, a very slight difference. Equation (12.1) predicts that, with price ratio P_I/P_R at the 1959 level in 1926, annual investment would have been 60 percent less than the predicted demand at the earlier date. If the equity variable, E, is set at the 1959 level for 1926, ceteris paribus, the predicted demand quantity for the earlier date would have been 69 percent greater than the predicted amount for 1926 with E and other variables at the values of the earlier year. Hence, the price and financial influences nearly offset each other. If the price and equity variables both are set at the 1926 level, (12.1) predicts a 99 percent increase in demand by 1959 due to slowly changing forces aggregated into the time variable, T. These forces represent new technology such as improved machinery, increased general knowledge by farmers and related influences tending to increase farm investment. The replacement demand is ignored in equation (12.1). If the adjustment and depreciation rates are equal, as indicated by equation (12.8), the "adjustment quantity" and replacement demand are offsetting, and both may be ignored according to model G.

Trends and Projections

Figure 12.1 compares historic trends in annual gross investment, Q_I, and stock, S_I. Equation (12.12) is used for prediction in the figure.

The two series displayed similar trends prior to the war. Annual investment and stock both were much greater in 1948 than in 1941. Farmers evidently obtained sufficient quantities of investment items to more than replace depreciated stock during the 1942-47 period. While annual investment declined in the postwar period, stock continued to increase because annual investment exceeded replacement requirements. By 1955, annual purchases approached replacement requirements, and total stock began to level off. In 1956 and 1957, depreciation was greater than purchases, and the stock of durables S_I declined. However, price and income improvement in 1958 and 1959 again allowed additions to stock.

The predictions in Figure 12.1 (solid line) are made with equation (12.12) through the identity in (12.20), where $\Delta S'_{It}$ is the change in stock predicted by equation (12.12) and S_{It} is the known beginning year stock. (The notation "t+1" is used because the "ending year" stock actually is the January 1 stock of the following year t+1.)

$$S_{It+1} - S_{It} = \Delta S_{It} \tag{12.19}$$

$$S'_{It+i} = \Delta S'_I + S_{It} \tag{12.20}$$

The predicted annual gross investment, Q'_{It}, is computed from identity equation (12.9) as

$$Q'_{It} = \Delta S'_{It} + hS_{It} \,. \tag{12.21}$$

The depreciation rate h is the coefficient of lagged stock according to model J. While equation (12.12) predicts well in the postwar years, the depreciation rate appears to be inaccurate in the prewar years. The assumption of a fixed rate h over the entire period may be too rigid. The depreciation rate may well have declined over the period covered. Equation (12.12) predicts annual investment more accurately in recent years than did several equations used to predict machinery quantities in Chapter 11. The equation predicts stock very well over the entire period (the upper graph of S_I).

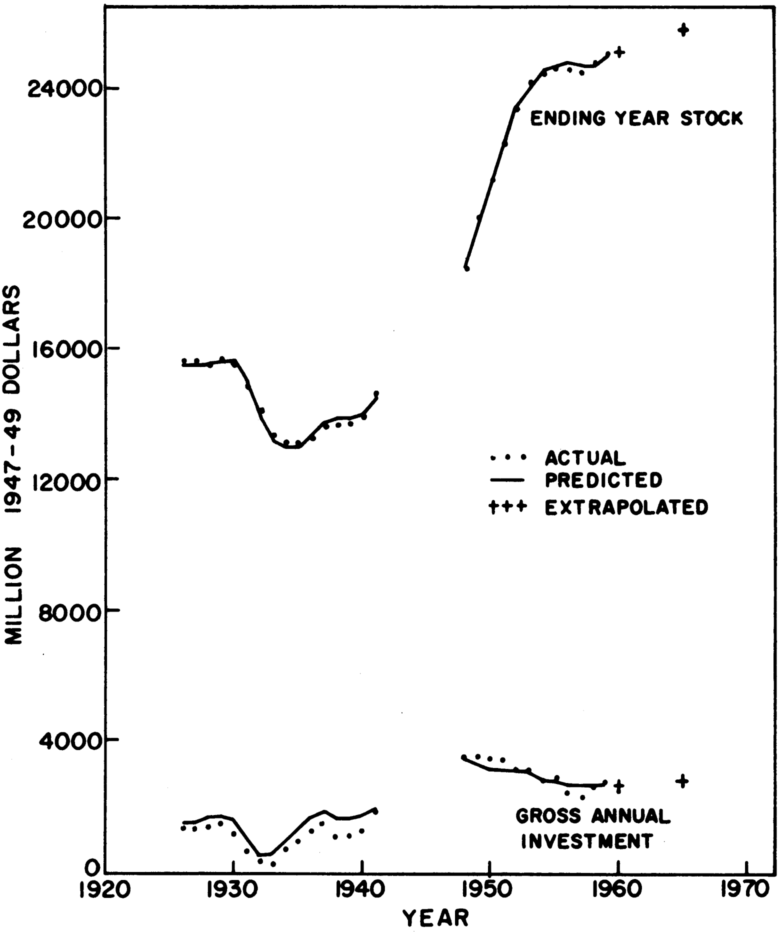

Figure 12.1. Trends in ending year stock S_I and gross annual investment Q_I in all farm machinery and building improvements from 1926 to 1960 (predicted and projected estimates from equation 12.12).

Equation (12.12) also was used for projecting investment stock and purchases to 1965. (The term "projection" is used because assumptions are made for the 1965 levels of the price and net income variables.) Based on assumptions of income at the 1955-59 average level, and prices 10 percent above 1960 prices (the price increase spread proportionately over the 1960-65 period), 1965 gross annual investment and stocks both are projected to be 3 percent above their predicted 1960 levels. Using (12.4) with Q_I the dependent variable, projected 1965 annual investment is 2.8 billion 1947-49 dollars, or 3.5 percent greater than the 1960 predicted level under the same assumptions. These results are quite similar, but other projections would be obtained for alternative price and income assumptions. (The standard errors of the projected estimates were not computed but would be large for distant extrapolations.)

TOTAL FARM INVESTMENT IN ALL PRODUCTIVE ASSETS

We now make an even more highly aggregated analysis of farm investment, with the measure being all productive assets on farms. This dependent variable includes machinery, real estate, livestock, feed and cash held for use in production. The specification of the investment function for this measure of productive assets is similar to that for machinery and building improvements discussed above. Some differences should be mentioned, however. The price of all productive assets is not readily available and was not constructed for the analysis which follows. A quantity indirectly representing an imputed price or net value productivity is net farm income. Net farm income is the residual after paying production costs, and is the approximate return on durable assets and family labor (assuming constant returns to scale). If farmers ignore the family labor component, and subjectively impute the entire residual return to durable assets, net income can be considered an imputed price for productive assets.

Specification of Investment Function for All Productive Assets

The following variables are included in the investment function for all productive assets:

S_{pt} = the stock of productive assets on farms January 1 of the current year. The variable includes machinery, real estate, feed, livestock and cash inventories held for productive purposes and is measured in 10 millions of 1947-49 dollars.

ΔS_{pt} = the first difference of the foregoing variable, S_p, is the dependent variable. It is the net annual investment in productive assets, i.e., the change in total stock during the current year.

Y_{Ft} = the net income of farm operators from farming during the current year, deflated by the index of prices paid by farmers for items used in production, including interest, taxes and wage rates. Net income includes cash receipts, government payments and nonmoney income less production expenses in millions of 1947-49 dollars.

Y_{DFt} = the declining three year arithmetic average of Y_F. Current year income, Y_{Ft}, is weighted by .50, the past year, Y_{Ft-1}, by .33 and the previous year, Y_{Ft-2}, by .17.

Table 12.5. Annual Net Investment in Productive Farm Assets ΔS_p Estimated by Least Squares With Annual Data From 1926 to 1959 and 1913 to 1959, Omitting 1942 to 1947 in Each Series; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation and Years†	R^2	d‡	Constant	Y_F t	Y_{DF} t	Y_{DF} t-1	Y_{AF} t-1	O t-1	$\bar{O}$ t-1	W t	T	S_p t
(12.22) (1926-59)	.751	1.67	-142.53	.0242		.0083				2.10	3.67	-.052
				(.0090)		(.0077)				(1.19)	(3.64)	(.040)
(1913-59)	.690	1.19	-106.85	.0261		.0084				1.14	2.88	-.044
				(.0061)		(.0063)				(.88)	(1.32)	(.025)
(12.23) (1926-59)	.734	1.67	-72.89		.0305					2.42	4.93	-.067
					(.0066)					(1.17)	(3.50)	(.025)
(1913-59)	.663	1.20	-67.56		.0339					1.38	3.20	-.052
					(.0050)					(.90)	(1.34)	(.025)
(12.24) (1926-59)	.759	1.72	-105.64	.0234			.0099			2.15	3.73	-.058
				(.0084)			(.0072)			(1.17)	(3.58)	(.040)
(1913-59)	.700	1.19	-67.96	.0261			.0101			1.13	2.98	-.051
				(.0054)			(.0058)			(.86)	(1.30)	(.025)
(12.25) (1926-59)	.738	1.64	-195.46	.0309						1.99	3.36	-.042
				(.0065)						(1.19)	(3.64)	(.039)
(1913-59)	.675	1.19	-166.20	.0316						1.09	2.65	-.033
				(.0046)						(.89)	(1.32)	(.024)
(12.26) (1926-59)	.821	2.10	455.13	.0320		-.0032			.043	1.35	-3.19	-.188
				(.0083)		(.0078)			(.015)	(1.06)	(3.96)	(.059)
(12.27) (1913-59)	.740	1.62	202.71	.0319		.0018		.0216		.87	-1.21	-.114
				(.0061)		(.0064)		(.0085)		(.82)	(2.02)	(.036)
(12.28) (1926-59)	.778	1.88	412.00		.0273				.030	2.10	.95	-.175
					(.0063)				(.014)	(1.10)	(3.78)	(.062)
(12.29) (1913-59)	.683	1.49	138.37		.0336			.0126		1.29	.96	-.0971
					(.0050)			(.0084)		(.88)	(1.99)	(.0386)
(12.30) (1926-59)	.820	2.05	426.84	.0295					.040	1.44	-2.60	-.181
				(.0056)					(.013)	(1.02)	(3.62)	(.055)
(12.31) (1913-59)	.739	1.63	205.99	.0332				.0226		.85	-1.44	-.115
				(.0042)				(.0077)		(.81)	(1.84)	(.035)

*Sources and composition of the dependent variable ΔS_p and of the indicated dependent variables are discussed in the text.

† Estimated only from original observations. Adjustment models I or J are combined with expectation models discussed in Chapter 10.

‡ The Durbin-Watson autocorrelation statistic d.

Y_{AFt-1} = the simple past four year average of Y_F.

O_{t-1} = farm output during the past year in millions of 1947-49 dollars.

$\bar{O}_{t-1}$ = the simple average of farm output over the past two years.

W_t = Stallings' index of the influence of weather on farm output in the current year. Stalling's data extend only to 1957. Observations for 1958 and 1959 are computed from the deviations from a linear yield trend.

T = time, an index composed of the last two digits of the current year.

All variables are aggregate annual observations for the United States from 1913 to 1941 and from 1948 to 1959 except $\bar{O}_{t-1}$ which was not computed for 1913 to 1925.

Past output is included in the investment function for all productive assets because of the "fixed relationship" between asset stocks and output. Output may be increased in the short run by substituting more operating inputs into the resource mix, but output also is quite closely a function of fixed asset stocks or durable capital. Livestock and feed inventories are sensitive to weather conditions. Accordingly, a measure of weather was included in the investment function. Theoretically, the decision to invest is a function of the discount rate as well as expected future returns. Two measures of the discount rate were included in the investment function: (a) the short-term interest rate on loans to farmers and (b) the rate of return on industrial common stock. These rates were included directly in the investment function and also as ratios to the rate of return on investment in agriculture (residual farm income divided by the total farm assets). However, the coefficients of all these variables were not significant.

Because estimates of gross annual investment are not available, but estimates of stock are contained in secondary sources, model I or J appears appropriate and is used.

First differences of income and output variables were included in the functions, but they did not significantly improve the explanation of net investment. Depending on the variables specified in the function, it might appear that a regression coefficient for farm size might be significant in explaining total investment. However, because of the high correlation between beginning year stock and farm size, the latter variable is excluded from the investment function.

Least-Squares Estimates of Investment

Income, weather, time and beginning year stock explain 75 percent of the variation in annual net investment in equation (12.22), Table 12.5. Current year income exerts the major proportion of the total influence of income on annual investment. Some least-squares bias is suspected, since Y_{Ft} and the errors in the dependent variable are correlated. The variable in equation (12.23) which forces the income influence to be spread over three years has logical appeal because of the nature of farm decision process, and is consistent with results of the investment analyses presented previously. The time variable is not significant in the equations estimated for the 1926-59 period. The technological forces and other influences represented by it may be absorbed by the beginning year stock variable. Over the longer period, however, the stock variable evidently does not adequately incorporate these forces, and the time variable is significant in equations (12.22)-(12.25) for the 1913-59 period. The degree of autocorrelation in the residuals, as indicated by the d statistic, is low for the equations from 1926-59 data. However, structural changes over time not accommodated in the model appear to produce autocorrelation in the residuals for equations from 1913-59 data.

The introduction of an accelerator effect through inclusion of the lagged output variable reduces autocorrelation in investment equations (12.26)-(12.31). The absolute magnitude and significance of the coefficient of the lagged stock variable also are increased. Some instability is exhibited in the magnitude of the accelerator coefficient, depending on the form of the output variable. Coefficients of both output variables are significant, but the variable measured as a two year average has a greater quantitative effect on net annual investment.

Although introduction of an accelerator effect increases the R^2 and reduces autocorrelation, it introduces more collinearity among variables. In (12.23) for example, the highest simple correlation, .82, was between S_{pt} and T. Correlations are higher in equations which include lagged output, the simple correlation being .93 between $\bar{O}_{t-i}$ and S_{pt} in (12.30). Introduction of lagged output in the equation thus creates problems of coefficient instability, interpretation difficulties and other features associated with multicollinearity. Given these limitations, lagged output does improve the explanation of annual net investment, and the specification does not seem to be complete without some type of accelerator variable.

The measurement unit for the dependent variable is ten times larger than that for income and output. The effect of a one-unit increase in income or output on an investment unit can be expressed, however, by shifting the decimal point of the respective coefficients one place to the right. The "marginal propensity to invest," in relation to net income is approximately .3. The finding should not be interpreted to mean that farmers invest 30 cents from each dollar of net income. The interpretation must be less precise and more nearly mean that a sustained 1 million dollar increase in net income eventually will increase annual investment 300 thousand dollars or more in U.S. agriculture. The term "or more" is used because a recursive or "lagged adjustment" influence on investment is expected through the accelerator. There is a direct influence on investment from farm income (from the explicitly specified income variables in the equations), and an indirect influence from favorable farm prices which increase farm output, causing additional investment through the technical relations discussed earlier. The relationship between income and investment also is indirect because: (a) The measure of income, Y_F, used in this study includes nonmoney income, for example. Other concepts of income would result in other estimates of the marginal propensity to invest. (b) Many components of S_p are farm produced rather than cash purchases, and additional net income may first be invested in operating inputs, before inventories of livestock and feed are increased. (c) External credit sources may become more favorable and provide funds for investment when net farm income increases.

Elasticities With Respect to Price and Income

Table 12.6 includes price and income elasticities, for investment stock, S_p, with respect to prices and net income, computed from equations in Table 12.5. The income elasticities are translated into price elasticities by the definitional equation discussed elsewhere. The definitional equation indicates that a 1 percent increase in the parity ratio has been associated, as an average for the period analyzed, with a 2 percent increase in net income. The elasticities with respect to prices paid, P_P, are those (or "the same as those") given for P_R/P_P but with a negative sign. The results indicate the price or income elasticity of stock is low in the short run. A sustained 1 percent increase in net income increases the stock of productive assets only .02 percent in the short run and .04 percent in the intermediate run. Demand for investment stock is highly inelastic in the short run because time and capital restrain the rate at which livestock, feed and other inventories and resources can be increased. Demand becomes much more responsive in the long run. The long-run elasticities, computed by dividing the

Table 12.6. Elasticities of Investment Demand for the Stock of All Productive Assets S_p With Respect to Price and Net Farm Income Computed From the Equations in Table 12.5*

	Short Run (1-2 years)		Intermediate Run (3-4 years)		Long Run (many years)		Adjustment or Depreciation Coefficient
Equation and Year	Y_F†	P_R/P_P‡	Y_F†	P_R/P_P‡	Y_F§	P_R/P_P‡	
(12.23) (1926-59)	.017	.035	.035	.069	.52	1.03	.067
(12.23) (1913-59)	.019	.039	.039	.077	.74	1.49	.052
(12.28) (1926-59)	.016	.031	.031	.062	.20	.39	.175
(12.29) (1913-59)	.019	.038	.038	.077	.41	.82	.097

*See the text and Table 12.5 for discussion of data, methodology, coefficients, standard errors and related statistics. Elasticities are computed at the means.

†Computed from the declining three year average net farm income variable Y_{DFt}, which implies that one-half the elasticity is attributed to the current year.

‡Assuming that on the average a 1 percent increase in price is associated with a 2 percent increase in net income.

§Found by dividing the intermediate-run elasticity by the adjustment coefficient g. If the adjustment coefficient is .10, over 20 years are required to make 90 percent of the total long-run adjustment.

intermediate-run elasticities by the coefficient of lagged stock, lack uniformity among equations incorporating the lagged variable because the adjustment coefficients vary considerably in magnitude among models. Within this framework, and as an "average," a sustained 1 percent increase in income Y_F may increase annual investment stock by 1/2 of 1 percent in the long run. Similarly, a 1 percent sustained increase in P_R (decrease in P_P) in the long run is expected to increase the level of investment stock 1 percent. The "long run" is distant, however. Twenty-two years are required to make 90 percent of the long-run adjustment if the adjustment rate is .10.[2]

Shifts in Investment

The aggregate stock of productive assets, S_p, as defined above, increased by 30 percent between 1926 and 1959. Stock at the end of a given year is the sum of the carryover from the past years plus annual investment in the particular year. The 1959 stock was much greater than the 1926 stock because a larger volume of inventories was accumulated over the period as a result of net positive investment. Interpretation of the effect of individual variables on S_p through investment for each year 1926 to 1959 is cumbersome. Hence, to provide some insight into the annual investment process, equation (12.22) is assumed to be model J, and the influence of income and the time variable on annual investment is compared for the two extreme years only. It is likely that the types of influences registered for these years will also provide some insight into a comparison of annual investment behavior between other years.

Predicted from (12.22), gross annual investment in 1959 was 42 percent greater than in 1926. Had net farm income been at the 1959 level in 1926, ceteris paribus, the equation indicates that the demand quantity would have been only 7 percent greater. Setting only the time variable at the 1959 value, leaving other variables at 1926 values, a 27 percent increase in demand is predicted. (The weather variable explains the difference between the total increase, 42 percent, and the sum of the income and time influences, 34 percent.)

To further examine sources of the increase in gross annual investment, estimates from equation (12.29) are used. The equation predicts a 34 percent total increase in annual investment between 1926 and 1959. Setting the income variable at the 1959 level, other variables at the 1926 level, the equation indicates only a 5 percent increase in investment. If the income component of output could be included, the increase due to income would be more consistent with the 7 percent increase due to income estimated from equation (12.22). If time is set at the 1959

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[2] In these estimates, the coefficients from equation (16.3) are taken as the influence of prices on output, and this accelerator influence is added to the elasticities computed from equations (12.28) and (12.29).

level and other variables at 1926 values, equation (12.29) predicts only a 4 percent increase in annual investment. Following the same procedure for the output variable, the equation predicts a 22 percent increase in demand. The sum of the increase attributed to time and to output is 26 percent, an amount agreeing closely with the 27 percent increase associated with time in equation (12.22) which excluded the output variable. Time and output are highly correlated, and information is unavailable to distinguish the relative influence on annual investment of factors reflected in each. Mainly, our results indicate that a major portion of the secular increase in annual investment in productive assets is associated with gradually shifting variables related to time and output rather than to net income. These "shift" variables include technical changes which increase the marginal productivity of capital. Evidently these forces were more important than income in explaining the secular trend of investment. Although these forces largely explain the secular shift, year-to-year fluctuations in investment are more closely identified with changes in the volatile net income variable. Caution is suggested in interpreting the above results because of inadequate specification of labor price and of the recursive price influence on output and investment.

Trends and Projections

The stock of productive assets increased slowly from 1928 to 1930, then dropped during the depression years up to 1935 (Figure 12.2). The stock of productive assets then began a continuous increase. While the upward trend showed signs of reversal in 1956 and 1957, the 1958 and 1959 observations suggest a linear rather than declining postwar trend. Equation (12.28) predicts close to actual observations over the entire period; it does not predict so well in periods of sluggish investment such as 1938-39 and 1956-57.

With 1955-59 average net income, an 8 percent increase in farm output[3] and $T = 65$, equation (12.28) projects 1965 investment stock to be 5.5 percent above the 1960 stock. Thus, the upward trend in stock, depicted in Figure 12.2, is projected to continue.

Gross annual investment is estimated from equation (12.28) (bottom of Figure 12.2) assuming it is model J and employing the prediction relationship indicated by equation (12.21). So estimated, gross annual investment has been fairly stable over the entire period. Except for the early 1930's, gross annual investment was greater than replacement requirements, and net additions were made to total stock.

Investment in all productive assets has been less volatile than investment in machinery and buildings. Buildings and machinery investment is more sensitive to economic conditions than investment in all

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[3] Johnson, Sherman. Agricultural outlook in the 1960's. 38th Annual National Agricultural Outlook Conference. USDA. 1960.

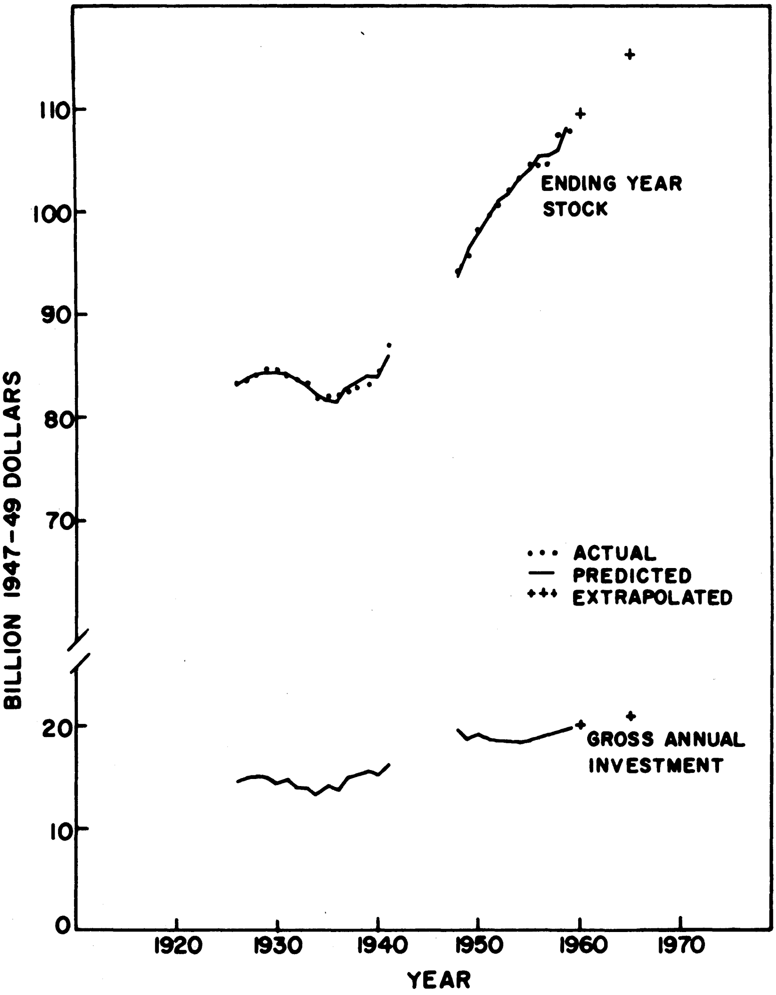

Figure 12.2. Trends in ending year stock S_p and gross annual investment Q_p in productive assets (predicted and projected estimates from equation 12.28).

productive assets because farm produced durables are included in the latter. The supply elasticity and reservation price for farm resources such as land and secondhand buildings and equipment are low. Even when market prices are relatively unfavorable, there are few alternative uses for these "fixed" resources. "Productive" livestock and feed inventories which are not held for current or even future production but are for direct future sales should not be classified as productive assets. However, techniques used to ascertain the quantities of assets are not always adequate for distinguishing between these two categories of farm produced assets.

Based on the same assumptions used above to project S_p to 1965, annual investment Q_p is projected to be 5 percent above the 1960 predicted quantity by 1965 (Figure 12.2). It is expected that this equation predicts the changes in annual investment more accurately than the level of annual investment. The depreciation rate may be too high, and the estimated level of gross investment may contain an upward bias.

POLICY IMPLICATIONS

Farm investment behavior for two aggregate categories of investment, the productive portion of building improvements and farm machinery, and all farm productive assets have been investigated in this chapter. The models used are somewhat simple and do not exploit all alternatives which might be investigated. They have obvious limitations. Within this framwork of limitations, however, the equations suggest a propensity to invest in relation to net income of .2 for machinery and buildings as an aggregate and .3 for all productive farm assets. Since more items are included in the second category, a higher marginal propensity to invest is expected.

Some modern theories of economic growth express national development as a function of two parameters (a) the marginal propensity to invest and (b) the output/capital ratio. The high marginal propensity of U.S. farmers to invest, coupled with the tendency to substitute more productive for less productive capital, accounts for a pattern of growth in output per man-hour unequaled on farms in other parts of the world. The marginal propensity to invest is a function of the education of farmers and of the availability and profitability of investment items, making them attractive to farmers. Both the public and private nonfarm sectors have been important causal agents creating this environment which encourages capital accumulation. Also important is the value system of farmers and the stage of economic development on farms. If farmers had consumed all surplus output (income) because of the necessity to meet subsistence living requirements or because their value structure contained no savings and accumulation ethic, the growth pattern, not only of agriculture but also of the nation, would have been different indeed.

The elasticity of aggregate investment stock, S_I, with respect to own price, P_I, is estimated as approximately -.1 in the short run (one or two years) and -.7 in the long run (over 20 years). The elasticity of S_I with respect to P_R is .1 in the short run (one or two years), .2 in the intermediate run (three to four years) and 2.0 in the long run (over 20 years). The elasticity of investment stock in productive assets, S_p, with respect to P_R is estimated to be .04 in the short run (one or two years), .07 in the intermediate run (three or four years) and 1.0 in the long run (over 20 years).

Some interesting patterns in the elasticities are apparent. As expected, the price elasticities of productive assets, S_p, are consistently lower than those of machinery and improvements, S_I. Because of the nature of the production process in agriculture, livestock inventories cannot be readily increased, and some components of real estate inputs are highly restricted. Stock has a low price elasticity in the short run for reasons explained earlier. In the long run, however, stock appears to be very responsive to price changes according to the analysis. Government policies and other influences on farm product prices thus may have little influence on stock, and consequently on output through S_P, in the short run. The influence on stock might be sizeable in the long run, however. Although stock is not sensitive to price changes in the short run, annual investment is highly responsive. For example, the elasticity of Q_I with respect to P_R is approximately 1.0 in the short run (one or two years) and more than 2.0 in the long run (three or four years). This sensitivity of annual investment to prices is a potential source of business fluctuations, but the effect can be dampened by the remaining large private economic sector and by government spending.

13.

The Market Structure of Operating Inputs

OPERATING inputs perhaps are more closely associated with the rising total output, output per man hour and output per unit of all resources in agriculture than any other particular class of inputs. Operating inputs, sometimes called working capital, include materials representing new biological and chemical innovations, fuel and other items representing mechanical innovations. Operating inputs increased by approximately 200 percent between 1926 to 1960, a period in which total farm employment declined by 43 percent, machinery inventories increased by nearly 80 percent and farm output increased by 70 percent. Accompanying these changes was an increase of 280 percent of productivity per man hour and 60 percent in output per unit of all inputs.

Current operating inputs are here defined as purchased, capital inputs which are consumed and transformed into products in a single year. These nondurable resources generally are not stored on farms for extended periods, but are purchased by farmers in quantities considered appropriate for the needs of the forthcoming production period. The profitability of these items depends on prices and output in the current year, thus less judgment has to be made of economic conditions in future years. They do not ordinarily give rise to a fixed plant, although the productivity of this working capital partly is a function of the durable resource with which they are used. Because of divisibility, expendability and other characteristics listed above, operating inputs are the most flexible of the major farm resources.

The following inputs are included in the category of current operating inputs: (a) fertilizer and lime, (b) seed, (c) machinery supplies, including fuel, lubrication and repairs, (d) building repairs, (e) feed, (f) livestock and (g) miscellaneous inputs such as dairy supplies, hand tools, twine, etc.[1] Inter-farm sales of feed, seed and livestock are excluded. These several inputs are considered as a single aggregate in this chapter. A previous chapter included a detailed analysis of

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[1] Sources of data and aggregation procedures and criteria are in Tweeten, Luther G. An Economic Analysis of the Resource Structure of United States Agriculture. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962. Chap. 5. Only the nonfarm share of livestock, feed and seed sales are included. The portion for livestock, for example, includes mainly marketing charges and is only a small proportion of total farm expenditures for livestock in the current year.

fertilizer demand. Demand structure for five additional component categories are included in the following chapter.

Several hypotheses potentially explaining the growth in use of operating inputs are: (a) relative prices of operating inputs have fallen, encouraging greater input of these resources for agricultural production and causing substitution of them for other resources, (b) growing inventories of durable assets such as machinery have increased demand for operating inputs because of strong complementarity between the resources and (c) introduction of new and improved operating inputs have increased their marginal productivity, causing demand to grow because of higher transformation rates. This last condition includes not only new discoveries of their existence and productivity but also greater farmer knowledge of them. As mentioned in Chapters 2 and 4, economic development provides conditions for joint occurrence of these hypotheses. A decline in the relative price may be due to technological changes or decreasing costs in nonfarm industries which supply operating items. A fall in the price of operating inputs may encourage their use and further research on their discovery and productivity. Also a declining real price (hypothesis a) may encourage investment in durable assets and indirectly increase demand for operating inputs through complementarity (hypothesis b). Because all the above conditions influence purchase of operating items, no attempt is made to select one hypothesis from among the set for particular verification. Instead, we attempt a quantitative measure of the existence of all of them.

Demand for operating inputs in aggregate at the farm level is estimated by least-squares and limited information techniques. The supply function for operating inputs is also estimated by limited information. Conditions suggesting that major criteria for aggregation are met in use of the category as a single resource include: Trends in prices of the several components of operating inputs are similar.[2] With the exception of building repairs, trends in purchases of individual categories are somewhat similar over the time period. Since there are, however, obvious advantages in considering demand relationships for separate operating inputs, demand functions are estimated individually for five categories of operating inputs in the following chapter.

TRENDS IN PRICES AND QUANTITIES

Current operating inputs serve as substitutes for some categories of resources and as technical complements for others. Thus, decline in relative prices and growth in knowledge of productivity of various operating inputs have caused divergent trends in their use relative to other categories of farm resources. These variations might be grounds for arguing that demand for current inputs should be considered only in less aggregate categories. However, because certain sectors of the

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[2] *Ibid.*, Chap. 4.

economy have interest in the more aggregate category, we attempt to estimate economic relationships surrounding it.

To better visualize patterns of interrelationships between aggregate operating inputs and other broad categories of farm resources, detailed analysis is made of historic trends in this chapter. Figures 13.1 through 13.4 trace trends in the ratio of price and use for operating inputs as compared to three other resources and to output. Each figure contains graphs of P_O/P_i and Q_O/Q_i where P_O and Q_O are respectively the price and quantity of operating inputs and P_i and Q_i are the respective price and quantity of other major farm resources (or farm output). Substitution is expected as a result of price trends since generally P_O has fallen relative to other prices, P_i (i.e. the ratio of Q_O to Q_i is expected to rise). If a decline in P_O/P_i is not accompanied by a rise in Q_O/Q_i, a complementary effect prevails or price effects may be obscured by more fundamental technological or other phenomena.

Figure 13.1 includes comparison in the ratios of (a) operating inputs, Q'_O, to machinery inputs, Q'_M, and (b) operating input price, P_O, to machinery price, P_M, for 1910-59.[3] Prices of operating inputs have declined relative to machinery prices since the late 1920's. The quantity ratio, however, remained quite stable, except for the war periods. Increases in the ratio for 1917-19 and 1942-48 were due mainly to machinery shortages. Farmers substituted operating inputs for machinery by working the old tractors, for example, longer hours. Because motor supplies in general are complements of machinery and are an important component of Q'_O, a tendency exists for complementarity between Q'_O and Q'_M. Other components of Q'_O, such as weedicides, allow crop production with fewer tillage operations; hence a tendency also

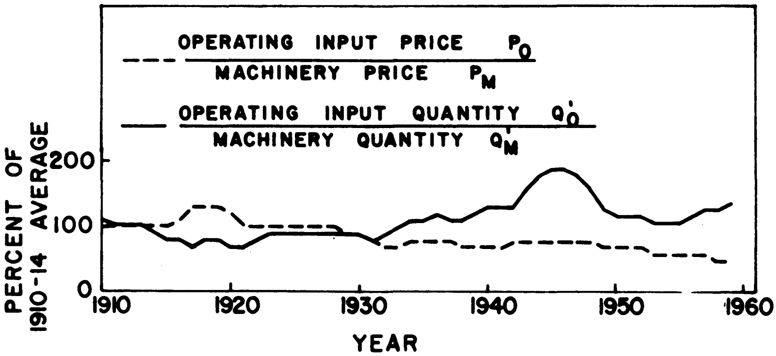

Figure 13.1. Ratios of farm operating input and machinery prices and quantities from 1910 to 1959 (1910-14=100).

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[3] Machinery inputs Q'_M are valued as services required to maintain farm equipment and motor vehicles used for productive purposes. Q'_M includes depreciation, license fees, insurance and interest on inventory.

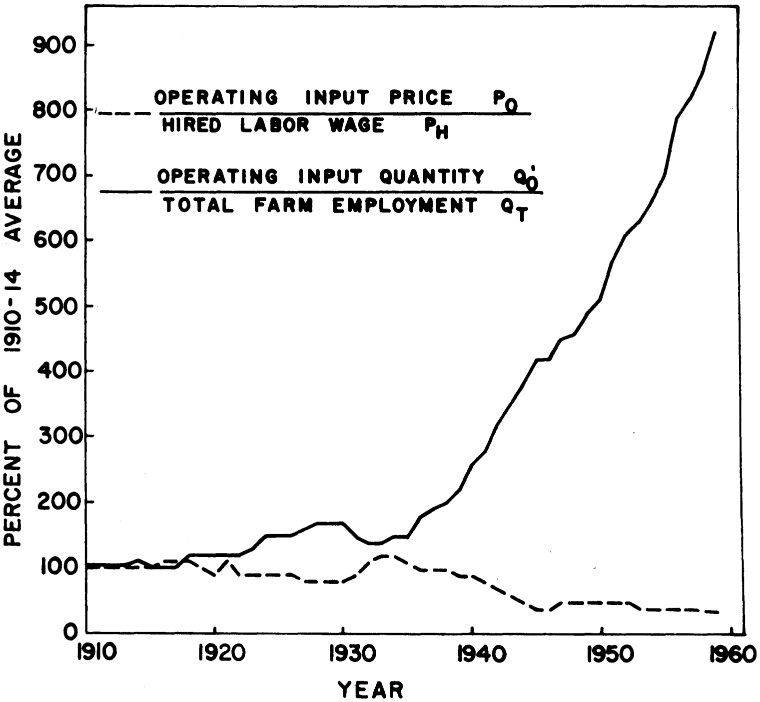

Figure 13.2. Ratios of farm operating input and labor prices and quantities from 1910 to 1959 (1910-14=100).

exists for substitution of Q'_O for Q'_M. These forces influencing the ratio of operating to machinery inputs to a large extent have offset each other over the period 1910-60.

Figure 13.2 includes similar comparisons for operating inputs and labor prices and quantities from 1910 to 1959. Increase in operating inputs was associated with a sharp decrease in labor after 1935; the substitution was at a slower rate before 1935. Substitution is consistent with trends in relative prices of the two inputs over the 50-year period.

While the price of operating inputs relative to labor price declined by 60 percent in the period 1910-59, the quantity ratio increased 800 percent. This suggests a "gross" price elasticity of substitution of approximately -13. (It is "gross" since other forces not included also influenced the ratio of Q'_O to Q_T.) Machinery, for example, is a principal and direct substitute for labor. Since Q'_O and Q'_M are complements, the ratio of Q'_O to Q_T increases concurrently with the ratio of Q'_M to Q_T. Figure 13.2 illustrates, however, the indirect substitution of operating inputs for labor in a developing agriculture. Commercial fertilizer, for example, permits the same or more output with fewer labor resources.

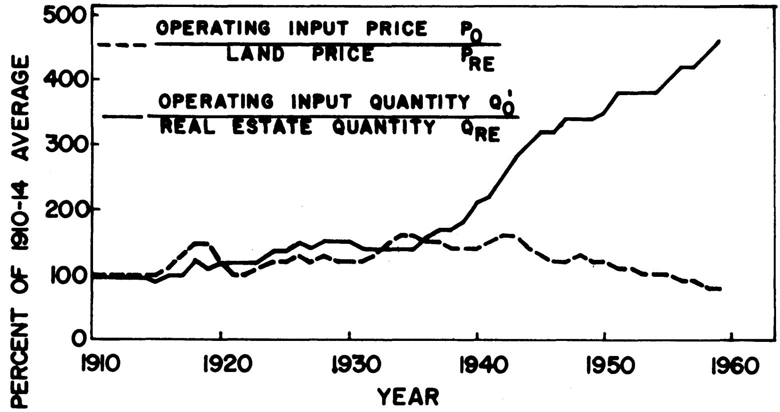

Figure 13.3. Ratios of farm operating input and real estate prices and quantities, 1910-59 (1910-14=100).

Figure 13.3 compares similar ratios of price and input quantity for operating inputs and real estate. Real estate input, Q_{RE}, is measured as interest on investment and other costs necessary to maintain the real estate investment. A tendency to substitute Q'_O for real estate inputs is prominent after the mid-1930's when operating inputs such as hybrid corn and fertilizer were becoming widely accepted. These inputs allow more output without a corresponding increase in the land resource. The price of operating inputs declined 20 percent relative to real estate prices over the 50 years, and the quantity ratio Q'_O/Q_{RE} increased 350 percent. The "gross" price substitution elasticity, -17, exaggerates the actual substitution rate because of confounding with other technological changes and price factors.

Figure 13.4 shows quantity and price ratios for operating inputs and farm output, O. P_R is prices received by farmers for crops and

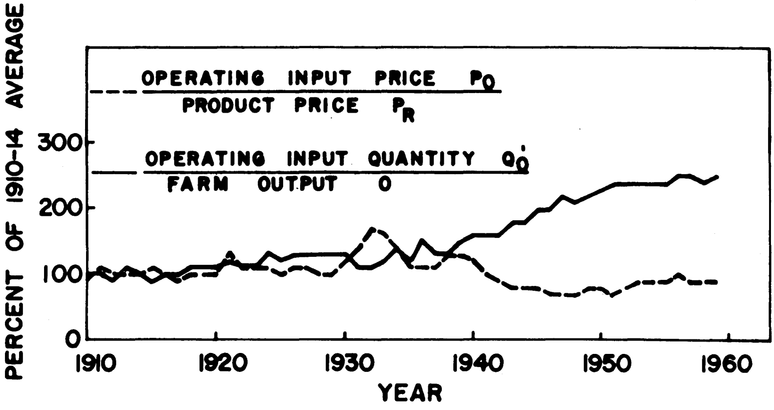

Figure 13.4. Ratios of farm operating input and farm output prices and quantities from 1910 to 1959 (1910-14=100).

livestock. The price ratio P_O/P_R increased during the depression years, remained relatively uniform until 1940, and then declined slightly. Inputs of Q'_O relative to O increased accordingly, rising approximately 120 percent from 1910 to 1959.

The above figures particularly emphasize the gross substitution of operating items for labor and real estate. The ratio of Q_O to other major classes of inputs has been associated with a decline in P_O relative to other prices. The substitution is also consistent with a more rapid increase in the marginal product of operating inputs than of other resources. Remaining sections include attempts at quantification of parameters of structures which determine the use of operating inputs.

THE DEMAND FOR OPERATING INPUTS

The demand function for operating inputs at the farm level is specified as

$$(13.1)\quad Q_O = f[(P_O/P_R)_t,\ (P_O/P_R)_{t-1},\ (P_O/P'_P)_t,\ (P_O/P'_P)_{t-1},\ S_{pt},\ W_t,\ G_t,\ T]$$

where the demand quantity, Q_O, is a function of operating input prices, P_O, prices received for crops and livestock, P_R, and prices paid for hired labor and machinery, P'_P.[4] S_p is the January 1 stock of productive assets, W is a measure of the influence of weather, G is an institutional variable indicating the existence of acreage controls and price supports and T is time. In the model, t refers to the current year, t-1 to the past year.

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[4] It is useful to note that the ratio form (a) below, indicated in equation (13.1) and used in this study, differs somewhat from the form (b) suggested by static economic theory. The two alternative least-squares input demand forms with input price P_i, other input prices P_P and prices received P_R are:

$$(a)\qquad Q_i = a + b\frac{P_i}{P_R} + c\frac{P_i}{P_P} + e$$

as in equation (13.1) above, and

$$(b)\qquad Q'_i = a' + b'\frac{P_i}{P_R} + c'\frac{P_P}{P_R} + e'$$

as in the static theory model. If the data are transformed into logarithms, the price elasticities of demand E with respect to prices in the above forms (a) and (b) are:

$E(P_i) = b + c$ in (a); b' in (b)

$E(P_P) = -c$ in (a); c' in (b)

$E(P_R) = -b$ in (a); $-b' - c'$ in (b).

Since input prices P_i and P_P often are highly correlated, the matrix of price variables in form (b) may tend to be singular; the coefficients b′ and c′ unstable and none of the elasticities estimated accurately. In form (a), the standard error of c is likely to be large and c insignificant. This does not necessarily preclude obtaining a realistic estimate of b. Hence, there appears to be some advantage in using form (a).

The Variables

The variables are defined specifically as:

Q_{Ot} = the weighted national aggregate of fertilizer, seed, motor supplies, building repairs, feed, livestock and miscellaneous inputs. Quantities are aggregated by 1935-39 prices prior to 1940, and by 1947-49 prices after 1940. Overlapping values for 1940 are used to value the final aggregated series in 1947-49 million dollars. Inter-farm sales are excluded; hence only a small portion of total livestock purchases are included.

$(P_O / P_R)_t$ = the current year index of the ratio of operating input prices to prices received by farmers for crops and livestock. The past year index is also included. Prices are weighted by quantities using the above procedure.

$(P_O / P'_P)_{t-1}$ = the past year index of the ratio of operating input prices to prices paid by farmers for machinery and hired labor.

S_{pt} = the stock of productive assets on January 1 of the current year. The variable includes real estate, machinery, livestock, feed and cash inventories held for productive purposes, in billions of 1947-49 dollars.

G_t = a current year index of the role of government policies. Years of acreage allotments production controls are given the value -1. Years when farm prices are supported are assigned the value +1. If supports are fixed, an additional +1 is added. These values are summed to form G.

W_t = Stallings' index of the influence of weather on farm output in the current year.[5] Indices for 1958 and 1959 are not computed by Stalling, but are constructed from an index of deviations from a linear trend of crop yields.

T = time, measured as the last two digits of the current year.

All price indices are adjusted to a base 1947-49 = 100. The variables are annual data from 1926 to 1959, omitting 1942 to 1945.[6]

Equation 13.1 is a single-equation model of demand and assumes a monocausal structure based on the nature of the supply for operating inputs. Short-run changes in Q_O are not expected appreciably to influence P_O, P_R or other input prices. Also, purchases of Q_O probably have little influence on the stock of productive assets S_p in the short run. We assume that explanatory variables influence Q_O, but are not influenced by it, in the short run. Because logic and empirical data do not entirely support this assumption, it also is desirable to estimate the operating input demand in an interdependent economic system.

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[5] Stallings, James L. Weather indexes. Journal of Farm Economics. 42:180-86. 1960.

[6] See Tweeten, op. cit., pp. 128, 129.

Hence, a simultaneous model of demand for operating inputs also is presented later. The variable specification is similar except that while a price ratio form is used in equation (13.1), prices of labor and machinery are included separately in the simultaneous model.

A more complete demand specification might include: (a) a farm income variable, (b) a farm size variable and (c) several categories of prices received and prices paid by farmers. Prices rather than income appear to be the relevant farmer decision variable in the demand function for operating inputs. Furthermore, income tends to be a function of prices, weather and technology variables already specified.

As farm size expands, a tendency exists to substitute additional motor supplies, fertilizer and other operating inputs for labor. Unfortunately, the very high correlation between farm size (cropland acres per farm) and the stock of productive assets, S_p, precludes including both variables in the statistical demand function. The coefficient of S_p must be interpreted as reflecting the influence of farm size as well as other scale effects.

It would be desirable to specify several categories of prices received for products and prices paid for inputs by farmers. High intercorrelations among prices over time prohibit such refinements. In fact, the high intercorrelations among input prices required the exclusion of the current year price ratio $(P_O / P'_P)_t$. The coefficient of the included past year ratio tends to reflect both current and past influences of P_O / P'_P on Q_O because of the high correlation in the time series.

The process by which farmers formulate price expectations and adjust input purchases to uncertain conditions may result in a demand pattern discussed extensively in the literature on the theory of distributed lags (see Chapter 3). Because of the time required for production, farmers maximizing profit must base input purchases on expected prices formulated from knowledge of past prices. It may be argued that prices lagged no more than one or two years provide a satisfactory estimate of farmers' price expectations in operating input demand functions. Input prices are determined primarily by slowly changing variables such as the nonfarm wage rate. Hence, prices of nonfarm produced inputs display very small annual variation and are free of cyclical fluctuations so characteristic of many farm product prices. Since input prices are known with considerable certainty when production plans are made, the principal expectation variable is output price. The nondurable production inputs are consumed in the forthcoming production period; hence their expected profitability is not a function of prices in several future production periods. It seems reasonable to assume that farmer decisions regarding the immediate future are based on the immediate past. Thus, inclusion of product price variables for only one or two past production periods appears adequate.

A second source of a distributed lag model of demand is a lagged adjustment to the equilibrium level of input, given prices and other predetermined variables. That is, a farmer who is subjectively certain of prices may adjust slowly to a profit maximizing level of resource use because of inertia of past decisions, institutional restraints, large investment requirements or indivisibility of inputs (see Chapter 3). The most logical source of the lagged adjustment to the desired Q_O level likely arises from incomplete knowledge or skepticism by farmers of the increased profitability, convenience and other advantages of using more operating inputs.

The inclusion of the productive assets, S_p, in the demand function adjusts for changes in scale of the farm plant. Hence, equation (13.1) is the short-run demand for Q_O, i.e., the demand for operating inputs given the plant size. The influence of S_p on the demand quantity depends on the interaction between Q_O and S_p and on the fixed level of productive assets. Higher levels of S_p might be expected to increase marginal productivity (and demand) for Q_O.

Least-Squares Demand Equations for Operating Inputs

Economic theory, introspection and logic do not dictate an exact demand function. The appropriateness of a given set of variables or form of the distributed lag cannot be determined solely from a priori considerations. To demonstrate the effect of alternative specifications several empirical forms are presented. The procedure in this section is to estimate (a) conventional models with short-run lags and (b) distributed lag models of the Koyck-Nerlove type. The functions include different sets of explanatory variables, beginning with models as completely specified as practical limitations of data and estimational procedures permit. Variables considered inappropriate because of low significance or high intercorrelation with other variables are deleted in subsequent regressions. All equations are estimated in original data (O) and in data transformed to logarithms (L). The two dummy variables, time, T, and government policies, G, are not well suited for logarithmic transformation. Hence, equations containing both variables are estimated in original data only. Where the Durbin-Watson test indicates probable autocorrelation in residuals, the equation also is run in first differences.

Single-equation least-squares estimates of the demand for Q_O as a function of price and other variables are presented in Table 13.1. The seven independent variables in equation (13.2) "explain" over 99 percent of the annual variation about the mean of Q_O.[7] The unusually high R^2 is

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[7] The term "explain" is a somewhat inexact generalization of the statistical multiple coefficient of determination R^2. R^2 is the ratio of the sum of squares of the estimated values of the dependent variable to the sum of squares of the actual values of the dependent variable. The R^2 may also be considered the square of the multiple correlation coefficient R between the dependent variable and a linear function of the independent variables. The R^2 may be made equal to 1 by including one less explanatory variable than the number of observations. The adjusted multiple coefficient of determination $\bar{R}^2$ is corrected for the influence of the number of explanatory variables.

Table 13.1. Demand Functions for Operating Inputs Q_O Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation and Transformation†	R^2	d‡	Constant	P_O/P_R t	P_O/P_R t-1	P_O/P'_P t	P_O/P'_P t-1	S_P t	G t	W t	T	Q_O t-1
(13.2-O)	.997	1.42	-5939.07	-7.64	-1.89		-10.32	117.98	6.47	6.57	53.81	
				(1.94)	(2.19)		(4.89)	(9.58)	(5.30)	(2.64)	(14.60)	
(13.3-O)	.996	1.21	-4557.10	-7.61	-2.77		-13.93	113.03		6.37	46.78	
				(1.96)	(2.09)		(3.94)	(8.77)		(2.67)	(13.55)	
(13.3-L)	.991	.73	2.25	-.29	-.23		-.17	1.18		.115	.0086	
				(.10)	(.10)		(.19)	(.31)		(.079)	(.0018)	
(13.3-F)	.507	1.51	-§	-5.87	-2.35		-13.65	72.81		1.89	82.82	
				(1.98)	(2.02)		(6.39)	(27.15)		(2.05)	-§	
(13.4-O)	.994	1.04	-4511.47		-9.06		-13.41	105.93		5.23	57.56	
					(1.66)		(4.95)	(10.80)		(3.33)	(16.69)	
(13.4-L)	.988	.80	2.73		-.465		-.24	.94		.103	.0091	
					(.076)		(.21)	(.34)		(.090)	(.0021)	
(13.4-F)	.309	1.65	-§		-4.79		-9.95	61.40		1.21	98.86	
					(2.14)		(7.25)	(31.11)		(2.35)	-§	
(13.5-O)	.997	1.60	-488.55	-4.58		3.16					34.65	.879
				(1.13)		(4.30)					(11.87)	(.054)
(13.5-L)	.996	1.49	.75	-.237		.17					.0050	.780
				(.041)		(.15)					(.0012)	(.083)
(13.6-O)	.997	1.60	230.18	-4.28							28.74	.857
				(1.05)							(8.63)	(.045)
(13.6-L)	.996	1.40	1.39	-.233							.00417	.711
				(.041)							(.00091)	(.056)

*The dependent variable Q_O and the indicated independent variables are defined in the text.

†Equations are estimated in the transformations indicated: original values, O, logarithms, L (T is in original value in L equations), and first differences of original values, F.

‡The Durbin-Watson autocorrelation statistic d.

§The intercept or constant coefficient in the first difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

caused by the tendency for aggregation to average out the error in Q_O. Also, a large proportion of the variability is due to the highly predictable trend variables S_p and T. The R^2 falls considerably when the functions are estimated in first differences of original values.

The coefficient of the institutional variable G is nonsignificant in the first equation and is deleted for the next one. There exists a high probability that the variable G used to represent the effect of government programs has no influence on Q_O. However, our inability to construct a better index of government policy does not necessarily mean that government programs lack influence on Q_O.

The Durbin-Watson test of the null hypothesis that the true residuals are uncorrelated is inconclusive in equation (13.3-O) and is rejected in equation (13.3-L). Hence, the equation is estimated in first differences of original values. After the first-difference transformation, the test for autocorrelation is still inconclusive.

The signs of the coefficients in all transformations of equation (13.3) are consistent with a priori theory, but the magnitudes of the coefficients differ among transformations. The influence of $(P_O/P_R)_{t-1}$ is stronger and the influence of $(P_O/P'_P)_{t-1}$ is weaker in (13.3-L) than in (13.3-O) and (13.3-F).

Some components of Q_O are expected to be influenced by current prices. These prices may not be available when needed by the economic forecaster, hence it may be necessary to base predictions on past values. The least-squares algorithm will result in a more efficient, though perhaps slightly biased, estimate of Q_O from equation (13.4), omitting $(P_O/P_R)_t$, than from equation (13.3) if only past values of the explanatory variables are known. Based on the sum of the price coefficients in (13.3), it appears that the coefficient of lagged price P_O/P_R in (13.4) tends to absorb the influence of current price. Failure to include the current price variable may not seriously bias the estimate if current and lagged values are sufficiently correlated. While we cannot accurately impute the entire price response to the lagged price variable, (13.4) explains a large portion of the variance in Q_O and is a useful predictive equation.

On the basis of equations (13.2), (13.3) and (13.4), it may be argued that the distributed lag model is not appropriate. A large proportion of the variance about the mean of Q_O is explained by the current and past year explanatory variables in these equations (untransformed data). It is also a fact that the current and past values of Q_O display a high serial correlation. The implication is that, from a statistical standpoint, the lagged quantity is likely to be highly correlated with a linear combination of the explanatory variables. In such instances, the matrix of predetermined variables tends to be singular and, statistically, we are unable to differentiate the influence of individual predetermined variables. The coefficients tend to be unstable, and statistical inference becomes difficult or impossible. The economic interpretation is that influence of past values of explanatory variables, represented in the demand equation by Q_{Ot-1}, on current quantity Q_{Ot} is expected to be small. Current demand quantity essentially is determined by exogenous variables of the current and past year. As an empirical test of this hypothesis, equations (13.3-O) and (13.3-L) were estimated with the addition of the predetermined variable Q_{Ot-1}. In the resulting equations (not included in the table) the coefficients of Q_{Ot-1} were highly nonsignificant. The implication is that farmers adjust operating input purchases to prices, scale of plant and technology in the short run. The adjustment coefficient is unitary according to these results, given the scale of plant.

This conclusion may be too restrictive since (13.5) and (13.6) indicate that if S_p is excluded, the coefficient of lagged quantity in the adjustment equations becomes highly significant. If it is not necessary to include S_p in the demand function (its significant coefficient reflects the lagged adjustment and technology effects that logically belong with variables T and Q_{Ot-1}), (13.5) and (13.6) are appropriate. Furthermore, the time variable could be removed and the price and lagged quantities could explain current demand for Q_O. The increase in demand quantity then would be entirely attributed to lagged adjustment to the secular price decline. While the preceding statements suggest the empirical results to be consistent with several alternative hypotheses, we cannot adequately distinguish the influence of adjustment to price changes, technology and scale of plant on purchases of Q_O. Variables reflecting these influences are too highly correlated through time and are subject to large error. Because of these limitations and the small sample size, two alternative methods of estimating long-run demand for operating inputs are considered. In the first, S_p is omitted and Q_{Ot-1} is included as an indication of long-run influences. From the resulting distributed lag equations, estimates of long-run and short-run elasticities and adjustment rates can be computed.

A second approach considers the long-run demand for Q_O to be a recursive process. Empirical results indicate there are no long-run influences of prices on Q_O, given the scale of plant indicated by S_p and technology indicated by T. But in the long run, prices do influence plant size. In equation (12.23), investment S_p is estimated as a function of farm income Y_F, but also can be expressed as a function of prices. Equation (12.23), estimated with original annual data from 1913 to 1959, omitting 1942 to 1947, may be written as

$$(13.7) \quad S_{pt} = K + .00017Y_{Ft-1} + .00011Y_{Ft-2} + .000056Y_{Ft-3}$$

where K represents the influence of time, weather and carryover of stock. Net income, Y_F, in millions of 1947-49 dollars, is translated to prices by a definitional equation:

$$(13.8) \qquad Y_{Ft} = K' + 209.46\ (P_R / P_P)_t$$

where P_R is prices received by farmers and P_P is prices paid by farmers for items used in production, including interest, taxes and wage rates. Equation (13.8) was estimated by least squares with annual data from 1910 to 1959, omitting 1942-45, but the price variable is the index of the ratio of P_R to P_P (1947-49 = 100) from 1946 to 1959 only.[8] The coefficient indicates that from 1946 to 1959 an increase of the parity index by one unit increased net farm income an average of slightly over 200 million 1947-49 dollars. K′ represents other influences such as weather, technology, etc., on farm income. The right side of (13.7) is substituted into (13.6) to define investment in terms of prices. This expression is then inserted into equation (13.3) to form the approximate "long-run" demand function:

$$
\begin{aligned}
(13.9) \qquad Q_O = K'' &- 7.61(P_O/P_R)_t - 2.77(P_O/P_R)_{t-1} \\
&- 13.93(P_O/P'_P)_{t-1} + 4.01(P_R/P_P)_{t-1} \\
&+ 2.67(P_R/P_P)_{t-2} + 1.33(P_R/P_P)_{t-3}
\end{aligned}
$$

where K″ is the sum of the influences of weather, technology and errors in predicting Q_O. Equation (13.9) is included to demonstrate the methodology for deriving long-run demand. Because (13.7) contains a distributed lag and up to 20 years are required to adjust stocks to prices, (13.8) is still not the "full" long-run demand function for operating inputs.[9] Use of further lags, however, make the equation cumbersome.

Demand for Operating Inputs
Estimated by Limited Information

The demand for Q_O also is estimated in an equation allowing prices and quantities of farm products and resources and farm numbers to be determined simultaneously. The limited information estimates of demand for operating inputs, computed with national aggregates of annual data from 1926 to 1959, excluding 1942 to 1945, are included in (13.10).

$$
\begin{aligned}
(13.10) \quad Q_O = - 14 &- \underset{[-2.23]}{110P_{Ot}} + \underset{[.51]}{25P_{Mt}} - \underset{[-.63]}{41P_{Ht}} + \underset{[1.12]}{112P_{Rt}} - \underset{[-.56]}{47N_t} \\
&- \underset{[-.078]}{2.9(P_O/P_R)_{t-i}} + \underset{[3.07]}{171S_{pt}} + \underset{[.0075]}{7.5G_t} + \underset{[.074]}{7.4W_t} - .40C_t
\end{aligned}
$$

where P_M is farm machinery price, P_H is the wage rate of hired labor, N is farm numbers and C is a structural variable with values of zero in prewar years, 100 in postwar years. Other variables are discussed

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[8] For the complete equation and others relating income and prices see Tweeten, op. cit., Appendix B.

[9] The nature of this lagged adjustment is not discussed in this chapter, but provision is made for the total long-run response of investment stock to prices in the later sections on price elasticities (see Model I, Chapter 10).

earlier in the chapter. Prices are deflated by the general price deflator of the Gross National Product (1947-49 = 100). The first six variables are endogenous; the remaining five are predetermined. Elasticities computed at the 1926-59 mean level of quantities are included in brackets below the coefficients. Standard errors were not computed.

With two exceptions, the signs of the coefficients are consistent with economic theory and with the results of past empirical studies. The equation indicates that the demand quantity Q_O increases as farm numbers decrease. Because total acreage is quite stable, the implication is that an increase in farm size is accompanied by an increase in demand for current operating inputs. The result may be due to the substitution of operating inputs for hired labor and machinery in the short run as additional land is purchased. A farmer who expands his operation by buying a contiguous unit of land tends to farm it with little additional machinery in the short run. In the long run, as his financial condition improves and his desire to reduce family labor requirements increases, he purchases additional large, more efficient machines.

Equation (13.10) approximately is homogeneous of degree zero with respect to prices. The equation is consistent with equations (13.2-O) and (13.4-O) in indicating the importance of current prices in the demand function. The signs of the P_O and P_R coefficients are as anticipated, but the magnitudes of the bracketed elasticities, unusually large, may be due to specification bias or to certain properties of limited information estimators. The coefficients of P_M and P_H indicate that operating inputs are short-run substitutes for machinery and complements of hired labor. The opposite relationship might have been expected, but a priori evidence on the nature of short-run substitutions is meager.

The coefficients of S_p, W and G are somewhat similar to those in equation (13.3). The coefficient of the structural variable, C, is very small, indicating that there has been little change in the demand structure not attributable to the other variables in equation (13.10).

PRICE ELASTICITIES OF DEMAND

This discussion of price elasticities rests particularly on short-run demand equation (13.2) and long-run equation (13.9). Considering first the elasticity with respect to P_O, some instability exists in the coefficients of the current and past year prices. Hence, the responses for these years are added and referred to as "short-run" price elasticity. The short-run price elasticity of demand for Q_O with respect to P_O / P_R is -.28, -.52 and -.22 computed from (13.2-O), (13.2-L) and (13.2-F), respectively. The elasticity of Q_O with respect to P_O / P_P' is -.36 from equation (13.2-O), -.17 from equation (13.2-L) and -.35 from equation (13.2-F). Thus, the total short-run elasticity with respect to P_O is -.64, -.69 and -.57 from the respective transformations. A 1 percent decrease in the price of operating items is expected to increase purchases by approximately .6 percent in the short run. The operating input price, P_O, does not explicitly occur in variables beyond the short run according to the long-run equation (13.9). A literal interpretation is that -.6 is also the long-run elasticity of Q_O with respect to P_O. P_O is a component of P_P, however, and for this reason the long-run elasticity is somewhat greater than -.6 due to the long-run influence of P_P on Q_O through the productive assets variable.

It is interesting to compare the estimate of the demand elasticity -.6 computed from equation (13.2) with the elasticities obtained from other estimational techniques: (a) a weighted average of the elasticities computed for the components of Q_O from the demand equations for five operating inputs estimated in the following chapter and the comparable demand equation for fertilizer in Chapter 7, (b) from the Koyck-Nerlove equation (13.5) and (c) from the limited information demand equation (13.10). The elasticity with respect to P_O estimated as a weighted average from the six components of Q_O discussed in Chapters 7 and 14 is -.66 and agrees closely with the single-aggregate estimate from equation (13.3).[10] The estimate of elasticity from the distributed lag equation (13.6-L) is -.2 in the short run, -.8 in the long run. This result is not necessarily in conflict with the -.6 estimate from (13.2). The lower estimate, -.2, is for the current year only and is expected to be small. The larger estimate, -.8, is for the long run, and if the component of P_O in P_P were included in the estimate from equation (13.2), the elasticity estimates for the long run from equations (13.2) and (13.6) might be very similar. The elasticity of Q_O with respect to P_O computed from the limited information demand equation (13.10) is -2.3. The estimate from the limited information technique may be too large because of specification errors or properties of the estimational technique. On the basis of statistical properties of the functions and past empirical studies, the results from the least-squares demand equations in Table 13.1 appear to be most realistic.

Thus far we have discussed the elasticity with respect to P_O. From a policy standpoint and for other reasons, the elasticity with respect to P_R is very important. The elasticity with respect to P_R computed from equation (13.3-O) is .28, from equation (13.6-L) is .22 in the short run. In the long run, an increase in P_R also increases Q_O through the investment process. Equation (13.9) suggests that after three or four years a 1 percent increase in P_R increases Q_O about .13 percent through S_p alone. The total intermediate-run (three or four years) elasticity with respect to P_R is estimated approximately at .28 plus .13, or .41. After several years a 1 percent increase in P_R may

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[10] The weighted estimate of short-run demand elasticity -.66 computed from individual demand equations and the estimate -.6 from (13.2) differ somewhat in concept. First, inter-farm sales are excluded in Q_O but are included in the individual quantities (dependent variables) used in Chapter 14. However, the weights for the component demand elasticities are averages of constant dollar purchases from 1926 to 1959, omitting the war years, and excluding inter-farm sales. Second, the livestock component is included in Q_O but not in the component estimates from Chapters 7 and 14.

increase S_p as much as 1 percent. Since a 1 percent increase in S_p tends to increase Q_O approximately 2 percent according to equation (13.3), the long-run elasticity of Q_O with respect to P_R potentially is more than 2.0.[11] Purchases of operating inputs can be very responsive to prices received by farmers in the very long run.

DEMAND AND ECONOMIC DEVELOPMENT

Forces of economic development mentioned previously which might explain the increased use of operating inputs are: (a) falling relative prices of operating inputs, (b) increases in the level of durable assets which are complementary with operating inputs, (c) technological innovations, resulting in new inputs and increasing marginal productivities of existing inputs (including greater knowledge by farmers).

The first developmental force is represented by the variables P_O/P_R and P_O/P_P', the second by S_p and the third by T. The several forces are not unrelated in a developmental complex. Equation (13.4) suggests that all three forces have contributed significantly to growth in demand for operating inputs in the period 1926-59. Relative influences of these explanatory variables in the equation on demand quantity is suggested in the standard partial regression coefficients: -.13 for $(P_O/P_R)_{t-i}$, -.22 for $(P_O/P_P)_{t-1}$, .03 for W_t, .42 for S_p and .27 for T.[12] The results suggest little influence of weather on Q_O. The most important variable relating to change in demand quantity, from our formulation in (13.4), evidently is S_p, the stock of productive assets.

Aside from statistical significance and relative magnitudes of coefficients, the importance of a given variable in explaining the 216 percent

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[11] Elasticity derived from equations estimated in original observations are not strictly additive. That is, it is not completely accurate to multiply the elasticity of S_p with respect to P_R times the elasticity of Q_O with respect to S_p to find the elasticity of Q_O with respect to P_R. The correct procedure is to compute the coefficient of the influence of P_R on Q_O by the recursive process indicated in (13.9). This latter method is laborious, and it is sometimes more desirable from a computation and expository standpoint simply to multiply elasticities. Elasticities often are multiplied in this study for this reason, and in most instances the error is very small in relation to other possible sources of discrepancies.

[12] The standard partial regression coefficient b′ is computed as

$$b_i' = b_i \sqrt{\frac{\sum x_i^2}{\sum y^2}} \tag{a}$$

where b_i is the multiple correlation coefficient, $\sum x_i^2$ is the corrected sum of squares for independent variable X_i, and $\sum y^2$ is the corrected sum of squares for the dependent variable. The standard partial regression coefficients are corrected for the estimated differences in variance and are intended to reflect the relative influence of the independent variables on Y. They are somewhat comparable to the usual estimates of elasticities E_i, of Y with respect to X_i, computed at the means, i.e.

$$E_i = b_i \frac{\bar{X}_i}{\bar{Y}} \tag{b}$$

The elasticities are corrected by the ratio of the means; standard partial regressions by the square root of the ratio of estimated variances.

increase in Q_O from 1926 to 1959 also depends on trends in the explanatory variable over the period. P_O/P_R and P_O/P_P fell 17 and 60 percent respectively during the period. Equation (13.3-O) suggests that the falling real price of operating inputs might explain a third of the total Q_O increase. That is, if the short-run price variables in the equation are set at the 1959 level, with other variables left at the 1926 level, the predicted value of Q_O is 67 percent above the 1926 predicted value.[13] The stock of productive assets, S_p, rose 31 percent from 1926 to 1959. Ceteris paribus, the predicted demand for Q_O would have increased 112 percent alone because of complementarity with S_p. Setting the time variable at the 1959 value, to reflect "gross technical trends," and other variables at the 1926 values, equation (13.3) predicts an increase of 61 percent in Q_O. The sum of the three sources suggests a 240 percent increase. Hence, together the hypotheses "overexplain" the actual 216 percent increase in purchases of Q_O. While discrepancy arises from statistical error, the results indicate that the major source of increase in demand for operating inputs arises from the growth of productive assets. However, this conclusion must be qualified since S_p is one of several trend variables moving similarly through time.

Because of the high correlation between these trend variables reflecting the growth of productive assets, technological conditions, knowledge, managerial ability and long-run price effects, it is not possible to estimate the exact relative influence of each on Q_O from time series. Perhaps a more realistic statement is that about one-third of the total increase in purchases of Q_O from 1926 to 1959 is due to short-run price influences. The remaining two-thirds of the total increase is ascribed to interrelated technological and managerial influences, to complementarity with the growing agricultural plant, and to long-term adjustments to price. The variables other than short-run prices have moved similarly through time and have not registered observable individual effects. The increase in demand substantially can be "explained" in terms of any one of several correlated variables simply by inserting the "proper" trend variables in the demand function.

---

[13] The estimated demand equation may be used as an approximate device to determine the sources of increasing demand from year 1 to year k. A least-squares demand equation with time subscripts for year i is of the form

$$\text{(a)} \qquad Q_i = a + bP_i + CT_i \qquad (i = 1, 2, \cdots n)$$

where Q is predicted quantity, P is price and T is the demand shifter. Assuming the error in prediction is negligible, then the percentage change in Q from year 1 to year k due to P is

$$\text{(b)} \qquad \%\ \text{change} = \frac{b(P_k - P_1)}{Q_1} \cdot 100$$

and due to T is

$$\text{(c)} \qquad \%\ \text{change} = \frac{c(T_k - T_1)}{Q_1} \cdot 100.$$

TRENDS AND PROJECTIONS

Figure 13.5 compares actual and predicted values from (13.4-O) of Q_O from 1926 to 1959. Purchases fell sharply in the depression years of the early 1930's, but recovered quickly. Thereafter, inputs of Q_O tended to increase at a uniform rate except for interruptions in 1938 and 1953. The trend in the postwar era has continued upward and is nearly linear with no signs of saturation in demand growth. Predicted values of Q_O provide reasonably accurate ex post predictions of the actual data. The extrapolated value for 1960 underestimates the actual value by only 1.5 percent. However, even a linear trend fitted to the period 1946-59 also would provide predictions conforming closely with actual purchases.

The value of Q_O is projected to 1965 assuming prices at 1955-59

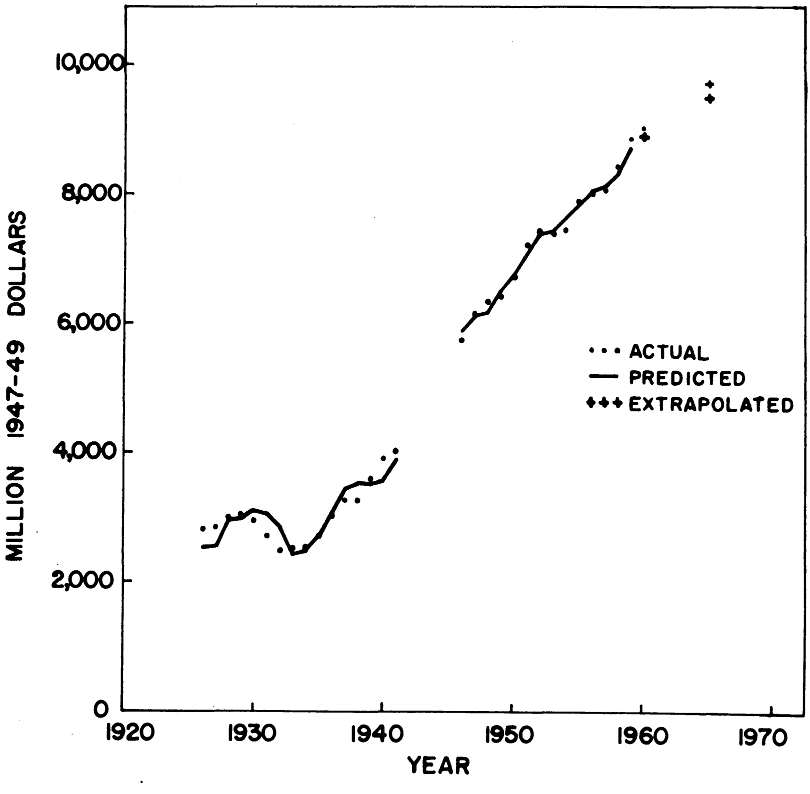

Figure 13.5. Trends in purchases of operating inputs Q_O from 1926 to 1960 (predicted and projected estimates from equation 13.3-0).

levels and that equation (13.4-O) is the appropriate demand relation.[14] Two estimates of S_p are used. The first is based on a USDA projection of 112.4 billion 1947-49 dollars by 1965. This projection agrees with the projected stocks from (13.7) assuming net farm income will remain at the 1955-59 level. A second estimate of S_p of 114.4 billion 1947-49 dollars by 1965 is based on an investment function (12.28) which contains an accelerator.[15] Stocks are estimated from this investment equation assuming farm output will increase 8 percent by 1965. The demand quantities so projected by equation (13.4-O) for 1965 are 7 and 10 percent above predicted 1960 levels if S_p is 112.4 or 114.4 billion dollars, respectively. Unless important changes in the demand structure occur, purchases of Q_O are expected to increase considerably by 1965. The standard error and confidence limits of the projected quantity are not computed, but are expected to be large for extrapolations several years ahead.

SUPPLY OF OPERATING INPUTS ESTIMATED BY LIMITED INFORMATION

We now consider the supply functions paralleling the demand function (13.10) in an interdependent model of market structure for operating inputs. A supply function for operating inputs, estimated by limited information techniques, is

$$P_{Ot} = 83.10 - \underset{(.064)}{.024Q_{Ot}} + \underset{(.46)}{1.37P_{Nt}} + \underset{(.10)}{.34C_t} \tag{13.11}$$

where P_N is the price of nonfarm labor, C is a structural variable with value zero in the prewar years, 100 in the postwar years. P_O and Q_O, the endogenous variables, were defined earlier. P_N and C are considered to be exogenous. The equation was estimated as part of an interdependent system of supply and demand equations for factor and product markets in agriculture from annual time series from 1926 to 1959, omitting 1942 to 1946.[16]

The standard error (in parentheses) of the coefficient of Q_O is more than twice as large as the coefficient. This evidence supports the hypothesis that the coefficient is zero and also supports our hypotheses that (a) the supply elasticity is very large in the short run and

---

[14] Values of the dependent variables are predicted only for years when values of the independent variables are known. If Q_O is a function of past year variables, the quantity of Q_O can be predicted for 1960 from known 1959 values of the explanatory variables. Estimates of the dependent variable outside the range of data to which the equation is fitted are called extrapolations. When the extrapolation involves arbitrary assumptions about the level of prices and other explanatory variables as for the year 1965, the estimates of the dependent variable are called projections.

[15] These projections should not be confused with those made for S_p in Chapter 12 where we project S_p to the end of 1965, in this section of the beginning of 1965.

[16] The entire interdependent model of agriculture is found in Tweeten, op. cit., Chap. 2.

(b) the price of operating inputs is determined largely in the nonfarm sector. The results are consistent with our previous assumption; namely, that the price, P_O , can be considered an exogenous variable in the least-squares demand functions for Q_O.

Equation (13.11) indicates that a 1 percent increase in nonfarm labor price is associated with a 1.2 percent increase in P_O , an important interrelation of economic forces in the farm and nonfarm sectors.

In a second limited information model, estimated with slight modifications, machinery purchases were adjusted to reflect the latent demand in 1946 and 1947. Also the weather variable, W, and government program variable, G, were omitted from the matrix of predetermined variables in the reduced-form equations. (All the equations except (13.11) of the limited information empirical equations included in this study are from the second formulation.) The changes in the coefficients of the supply equation (13.12), estimated from the second model, are a manifestation of the sensitivity of the model to a change in specification.

$$P_{Ot} = 63.89 - \underset{(.011)}{.034}Q_{Ot} + \underset{(.78)}{2.03}P_{Nt} + \underset{(.17)}{.47}C_t \tag{13.12}$$

The same variables are included as in equation (13.11); however, the magnitudes of the coefficients are somewhat larger in (13.12). The coefficient of Q_O is negative and large relative to the standard error. The positive coefficient of C would indicate that the real supply price (the price of operating inputs relative to the implicit price deflator of the Gross National Product) of operating inputs has increased in the postwar period. Equation (13.12) also might suggest the hypothesis that the real price of operating inputs has declined because of a negatively sloped supply curve rather than because of technological changes that would be indicated by a negative coefficient of C. However, because of the incomplete specification of the supply function and the particular characteristics of the limited information method, we rest no conclusions on equation (13.12).

SUMMARY OF EMPIRICAL RESULTS

The increase in annual purchases of operating inputs by more than 200 percent from 1926 to 1959 has been a particular reflection of economic development in agriculture. Nearly all operating inputs represent new capital forms. Some have increased in demand since they are complements with other innovations such as farm machinery. Others serve directly as substitutes for old capital forms, as in the case of new seed varieties and insecticides. On aggregate effect, operating inputs are strong substitutes for both land and labor. The great increase in their use unquestionably stems from both their favorable real price and increase in productivity.

Based on a priori considerations and the results of our statistical analysis, least-squares equations tended to give the most realistic and meaningful estimates of demand for operating inputs. Whether estimated from data in original values, logarithms or first differences, the several sets of least-squares estimates gave quite comparable results. However, logarithm equations explained slightly less of the annual variation in Q_O and displayed more evidence of autocorrelation in the residuals than the single equations in original values. The demand elasticity with respect to operating input price was estimated as -.6 in the short run. Since operating input prices lagged more than one year were not significant, the elasticity with respect to P_O appears to be not much greater in the long run than in the short run. According to the results in Table 13.1, the short-run demand elasticity with respect to farm prices received, P_R, is approximately .3. The long-run elasticity potentially is greater than 2.0 because of the influence of product prices on the scale of plant. The equations suggest that an increase of 1 percent in the scale of the agricultural plant S_p may increase demand for operating inputs 2 percent after several years. These estimates of elasticity are considered "gross" and need further verification. The following chapter treats individual items with more detail.

14.

Demand Structure for Five Operating Inputs

THE DEMAND for each of five components of operating inputs is analyzed in this chapter. The categories included are: (a) seed, (b) machinery supplies, (c) building repairs, (d) feed and (e) miscellaneous inputs including dairy supplies, hand tools, electricity, etc. The livestock component is not considered because only a small portion of livestock inputs are of nonfarm origin. Livestock marketing costs are included in miscellaneous inputs. The structure of the livestock market has been analyzed in some detail in another study.[1]

This analysis of operating inputs represents some attempt at disaggregation. The optimum degree of aggregation in econometric analyses depends on both the research resources available and the intended purpose of the analyses. Some implications of policy proposals can be observed more conveniently from a single macro equation. While some aggregation bias may be present, the macro equation may provide a better over-all guide than a series of highly refined but somewhat unrelated micro equations. For some purposes it is desirable to estimate the individual demand functions for several categories of operating inputs, Q_O. The various components of operating inputs do not react uniformly to prices and other economic stimuli. For example, some operating inputs such as seed are more closely identified with the rising output and efficiency in agriculture than are building repairs.

In each section of this chapter we review relevant literature and specify the demand function derived from time series. All demand functions are estimated by single-equation least-squares methods for the periods 1926-59, excluding 1942-45. After the characteristics of the estimated demand equations are discussed, computed price elasticities are presented and demand quantities are projected to 1965.

DEMAND FOR SEED

Seed purchases by U.S. farmers increased over 200 percent, or at an average compound rate of 3.5 percent per year over the period

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[1] Mauldon, Roger Gregory. An Econometric Analysis of the Supply of Livestock Products and Demand for Feed Grains. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962.

1926-59. Substitution of purchased seed for farm produced seed is a notable characteristic of the changing resource demand structure of agriculture.

Although there have been no previous estimates of the demand function for seed in the United States, Griliches explored the factors responsible for the differential rate of adoption of hybrid corn in a study published in 1957.[2] He fitted a logistic curve to data from crop areas in several states. The rate of adoption was best predicted by the relative profitability of hybrid corn, market density, corn acres per farm, date of origin of hybrid introduction and other less important factors.

Specification of the Demand Function

The above variables provide a basis for the specification of the seed demand function. The relative profitability of seed is represented by price variables. At a national level, several technological influences have appeared gradually and can be represented by a time variable. The lag effect in adoption of innovations and in adjustment to price is allowed by lagging the dependent variable. In the following analysis the quantity of seed purchases is estimated as a function of the ratios of seed prices to prices received and to prices paid, the scale of the agricultural plant, government policies, weather and slowly changing factors represented by the time variable. The variables are defined as:

Q_{St} = the annual seed purchases by U.S. farmers during the current year in millions of 1947-49 dollars, including inter-farm sales. Total farm expenditures for seed are divided by the index of prices paid by farmers for seed to convert expenditure data to "quantity" measured in constant 1947-49 dollars.

$(P_S / P_R)_{t-1}$ = the index of the past year ratio of seed prices to prices received by farmers for crops and livestock. Livestock prices are included because, for many crops fed to livestock, the crop price is not the only decision variable.

$(P_S / P_P)_{t-1}$ = an index of the past year ratio of seed price to prices paid for items used in production, including interest, taxes and wage rates.

S_{pt} = the stock of all productive farm assets on January 1 of the current year (see Chapters 12 and 13).

G_t = a current year index of government policies. Years with production control in force are given a -1 value. Years when farm prices are supported are given a +1 value. A +1 value is added if price supports are fixed. These values are summed to form G.

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[2] Griliches, Zvi. An exploration in the economics of technological change. Econometrica. 25:501-22. 1957.

W_t = an index of the influence of weather on farm output in the current year.[3] (See Chapter 13.)

T = time, measured as the last two digits of the current year.

The Estimated Demand Equations

The coefficients, standard errors and other statistics of single-equation estimates of seed demand are presented in Table 14.1 where O and L refer respectively to functions with observations in original and logarithmic form. The F refers to observations in first differences. A large percent of the annual variation ($R^2 = .95$) is explained by the six independent variables in (14.1). The institutional variable, G, is significant at the 95 percent probability level, but the approximate nature of the variable prohibits placing great reliance on its coefficient. The significance of the coefficient is not surprising, however, since acreage restrictions that reduce cropland acres are expected to reduce seed demand. Because of the somewhat dubious construction of the G variable, it is dropped to form equation (14.2) where the coefficients of

Table 14.1. Demand Functions for Seed Q_S Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1945 (Coefficients, Standard Errors, in Parentheses, and Related Statistics Are Included)*

Equation and Transformation†	R^2	d‡	Constant	P_S/P_R t-1	P_S/P_P t-1	S_p t	G t	W t	T	Q_S t-1
(14.1-O)	.95	1.29	-156.93	.80	.47	-3.49	2.89	.85	16.02	
				(.84)	(.76)	(2.28)	(1.08)	(.67)	(1.87)	
(14.2-O)	.94	1.09	-61.57	-.59	1.55	-4.43		.88	17.28	
				(.73)	(.72)	(2.52)		(.75)	(2.03)	
(14.2-L)	.92	1.30	4.23	-.12	.43	-1.81		.19	.0222	
				(.25)	(.19)	(.72)		(.21)	(.0027)	
(14.3-O)	.93	.63	-322.64	-.31	2.02				14.35	
				(.74)	(.69)				(.91)	
(14.3-L)	.90	.69	.76	.028	.56				.0162	
				(.259)	(.19)				(.0012)	
(14.4-O)	.93	.61	-357.38		1.93				14.55	
					(.65)				(.76)	
(14.4-L)	.90	.69	.81		.57				.0162	
					(.18)				(.0010)	
(14.5-F)	.33	2.25	--§		1.84				17.20	
					(.52)				--§	
(14.6-O)	.97	2.03	-229.75		1.80				5.70	.62
					(.47)				(1.84)	(.12)
(14.6-L)	.95	2.21	-.23		.52				.0064	.60
					(.14)				(.0022)	(.13)

*Sources and composition of the dependent variable, Q_S, and the indicated independent variables are discussed in the text and in Tweeten, Luther G. An Economic Analysis of the Resource Structure of U.S. Agriculture. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962.

†Equations are estimated in the transformations indicated: original values, O, logarithms, L, (T is in original values in L equations), and first differences of original values, F.

‡The Durbin-Watson autocorrelation statistic d.

§The intercept, or constant, coefficient in the first-difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

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[3] Stallings, James L. Weather indexes. Journal of Farm Economics. 42:180-86. 1960.

the weather variable are not significantly different from zero. If weather affects seed demand, the specification in (14.1) and (14.2) does not detect it. The coefficient of S_p is not significantly different from zero in equations (14.1) and (14.2-O) and is just significant at the 95 percent level in equation (14.2-L). Because of the low significance of S_p in original values, its relatively high correlation with T and the questionable sign of its coefficient, the variable S_p and W are dropped to form equation (14.3). The omission of the variables reduces the R^2 only slightly and increases the magnitude and significance of the coefficient of $(P_S/P_P)_{t-1}$. Since the coefficients of $(P_S/P_R)_{t-1}$ are not significantly different from zero in the first equations, the variable is dropped and equation (14.4) results. The two variables $(P_S/P_P)_{t-1}$ and T evidently predict seed purchases as well as possible in the single-equation approach and from the time series data available.

Unfortunately, autocorrelation in the residuals increases considerably as variables are dropped. The presence of autocorrelation as measured by d is inconclusive in (14.1) and (14.2), but is significant in (14.3) and (14.4). Equation (14.5-F), estimated in first differences of original values, reduces autocorrelation to a nonsignificant level. The magnitude and significance of the price coefficients in equations (14.4-O) and (14.4-F) are not appreciably different.

Statistical properties of (14.6), estimated with lagged Q_S, and considerations from previous analyses suggest that the distributed lag equation might be a useful model of seed demand. The R^2 is increased, autocorrelation is reduced (the test is biased, however) and significance of the price coefficients is greater in (14.6) than in (14.4). Furthermore, the lagged adjustment to new seed varieties, because of limitations on seed stock expansion, or lack of awareness and cautious recognition of new varieties by farmers, may justify the lagged adjustment model. The coefficients indicate that approximately 40 percent of the adjustments to equilibrium prices and technological conditions indicated by T are made in the short run.

Price Elasticity of Demand

The equations in Table 14.1 would suggest that the price elasticity of seed demand with respect to prices received by farmers is zero in the short run. That an increase in seed prices relative to prices received would depress seed purchases very little seems reasonable from considerations of the production process. Important substitutes for seed do not exist in the production process. If production is to take place, seed must be used. Seed represents a small portion of total production costs, hence, a change in seed price normally is expected to influence production decisions but slightly. Complementarity of seed with a relatively fixed land input also causes stability in seed sales since land inputs have a low reservation price and are highly fixed in the short run.

The coefficient for P_S/P_P is not significantly different from zero in equation (14.1). If the equation is specified correctly, changes in seed prices relative to other input prices can be expected to result in little change in seed purchases. In the remaining equations in Table 14.1, however, the coefficient of the variable is significant. The significant coefficient may reflect the influence of variable G, omitted in subsequent equations. The variable P_S/P_P contributes significantly to the explanation of Q_S and is useful from a positivistic, predictive standpoint. Additional analyses are needed, however, to determine the structural role of the variable in the demand function.

Shifts in Demand

Structural changes represented by a linear trend evidently account for a major portion of the 213 percent growth in seed demand from 1926 to 1959. The dominance of time in the demand equation (14.4-O) in Table 14.1 is illustrated by the standard partial regression coefficients .15 and .97 for P_S/P_P and T, respectively. If price is at the 1959 level and T is at the 1926 value, the demand quantity is predicted at approximately 14 percent <u>less</u> than the predicted quantity for 1926 in equation (14.4-O). Nearly the entire 3.5 percent annual compound rate of increase in demand is explained by structural, rather than price, changes.

The most important element in changing the structure of the seed market is the introduction of improved seeds such as hybrid corn. The improved seeds are more resistant to insects and fungi. In many instances, improved varieties not only maintain yields against natural enemies, but their genetic vigor provides opportunities for raising yields and increasing factor-product transformation rates despite declining product prices. Other related factors responsible for the rising demand for purchased seed, through the effect of changed production coefficients, are the weakened resistance of farm produced seeds to natural enemies, shifts toward more seed intensive rotations, and improved management encouraged by the cost-price squeeze. According to the theory of Chapter 3, changes in production coefficients and price ratios primarily determine demand for a resource. We believe technical change, which has increased the productivity (production coefficients) over time, to be a dominant factor explaining changes in farmer demand for seed. This explanation does not rule out price as a potentially important variable relating to seed demand. Obviously, if wheat seed cost $1,000 per bushel, little of it would be used. But with a relatively favorable price of seed resources, as compared to their productivity and the prices of products, technical change has dominated in driving seed purchases upward.

Trends and Projections

Figure 14.1 indicates that seed purchases remained relatively stable during the late 1920's and early 1930's. Purchases rose sharply after the depression and continued to increase in the postwar years, but at a lower rate. This phenomenon perhaps suggests that technical change was somewhat lacking in the earlier period and that capital limitations (a factor highly related to price relatives) were important during the depression. However, we could not specify a model which served to bring out these details.

Predicted values of seed purchases from equation (14.6-O) provide reasonable approximations to the actual values for past years. Extrapolation of the quantity estimate for 1960 from past data underestimated the actual 1960 purchases by 2 percent. Seed purchases, estimated from this equation for 1965, indicate a quantity of 706 million 1947-49 dollars which is 12 percent above the 1960 predicted level. The projection is based on the assumptions that prices will remain at average 1955-59 levels, and that the structure will continue to change as indicated by the time coefficient. Since errors accumulate in equations containing lagged dependent variables, caution must be used in interpreting projections several years in advance. The projected estimate for 1965 is comparable to a linear extension of the postwar trend in seed purchases.

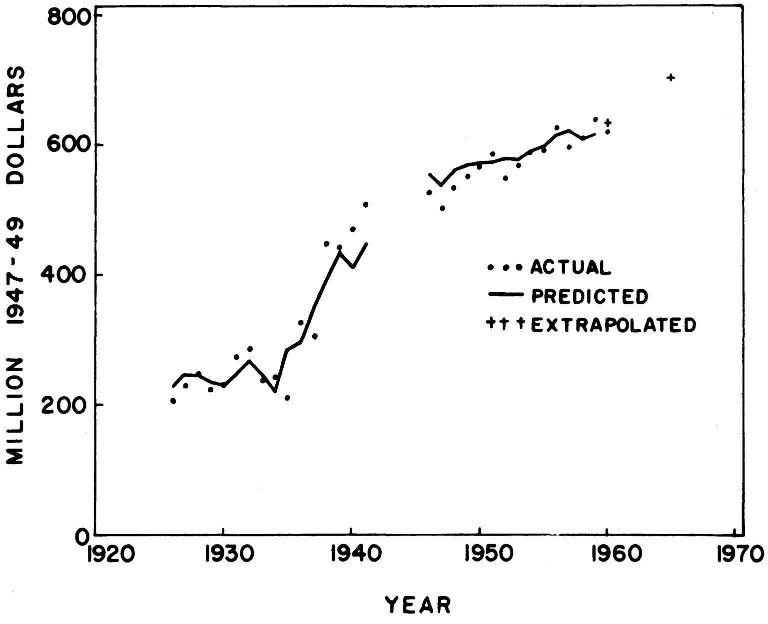

Figure 14.1. Trends in seed purchases Q_S from 1926 to 1960 (predicted and projected estimates from equation 14.6-O).

DEMAND FOR MACHINERY SUPPLIES

Inputs of machinery supplies — fuel, oil, lubrication and repairs — increased 365 percent between 1926 and 1959. The average compound growth rate was 4.8 percent per year. Growth in purchases of machinery supplies has been closely associated with the growth of machinery inventories because the inputs are complements. Price factors also may have been important in causing the demand structure for machinery supplies to change. The purpose of this section is to analyze the role of prices and other factors in determining the demand quantities of machinery supplies.

Specification of the Demand Function

The demand quantity of machinery supplies is considered to be a function of current and past year prices of machinery supplies, prices received by farmers, prices paid by farmers for production items, the stock of productive assets, government agricultural policies, weather and gradually shifting influences represented by a time variable.

Due to the anticipated strong complementarity between machinery stocks and machinery operating inputs (supplies), the specification of machinery stocks in the demand function was deemed appropriate. Productive assets other than machinery stocks also influence sales of machinery supplies, but due to the high correlation between machinery inventories and other components of productive assets, it was not feasible to include more than one variable. The variable included, total stocks of productive assets, S_p, is correlated with machinery stocks from 1926 to 1959 to the extent $r = .98$. Thus the coefficient of S_p in the demand equation must be interpreted as the joint influence of machinery stocks and other productive assets on the demand quantity.

The variables in the demand function are:

Q_{MSt} = the annual U.S. purchases of machinery supplies, the variable to be predicted, during the current calendar year in millions of 1947-49 dollars. Machinery supplies included fuel, lubrication, oil and repairs of motor vehicles and other farm machinery used for productive purposes.

$(P_{MS}/P_R)_t$ = the current year index of the ratio of prices paid by farmers for motor supplies to prices received by farmers for crops and livestock. Both current and past year prices are included in the demand function.

$(P_{MS}/P_P)_{t-1}$ = the past year index of the ratio of prices paid by farmers for motor supplies to prices paid by farmers for items used in production, including interest, taxes and wage rates.

The demand function also includes an index of government policies, G, a weather index, W, the stock of productive assets on January 1, S_p, and a time variable, T. The logic and sources of these variables is discussed in more detail in the section on seed demand. The resulting equations are presented in Table 14.2. The O denotes observations in original values, and L denotes observations transformed to logarithms.

The Estimated Demand Equations

Equation (14.7-O) in Table 14.2 contains current and past prices of motor supplies and other variables which together explain 99 percent of the variance around the mean of Q_{MS}. If government policies influence demand for machinery supplies, it is not strongly expressed from the nonsignificant coefficient and standard errors of G in equation (14.7). The variable is dropped in estimating equation (14.8). The coefficient of the past year price of motor supplies relative to prices received is not significantly different from zero for this equation. The complete dominance of current price over past year price is inconsistent with a priori considerations. The magnitude of the $(P_{MS}/P_R)_{t-1}$ coefficient may partially be explained by high correlation (r=.89) between current and past year price, with the current price variable tending to absorb the effect of past year price. A similar result is avoided for the second major price variable, P_{MS}/P_P, by including only past price. It is impossible to differentiate effects of the variable between years because of the high correlation (r=.96) between current and past year values of P_{MS}/P_P.

The tendency for current or past year price to absorb the effect of the other in regression analysis is apparent in (14.9) and (14.10). The weather and current price variables are nonsignificant and are deleted from (14.8) to form (14.9). Equation (14.10) is similar to equation (14.9), with current values substituted for past values of P_{MS}/P_R. The coefficient of $(P_{MS}/P_R)_{t-1}$ is negative and significant in equation (14.9) although it was not significantly different from zero in equation (14.8). Equation (14.9) is useful for predictive purposes when current price is unknown. If current and past year prices continue to be related, prediction from past prices can be made with suitable accuracy.

All coefficients are significant in (14.9) and (14.10) except the coefficient of S_p in the equations estimated in logarithms. S_p is specified in the demand function to reflect the influence of durable assets, particularly machinery inventories, on the demand for machinery supplies. Previous knowledge of the complementary relationship between machinery inventories and purchases of Q_{MS} suggests a significant positive coefficient of S_p is appropriate. From this standpoint, the equations in original values are most acceptable. The equations estimated in logarithms, however, display less autocorrelation as indicated by d. The test of the null hypotheses that the residuals are uncorrelated in the logarithm equations is inconclusive in (14.8-L) and (14.9-L), but is rejected at the 95 percent level in equation (14.10-L).

Table 14.2. Demand Functions for Machinery Supplies Q_{MS} Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1945; Coefficients, Standard Errors and Related Statistics Are Included*

Equation and Transformation †	R^2	d‡	Constant	P_{MS}/P_R t	P_{MS}/P_R t-1	P_{MS}/P_P t-1	S_P t	G t	W t	T	Q_{MS} t-1
(14.7-O)	.99	.96	-798.38	-2.02	.78	-7.72	22.55	3.82	1.09	26.58	
				(.64)	(.86)	(2.42)	(4.68)	(2.71)	(1.22)	(3.63)	
(14.8-O)	.99	.97	-162.97	-2.28	.95	-10.00	19.16		1.14	26.58	
				(.62)	(.87)	(1.84)	(4.10)			(3.70)	
(14.8-L)	.996	1.23	4.05	-.298	-.067	-.72	.27		.084	.01448	
				(.072)	(.109)	(.18)	(.25)		(.067)	(.00096)	
(14.9-O)	.99	.98	-383.08		-1.47	-7.95	17.78			31.66	
					(.67)	(2.10)	(4.85)			(4.15)	
(14.9-L)	.99	1.25	3.91		-.412	-.49	.21			.0159	
					(.091)	(.22)	(.31)			(.0011)	
(14.10-O)	.99	.91	-270.65	-1.79		-8.56	19.80			27.82	
				(.41)		(1.25)	(4.02)			(3.46)	
(14.10-L)	.996	.98	4.30	-.336		-.80	.29			.01423	
				(.049)		(.12)	(.24)			(.00092)	
(14.11-O)	.997	1.29	350.56	-1.11		-1.75				9.35	.765
				(.25)		(1.18)				(3.47)	(.077)
(14.11-L)	.998	1.45	1.16	-.264		.046				.0044	.72
				(.029)		(.148)				(.0016)	(.11)
(14.12-O)	.997	1.29	143.95	-1.20						6.63	.855
				(.25)						(3.02)	(.050)
(14.12-L)	.998	1.40	1.33	-.264						.00479	.690
				(.028)						(.00091)	(.044)

*For sources and composition of the dependent variable Q_{MS} and the indicated independent variables, see Table 14.1.

†Equations are estimated in the transformations indicated: O, original values; L, logarithms (T is in original values in L equations).

‡The Durbin-Watson autocorrelation statistic d.

Equations (14.11) and (14.12) are equivalent to equation (14.10) with the lagged quantity substituted for S_p to form an alternative estimate of the long-run properties of the demand function. Equations (14.7) to (14.10) indicate that the particular distributed lag model may be inappropriate because a large proportion of the variation in demand quantity is explained by variables lagged no more than one year. The coefficient of $(P_{MS}/P_R)_t$ is relatively stable and is significant in (14.11). The coefficient of $(P_{MS}/P_P)_{t-1}$ is insignificant, however, perhaps because of inappropriate model specification. The latter variable is omitted in equation (14.12) where all variables are significant and possess the anticipated signs. Together the variables explain over 99 percent of the annual variation about the mean of Q_{MS}. The distributed lag equation (14.11) suggests that about 25 percent of the adjustment in Q_{MS} to the equilibrium level is made in the short run.

Price Elasticity of Demand

From Table 14.2 the estimated price elasticity may be computed with respect to each of the price variables P_R , P_P and P_{MS} . Considering P_{MS} first, the total price elasticity of demand with respect to P_{MS} is the sum of the direct component (P_R) and the substitution component (P_P). On the basis of (14.10-O) the estimated total elasticity with respect to P_{MS} is -.22 (the direct component) plus -.82 (the substitution component) or -1.0. Similarly, the estimated elasticity from equation (14.10-L) is -.34 (the direct component) plus -.80 (the substitution component) or -1.1. These estimates are comparable to the long-run estimates of elasticity with respect to P_{MS} from (14.12-O) and (14.12-L) of -1.0 and -.9, respectively.

Equation (14.10) suggests a short-run demand elasticity of .22 with respect to P_R. The same equation in logarithms gives a point estimate and 95 percent confidence interval of -.34 ± .10 for the elasticity. The results imply that the short-run price elasticity with respect to P_R is approximately .3. The long-run elasticity is much greater, however; a sustained rise in prices received by farmers is predicted to increase machinery stock from 2 to 3 percent according to the estimates in Chapter 11 on machinery demand. Equation (14.10) indicates that a 1 percent rise in S_p increases demand for Q_{MS} by more than 1 percent. Hence, the demand elasticity of machinery supplies may be more than 2 in the long run. Purchases of motor supplies are more sensitive to P_R than to P_{MS} in the long run because of the complementarity of the input with durables, particularly with machinery. The "long run" is more than 10 years, however, according to Chapter 11.

Shifts in Demand

Equation (14.10) predicts, with prices at 1959 levels and other variables at 1926 levels, a demand quantity of machinery supplies 119 percent greater than the predicted 1926 demand quantity. Even if allowances are made for lagged adjustment to short-run price changes, it is likely that much of the increase in demand remains to be explained by factors other than price. The strongest influence on demand for machinery supplies has been the rising investment in farm machinery, particularly motor vehicles. The complementarity between machinery stock and Q_{MS} is indicated by the positive coefficient of S_p and T. Due to incomplete specification and correlations among trend variables, the exact influence of machinery investment on purchases of supplies is not ascertainable. Stocks of all farm machinery increased nearly 150 percent from 1926 to 1959. If purchases of machinery supplies increase accordingly, this would explain a considerable portion of the total increase in demand for machinery supplies.

After exhausting (a) the short-run price and (b) the above complementarity hypotheses, approximately one-third of the total increase in annual sales remains to be explained by additional influences. One important influence is the increased requirement of fuel and oil per unit of machinery stock. As motor vehicles become a more prominent component of machinery stock, requirements for gasoline and oil increase accordingly.

Trends and Projections

Except for a small dip during the early 1930's, the quantity of machinery supplies purchased by farmers has increased steadily until 1949 (Figure 14.2). From 1950 to the early 1960's the upward trend has not been so steep and some slight depressions in sales are apparent. The predicted values of annual purchases from (14.9-O) provide reasonable approximations to the actual data of the various years. The equation predicts the downturns in the early 1930's, in 1950 and 1954, but does not correctly gauge their magnitudes. The extrapolated demand "quantity" in 1960 is 2,415 million 1947-49 dollars, and is 3 percent greater than the actual estimate of 2,341 million 1947-49 dollars. (The 1960 figure is preliminary from USDA statistics. The "actual" estimates are often revised and the percent of error may change.) Assuming prices at average 1955-59 values, stocks of productive assets at 112.4 million 1947-49 dollars in 1965, and that the influence of technology and other variables represented by the time variable continue as in the 1926-59 period, purchases of Q_{MS} totalling 2,622 million 1947-49 dollars are estimated for 1965. If productive assets increase to 114.4 billion 1947-49 dollars, the projected estimate of machinery supply purchases is estimated at 2,659 million 1947-49 dollars by 1965. The estimates are 9 and 10 percent, respectively, above 1960 predicted levels. The projections are approximately equivalent to projections from a linear extension of the postwar trend. Of course, the validity of the projections are subject to conformity with the underlying assumptions of the model.

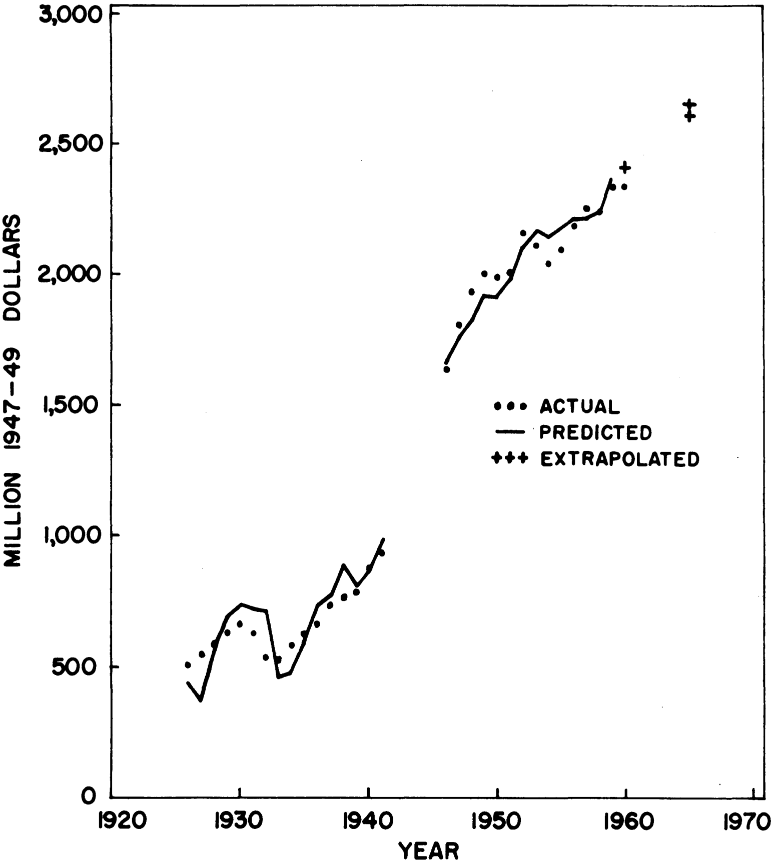

Figure 14.2. Trends in machinery supply purchases Q_{MS} from 1926 to 1960 (predicted and projected estimates from equation 14.9-O).

DEMAND FOR PURCHASED FEEDS

This section includes single-equation estimates of feed demand functions. Feed purchases, measured in constant 1947-49 dollars, increased 218 percent from 1926 to 1959. The compound growth rate was 3.6 percent per year.

In this study, feed purchases include feed grains and protein feeds. Components of operating inputs such as commercial fertilizer and motor supplies are produced almost completely by the nonfarm sector. Feeds, and to some extent seeds, even when purchased from nonfarm sources, contain an important portion produced on farms. Because of this connection, the index of the ratio of prices paid for feed to prices received by farmers for crops and livestock has been quite stable since

1926. The index was 98.9 in 1926 and 97.4 in 1959. The ratio of prices paid for feed to prices received for livestock displays a similar lack of trend, but annual variations in the series provide a basis for appraising the effects of prices on demand quantities of feed.

Hildreth and Jarrett estimated the demand for feed grains by single and simultaneous equations.[4] They specified the following variables in the demand equations: the quantity of feed grains fed, feed grain price, livestock price, protein price, beginning year animal units of livestock and roughage consumed by livestock. In the single equations the quantity of feed grains fed to livestock was the dependent variable. Additional details of their study, including elasticity estimates, are discussed later in this section.

Specification of the Demand Function

Feed demand quantity by farmers is estimated in this chapter as a function of feed prices, livestock prices, prices paid by farmers, stocks of productive assets, government policies, weather and time. The specification is somewhat similar to that of Hildreth and Jarrett except prices paid, P_P, rather than protein prices, are included. Also, inventories of productive assets are substituted for livestock inventories. The model in this study contains no estimate of roughage consumption, but contains variables G, W and T, representing the influence of institutions, weather and technology on feed demand. S_p is highly correlated with livestock inventories (r=.91), thus the coefficient of S_p broadly may be interpreted as the effect of livestock inventories, as well as of other assets, on feed demand.

The exact form of the variables in the feed demand function is as follows:

Q_{Fdt} = the dependent variable and is the purchases of feed by U.S. farmers during the current calendar year in millions of 1947-49 dollars. The "quantity" is derived by dividing expenditure data by prices paid by farmers for feed. Inter-farm sales are included. The estimate includes protein and feed grain purchases.

$(P_{Fd}/P_R)_t$ = the current year index of the ratio of prices paid by farmers for feed to prices received by farmers for crops and livestock. Both current and past year prices are included in the demand function.

$(P_{Fd}/P_{Lk})_t$ = the current year index of the ratio of prices paid by farmers for feed to prices received by farmers for livestock. The past year index is also included in the demand function.

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[4] Hildreth, Clifford, and Jarrett, F. G. A Statistical Study of Livestock Production and Marketing. John Wiley and Sons. New York. 1955.

$(P_{Fd}/P_P)_{t-1}$ = the past year index of the ratio of prices paid by farmers for feed to prices paid by farmers for items used in production, interest, taxes and wage rates.

In addition, productive assets, S_p, an index of government programs, G, weather, W, and a time variable, T, are included in the demand function. The logic of these variables is discussed in a previous section. All equations (Table 14.3) are estimated with data from 1926 to 1959, excluding the war years.

Estimated Demand Equations for Feed

The independent variables in (14.13) and (14.14) of Table 14.3 explain a large proportion (R^2=.98) of the annual variation about the mean of Q_{Fdt}. Current and past prices, stocks of productive assets and time primarily are responsible for the high R^2. Coefficients of G, W and P_{Fd}/P_P are not significant in these equations. This, however, is not certain evidence that the effects of the "real" variables which they are constructed to represent lack influence on demand. Instead, given the form of the variables, coefficients of the magnitudes estimated occur frequently when the true coefficients are zero. Other variables, constructed differently but representing the same influences, might indicate a significant influence on feed demand.

Because the demand for feed is derived primarily from the demand for livestock, P_{Lk} is substituted for P_R in the remaining equation of Table 14.3. Equation (14.15) is the result of this substitution and the deletion of insignificant variables from (14.13) and (14.14). The coefficients of current and lagged price, P_{Fd}/P_{Lk}, in (14.15) are significant at lower probability levels than are comparable coefficients of P_{Fd}/P_R in (14.13). Based on the various transformations in equation (14.15), the significance of current and lagged price variables is inconclusive.

The Durbin-Watson statistic indicates significant autocorrelation in the residuals of (14.15-O) and (14.15-L). To reduce the autocorrelation in the residuals and to provide more consistent statistical tests of the coefficients, the equation also is estimated in first differences of original values. The d value is raised from .75 in (14.15-O) to 1.50 in (14.15-F). The degree of autocorrelation in the residuals as indicated by d is reduced somewhat, but the test of the null hypothesis of zero autocorrelation is on the borderline between insignificant and inconclusive. The drop in the R^2 from .95 in (14.15-O) to .12 in (14.15-F) indicates that a very large proportion of the variance around the mean of Q_{Fd} is explained by linear trends removed by the first-difference transformation. The instability of the coefficients of S_p and T in equation (14.15) may be explained by the high correlation between the variables (r=.92). Because of the expected complementary relationship between durable inventories and Q_{Fd}, the significant positive coefficient of S_p in equation (14.15-O) is most meaningful.

The magnitudes of the coefficients in the distributed lag equations

Table 14.3. Demand Functions for Purchased Feed Q_{Fd} Estimated by Least Squares with U.S. Data from 1926 to 1959, Omitting 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics are Included*

Equation and Transformation†	R^2	d‡	Constant	P_{Fd}/P_R t	P_{Fd}/P_R t-1	P_{Fd}/P_{Lk} t	P_{Fd}/P_{Lk} t-1	P_{Fd}/P_P t-1	S_P t	G t	W t	T	Q_{Fd} t-1
(14.13-O)	.98	1.05	800.06	-18.78 (8.67)	-27.10 (8.37)				39.53 (15.75)	-7.33 (7.08)	3.57 (4.64)	70.79 (12.53)	
(14.14-O)	.98	1.02	2117.02	-24.10 (8.13)	-25.80 (8.52)			-3.23 (5.47)	35.66 (17.15)	-7.19 (7.28)		73.18 (13.10)	
(14.15-O)	.96	.75	-3809.35			-11.09 (5.03)	-8.94 (5.20)		70.27 (16.80)			57.03 (14.21)	
(14.15-L)	.94	.71	2.56			-.62 (.29)	-.70 (.30)		1.55 (.75)			.0116 (.0029)	
(14.15-F)	.21	1.50	-- §			-2.34 (3.27)	-8.48 (3.31)		-14.14 (38.62)			94.03 -- §	
(14.16-O)	.98	1.74	119.46		-3.39 (3.60)	-3.20 (3.74)						31.02 (10.82)	.765 (.096)
(14.16-L)	.97	1.68	2.16		-.23 (.20)	-.37 (.21)						.0065 (.0019)	.65 (.10)
(14.17-O)	.98	1.73	-144.15			-4.19 (3.58)						29.63 (10.69)	.788 (.092)
(14.17-L)	.97	1.65	1.73			-.43 (.20)						.0062 (.0019)	.674 (.099)

*For sources and composition of the dependent variable, Q_{Fd}, and the indicated independent variables, see text and Table 14.1.

†Equations are estimated in the transformations indicated: original values, O, logarithms, L (T is in original values in L equations), and first differences of original values, F.

‡The Durbin-Watson autocorrelation statistic d.

§The intercept or constant coefficient in the first-difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

(14.16) and (14.17) are not consistent with the coefficients in previous conventional models. When a strong complementarity is expected to exist between inputs such as feed and livestock, the validity of a distributed lag model of the form indicated in these equations is questionable because different rates of adjustment of purchases apply to changes in complementary stocks, prices or other variables. The coefficient of the lagged quantity variable was insignificant in feed equations including durable assets. The implication is that there is no long-run adjustment of feed purchases, given the level of stock. In the long run, as inventories of livestock and other assets are changed, feed purchases also change. If this reasoning is accepted, equations such as (14.13), (14.14) and (14.15) are more appropriate expressions of feed demand than are (14.16) and (14.17).

The price coefficients in the latter equations are insignificant. An exception is the coefficient of $(P_{F_d}/P_{L_k})_{t-1}$ which is significant at the 95 percent probability level in (14.17-L). The coefficients of the lagged quantity and time are significant in the distributed lag equations. The results indicate that approximately one-fourth of the adjustment to the equilibrium or desired level of feed purchases is made in the short run. Whether the result can be taken seriously without specifically including complementary inventories such as livestock in the equation is, however, subject to doubt.

Price Elasticity of Demand

The total demand elasticities with respect to current and past year feed prices estimated from (14.15-O) and (14.15-L) are respectively -.8 and -1.3. Since price ratios are employed, the elasticities with respect to livestock prices are the same values but with positive algebraic signs. Because the reliability of the data from which the demand equations are generated is questionable, it is desirable to consider the estimated elasticities as hypotheses suitable for further testing rather than as accurate and final coefficients. It is notable, however, that these estimates conform closely with the results of the study by Hildreth and Jarrett.[5] Their average estimates from single and simultaneous equations of the demand elasticity of feed grains are, with respect to livestock prices, 1.1, and with respect to feed prices, -.8.

The estimated demand elasticity with respect to S_p from (14.15-O) is 2.3; from equation (14.15-L) is 1.6. A comparable statistic from Hildreth and Jarrett, the elasticity of demand for feed grains with respect to livestock inventories (an average of several estimates), was 1.6.

The techniques of this study are not suited for estimating the responsiveness of feed purchases to changes in cattle prices through the inventory effect. A more fundamental explanation of the responsiveness of feed demand to long-run changes in farm product prices

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[5] Ibid.

through S_p is available. If a sustained 1 percent increase in P_R increases S_p 1 percent, then feed inventories are predicted to increase from 1 to 2 percent according to (14.15). Because the data and procedures are somewhat crude, no attempt is made to evaluate the exact long-run elasticity with respect to P_R. It is expected, however, that a sustained 1 percent increase in product prices would increase feed purchases more than 2 percent in the long run.

Shifts in Demand

On the basis of equation (14.15-O), if prices had been at 1959 levels in 1926, the quantity demanded of feed would have been approximately 12 percent greater than the predicted quantity in 1926. Thus, nearly 200 of the total 218 percent increase in demand from 1926 to 1959 remains to be explained by factors other than short-run price changes.

Several factors other than short-run price changes have tended to increase demand for the two major components of feed purchases — high protein concentrates and feed grains. Improvements in the nutritive content of protein feeds may be defined as an improvement in feed quality or as a decrease in real cost per nutrient unit of feed. However defined, improvements in the vitamin, mineral, protein and other contents of "balancer" feeds, coupled with greater knowledge by farmers of these improvements, undoubtedly have been an important element in increased demand for them. Aside from price effects, these technologies have increased the productivity coefficients discussed in Chapter 3. The expected result is an increase in demand for the resources. Both commercial and public interests have assumed an important role in improvement of livestock rations and dissemination of knowledge about them to farmers.

Large increases in feed grain purchases, the second major component of total feed purchases, have also occurred since 1926. The rise in purchases reflects the tendency toward specialization in production of agricultural commodities. Whereas more Midwest or Great Plains farmers formerly produced both feed and livestock, many now raise grains only. More grain is shipped to the East where it is purchased by farmers specializing in broiler production and similar activities. As farming becomes more specialized, the proportion of purchased inputs tends to rise.

Trends and Projections

Figure 14.3 compares actual and predicted feed purchases from 1926 to 1960. After 1935 a general upward trend in purchases is apparent, despite occasional short-term reversals. There are no signs of a reversal of the strong upward trend in recent years.

Equation (14.17-O) is used for prediction although some doubt exists

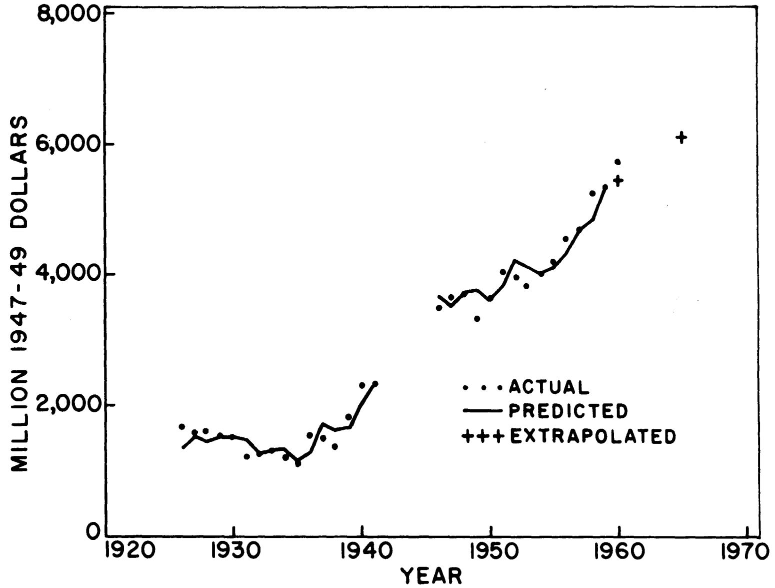

Figure 14.3. Trends in feed purchases Q_{Fd} from 1926 to 1960 (predicted and projected estimates from equation 14.17-O).

about the structural pertinence of this distributed lag equation. Its high predictive power (R^2=.98) and absence of current price, however, encourage use of it for predictive purposes. Some autocorrelation in the residuals of the conventional equations seems to be absorbed into the coefficients of the distributed lag equation. This autocorrelation may be due to systematic errors in the data or failure to specify variables which account for the cattle cycle. Predictive users of the equation, however, can be less concerned about the structural validity of the coefficients. The fit of the equation to the actual observations becomes a sufficient basis for its use in projections. While equation (14.17-O) predicts well for gradual year-to-year changes, it does not accurately indicate more violent changes such as occurred in the early 1950's.

The extrapolated estimate of feed purchases for 1960 is 6 percent below actual purchases. Projections from the equation for 1965 indicate purchases 12 percent above predicted 1960 values. Feed purchases are expected to increase approximately 2 percent per year, under the assumption of prices at 1955-59 levels, assuming that the structural relationships indicated by (14.17-O) remains appropriate. A linear extension of the trend in feed purchases from 1955 to 1960 would result in a much larger projected increase. Hence the estimate from equation (14.17-O) may be conservative.[6]

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[6] It also should be emphasized that the analysis is highly aggregative, and purchases of some individual feed resources, within the aggregate category of purchased feed resources, are expected to increase at greater rates.

DEMAND FOR BUILDING REPAIRS

This category includes a highly miscellaneous collection of resources, some relating to crops and some to livestock. On the other hand, some, such as repairs on machine sheds, are technical complements with machinery. Hence, it is not expected that highly efficient demand equations can be predicted from time series on expenditures for building repairs.

The USDA classifies expenditures on fences, windmills, wells and buildings other than the operator's dwelling under two categories — repairs and improvements. Building improvements include new construction, additions and major improvements and are classified as durable goods or investment in this study. Building repairs, inputs necessary to maintain the usefulness and productivity of buildings, fences, etc., have certain characteristics relating to the definition of operating inputs. A large number of these repairs is a function of the level of farm output. Hence, building repairs are classified as operating inputs, although some components of repairs undoubtedly do not fall into this classification.

Purchases of building repairs, measured in 1947-49 dollars, dropped from $424 million in 1926 to $345 million in 1959. This decrease in building repairs amounted to 19 percent during the 33-year period, a compound decline of .6 percent per year. The declining trend in purchases of building repairs is in contrast with the growth in purchases of aggregate operating inputs at an average annual rate of 3.6 percent.

Specification of the Demand Function

The demand quantity of building repairs is specified as a function of prices of building and fence materials, prices received by farmers, prices paid by farmers, beginning year stocks of buildings, beginning year stocks of productive assets, government programs, weather and slowly changing forces represented by the time variable. Stocks of buildings were not available when the statistical demand equations were computed. Later, an approximate estimate of building inventories was constructed. Since this estimate correlates highly (r=.92) with stocks of productive assets, only the latter is included in the demand functions. The variables are defined in more detail as follows:

Q_{BRt} = the purchases of building repairs by U.S. farmers during the current calendar year in millions of 1947-49 dollars. The estimate includes repairs on fences, windmills, wells and farm buildings other than the operator's dwelling.

$(P_B / P_R)_t$ = the current year index of the ratio of prices paid by farmers for building materials to the ratio of prices received by farmers for crops and livestock. Current and past year prices are included in the demand function.

$(P_B/P_P)_{t-1}$ = the past year index of the ratio of prices paid by farmers for building materials to prices paid by farmers for items used in production, including interest, taxes and wage rates. The simple correlation between current and past year values is 0.92, hence, only past year values are included in the demand function.

In addition to these price variables, the demand quantity is specified as a function of the beginning year stocks of productive assets, S_p, the index of government programs, G, weather, W, and time, T. All functions are estimated from aggregate annual data for the years 1926 to 1959, omitting 1942 to 1945.

The Estimated Demand Equations

In Table 14.4 the demand quantity of building repairs, Q_{BR}, is depicted as a function of the variables indicated. The coefficient of G is not significant in (14.18); therefore, the variable is omitted in (14.19). The coefficient of the current price, P_B/P_R, is low and nonsignificant in equation (14.19) where the past price ratio dominates. Beginning year stocks of productive assets appear to have little influence on Q_{BR}. The insignificant coefficient could be caused by conflicting effects on Q_{BR} of variables correlated with S_p. Examples of these variables are: (a) inventories of buildings, (b) stocks of cash and other assets held for production, (c) farm size and (d) structural changes in product demand, specialization and production techniques. Greater investment in buildings may tend to increase demand for repairs, but if the new investment replaces old buildings, repair costs are reduced. Cash for productive purposes and other assets may increase demand for building repairs, but shifts in demand from butter to margarine and improved methods of storing hay (bales) may decrease demand. The influence of each of these correlated variables may be significant, but the collective effect is zero in S_p. Undoubtedly, some of these influences are reflected in the significant coefficient of the time variable. Weather, at least in the form indicated by W, does not influence significantly the demand quantity. Only the variables with significant coefficients in (14.19) are retained to form (14.20).

Although all coefficients are significant in equation (14.20), the three variables explain only one-half of the variation about the mean of Q_{BR}. A linear time trend in purchases of building repairs is not as apparent as the time trend in purchases of other inputs previously discussed. Much of the R^2 in previous demand equations resulted from the time trend, and exaggerated the ability of the equations to predict annual variations in data.

The d statistic indicates significant autocorrelation of the residuals at the 95 percent probability level in equations (14.20-O) and (14.20-L). The Durbin-Watson test suggests that the first-difference transformation successfully eliminates the significant autocorrelation. The

Table 14.4. Demand Functions for Building Repairs Q_{BR} Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1945 (Including Coefficients, Standard Errors, in Parentheses, and Related Statistics)*

Equation and Transformation†	R^2	d‡	Constant	P_B/P_R t	P_B/P_R t-1	P_B/P_P t-1	S_P t	G t	W t	T	Q_{BR} t-1
(14.18-O)	.57	1.00	237.90	-.42	-2.89	7.56	.20	-.62	.37	-5.75	
				(.87)	(1.06)	(3.22)	(3.37)	(1.99)	(.98)	(4.48)	
(14.19-O)	.56	1.20	169.57	-.37	-2.84	8.28	.52		.40	-6.91	
				(.85)	(1.03)	(2.67)	(3.22)		(.95)	(3.43)	
(14.19-L)	.56	1.01	-.81	-.21	-.98	2.49	.53		.15	-.0098	
				(.31)	(.37)	(.76)	(.88)		(.25)	(.0046)	
(14.20-O)	.56	1.03	213.49		-3.23	8.56				-6.55	
					(.59)	(2.36)				(1.76)	
(14.20-L)	.54	1.00	.42		-1.16	2.46				-.0075	
					(.22)	(.67)				(.0022)	
(14.20-F)	.30	2.42	--§		-2.48	4.16				2.61	
					(.78)	(2.83)				--§	
(14.21-O)	.70	1.91	79.21		-2.35	6.51				-4.69	.40
					(.56)	(2.09)				(1.59)	(.12)
(14.21-L)	.68	1.95	-.097		-.88	1.90				-.0055	.37
					(.20)	(.59)				(.0019)	(.11)

*For sources and composition of the dependent variable, Q_{BR}, and the indicated independent variables, see Table 14.1.

†Equations are estimated in the transformations indicated: original values, O, logarithms, L (T is in original values in L equations), and first differences of original values, F.

‡The Durbin-Watson autocorrelation statistic d.

§The intercept or constant coefficient in the first-difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

coefficient of P_B/P_R after the transformation, which is expected to provide a more accurate estimate of the significance of the coefficients, is not significant. This casts some doubt on the validity of the complementarity of building repairs with other inputs inplied by the significant positive coefficients of P_B/P_P in these equations. The coefficient of T is 2.61 in equation (14.20-F) and indicates that after adjustments for prices, the demand for building repairs has increased during the years 1926 to 1959. Although the coefficient was not tested statistically, it is probably not significantly different from zero. In this respect, the coefficient of time in equation (14.20-F) agrees with the results of (14.18) and (14.19-O), i.e., the coefficients of time are not significant.

The statistical fit is improved considerably by including the lagged quantity as an independent variable (14.21). Although the magnitudes of the price coefficients are reduced from (14.20), all coefficients in (14.21) are significant. The variables explain 63 percent or more of the annual variation about the mean of Q_{BR}. Autocorrelation is insignificant in the equation. (However, the d statistic tends to underestimate the degree of autocorrelation in such equations.) Although equation (14.20) may be structurally deficient, because of failure to account for building and other inventories, the equation is useful for predictive purposes.

Price Elasticity of Demand

The price elasticities of demand for building repairs with respect to $(P_B/P_R)_{t-1}$ in (14.20-O) and (14.20-L), respectively, are -1.02 and -1.16, indicating that a 1 percent increase in prices received by farmers is associated with approximately a 1 percent increase in purchases of building repairs in the short run. Equation (14.21-L) suggests that a major portion, approximately 60 percent, of the adjustment of purchases to price changes is made in the short run. The long-run elasticity computed with respect to $(P_B/P_R)_{t-1}$ is -1.23 from equation (14.21-O) and -1.40 from equation (14.21-L). The long-run elasticities are not much larger than the short-run elasticities. This result is substantiated by the insignificance of the coefficients of S_p in (14.18) and (14.19).

The price elasticity of demand with respect to $(P_B/P_P)_{t-1}$, estimated from (14.20-O), is 2.18; from equation (14.20-L), is 2.46. The results suggest building repairs to be complements with other inputs; a 1 percent drop in the prices paid for agricultural inputs is associated with an increase in building repair purchases of approximately 2 percent. But as indicated previously, the magnitude of the elasticity of demand with respect to $(P_B/P_P)_{t-1}$ is not defined precisely here. The total elasticity of demand with respect to P_B from equation (14.20-L) is 1.3 (-1.16 due to the change in price relative to P_R plus 2.46 due to the change in price relative to P_P). If the complementarity effect is considered negligible, as indicated by (14.20-F), then the elasticity of demand with respect to P_B is approximately -1.0.

Shifts in Demand

Forces influencing demand have not remained constant, even for building repairs, and the relatively stable demand indicated by the equations results from opposing forces. We would expect the increasing output of agriculture directly to require more operating inputs. But more efficient use of resources, shifts in consumer demand and other structural changes reduce requirements for some resources.

Purchase of repairs was not commensurate with the 30 percent increased investment in farm buildings from 1926 to 1959. The necessity for repair of these buildings may be offset by other forces reducing demand for building repairs. Because of shifts in consumer demand for butter, a large investment in dairy barns and equipment is obsolete. Decreases in the number of farms, development of more durable and flexible construction materials, and adoption of certain farm practices also reduce building repair needs. Consolidation of farm units often makes the second set of buildings of little use; the marginal value product of obsolete buildings sometimes is greatest when used as repairs for other buildings. Such repairs are not included in Q_{BR}, the measure used in this report. The substitution of durable items such as bricks or blocks for wood in construction also lessens the need for repairs. Finally, bailing hay, storing shelled corn in steel bins, and other changes in farm practices tend to reduce demand for building repairs.

Trends and Projections

A highly volatile trend in purchases of building repairs is depicted in Figure 14.4. Inputs of building repairs fell sharply during the depression years but after 1936 recovered to the high pre-depression level. Sales made a rapid recovery after World War II until 1948, then leveled off and finally began a gradual, somewhat regular decline after 1952. A secular trend is not apparent except perhaps after 1948. The large fluctuations suggested during the early years may partially be because of measurement errors in available data.

Quantities estimated by the distributed lag equation (14.21-O) fit the observed values reasonably well in the postwar period. The extrapolated value, Q_{BR}, from the equation for 1960 is 317 million 1947-49 dollars. The actual 1960 purchases, 311 million 1947-49 dollars, are overestimated by only 2 percent. Assuming average 1955-59 prices, and that the structural relationship embodied in equation (14.21-O) is relevant until 1965, the projected 1965 quantity is 277 million 1947-49 dollars. The projected quantity is approximately 12 percent below the predicted 1960 quantity. Examination of the recent tendency for the

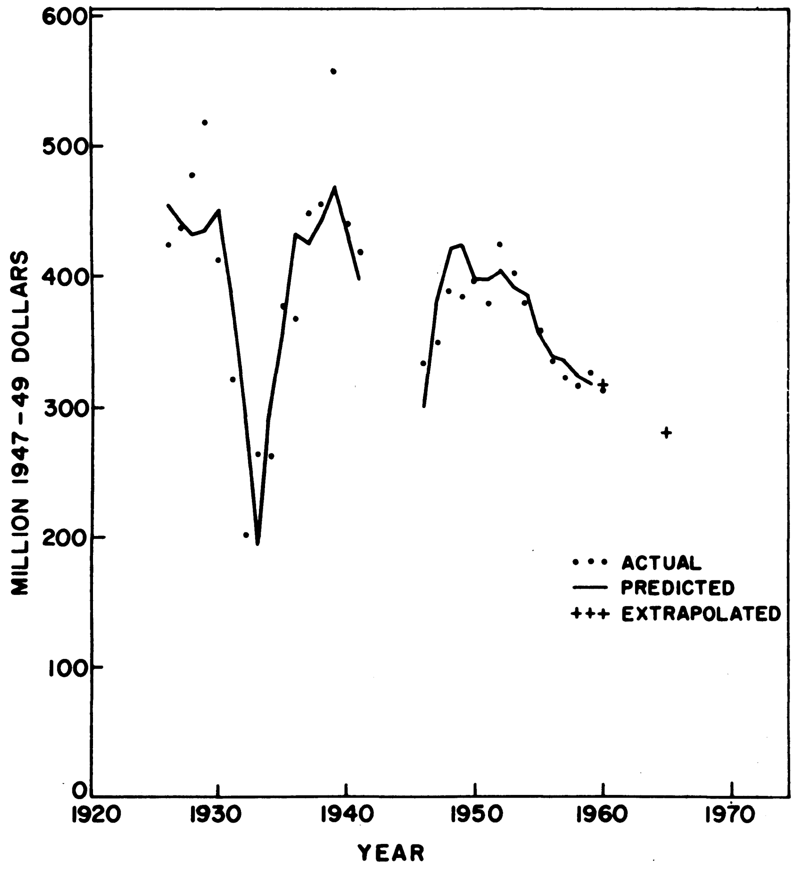

Figure 14.4. Trends in building repair purchases Q_{BR} from 1926 to 1960 (predicted and projected estimates from equation 14.21-O).

decline beginning in 1948 to level off, suggests that this projection may be overly pessimistic. Recent structural changes causing demand to fall less sharply may not be adequately represented in (14.21) because of the limited number of observations for the latest years.

DEMAND FOR MISCELLANEOUS OPERATING INPUTS

Minor operating inputs not included in the previous categories are classified as miscellaneous inputs. The category contains such heterogenous items as repairs by blacksmiths, expenditures for small hand tools and other hardware items, fire, crop and hail insurance, greenhouse and nursery supplies, binding materials, veterinary services and medicine, telephone, dairy supplies, livestock marketing services and milk hauling. Some of the items are not closely related to output but

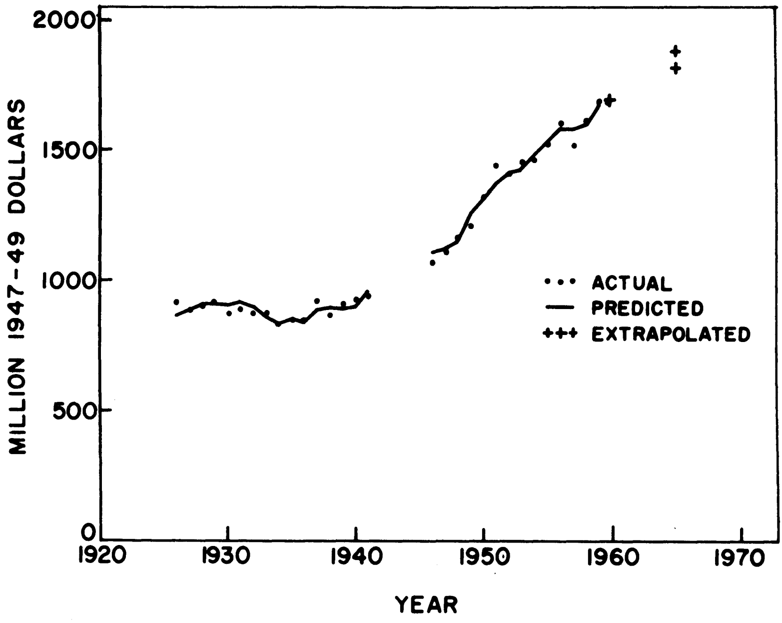

Figure 14.5. Trends in miscellaneous input purchases Q_{MI} from 1926 to 1960 (predicted and projected estimates from equation 14.24-O).

are fixed expenses or investments in minor durable items. The major portion of these inputs, however, falls within the definition of operating inputs discussed earlier. Since expenditures are not available by individual items, the entire grouping conveniently is classified and discussed within the framework of operating inputs.

Inputs of miscellaneous items increased 85 percent from 1926 to 1959, or at an average compound rate of 1.8 percent per year. During the same period, inputs of all agricultural resources increased only at the rate of .2 percent per year, or a total of only 5.5 percent. Hence, there was a net substitution of miscellaneous inputs for other inputs in the production process.

Specification of the Demand Function

In the following specification of the demand function, the quantity purchased is represented as a function of current and past prices of miscellaneous items, prices received and prices paid by farmers, inventories of productive assets, weather, government programs and slowly changing forces reflected by a time variable. Decisions to buy miscellaneous inputs are assumed to depend on both current and past year prices. Many of the items contained in the aggregate are a function of fixed resource levels as well as prices. Thus, the stock of productive assets is specified in the demand function to reflect changes in scale or plant size. Complementarity is anticipated between asset levels and purchases of miscellaneous items. The variables in the demand function are as follows:

Q_{MIt} = purchases of miscellaneous operating inputs by U.S. farmers during the current calendar year in millions of 1947-49 dollars.

$(P_{MI}/P_R)_t$ = the current year index of the ratio of prices paid by farmers for miscellaneous operating inputs (farm supplies) to the ratio of prices received by farmers for crops and livestock. Current and past year prices are included in the demand function.

$(P_{MI}/P_P)_{t-1}$ = the past year index of the ratio of prices paid by farmers for miscellaneous inputs to prices paid by farmers for items used in production including interest, taxes and wage rates. Since the simple correlation between current and past prices is high (r=.93), only past prices are included in the demand function.

Additional variables specified in the demand function are those explained earlier: the stock of productive assets, S_p, an index of government programs, G, the weather variable, W, and time, T. All variables are aggregate estimates for the United States from 1926 to 1959, 1942 to 1945 omitted.

The Estimated Demand Equations

Table 14.5 includes the five empirical demand functions estimated by least squares. The institutional variable as defined has little influence on demand, and is dropped from (14.22) to form (14.23). The coefficients of past year prices in (14.23) are of low significance. The past year prices may be important, but the current year price, P_{MI}/P_R, seems to be a "stronger" variable and absorbs the influence of the former. For predictive purposes, and to observe the influence of dropping the current price variable, (14.24) is estimated with lagged P_{MI}/P_R, S_p, W and T. The coefficients of lagged price and weather are significant at the 90 percent level in the logarithm equation. Since 99 percent of the annual variation about the mean of Q_{MI} is explained by the four independent variables in (14.24), it is used for predictive purposes. However, the coefficients of current price in (14.25) are larger in absolute terms and are significant at a higher probability level than those in equation (14.24). Coefficients of all variables, except T in (14.24), are significant at the 95 percent level. The d statistic indicates that autocorrelation is insignificant in the first two equations of (14.25).

Equation (14.25-F), a first-difference transformation, is included to aid in interpreting the price coefficients. The magnitudes of the

Table 14.5. Demand Functions for Miscellaneous Operating Inputs Q_{MI} Estimated by Least Squares With Annual Data From 1926 to 1959, Omitting 1942 to 1945 (Including Coefficients, Standard Errors in Parentheses, and Related Statistics)*

Equation and Transformation†	R^2	d‡	Constant	P_{MI}/P_R t	P_{MI}/P_R t-1	P_{MI}/P_P t-1	S_p t	G t	W t	T	Q_{MI} t-1
(14.22-O)	.99	1.90	-1689.76	-.44	.056	.13	29.96	-.59	1.16	.81	
				(.36)	(.557)	(2.43)	(2.99)	(.84)	(.59)	(1.81)	
(14.23-O)	.99	1.88	-1731.77	-.45	.16	.19	30.32		1.20	.44	
				(.35)	(.53)	(2.40)	(2.91)		(.58)	(1.71)	
(14.23-L)	.99	1.85	-1.62	-.067	-.018	.070	2.30		.097	.00043	
				(.050)	(.081)	(.265)	(.26)		(.046)	(.00063)	
(14.24-O)	.99	1.98	-1686.99		-.17		29.70		1.07	1.10	
					(.21)		(1.80)		(.56)	(1.53)	
(14.24-L)	.99	2.03	-1.34		-.057		2.20		.090	.00077	
					(.028)		(.15)		(.046)	(.00059)	
(14.25-O)	.99	1.93	-1674.40	-.30			29.93		1.11	.64	
				(.21)			(1.74)		(.53)	(1.53)	
(14.25-L)	.99	1.82	-1.41	-.070			2.24		.097	.00050	
				(.027)			(.14)		(.043)	(.00059)	
(14.25-F)	.37	2.53	-- §	-.62			28.01		1.29	2.51	
				(.43)			(8.12)		(.59)	-- §	
(14.26-O)	.98	2.55	46.59	-.43						3.71	.892
				(.29)						(2.03)	(.075)
(14.26-L)	.98	2.73	.52	-.074						.00140	.864
				(.037)						(.00076)	(.076)

*For sources and composition of the dependent variable, Q_{MI}, and the indicated independent variables, see text and Table 14.1.

† Equations are estimated in the transformations indicated: original values, O, logarithms, L (T is in original values in L equations), and first differences of original values, F.

‡ The Durbin-Watson autocorrelation statistic d.

§ The intercept or constant coefficient in the first-difference equation is comparable to the coefficient of T in the O and L equations. The standard error of the coefficient was not computed.

price coefficients in (14.25-F) and (14.25-L) are comparable with respective estimates -.08 and -.07 for price elasticities of demand.

The coefficient of the stock of productive assets, S_p, is highly significant in all equations. The trend in this variable is somewhat related to the time variable and may tend to reflect some of the influences usually associated with the latter, since the coefficient of T is not significant. The inclusion of S_p is intended to make the equations short run. As with other operating inputs, the coefficient of a lagged dependent variable added to equation (14.25) was not significant. (Equations including both S_p and Q_{MIt-1} are not included in Table 14.5.) The implication is that there is little influence of lagged prices, Q_{MIt-1}, and other past influences represented by Q_{MIt-1} on current demand quantities, if the scale of plant is fixed.

Equation (14.26-O) is estimated with S_P excluded as an approximate indication of demand when the agricultural plant size is allowed to vary. Weather, which appeared to be of some importance in explaining demand for Q_{MI} in equations (14.24) to (14.25), is not included. The short-run price coefficients in the equation are similar in magnitude to those estimated in (14.25). The distributed lag equation (14.26-L) indicates that adjustments of purchases to price changes occur slowly, approximately 13 percent in the short run.

Price Elasticity of Demand

The point estimate and 95 percent confidence interval of the short-run price elasticity of demand for Q_{MI} with respect to P_{MI} computed from (14.25-L) is -.07 ± .056. The short-run elasticity with respect to P_R is of the same magnitude but positive in sign. The results indicate that the short-run demand for miscellaneous inputs is highly inelastic. A 10 percent fall in P_{MI} could be expected to increase purchases less than 1 percent. The low price elasticity of demand for miscellaneous inputs may be explained by: (a) the minor importance of the individual components of the inputs in the farm budget, (b) the fact that some components of Q_{MI} are related to family living as well as production and (c) a strong complementarity of miscellaneous inputs with fixed assets which are relatively unresponsive to short-run price changes. Electricity and the telephone, for example, are closely related to family living expenses as well as production, and their use is often unresponsive to price changes. Insurance also tends to remain a relatively stable "quantity" in the short run despite changes in the price of insurance. Particular repairs and operating supplies are necessary to keep major machines and equipment in use, and expenditures for such items tend to remain at fixed levels if any production takes place.

The long-run elasticity of miscellaneous inputs with respect to P_R is found from the relationship between Q_{MI} and S_p in demand equation (14.25). Each of the three forms of the equation indicates that a 1 percent increase in S_p is associated with a 2.2 to 2.4 percent increase in

Q_{MI}. (The function for plant and equipment in Chapter 12 estimates the elasticity of S_p with respect to P_R to be approximately unity in the long run.) The implication above is that a sustained 1 percent rise in farm product prices potentially may increase demand for miscellaneous inputs by more than 2 percent. This arises from the strong complementarity of miscellaneous inputs with farm productive assets. Despite the inelastic response of miscellaneous inputs to short-run prices, the response in the long run may be large.[7] (The long run probably is more than 20 years away, according to results in Chapter 12.)

Shifts in Demand

Only a small portion (about 3 percent) of the 83 percent increase in purchases of miscellaneous operating inputs from 1926 to 1959 is explained by short-term price changes. Interpreted literally, the nonsignificant coefficient for T in equation (14.25) would indicate that there have been no shifts in demand for Q_{MI} that cannot be explained by the requirement to service the growing agricultural plant S_p. Technological changes which occur and are adopted at a slow rate may correlate more closely with S_p than T. Innovations decrease demand for certain inputs, and this tendency is evident in several components of Q_{MI}. Examples are blacksmith repairs, binder twine and dairy supplies used for butterfat production.

Trends and Projections

The general trend in purchases of miscellaneous inputs has been similar to that found previously for other categories of operating inputs. Purchases dropped slightly during the depression. Following the depression, purchases began an upward trend which persisted except for some short-run interruptions until 1960. Equation (14.24-O) predicts the actual observations quite well throughout the 33 year period, and the extrapolation to 1960 overestimates the actual observation by less than 1 percent. Since this equation does not contain current prices, the prediction is made from past values of P_{MI}/P_R, S_p and from T. Projections of Q_{MI} for 1965 are made assuming prices at 1955-59 levels and that the structure of demand indicated by the equation will remain applicable. Projections are based on two levels of S_p. The lower level is based on USDA estimates and agrees with projections from (12.23). The higher estimate of S_p is found from an investment equation containing an accelerator coefficient (Cf. equation (12.28)). Under the above assumptions, equation (14.24-O) projects the 1965 demand quantity to be 7 or 11 percent above the 1960 predicted quantity, depending on whether the higher or lower estimate of S_p is used.

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[7] The correlation of S_p with technological and other gradual changes in farming may impart positive bias to the coefficient of S_p.

SUMMARY OF EMPIRICAL RESULTS

The demand structures for five individual operating inputs have been estimated in this chapter. The generalized results, based on the "most reasonable equations" of each section, are summarized in Table 14.6. Despite similar trends in prices and quantities of several of the indicated operating inputs, the estimates of price effects and projected quantities often are dissimilar. The empirical results suggest that the short-run price elasticity of motor supplies, building repairs and feed is approximately unity. Seed and miscellaneous inputs evidently are unresponsive to short-run price changes.

The equations including a variable S_p for the scale of the agricultural plant generally provided the most meaningful structural demand functions. The coefficients of lagged dependent variable, introduced as a predetermined variable in equations containing S_p, were generally nonsignificant. This finding suggests that there are no long-run adjustments of operating input purchases, given the agricultural plant size. In the long run, the stock of productive assets is responsive to prices, and input of complementarity operating inputs is determined accordingly. The long-run elasticity of operating inputs with respect to product prices P_R thus is large because the latter variable has a strong influence on S_p.

Table 14.6. Summary of the Analysis of Demand Structure for Five Operating Inputs, including Short-run Demand Elasticities, Structural Changes and Projections of Quantities[*]

	Input				
	Q_S	Q_{MS}	Q_{Fd}	Q_{BR}	Q_{MI}
Approximate short-run demand elasticity estimates with respect to:					
P_i (own price)	0.0	-1.0	-1.0	-1.0	-0.1
P_R	0.0	0.3	1.0 [†]	1.0	0.1
Estimated percentage change in demand quantity from 1926 to 1959 due to short-run price changes [‡]	-15	119	12	15	3
Actual percentage change in demand quantity, 1926 to 1959 [‡]	212	365	218	-19	83
Projected percentage change in demand quantity from all sources, 1960 to 1965 [§]	12	10	12	-12	9

[*] See the respective sections for input codes, sources of data, type of analysis, qualifications of findings and other information.

[†] Elasticity with respect to P_{Lk} rather than P_R.

[‡] The difference between changes due to price and actual changes is explained by lagged adjustment to price, changes in investment in durable assets, farm size, technology, education and improved management.

[§] When projections were made from two estimates of S_p, the table contains only an average of the separate estimates.

Purchases of operating inputs are projected to increase from 9 percent (Q_{MI}) to 12 percent (Q_{Sd} and Q_{Fd}), except for building repairs. Their purchases are expected to decrease from 1960 to 1965 in constant dollars. The above findings are conditioned, of course, by limitations of the data and by other inadequacies of the models employed.

15.

Real Estate Prices and Investment, and Farm Numbers

TWO SEGMENTS of the real estate structure, land price and investment in land improvements [considered in this chapter], complete our analysis of the major resource categories. Though not a resource per se, farm numbers have been an integral part of the resource structure of agriculture. For this reason the final section of this chapter contains an attempt to estimate structural parameters determining farm numbers. The analysis again is based on aggregate data for the United States because time, space and dollar resources do not permit a further breakdown by region and commodity.

LAND PRICE

In the absence of structural change, we could expect variations in land price to correlate positively with changes in net farm income. That this relationship has not held is apparent from Table 15.1. Both net farm income and land prices increased during the war period. Net income began a general decline after 1950 and was only 84 percent of the 1947-49 average in 1961. Land prices continued to rise in the period, however, and in 1961 were 75 percent above the 1947-49 average. We examine hypotheses explaining this phenomenon in this chapter.

Another reason for exploring the structural basis of land prices is their role in farm policy and in resource adjustments. The effectiveness and incidence of a government program to raise farm incomes depend to some extent on the rate that these benefits are capitalized into land values. Additional incomes quickly capitalized into real estate prices benefit present land owners but the results for future generations may be quite different. Higher land values creating barriers to entry for beginning farmers may have both favorable and unfavorable effects on optimum resource adjustments.

Higher land values possibly encourage labor movement to nonfarm areas, but also potentially retard diversion of land into uses considered more worth while by society.

Farm appraisers, participants in land market operations and credit groups in agriculture also are concerned with the effects of structural variables on land values. Whether a real estate loan is granted may

Table 15.1. Indices of Farm Real Estate Values per Acre and Net Farm Income, 1940 to 1961*

Year	1947-49 = 100 Real Estate Value (per acre)	Total Net Income (Gross income less production expense)
1940	49	30
1945	76	80
1950	103	91
1955	133	76
1960	173	78
1961	175	84

*Statistical Abstract of the United States, 1961; and USDA. The Farm Income Situation. 1961 and March 1962.

depend on future trends in land prices, and knowledge of forces affecting these trends allows more accurate predictions. Finally, long-range public planning of recreation areas, industrial sites and residential zoning is tied to land values. Technologically improved inputs prompting a secular decline in land values in agriculture influence the purchase price of land for alternative uses and affect the tax base for land used to produce crops.

We hope that results in this section will begin to provide basic information for these and related problems by measuring not only the extent but also the rate at which additional net income and other effects are capitalized into land values.

Specification of the Land Price Function

While in most time series analysis there are more admissible hypotheses (variables) explaining the dependent variable than can be included in the regression equation, the dilemma appears especially acute for land prices. This prompts us to specify a land price model as a hierarchy of admissible hypotheses in an attempt to preserve structural validity and to avoid some of the difficulties of spurious correlations associated with collinearities.[1] Each of the following subsections may be considered a hierarchy of one or more variables. A variable from the higher echelon is selected before moving to the next lower echelon. When the intercorrelations become high, causing instability in the coefficients and large standard errors, no further variables are added.

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[1] Some of the theoretical advantages of this system are discussed in Tweeten, Luther G. An Economic Analysis of the Resource Structure of United States Agriculture. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1962. Chap. 3.

Farm Size and Machinery

The structural variable most frequently associated with recent trends in land prices is the growing demand for land to be used for farm enlargement. For example: A farmer owning 160 acres with receipts above variable costs of $50 per acre and with nonland fixed costs of $30 per acre earns $20 as the imputed return to land. Based on a discount rate of 10 percent, he could pay $20/.10 = $200 per acre for the "home" acreage. But suppose an additional 40 acres is available nearby and he can farm it with existing machinery and other "fixed," discrete inputs. Again the receipts above operating costs are $50 per acre, and since marginal machinery and other overhead costs are near zero, the return to land is nearly $50. Discounting at the same rate as before, the farmer may pay up to $50/.10 = $500 per acre for the additional 40 acres. It is clear that in circumstances where available equipment can be used profitably on more acres, farmers intending to expand acreage can outbid those intending to farm only the purchased land. This effect is included in the land price function with a farm size variable, A. Since the effect is also closely tied with machinery investment, it is also partially represented by a machinery stock variable, S_M. The first hierarchy is therefore (15.1) where P is land price.

$$P = f_1(A, S_M) \tag{15.1}$$

Income and Discount Rate

The land value model essentially is a modification of the capitalization formula $P = Y/r$ where P is land price per acre, Y is the residual income per acre of land and r is the discount rate or highest rate of return on alternative investments. Assuming the annual return, Y, is sustained in perpetuity, the discounted present value of one acre is P. If the price asked for land is greater than P, investors would find other alternatives more profitable; if the asking price is less than P, investors would find land a profitable investment and would bid up the selling price. Thus, under competitive conditions land values would move toward the discounted value of the annual residual income or imputed return to land.

This analysis is predictive rather than normative, hence, we are concerned with the residual income farmers subjectively impute to land rather than what is, in fact, the residual return to land.[2] For example, many farmers may impute little return to their own labor,

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[2] The accounting residual return to land is equal to the contribution (value of marginal product) of land to returns only under restricted assumptions. Let the production function be

$$O = f(X, L) \tag{a}$$

where O is output, X is inputs other than land and L is land input. With constant returns, according to the Euler theorem.

rather imputing their labor return to land. Several suggested variables which may correlate with or represent the subjective return are gross farm income, Y_1, gross income less operating and hired labor expense, Y_2, gross income less all cash expenses, Y_3, and gross income less all cash operating and labor expenses and service costs of nonreal estate farm durables, Y_4. These and other measures of Y variables constitute the second hierarchy (15.2).

$$P = f_2(Y_1, Y_2, \ldots, Y_n) \tag{15.2}$$

These measures of land returns are influenced by farm size, machinery investment and other variables, hence the hierarchies are not independent or orthogonal.

The discount rate, r, may be interpreted as the opportunity cost of land investment, or the highest alternative rate on investment, allowing for uncertainty. A rational investor who can obtain a higher return by investing capital in farm operating inputs, mortgages or municipal bonds would not invest in real estate. If capital is plentiful the effective discount rate may be the short-term or bank interest rate, r_S, farm mortgage rate, r_L, or the rate of return on common industrial stock, r. The discount rate may be the return, r_I, on internal investment in machinery, fertilizer or other inputs if capital is more limited. This set of discount rates constitutes the third hierarchy (15.3).

$$P = f_3(r_S, r_L, r, r_I) \tag{15.3}$$

Assets and Technology

The form and magnitude of assets influence land prices both directly and indirectly through variables such as Y and r listed previously. A monetary surplus accumulated through a period of favorable farm prices reflected by liquid assets, S_L, or the equity ratio, E, could be expected to create pressures for higher land values. Rising

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$$O = \frac{\partial O}{\partial X} X + \frac{\partial O}{\partial L} L \tag{b}$$

In equilibrium

$$\frac{\partial O}{\partial X} P_y = P_x \tag{c}$$

where P_x is the price of input X, and P_y is output price. Multiplying (b) by product price, P_y, and substituting P_x from (c) for the value of marginal product, $\frac{\partial O}{\partial X} P_y$, the result is

$$O\ P_y = X\ P_x + \left(\frac{\partial O}{\partial L} P_y\right) L \tag{d}$$

and the accounting residual to land is equal to contribution of land to returns (e) under these restricted assumption.

$$O\ P_y - X\ P_x = \left(\frac{\partial O}{\partial L} P_y\right) L \tag{e}$$

Measure Y_4 in the text most nearly is equivalent to the left side of (e).

investment stocks, S_B, of buildings and other real estate improvements also increase land values. The effect on land price from expansion of cropland area by irrigation, drainage and clearing, or contraction from urban growth or other nonfarm uses is represented by total cropland acres, L_d. Both acreage, L_d, and real estate improvements, S_B, are included in the physical volume of real estate, S_{RE}.

The assumption of the single equation is that these variables influence land price but are not influenced by it. If the predicted value of L_d from a land supply function (see equation 16.14 in the following chapter) is used as the independent variable, then the land price function of this chapter may be considered the demand equation in a recursive model of land supply and demand. The recursive model allows price and quantity to be determined interdependently but not simultaneously in time (see Chapter 3). Investments in technologically improved inputs such as fertilizer, Q_{Fr}, and irrigation tend to increase the residual return to land and thus increase land values in the short run, particularly for early adopters. In the long run, as farmers use these inputs more intensively and additional farmers adopt the productive inputs, output rises, product price falls and farm income and land returns are depressed. The influence on land values of many of these gradual changes in capital structure can perhaps only be summarized in a time variable, T.

The fourth hierarchy therefore is summarized as (15.4) in terms of the variables defined above.

$$P = f_4(S_L, E, S_B, L_d, S_{RE}, Q_{Fr}, T) \tag{15.4}$$

Miscellaneous Variables

Inflationary trends, P_T, government programs, G, and weather, W, are largely exogenous to the farm sector, and potentially influence farm real estate prices. Government action may change land values through (a) national employment and income policies which shift demand for farm products and consequently farm prices, incomes and land demand, (b) acreage control programs which directly limit land supply, (c) programs fostering creation and adoption of new technologies through research and education and (d) institutional arrangements affecting interest rates and credit supply. Government reclamation and conservation programs also influence land prices through means discussed earlier. Past and future inflationary trends may also be tied closely to actions and policies at the federal level.

Numerous other variables might be specified, but we add only the percent of forced farm sales, F, institutional credit arrangements, C, and the rate of migration from agriculture, M. It may be argued that the financial crisis of the 1930's imposed a different land price structure, an influence reflected by the percent of forced sales, F. A variable, M, representing new credit forms (e.g. land contracts), types and numbers of agencies making loans and other institutional factors was not specified in the equations but undoubtedly has had some effect on land values. High rural birth rates coupled with declining farm numbers create growing competition for existing opportunities. This influence on real estate values is summarized in the variable, M. Thus, the fifth hierarchy of variables in the price function is (15.5).

$$P = f_5(P_T, G, W, F, C, M) \tag{15.5}$$

The procedure, as stated above, was to select the one "best" variable from each hierarchy before proceeding to the next. All variables indicated in (15.1) to (15.5) were fitted, except C, M and some parts of others such as G.

Land prices do not adjust to equilibrium in the short run because of caution and inertia of past decisions, transactions too few and scattered to register a full short-run impact and for other reasons. Thus, we use the adjustment model (see model F, Chapter 10) with land price lagged one year in the following empirical section.

Least-Squares Land Price Functions

The variables in the following empirical equations are defined as follows:

P_t = the dependent variable, an index of the average U.S. farm real estate value per acre in the current year, divided by the implicit price deflator of the Gross National Product, P_G.

Y_{1t-1} = gross farm income, including government payments in the past year, deflated by P_G.

Y_{2t-1} = gross farm income, less operating and hired labor expenses of the past year, deflated by P_G.

Y_{3t-1} = gross farm income less all cash expenses of the past year, deflated by P_G.

Y_{4t-1} = gross farm income less operating and all labor expenses, machinery, livestock, feed and other asset costs of the past year, deflated by P_G. Asset costs are based on depreciation, interest and taxes; and family labor cost is based on the hired labor wage rate.

Y_{5t-1} = gross farm income less production expenses in the past year, deflated by P_G.

r_{t-1} = the rate of return on 200 (nonfarm) common stocks in the past year.

A_{t-1} = cropland acres used for crops per farm in the past year.

T = time, the last two digits of the current year.

The equations are estimated from untransformed annual U.S. data from 1914 to 1960, without 1942-45. Land price and the deflator, P_G, are expressed as a percent of the 1947-49 average.

The R^2 in Table 15.2 increases from .77 to .93 when the lagged price P_{t-1} is added to (15.6), forming (15.7). However, the magnitude and significance of the A and T coefficients decline markedly. When the values in (15.7) are divided by the adjustment rate .2, the coefficients are similar, suggesting that the coefficients of A and T in (15.6) are for the long run rather than short run.

Equations (15.7) to (15.11), illustrating the results from different income variables, consistently show a rising coefficient as more inputs are subtracted from gross income. In general, the standard error also rises with the coefficient, hence the t value is not appreciably enhanced. Based on the R^2 and t tests, however, there appears to be some advantage for Y_4, the variable most closely measuring and actual return to real estate.

Excluding P_{t-1}, the variables in (15.12) are from each of the first four hierarchies previously presented. The variables from hierarchy 5 either were not significant or caused instability in other coefficients, hence were excluded.

Equation (15.13) is comparable to (15.12) with a more readily available measure of income, Y_5, substituted for Y_4. Based on the one-tailed test, the coefficients of all variables but T are highly significant in (15.13). The coefficient of T is significant at greater than the 90 percent probability level (two-tailed). The R^2 is .94, the test for autocorrelation is inconclusive at the 95 percent probability level and the coefficients display the anticipated signs. Equation (15.14) includes the same variables as (15.13) but is estimated for a shorter period, 1926-59, excluding the war years. The coefficient of income is slightly lower, of opportunity returns, r, and farm size, A, slightly higher. The differences are too small to indicate significant changes, but suggest that the importance of income may be declining relative to farm enlargement and alternative investments in determining land prices.

The coefficients in (15.13) are the basis for several inferences about the structure of land price determination over various lengths of time. The long-run coefficient of T, -2.32, suggests a secular decline in land price, currently at the annual rate of 1.8 percent. The decline probably reflects the output increasing and aggregate income depressing effects of land substitutes such as fertilizer, irrigation and other technologically improved inputs (see Chapter 5). Based on the coefficient of r in (15.13), land price is decreased only .03 percent in the short run and .14 percent in the long run by a 1 percent increase in the rate of return on an alternative investment, common stock.[3]

The estimated elasticity of land price, P, with respect to income,

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[3] Computed at the 1960 observations. The respective elasticities computed at the 1914-60 means are -.08 and -.34. The long-run elasticity is the short-run elasticity divided by the adjustment rate .22.

Table 15.2. Land Price Functions Estimated With U.S. Data From 1914 to 1960, Without 1942-45; Including Coefficients, Standard Errors (in Parentheses) and Other Statistics*

Equation	R^2	d†	Constant	Y_5 t-1	Y_4 t-1	Y_3 t-1	Y_2 t-1	Y_1 t-1	r t-1	A t-1	T	P t-1
(15.6)	.767	.56	-80	.092						4.59	-2.66	
				(.050)						(.48)	(.24)	
(15.7)	.929	1.36	-23	.065						.83	-.35	.804
				(.028)						(.48)	(.28)	(.087)
(15.8)	.928	1.35	-16					.044		.73	-.41	.785
								(.020)		(.49)	(.29)	(.088)
(15.9)	.928	1.38	-21				.063			.74	-.33	.802
							(.028)			(.49)	(.28)	(.087)
(15.10)	.928	1.37	-21			.068				.74	-.33	.804
						(.030)				(.49)	(.28)	(.087)
(15.11)	.930	1.51	-23		.106					.66	-.19	.852
					(.043)					(.48)	(.28)	(.086)
(15.12)	.937	1.37	-19		.131				-1.52	.80	-.29	.840
					(.043)				(.73)	(.47)	(.27)	(.083)
(15.13) ‡	.937	1.48	-19	.088					-1.70	1.03	-.52	.776
				(.028)					(.74)	(.47)	(.28)	(.083)
(15.14) §	.942	1.55	-16	.061					-2.48	1.15	-.45	.699
				(.022)					(.65)	(.64)	(.35)	(.166)

*Variables are defined in the text; all equations are estimated from data linear in original observations.

†The Durbin-Watson d statistic.

‡In the same equation with ΔP rather than P the dependent variable, the R^2 was .44; other results were the same as in (15.13).

§Estimated linear in original observations from 1926 to 1959, excluding 1942-45.

Y_5, is .09 in the short run and .3 in the long run (15.13).[4] The adjustment coefficient, 1 minus the coefficient of P_{t-1}, or .22, indicates that 10 years are required to make 90 percent of the total desired adjustment. Thus, a 10 percent increase in net income resulting from a favorable government program, increase in demand for farm products, or from other sources, is expected to increase land values only 1 percent in one or two years and 3 percent in about 10 years. Computed from the ratio of 1960 observations, the short-run and long-run elasticities of P with respect to farm size are .61 and 2.7 respectively. Obviously, changes in farm size are predicted to strongly influence land prices. Based on the strong upward trend in farm size and the coefficient of A in (15.13), the major source of real estate price increases in the past decade has been farm consolidation and associated scale economies from larger acreages.

Trends and Projections

Figure 15.1 depicts a U-shaped trend in land prices, the low being centered in the depression years of the 1930's. By 1960, land prices in relation to other prices in the economy (represented by the implicit price deflator of the Gross National Product) were equivalent to the early 1920's price and somewhat below the 1914 and 1915 prices. The upward trend since World War II was interrupted from 1952 to 1954, but has persisted strongly since 1954 despite less favorable farm incomes.

Land values are predicted from 1914 to 1960 and projected to 1965 by equation (15.13). The projection is based on a 6 percent increase in farm size (an extension of the past rate), and on 1955-59 average net farm income, Y_5, and opportunity returns, r. The positive influence of larger farms offsets the negative influence of trend, T, and (15.13) projects an 8 percent increase in land values from 1960 to 1965. The increase is less than indicated by a linear extension of the 1956-60 trend, but is consistent with an extension of the entire postwar trend.

DEMAND FOR BUILDING IMPROVEMENTS

We now turn to analysis of a particular component of farm real estate demand, namely, farm buildings. Estimates are made by single-equation least squares. The specification of investment or demand functions follows the general formulation in Chapter 10 and the specific applications in Chapters 11 and 12, with modifications as mentioned later.

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[4] These elasticity estimates are computed at 1960 values. Comparable results, .10 (short run) and .44 (long run) are found when computed at the 1914-60 means. Elasticities are more stable, of course, when computed at the means, but may not accurately reflect the current situation.

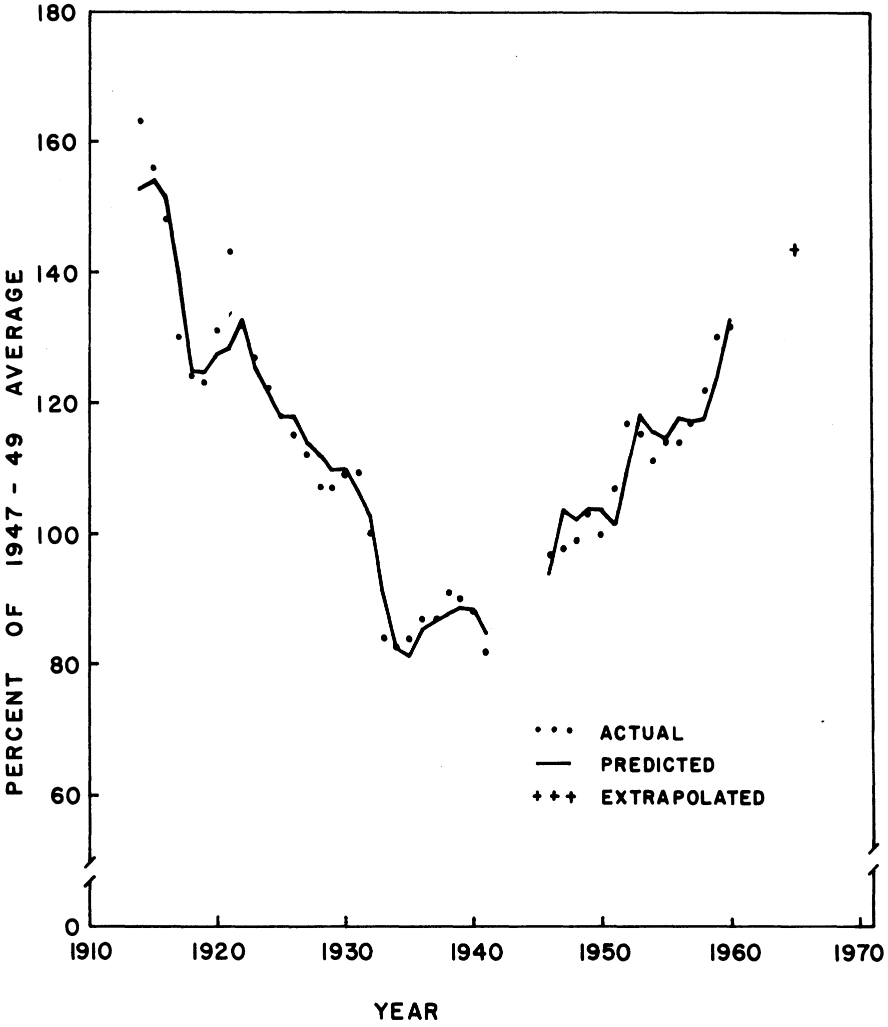

Figure 15.1. Trends in per acre real estate prices P from 1914 to 1960 (predicted and projected estimates from equation 15.13).

While virgin soil resources remained stable or declined because of cropping attrition and requirements for nonagricultural uses, the physical volume of total real estate increased 10 to 20 percent from 1926 to 1960. The increase is due largely to annual investment in building improvements, including fences, windmills and wells. In this study, the demand quantity (annual gross investment) of building materials is specified as a function of prices, beginning year stock of assets, equity,

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[5] See USDA. Agricultural Research Service. Changes in farm production and efficiency. Stat. Bul. 233. 1961; The balance sheet of agriculture. Agr. Information Bul. 247 (1961) and previous issues.

net farm income, farm size, the interest rate and slowly changing influences represented by time.[6] The variables not defined earlier but included in the least-squares equations are:

Q_{BIt} = the dependent variable, the national annual aggregate expenditures on building improvements measured in millions of 1947-49 dollars, includes fences, windmills, wells and dwellings not occupied by the farm operators, deflated by prices paid by farmers for building materials.

$(P_B/P_R)_t$ = the current year index of the ratio of the price of building materials to prices received by farmers for crops and livestock.

$(P_B/P_P)_{t-1}$ = the past year index of the ratio of the price of building materials to prices paid by farmers for items used in production, including interest, taxes and wage rates.

S_{Bt} = the stock of farm buildings, excluding operators' dwellings on farms at the beginning of the current year. The variable is constructed from bench mark (census year) estimates by Tostlebe and interpolating between these bench marks from USDA data on building expenditures and depreciation.[7] The variable is in millions of 1947-49 dollars.

Variables are U.S. data from 1926 to 1959 with price indices constructed with 1947-49 = 100. Only the years 1942 to 1945 are omitted since the supply of building materials was comparatively less restricted than the supply of machinery in 1946 and 1947. Equations were estimated in original values and logarithms, but the latter were less satisfactory. Hence, all equations in Table 15.3 are in original values.

Least-Squares Demand Equations

The five independent variables in equation (15.15), Table 15.3, explain 98 percent of the variance about the mean of Q_{BIt}. Coefficients of current price, the beginning year stock of productive assets, S_p, and the equity ratio, E, are highly significant. Inclusion of net farm income, Y_F, does not improve the equation and, since E reflects the influence of income, there is no need to include both variables in subsequent equations.

Equations (15.15) and (15.16) suggest that current and past values of P_B/P_R compete in explaining the demand quantity, the significance and magnitude of the coefficient falling for the past value of price. Although the equation is useful for predicting quantities when current

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[6] In addition to the demand or price function for real estate in the previous section, for further related analysis see the investment functions including buildings and other durables in Chapter 12, and the "supply" function (16.14) and discussion for farm land in Chapter 16.

[7] Tostlebe, Alvin S. Capital in Agriculture: Its Formation and Financing Since 1870. Princeton University Press. Princeton, N. J. 1957; USDA. Economic Research Service. The farm income situation. F15-183. 1961.

Table 15.3. Demand (Annual Gross Investment) Functions for Building Improvements, Q_{BI}, Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1945; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation, and Model†	R^2	d‡	Constant	P_B/P_R t	P_B/P_R t-1	P_B/P_P t-1	S_P t	E t-1	Y_F t-1	Y_{DF} t-1	T	Q_{BI} t-1	S_B t
(15.15) AB	.98	1.48	-895.83	-3.58 (.77)			18.69 (2.04)	59.22 (10.03)	-.0058 (.0100)		-5.05 (3.00)		
(15.16) B	.96	1.18	-923.30		-2.52 (.91)	.57 (3.56)	15.86 (4.01)	56.79 (10.68)			-4.02 (6.33)		
(15.17) B	.98	1.58	-990.70	-3.27 (.55)			19.04 (2.84)	54.65 (6.15)			-5.27 (2.94)		
(15.18) A	.94	1.77	-1631.95	-2.44 (1.14)			21.76 (4.44)		.0406 (.0096)		-.47 (4.45)		
(15.19) A	.97	1.45	-1659.44	-2.18 (.77)			21.68 (3.34)			.0482 (.0068)	-2.56 (3.30)		
(15.20) BF	.95	1.29	76.71	-2.35 (.75)				31.81 (10.99)			6.91 (2.81)	.39 (.11)	
(15.21) F	.94	1.53	-45.16	-2.30 (1.14)					.021 (.011)		9.70 (2.95)	.54 (.11)	
(15.22) BG	.97	1.42	-289.21	-3.24 (.58)				59.40 (6.56)			2.16 (2.40)		.060 (.010)
(15.23) G	.93	1.45	-828.20	-2.42 (1.25)					.043 (.011)		9.60 (3.39)		.063 (.016)

*The dependent variable, Q_{BI}, and the indicated independent variables are defined in the text and in Chapter 11. All equations are estimated linear in original data.

†Expectation and adjustment models are presented in Chapter 10.

‡The Durbin-Watson autocorrelation statistic d.

price is unavailable, it may result in some bias. We select to include only current price and to interpret the coefficient as the influence of both current and past prices. Equation (15.17) is equation (15.15) with the nonsignificant income variable omitted.

Equations (15.18) and (15.19) indicate the influence of past income on annual investment in building improvements. The coefficient of income increases from .041 to .048 as additional lagged values of income are included. The small size of the increment indicates that additional lags add little to the coefficient of income.

Some support for using an adjustment model to represent annual gross building investment is provided by (15.20) and (15.21). If expectations are specified as in (15.20), the adjustment apparently is very rapid — about 60 percent in the short run. The magnitude implies that the adjustment of annual purchases to desired levels occurs quickly, but does not indicate the speed of adjustment to the desired level of stock. Inclusion of lagged building stock in investment equation (15.22) improves the fit over (15.20) and allows approximate determination of the adjustment coefficient. The coefficient of lagged stock is positive and highly significant. Because it is the depreciation coefficient, h, less the adjustment coefficient, g, (see model G, Chapter 10), it indicates h exceeds g by .06. The exact depreciation rate is unknown but probably is considerably below the machinery depreciation rate. If the depreciation rate were .10, the adjustment rate would be .10 - .06 = .04, // a slow rate of adjustment indeed. Since the depreciation rate is low, a large number of years may pass before the equilibrium stock is reached, i.e. where $Q_{BI} = h S_B$.

The R^2's are somewhat lower and evidence of autocorrelation is higher for adjustment equations (15.20) and (15.22) than for the previous conventional equation (15.17). Two additional variables, cropland acres per farm and the short-term interest rate, were included in an equation with P_B/P_R, S_p, E and T. The coefficients of both added variables statistically were insignificant, and the equation is not included in Table 15.3.

Price and Income Elasticities of Demand

Computed from (15.17), the short-run elasticity of Q_{BI} with respect to $(P_B/P_R)_t$ is -.88. A sustained 1 percent increase in net income raises E by 1.57 percent according to equation (11.15). Using this relationship, the elasticity of Q_{BI} with respect to net income is 1.30. If a 1 percent increase in P_R/P_P increases net income 2 percent, the long-run elasticity of demand for Q_{BI} with respect to P_R is .88 (from $(P_M/P_R)_t$) plus 2.60 (from E), or 3.48. The elasticity is computed at the means of the variables for the 1926-59 period.

The result suggests that investment in real estate improvements is more responsive than investment in machinery to long-run price changes (see Chapter 11). Average annual investment in building improvements is a small proportion of building stock because depreciation (replacement requirement) is low. A large percentage change in annual investment is required if only a small increase in stock is desired. This structure perhaps explains the high elasticity of annual investment, particularly of annual investment in building improvements. Three or four years after a sustained 1 percent rise in prices received by farmers, annual investment is predicted to be more than 3 percent above the initial investment according to the above results. The depreciation rate and pattern of resource use is such that farmers may easily postpone investment in real estate improvements in unfavorable years without seriously reducing production. In favorable years the opportunity and need to expand investment in building improvements are great, partially because an improved financial situation permits purchase of building improvements (which are a major nondivisible expenditure in many instances) and also because a backlog of improvements may have developed during depressed periods.

Since annual investment tends to be a small proportion of the stock of buildings on farms, the elasticity with respect to S_B is much below the above estimates. The elasticity of S_B with respect to $(P_B / P_R)_t$ from equation (15.22) is only -.06. The intermediate-run elasticity (four or five years — after Q_{BI} has reached the desired level) of S_B with respect to P_R is .14, computed from the same equation. In spite of the elastic demand for Q_{BI}, a sustained 1 percent increase in P_R would increase building stocks only .14 percent in about four years based on the above estimate. If the adjustment coefficient is .04, the long-run elasticity of stock with respect to P_R is 3.5. The "long-run" is indeed long; more than 50 years are required to make 90 percent of the desired adjustment! Since the data are subject to large errors, the above results should be considered hypotheses for further testing, rather than as conclusive estimates.

Shifts in Demand

In 1959, annual gross investment in building improvements was 140 percent above the 1926 level. Equation (15.17) is used as a basis for estimating the sources of this increase in annual investment. Three possible sources are: (a) prices, P_B / P_R, (b) earnings and equity, E, and (c) structure, S_p and T. Because of the correlation between S_p and T, it is advisable to give the variables a joint interpretation. If these variables are given 1959 values, (15.17) predicts that demand would have been 155 percent greater than in 1926. Hence, some discrepancy exists between the actual and predicted changes in demand quantity. If price, P_B / P_R, has been at 1959 level in 1926, other things equal, the predicted demand quantity would have been 50 percent <u>less</u> than the actual demand in 1926 according to equation (15.17). If earnings and equity had been at the 1959 value in 1926, the predicted demand quantity would have been 100 percent above the 1926 level, other things being equal.

Because other input prices fell and because efficiency increased, farmers apparently improved their financial status sufficiently to increase purchases of building improvements by a sizeable amount. The influence of both price and equity would increase demand by a net of about 50 percent. Hence, the remaining portion of the total 140 percent increase remains to be explained by structural changes. Included in structural changes are a broad range of physical and technological influences. Examples are the large building investment needed to store and house increased inventories of livestock and feed.

Technological influence may not be as dramatic as for farm machinery. Nevertheless, changes in methods of storing feeds, handling dairy cattle, etc. have influenced demand for buildings. Influences tending to reduce farm numbers and replace labor with other resources also have created an impact on the investment in real estate improvements. Some of these influences reduce demand, others increase demand, but the net influence according to (15.17) is to shift demand to the right approximately 2 percent per year. Buildings themselves (e.g. loose housing as compared to stanchion arrangements for cows or silos for storing green cut forage as compared to barn storage) are substitutes for labor. We have not, however, established these relationships in this study.

Trends and Projections

Investment in building improvements fell appreciably in the depression years, then recovered in the late 1930's but not to the immediate predepression level (Figure 15.2). Annual investment in the postwar period was on a totally higher plane than during the prewar period. As the backlog of demand created by depreciated stocks, latent technology, rationing of material and improved farm financial situation was filled, the demand quantity declined in the mid 1950's. There is some evidence that the downward trend is slowing.

Equation (15.19) is used for prediction. Statistically it appears to be one of the better estimates, but some large ex post errors are apparent. Gross investment, Q_{BI}, is projected to 1965 from the equation assuming that farm income will be at the 1955-59 level. Prices of building improvements have not increased as much as machinery but, based on past trends, P_B / P_R is set 5 percent above the 1960 level. Using these values and S_p = 112.4 billion 1947-49 dollars from equation (12.23), the projected quantity of Q_{BI} is 7 percent above the predicted value for 1960. The projection suggests a reversal of the downward trend in purchases, but alternative assumptions about prices and incomes could yield different conclusions.

FARM NUMBERS

Changes in farm size and numbers have been closely identified with

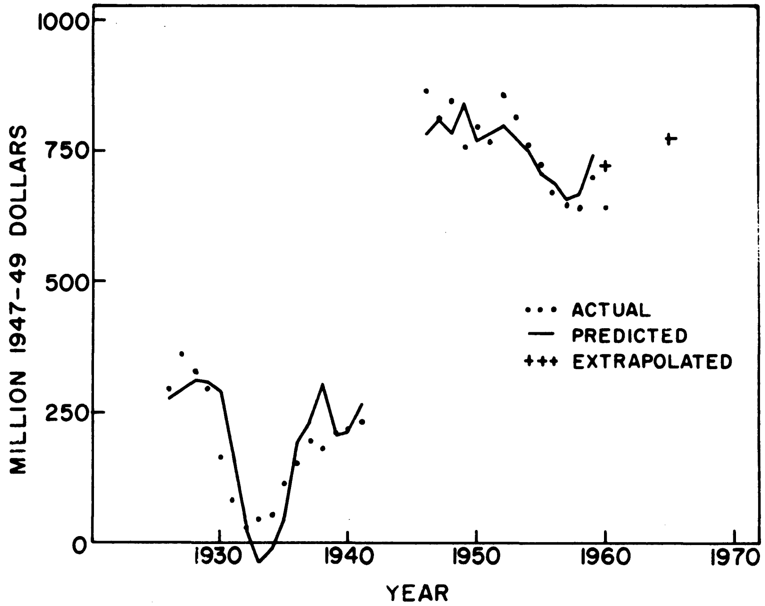

Figure 15.2. Trends in purchases of building improvements Q_{BI} from 1926 to 1960 (predicted and projected estimates from equation 15.19).

dynamic trends in the resource structure of agriculture. (Farm size and numbers essentially are equivalent concepts since total acreage has been quite fixed.) Farm numbers grew 6 percent from 1910 to 1935.[8] It is interesting to note that the peak year for farm numbers, 1935, also is a bench mark for the beginning of the major technological revolution in farm input structure. It was after 1935 that the major substitution of purchased for farm-produced inputs took place, and the rapid upward trend in the output-input index began. By 1960, farm numbers were much below the 1935 peak, and the decline is certain to continue.

In Chapters 3 and 11 we emphasized the interrelationships of farm size and machinery demand. It also may be stated that forces determining farm numbers and size of the family work force are almost equivalent. Since agriculture is geared to a family farm organization,

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[8] Economic report of the President. U.S. Government Printing Office. Washington, D.C. 1961. The "old" definition of a farm is used in this chapter because "new" data were not available when the analysis was made. The two measures, discussed more extensively in Chapter 18, are similar to 1940 but the "old" measure is greater after 1940. The measure in this study comprises all farms and hence includes many small acreages with a minor portion of income from farming. These small units more realistically might be classified as urban units. Unfortunately, annual data necessary for regression analysis are not now available for a more sensible breakdown of farm numbers into size and income classifications. It is hoped that although the measure used in this study tends to overestimate total farm numbers, it is a reasonable approximation of relative changes in numbers.

a reduction in family workers tends to be reflected in farm numbers. Government programs to increase family labor mobility are almost synonymous with programs to reduce farm numbers. These considerations suggest a specification of farm numbers function equivalent to that for family labor in Chapter 9. We review briefly that model (15.24) where N is farm numbers, Y_R is the ratio of factory to farm income per worker, U is the national unemployment rate and V is the critical rate of unemployment at which changes in Y_R no longer are effective in adjusting the work force between sectors, and mobility between the farm and nonfarm sector ceases.

$$(15.24) \qquad N_t = a - b[Y_R(1 - U/V)]_{t-1} - c\, S_{Mt}$$

S_M is the stock of farm machinery on January 1. Multiplying the bracketed term by b, the model (15.25) is suitable for least-squares estimation.

$$(15.25) \qquad N_t = a - b\, Y_{Rt-1} + \frac{b}{V}(U\, Y_R)_{t-1} - c\, S_{Mt}$$

An estimate of V is found by dividing the coefficient of Y_R by the coefficient of U Y_R. We may interpret the above model as explaining farm numbers by the "pull" and "push" hypotheses. More favorable nonfarm incomes indicated by Y_R "pull" family workers to nonfarm employment, subject to the restraints of the national unemployment, U. Higher stocks of machinery, S_M, tend to "push" workers from agriculture and reduce farm numbers by decreasing labor demand and creating pressures for worker exodus and farm consolidation. The logic of other variables specified in the farm numbers functions is discussed in Chapter 9.

The variables are defined explicitly as:

N_t = the dependent variable, the average number of all U.S. farms in the current year, expressed in thousands.

Y_{Rt-1} = the past year index of the ratio of average annual wages per employed factory worker to the net farm income per family worker in agriculture, 1947-49 = 100.

U_{t-1} = the proportion of the total national work force unemployed in the past year.

S_{Mt} = the stock of all machinery (40 percent of auto stock) on farms January 1 of the current year.

E_{t-1} = the past year ratio of owners' equity to all farm debts.

G_t = an index of current government programs.

The above variables and time, T, extend from 1926 to 1959, excluding the war years 1942 to 1945. All equations are estimated only in original observations.

Table 15.4. Farm Number Functions Estimated by Least Squares With U.S. Data From 1926 to 1959, Without 1942-45; Including Coefficients, Standard Errors (in Parentheses) and Related Statistics*

Equation	R^2	d†	Constant	Y_R t	Y_R t-1	UY_R t	UY_R t-1	E t-1	S_M t	G t	T	N t-1
(15.26)	.963	.89	9052		-6.59 (1.52)		25.81 (3.43)	22.68 (17.13)			-62.35 (4.47)	
(15.27)	.966	.66	8708		-5.24 (1.79)		19.39 (5.02)		-.052 (.028)		-45.32 (7.21)	
(15.28)	.965	.96	9031		-6.65 (1.41)		26.20 (3.32)			6.24 (3.60)	-59.01 (2.85)	
(15.29)	.961	.90	9131		-7.54 (1.36)		26.48 (3.44)				-57.77 (2.86)	
(15.30)	.965	1.05	9328	-9.02 (1.26)		28.02 (3.22)					-57.81 (2.75)	
(15.31)	.996	2.11	1851		-1.39 (.626)		5.71 (1.85)				-14.05 (3.19)	.801 (.056)
(15.32)	.996	2.22	2136	-2.16 (.67)		6.97 (1.92)					-15.48 (3.26)	.780 (.057)

†The Durbin-Watson statistic d.

Farm Numbers Estimated by Least Squares

Equations (15.26) to (15.28), Table 15.4, illustrate the statistical influence of E, S_M and G on farm numbers. The coefficients possess the anticipated signs, but each is less than twice the standard errors. When these variables are included in equations along with the lagged dependent variable, the coefficients are much less significant and hence the variables are not included in the last two equations of Table 15.4. The influences represented by the excluded variables are often confounded with other variables, and their total influence perhaps can only be represented by time, T.

The coefficients of the three independent variables in equations (15.29) and (15.30) are highly significant, but the hypothesis of zero autocorrelation is rejected. Adjustment equations (15.31) and (15.32), formed by adding N_{t-1} to the preceding equations, seem appropriate not only on a priori grounds, but also because of favorable statistical properties. Autocorrelation is not evident, the R^2 is increased and all coefficients are significant in the latter equations. Comparisons of coefficients in the conventional and adjustment equations suggest that the coefficients in (15.26) to (15.30) are long run rather than short run. That is, the long-run coefficients in (15.31) and (15.32), found by dividing the short-run coefficients by the adjustment rate .2, are somewhat comparable to the coefficients in the conventional equations.

Equations including current rather than past year income and unemployment variables give slightly larger and more significant coefficients. Collinearities preclude isolation of the separate influences of current and past year income, Y_R, on N; therefore, coefficients of either are called "short run." Combining the current unemployment variable with past income (U_t Y_{Rt-1}) in an equation similar to (15.31), and other "refinements" did not improve results; hence, these modified equations are not included in Table 15.4.

Table 15.5. Elasticities of Farm Numbers, N, With Respect to the Factory/Farm Worker Income Ratio, Y_R , Computed at the 1926-59 Means From Equation (15.31)*

Unemployment (percent) †	Short Run (1-2 years)	Long Run (about 10 years)
0	-.034	-.171
5	-.027	-.136
10	-.020	-.101
15	-.013	-.066
20	-.006	-.030
25	.001	.005

*The elasticities with respect to nonfarm wages have the signs indicated; with respect to per worker, farm incomes are opposite the signs indicated.

†The 1960 unemployment rate was 6 percent, and the 1946-59 average was 4 percent.

Elasticities With Respect to Income

The long-run influence of machinery investment and other factors embodied in the time variable annually reduce farm numbers by 70,000 according to (15.32). Since farm numbers were 4.5 million (old definition) in 1960, the reduction that year would have represented 1.5 percent of all farms.

The influence of wage and employment structure on farm numbers is illustrated in Table 15.5. The elasticity of N with respect to Y_R is low in all cases but reaches zero when U is 24 percent. Under the

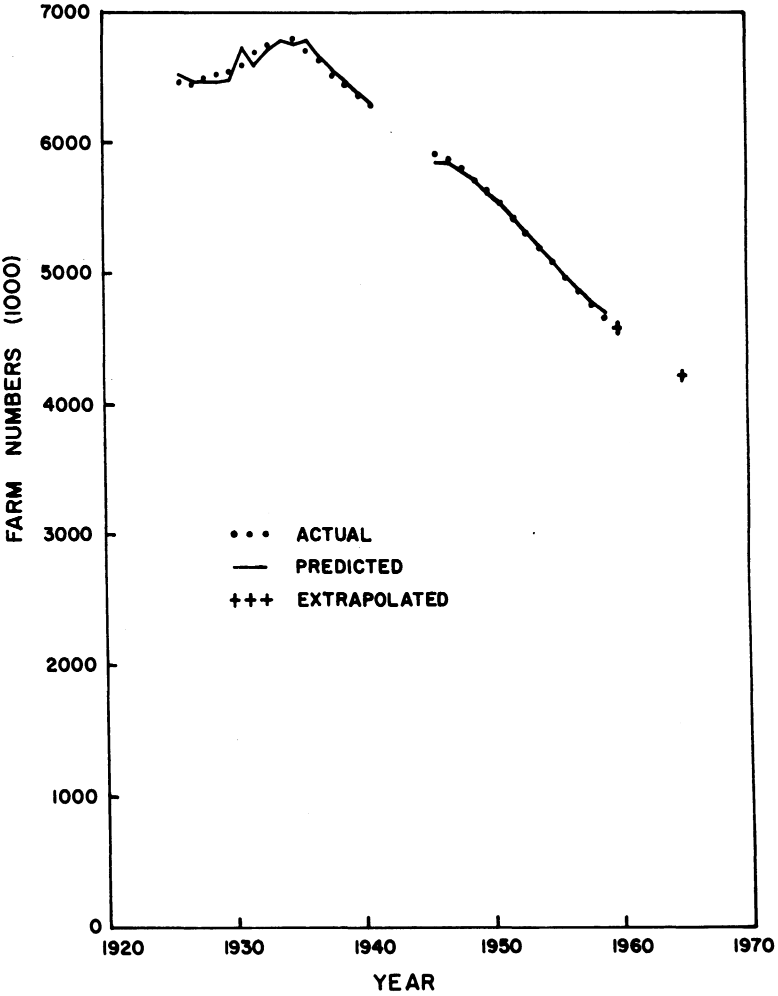

Figure 15.3. Trends in farm numbers N from 1926 to 1960 (predicted and projected estimates from equation 15.31).

most favorable employment conditions, a sustained 10 percent increase in nonfarm income reduces farm numbers .3 percent in one or two years and 2 percent in roughly 10 years. The impact of higher unemployment on labor mobility and farm numbers becomes greater as the rate of unemployment rises. For example, a drop in unemployment from 20 to 15 percent increases the elasticity over 100 percent, but a drop from 10 to 5 percent increases the elasticity only 35 percent.

Trends and Projections

The stable downward trend (Figure 15.3) in farm numbers since 1936 explains why some R^2's were more than .99 in Table 15.4. A simple linear function would fit the data very well since that date. Equation (15.31) predicted 4.6 million farms in 1960; the actual number was 4.5 million. Projecting farm numbers to 1965 from average 1955-59 income and employment data, equation (15.31) indicates 360 thousand fewer farms than in 1960. The projection, 4.2 million farms, is nearly 8 percent below the 1960 number.[9]

Again, inferences are subject to the data limitations. The uniform trends in Figure 15.3 to some extent arise from insufficient yearly data; e.g., some of the published annual estimates may reflect a simple interpolation between bench mark census years. We hope, nevertheless, that the income elasticities have sufficient validity to be of some use in converting income projections such as those made in the following chapter to a per farm basis.

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[9] The latest estimate of 1960 farm numbers is 3.95 million, or .6 million less than the old estimate, 4.54 million, used above. Projected 1965 numbers would also have to be adjusted accordingly. The number projected to 1965 would be considerably less under the new definition, because it depicts a more sharply falling trend after the war.

16.

Aggregate Commodity Supply Function and Income Adjustments

THE INCOME PROBLEMS of agriculture arise mainly from the nature of product supply and resource demand functions and their short-run and long-run elasticities. We have illustrated, within the static framework of Chapters 2 and 6, that commodity supply response depends on the productivity of resources and their sensitivity to price changes. Several approaches are possible for estimating aggregate supply response and its income effects. Optimally, we would desire to incorporate factor demand and product supply into a single, complete simultaneous system and, from knowledge of the predetermined policy variables, predict the organization and income of agriculture at various points in the future under alternative policies.

The attempts to estimate such an interdependent model in this study have not been very successful. In this chapter, however, we do attempt to predict the results of a restricted set of policy alternatives from single-equation least-squares demand and supply functions. The commodity supply elasticity is determined by direct estimates and also from the production function in Chapter 4 and the input demand functions in Chapters 12 and 13. The estimates of commodity supply and policy implications for various time periods have mainly methodological importance but, it is hoped, also have predictive value.

Greater knowledge of the aggregate agricultural supply function is essential for informed national policy. Policy debate has revolved around the nature of the supply function and its elasticity. At one extreme has been the proposition that the supply function is backward sloping and has a negative elasticity because farmers increase output to meet fixed expenses when commodity prices fall. Under this condition, a reduction in support prices or return to free markets would cause output to increase, thus aggravating the problem of depressed income. At another extreme is the proposition that the supply elasticity is sufficiently great to bring needed resource, output and income adjustments in a short time. Under this condition, a drop in support price or return to the free market would cause a relatively large decrease in output with only a small decrease in product price or income.

A more prevalent view is that the commodity supply curve is positively sloped but that supply is not sufficiently elastic even in the long run to cope with the "nonprice" influences shifting supply to the right.

These supply shifters are innovations which increase the quantities and productivities of resources, raising output and lowering returns to conventional resources. Quantitative measures of the supply elasticity and supply shifters can lead to more efficient public selection of farm programs.

In this chapter we attempt to measure both the time and size dimensions of aggregate supply response to price in agriculture. While still quantitatively imperfect, it is hoped that the analysis can help resolve some of the conflicting concepts about the nature of product supply in agriculture. The aggregate supply response depends fundamentally on the resource flexibility in agriculture. Hence, it is logical for this study emphasizing resources to turn its emphasis to an explanation of aggregate commodity supply. The procedure is to base estimates of supply indirectly on previously estimated input demand functions, and directly on separate estimates of the supply function. The U.S. farm output of crops and livestock is estimated by least squares. In addition, the sales of agricultural products (current output less changes in farm inventories) are estimated by least squares and by limited information simultaneous techniques.

Some excellent studies of supply response for several individual farm commodities have been made.[1] Unfortunately these studies provide but little basis for inferences about aggregate supply response. Opportunities for substituting one commodity for another are great because farm resources are flexible among commodities; i.e., the same resources can be used to produce any one of several products. Perhaps many inferences about aggregate supply response have been based on observations of the relatively large supply elasticities for individual commodities.

Several attempts have been made to determine the nature of aggregate supply response and resource flexibility in agriculture.[2] In general, these "less quantitative studies" lead to the conclusion that the supply elasticity in response to falling product prices is low because there are few short-run alternative uses outside agriculture for farm resources.

Griliches has made recent quantitative estimates of the aggregate output function, his most successful equations expressing output as a function of relative price, weather, trend and lagged output.[3] The price

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[1] For a bibliography and brief review of supply studies see: Knight, Dale A. Evaluation of time series as data for estimating supply parameters. In Heady, Earl O., Baker, C. B., Diesslin, Howard G., Kehrberg, Earl, and Staniforth, Sydney. Agricultural Supply Functions. pp. 74-104. Iowa State University Press. Ames. 1961.

[2] Cf. Heady, Earl O. The supply of U.S. farm products under conditions of full employment. American Economic Review, Papers and Proceedings. 45:228-38. 1958. Johnson, D. Gale. The nature of the supply function for agricultural products. American Economic Review. 40:722-29. 1951. Johnson, Glenn L. Supply functions - some facts and notions. In Heady, Earl O., Diesslin, Howard G., Jensen, Harald R., and Johnson, Glenn L. (eds.) Agricultural Adjustment Problems in a Growing Economy. Iowa State University Press. Ames. 1958.

[3] Griliches, Zvi. The aggregate U.S. farm supply function. Journal of Farm Economics. 42:282-93. 1960.

variable was specified as the ratio of prices received by farmers to prices paid by farmers for items used in production, including interest, taxes and wage rates on March 15 of the current year. Inclusion of relative price in the previous year, prices received deflated by prices paid for items used in production only (excluding interest, taxes and wage rates), farm wage rates, farm income, nonfarm income, unemployment in the nonfarm economy, land prices and lagged weather did not improve the least-squares equation. Inclusion of lagged output in the output function reduced the extent of autocorrelation in the residuals, but the coefficient of the lagged variable was highly sensitive to the specification of the time period and variables. Griliches' equations suggest that the short-run supply function is shifting to the right at the rate of 1.5 to 1.7 percent per year, with the shift accelerating in recent years.

SPECIFICATION AND ESTIMATION OF THE AGGREGATE SUPPLY FUNCTION FOR FARM PRODUCTS

Two measures of the agricultural supply quantity are used in this chapter. The first, agricultural output, O, is the production of feed and livestock during the current year, excluding inter-farm sales and crops fed to livestock. It represents the current product of agricultural resources available for eventual human consumption. The concept is considered the most relevant long-run measure of supply quantity since it is closely tied with the resource structure and is not influenced by fluctuations of nonproductive farm inventories.

The second measure of the supply quantity, Q_S, is output, O, less changes in farm inventories of livestock and feed. It measures the quantity of farm commodities entering the marketing system in a given year and is useful in explaining current farm prices. It can be a biased indicator of production because of inventory changes. Since there is no production period for farm inventories, decisions regarding the level of inventories can be based on current supply and demand for farm inputs and products. For this reason, the supply concept Q_S which includes inventory changes is estimated as part of an interdependent system of demand equations for farm products and demand and supply equations for farm inputs. The supply concept O is analyzed only by ordinary least squares. The assumption for the latter is that current output is predetermined by past prices, P_R/P_P, durable input levels, S_p, government programs, G, weather, W, and trend, T. The output supply function is

$$O_t = f((P_R/P_P)_{t-1}, S_{pt}, G_t, W_t, T). \tag{16.1}$$

A technology or productivity variable, T', is the aggregate measure of output per unit of input in agriculture. It is composed of a long-term trend (approximately T) determined by efficiency (management, specialization, etc.) and technology (changes in the true physical production function). Short-term fluctuations in the productivity variable T' are determined mainly by the weather. Thus, in a second formulation of (16.1), T' is substituted for W and T. Given the level of inputs and T', the output also is known. It follows that the variables P_R/P_P, S_p and G primarily are concerned with predicting the aggregate input level in agriculture. But with the beginning year stock of productive assets, S_p, in the function, only operating inputs, labor and current inputs of durables are left to be determined by P_R/P_P and G.

Since durable assets and labor have little short-run effect on output, the price variable primarily reflects the short-run influence of operating inputs. In one sense, equation (16.1) may be regarded as a dynamic agricultural production function with price substituted for the quantity of operating inputs. The supply equation is extremely simplified and is short run, but can be made long run by substituting an investment function for S_p from Chapter 12 into the supply function. The supply function is specified in a highly simplified form to avoid statistical complications. But from knowledge of the input structure (investment function) much can be learned about the nature of supply elasticity in agriculture.

There are several reasons for supposing that short-run supply elasticity might have increased in agriculture. As the proportion of purchased, flexible, operating inputs in the resource mix increases, opportunities become greater for adjusting output to price changes. More emphasis on cash, nonfarm produced resources makes farmers' short-run net returns more sensitive to price changes. Switching from slowly reproducible farm produced resources to nonfarm inputs with high production elasticity and input supply elasticity, is expected to increase the farm output supply elasticity. More education and emphasis on management increases farmers' awareness of the gains from optimum adjustments to price changes. Improved outlook information also might be expected to increase the supply elasticity.

There are, of course, forces which might depress supply elasticity. The gradual awareness by farmers of the cyclical nature of agricultural production (commodity cycles) may tend to reduce the short-run supply elasticity. Increased application of inputs, given the technology, moves agriculture farther up the aggregate output-input transformation curve, lowering production and supply elasticities. Finally, improved technology and increasing proportions of flexible inputs may raise the marginal response to a price change. But because the elasticity is computed at a larger output for any given price, the magnitude of the elasticity may remain unchanged or may decline. The supply elasticity is $(dQ/dP)(P/Q)$, and if the decline in the ratio P/Q is more rapid because of improved technology than is the increase in marginal response dQ/dP, the supply elasticity will decline.

To determine if the supply response has increased, two methods are used. The first is to include separate price variables for (a) 1926 to 1941 and (b) 1946 to 1959 in a supply equation including other variables for the 1926 to 1959 period. If the estimated coefficients of the separate price variables are significantly different, the null hypothesis that the supply response or elasticity has not changed is rejected. The influences other than price are assumed to be homogeneous over the entire period. Some of these influences (e.g., S_p, T and T′) are quite highly correlated, especially over short periods. It is not considered feasible to estimate the individual effects of these variables in equations including less than 30 observations.

The second method for determining supply response through time is to include an interaction variable of price with time.[4] The interaction variable allows a gradual increase in the price coefficient through time, rather than a single shift as in the first method. The interaction of price with time or technology may be regarded broadly as a "real price." The fact that technology has improved leads to greater production for a given price.[5]

The variables in the supply functions are:

O = a dependent variable, measured as the production of crops and livestock on U.S. farms during the current calendar year for eventual human consumption; corrected for intermediate use of resources such as farm produced seed, feed and livestock, and farm produced power. It is expressed in millions of 1947-49 dollars.

Q_S = a dependent variable, measured as the quantity of farm products supplied to the markets during the current year. It includes current farm output and quantities sold from farm inventories of feed and livestock.

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[4] The least-squares equation for output estimated as a function of price, P, time, T, and other variables, X, is

$$O = a + b\,P + c\,(TP) + d\,X. \qquad \text{(a)}$$

After the form (a) is estimated, the equation may be written

$$O = a + (b + cT)\,P + d\,X. \qquad \text{(b)}$$

The coefficient (elasticity if O and P are in logarithms) of O with respect to P is b + cT and may either increase, decrease or remain constant through time, depending on the sign of c. If c is significant, the hypothesis is rejected that the coefficient of P has remained stable (has not changed at a linear rate) through time.

[5] The meaning of "real price" may be illustrated by a simple example. In competitive equilibrium with constant returns to scale, the input cost, XP_P, equals output returns, OP_R.

$$OP_R = XP_P\,. \qquad \text{(a)}$$

The expression may be written

$$\frac{O}{X} = \frac{P_P}{P_R}\,. \qquad \text{(b)}$$

It is apparent that a change in the output-input or productivity ratio $O/X = T'$ will lead to a new long-run equilibrium at a lower relative product price, commensurate with the increased efficiency. The output forthcoming for any price $O = f(P_R/P_P)$ approximately can be corrected for structural change by multiplying the price ratio by T′, thus

$$O = f\left(\frac{P_R}{P_P}\,T'\right).$$

$(P_R/P_P)_{t-1}$ = the past year index of the ratio of prices received by farmers for crops and livestock to prices paid by farmers for items used in production, including interest, taxes and wage rates. When the price variable is specified as 1926-41 or 1946-59, it is the actual observations in the period indicated but it has zero value for other years of the over-all period.

S_{pt} = the beginning year stock of productive farm assets, including real estate, machinery, feed, livestock and cash held for productive purposes in billions of 1947-49 dollars.

W_t = Stalling's weather index with 1958 and 1959 observations computed as deviations from a linear yield trend.

T' = an index of productivity, the ratio of farm output to all farm inputs in the current year. The variable is expressed as a percent of the 1947-49 average ratio of output to input.

T = time, an index composed of the last two digits of the current year.

The variables, measured as national aggregates, extend from 1926 to 1959, excluding 1942 through 1945. Modifications discussed earlier are introduced to allow estimation of the parameters of price for segments of the entire period.

Supply (Output) Function Estimated by Least Squares

Table 16.1 includes the coefficients, standard errors and other least-squares statistics for farm output, O, as a function of prices, productive assets and other variables. The equations are all estimated in linear form of original observations. The coefficient of each variable is highly significant and displays the anticipated sign in equation (16.2). A quantified measure of the direct influence of government policies, G, was included with the variables in (16.2) but the coefficient of G was not significant. The coefficient of current price variable $(P_R/P_P)_t$, included with the variables in equation (16.2); also was not significant. Thus statistics for $(P_R/P_P)_t$ and G are not included in Table 16.1. The productivity index T' is substituted for T and W in equation (16.3). Together, the three variables $(P_R/P_P)_{t-1}$, S_{pt} and T' explain 99 percent of the variation in O, and all coefficients are highly significant. The magnitude of the coefficient of S_p is considerably less, of price slightly less, than the comparable coefficients in equation (16.2). The degree of autocorrelation, indicated by d, is greater in (16.2) than in (16.3).

As one method of determining if the marginal response to price has changed, (16.2) and (16.3) are estimated with P_R/P_P divided into two subperiods. The resulting equations (16.4) and (16.5) provide conflicting estimates of the direction of change in the coefficient of price

Table 16.1. Supply Functions for Aggregate Farm Output, O, Estimated by Least Squares With U.S. Data From 1926 to 1959, Omitting 1942 to 1945; Coefficients, Standard Errors (in Parentheses) and Related Statistics Are Included*

Equation†	R^2	d‡	Constant	P_R/P_P t-1 (1926-59)	P_R/P_P t-1 (1926-41)	P_R/P_P t-1 (1946-59)	TP_R/P_P t-1 (1926-59)	S_P t	W t	T	T′	O t-1
(16.2)	.980	1.80	-19174	35.22				261.35	87.57	211.69		
				(12.58)				(44.20)	(13.61)	(38.16)		
(16.3)	.990	.94	-12710	31.95				123.17			258.99	
				(8.59)				(32.33)			(19.59)	
(16.4)	.980	1.79	-17929		28.43	32.81		254.68	88.71	202.78		
					(20.44)	(13.99)		(47.63)	(14.09)	(44.04)		
(16.5)	.990	.97	-13712		36.15	33.49		129.62			260.99	
					(13.13)	(9.43)		(36.09)			(20.45)	
(16.6)	.991	.94	-15109	49.48			-.420	132.29			276.06	
				(16.99)			(.352)	(32.98)			(24.14)	
(16.7)	.989	1.44	-7802		30.12	25.60					270.69	.223
					(13.53)	(9.59)					(21.17)	(.077)

*Composition of the dependent variable, O, and of the indicated independent variables is discussed in the text.

†All equations are estimated linear in original values.

‡The Durbin-Watson autocorrelation statistic d.

between the prewar and postwar periods. The null hypothesis that the coefficients are equal was not tested statistically but undoubtedly would not be rejected. Since the estimates of Table 16.1 are for original values only, they indicate the marginal response to price and not directly the elasticities. The elasticities computed for equations (16.4) and (16.5) are discussed later.

The variables in equation (16.6) allow the coefficient of price to change uniformly through time. The coefficient of TP_R/P_P is not significant for our specification, therefore we have no basis for rejecting the hypothesis that the coefficient of price has remained stable through time.

The coefficient of lagged output, O_{t-1}, was insignificant when included with the variables in (16.2) and (16.3). The interpretation is that there is no long-run adjustment, given the stock of productive assets and technology. An alternative formulation is that in the long run P_R/P_P determines S_p; this effect may be allowed by substituting lagged output for S_p in the supply function. The resulting equation (16.7) provides estimates of short-run price coefficients similar to those in (16.4) and (16.5). The estimated adjustment coefficient, .78, indicates that the movement, on aggregate resource adjustment, to the desired or equilibrium output is rapid. The adjustment of some resources such as operating inputs takes place in a short period according to earlier results, but adjustments of durable capital and labor were found to take place over a number of years. For this reason, we reject the distributed lag equation (16.7) as a suitable expression of long-run agricultural supply.

Elasticity of Supply (Output)

On the basis of the equations in Table 16.1 and the derived demand equations for agricultural inputs, the elasticity of farm output may be estimated over various periods of time. We first consider the short-run elasticity. The elasticity of output, O, with respect to $(P_R/P_P)_{t-1}$ computed from equations (16.2) and (16.3) at the 1926-59 mean is .12 and .10, respectively. The elasticities computed for the 1926-41 and 1946-59 subperiods at the means of these periods are both .10 according to equation (16.4). Computed from equation (16.5), the elasticity for the first subperiod is .13 and for the last subperiod is .10. These results do not provide support for the hypothesis that the aggregate short-run supply elasticity has increased between the two periods. They indicate a low supply elasticity for both earlier and later periods. Or stated otherwise, to the extent that income problems of agriculture stem from low short-run supply elasticity, the situation has not improved in recent decades.

The output elasticity may also be computed as the sum of the elasticities of demand for input X_i with respect to output price P_R multiplied by the respective elasticities of production with respect to X_i. (See equation (3.45).) This relationship is dynamic when we consider the input demand elasticities over various periods of time. Results in Chapter 14 indicate a demand elasticity for operating inputs with respect to product price of approximately .3 in the short run. The elasticity of durable assets, S_p, with respect to P_R was estimated to be approximately .04 in the short run in Chapter 12. If we are to accept the aggregate production functions in Chapter 4 and the demand functions in Chapters 12 and 14, we can make some further checks on output elasticity. From Chapter 4, the production elasticity for operating inputs is approximately .3, for durable capital is .6.[6] Hence, using the demand elasticities from Chapters 12 and 14 and the production elasticities from Chapter 4, the short-run elasticity of output is (.3) (.3) = .09 plus (.04) (.6) = .024, a total output elasticity of .114. This estimated short-run elasticity agrees closely with the estimates of equations (16.2) and (16.3). It must be noted, however, that the reliability of the production elasticity estimates is questionable. (Since the labor production elasticity is highly nonsignificant and probably is zero, it was not used in deriving supply elasticity.) Griliches' estimates of the short-run supply elasticity agree very closely with the above results.[7] Based on the foregoing statements, we conclude that a 10 percent drop in prices received by farmers likely has reduced aggregate farm output by approximately 1 percent in two years.

The intermediate- and long-run elasticity of farm output is found by substituting the investment function for S_p from Chapter 12 into the supply equation. Equations (16.2) and (16.3) indicate that a 1 percent decrease in S_p reduces farm output .95 and .46 percent, respectively. These estimates essentially are production elasticities, and the estimate .95 from equation (16.2) appears too large. An average of the estimates from equations (16.2) and (16.3), .7, agrees quite closely with the production elasticity based on the production functions in Chapter 4. Hence, the intermediate-run elasticities are based on equation (16.3) and on the average of the estimates from equations (16.2) and (16.3). The intermediate-run (approximately four years) elasticity of S_p with respect to P_R was found to be .07 in Chapter 12. The supply elasticity therefore is increased (.07) (.46) = .03 (equation 16.3) or (.07) (.7) = .05 (average of equations (16.2) and (16.3)) by the intermediate-run effect of S_p. The <u>total</u> intermediate-run elasticity is the short-run elasticity .10 plus the additional intermediate component due to S_p and is .13 to .15.

We also can use the demand elasticities derived in Chapters 10-14

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[6] While S_p is not included directly in the production function of Chapter 4, the production elasticity of this variable is taken as the sum of that for real estate, machinery and livestock inputs. Since the elasticity for real estate is .4 or .5 and the elasticity for other durable assets is considered to be .1 or .2, the total is approximately .6. Because the production elasticity of Q_O is measured most accurately in Chapter 4 and the elasticity of S_p is approximately one minus this estimate, the elasticity of output with respect to S_p perhaps is more accurate than with respect to any one component of S_p (e.g. machinery, livestock and feed inventories, real estate, etc.).

[7] Griliches, <u>op</u>. <u>cit</u>.

and the production elasticities in Chapter 4 to estimate some intermediate-run supply elasticities. These should be looked upon largely as illustrations because of the uncertain validity of the estimated production elasticities. The intermediate-run supply elasticity is the component due to S_p or (.07) (.06) = .04, plus the component due to operating inputs, .09. The sum is .13 for the intermediate-run elasticity, with the component due to labor omitted since it is nearly zero. The operating input component also is omitted here because the response of these inputs to P_R (except through S_p) is zero after two years, according to the estimates in Chapter 13. It seems reasonable to conclude that the intermediate-run elasticity of output with respect to P_R is not much greater than .15. A sustained fall of 10 percent in prices received by farmers is expected to reduce aggregate output about 1.5 percent in four years.

The long-run elasticity of output with respect to prices received by farmers appears to be much greater. Based on the analysis in Chapter 12, the elasticity of S_p with respect to P_R is nearly unitary in the long run. Equation (16.3) indicates that the elasticity of O with respect to S_p is approximately .46; hence, the elasticity of output with respect to S_p can be estimated at (1.0) (.46), or .46. If the short-run elasticity is added, the <u>total</u> long-run elasticity with respect to P_R is between .5 and .6.[8] Based on the foregoing, a sustained 10 percent decrease in prices received by farmers might reduce farm output from 5 to 7 percent in the long run. The long run is more than 20 years away if the coefficient of adjustment for S_p is .10. It must be remembered that the computation of supply elasticities is a partial analysis, sizeable changes in output being possible due to other sources such as changes in technology. Thus, the supply elasticity of .5 to .6 may not be meaningful as a basis for projections because structural changes distort the long-term price influences. But the long-run supply elasticity is a useful indicator of the potential responsiveness of output to prices. The foregoing estimates of supply elasticity are subject to all the limitations of the data, techniques and models employed in this analysis, of course.

Shifts in Aggregate Supply (Output)

Farm output O increased over 70 percent from 1926 to 1959, or at an average compound rate of 1.71 percent per year. (See Figure 16.1.) The variables in equation (16.3) provide the basis for ascertaining two general sources of the increased output: (a) changes in the input level reflected in the variables P_R / P_P and S_p and (b) changes in the output with a given level of conventional inputs indicated by the variable T′. The output-input or productivity index indicates the change in output due to weather, management and efficiency. If T′ is at the 1959 value and

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[8] The derived long-run supply elasticity computed from the production functions in Chapter 4 and the demand equations in Chapters 10 to 14 is (.3) (.3) = .09 (operating inputs) plus (1.0) (.6) = .6 (productive assets), or a total of .7.

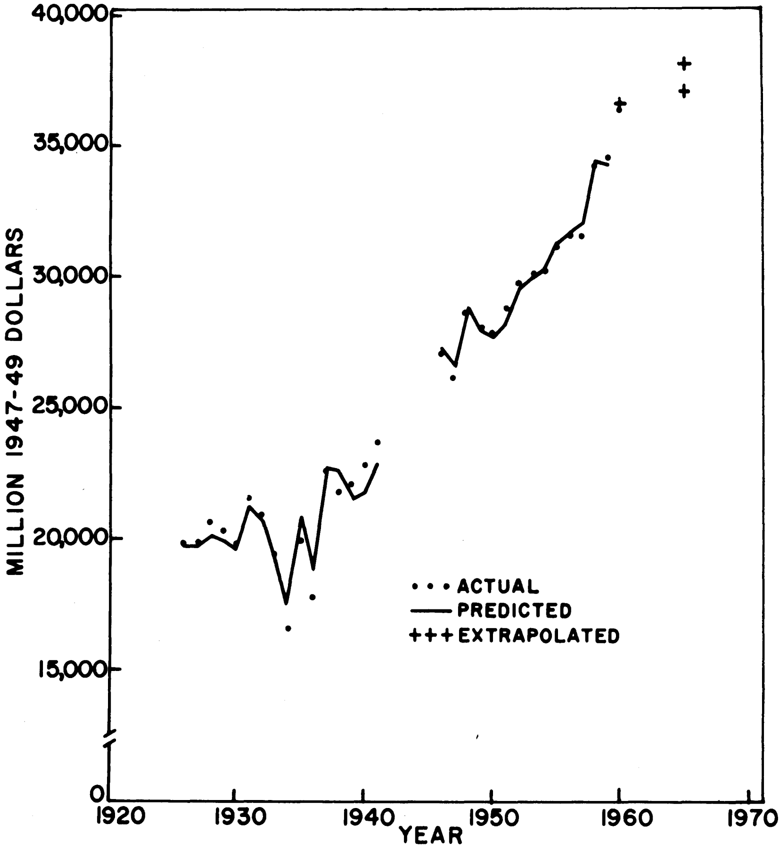

Figure 16.1. Trends in aggregate farm output O from 1926 to 1960 (predictions and projections from equation 16.3).

other variables are at the 1926 value, equation (16.3) indicates output would have been 61 percent greater than the predicted 1926 output. Of course we could predict the quantity directly. The productivity index increased from 75 in 1926 to 121 in 1959, a 61 percent increase. The equivalent results give credence to the estimational procedure. The implication is that the value aggregate of farm resource could have remained stable and farm output would have increased 61 percent or 1.45 percent per year due to changes in productivity.

Equation (16.3) suggests that output increased 16 percent from 1926 to 1959 due to investment in agriculture as indicated by S_p. If (16.2) were used to compute the portion of increased output imputed to S_p, the estimate would be higher. Equation (16.3) further indicates that output would have been 2 percent lower in 1926 if relative prices had been at 1959 levels, ceteris paribus. To summarize, the major portion of the increase in output from 1926 to 1959 is associated with increased productivity. Short-run price influences have had less relative effect on the secular increase in output.

It must be emphasized that the foregoing breakdown of sources of rising output primarily explain the aggregate resource movements in response to the direct price, P_R/P_P. It is not surprising that aggregate inputs increased only 6 percent from 1926 to 1959 since P_R/P_P decreased 12 percent. Ascribing the major portion of increased output to productivity hides many important resource substitutions. These substitutions are prompted by relative input prices (not reflected in the single-price variable P_R/P_P) and by improvements in relative quality, convenience and productivity of resources. To a considerable extent the rise in productivity associated with T' is caused by the substitution of more productive fertilizer, protein feed, hybrid seed, etc., for less productive farm produced labor, power, seed and feed. Resource movements and substitutions are a more important facet of rising productivity and output than the above discussion might lead one to believe. Substitutions are the result of long-run adjustments to both changing productivity and price ratios. More fundamental models to explain increasing output would include individual input price ratios in the supply equation. Problems of multicollinearity cause this degree of refinement to be impractical for our study, however.

Trends and Projections

Figure 16.1 illustrates graphically some of the economic and technological interpretations discussed earlier. The influence of weather is apparent from the low output in 1934 and 1936 and the high output in 1958, 1959 and 1960. If data for these years were corrected for weather, the trend in farm output would be considerably more uniform and would dramatize the short-run unresponsiveness of output to economic stimuli. The insensitivity of short-run supply response to price changes is demonstrated by the low response to falling prices in the early 1930's and in recent years. Despite the fact that relative farm prices P_R/P_P gradually declined in the past decade, and in 1960 were only 73 percent of the 1947-49 average, the increase in farm output was spectacular. The increased output is attributed to better weather, long-run price effects and to general changes in the production function reflecting improved technology and farming efficiency.

Equation (16.3) predicts quite well the changes in output. Figure 16.1 indicates that the prediction errors were considerably greater in the prewar than in the postwar period. The extrapolated estimate of 1960 output predicts the actual output very well. The prediction accuracy is misleading, however, since the actual index of productivity, T', for 1960 was known and used in the extrapolation. The error might have been large if an estimated value of T' had been used. The systematic component of T' is quite predictable, but the random component, due mainly to weather, can result in large prediction errors when T' is unknown.

The level of output is projected to 1965 assuming prices will remain at the 1955-59 average level and that S_p will be 112.4 billion 1947-49 dollars by 1965. The estimate of S_p is based on equation (12.23) and is consistent with a USDA estimate.[9] T' is assumed to continue increasing at the same average rate as in the 1926 to 1959 period. The lowest projected output is based on an extension of T' for six years beginning with 1959. The second, higher estimate is based on an extension of T' for five years beginning with 1960. The second estimate of T', and consequently of output, is much greater because of the large increase in T' from 1959 to 1960. The increase may represent the random influence of weather; hence, the lower estimate is included. The two results suggest 1965 output will be 4 and 7 percent above the 1960 predicted value.

The Market Supply (Output Less Change in Farm Inventories) Functions Estimated by Least Squares and Limited Information

Since the short-run market supply of farm products can be increased by depleting inventories of livestock and feed, its short-run elasticity is somewhat greater than output elasticity. In the long run the two measures of supply elasticity could be equivalent, depending on the future output sacrificed by depletion of current production stock. We are less concerned with the short-run inventory changes and give Q_S only a cursory examination. A single-market supply equation estimated by least squares with annual data from 1926 to 1959, excluding 1942 to 1945 is

$$(16.8)\quad Q_S = -16285 + \underset{(14.45)}{44.56}\,(P_R/P_P)_{t-1} + \underset{(50.79)}{331.91}\,S_{pt} + \underset{(44.51)}{173.13}\,T,$$

$$d = 1.08 \qquad R^2 = .97$$

where Q_S is the predicted supply quantity, including changes in inventories. (Standard errors are in parentheses.) The equation is linear in original values of variables defined earlier. The coefficients of current price, $(P_R/P_P)_t$, weather, W, and a measure of government programs, G, were not significant and were excluded from the equation. The coefficient of the weather variable was not significant because of the conflicting influences of weather on farm output and inventory components of Q_S. The elasticity of Q_S with respect to P_R/P_P is .15; with respect to S_p is 1.21 in (16.8). If the data except T are transformed to logarithms, the resulting equation is

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[9] Johnson, Sherman. Agricultural outlook in the 1960's. (Multilith.) USDA. Agricultural Research Service. Washington. 1960.

$$(16.9) \qquad Q_S = 1.80 + \underset{(.050)}{.151} \, (P_R/P_P)_{t-1} + \underset{(.21)}{1.10} \, S_p + \underset{(.00086)}{.00344} \, T.$$

$$d = 1.17 \qquad R^2 = .96$$

Equations (16.8) and (16.9) are quite comparable, both indicating a short-run supply elasticity of .15. The coefficients of the variables in these equations are highly significant and the variables explain a high proportion of the annual variation in Q_S. The hypothesis that the residuals are not autocorrelated is rejected at the 95 percent level in (16.8) and is inconclusive in equation (16.9).

Because opportunities exist to adjust farm inventories and, hence, market supply in response to current changes in demand for farm products, it was considered advisable to estimate the supply function as part of an interdependent system. The assumption is that the current supply is determined jointly with the markets for farm inputs and farm output. The supply equation, estimated by limited information techniques with annual data from 1926 to 1959, omitting 1942 to 1945, is

$$(16.10) \qquad Q_S = 3100 - \underset{[-14.08]}{3427} \, P_{Ot} - \underset{[-5.41]}{1740} \, P_{Ht} + \underset{[5.15]}{1658} \, P_{Rt} - \underset{[-6.17]}{2548} \, N_t$$

$$+ \underset{[5.29]}{1448} \, S_{pt} + \underset{[.71]}{2132} \, G_t + 1740 \, T$$

where P_O is the price of operating inputs, P_H is the wage of hired farm labor, N is farm numbers and G is an index of government programs. Other variables are defined earlier in the chapter. Prices are deflated by the implicit price deflator of the Gross National Product. Elasticities are given in brackets below the coefficients; standard errors are not computed. All coefficients possess the anticipated signs, but the magnitudes appear too large. Because the elasticities are too large to be meaningful, we do not discuss the individual parameter estimates.

SUPPLY RESPONSE FOR CROPS AND LIVESTOCK COMPONENTS OF OUTPUT

The complications from substitutions among components of output are avoided by estimating the aggregate supply function in Table 16.1. The conclusion that the response of output to price has not increased in the postwar period does not preclude the existence of changing responses to price for components of output. In this section, a brief analysis of the supply functions of output, yield and production units for (a) crops and (b) livestock is presented to determine the sources of output elasticity (from changes in acreage and animal units or yield).

Total output, O, is equal to the number of production units, L, multiplied by the yield per unit, O/L. Tweeten and Heady show that the elasticity of O with respect to price, P, is equal to the elasticity of L with respect to P plus the elasticity of yield, O/L, with respect to P if yield is independent of L.[10] Knowledge of the response of production units and yield to price, therefore, helps to identify the source (change in yield or production units) and magnitude of the total supply elasticity. The assumption that yield is independent of acreage or livestock numbers is unrealistic, however. It is reasonable that crop yields diminish as cropland is extended to inferior lands in the short run. If prices fall, low producing cows or chickens are culled, increasing average production per remaining head. It follows that, in the short run, yield and the number of production units are inversely related. This short-run interdependence may be accommodated in a recursive model. The nature of the production process suggests that the "units" decision (how many acres or animals to use in production) is made before the "yield" decision. We assume that the current number of production units, L, is a function of past price, P_{t-1}, other variables, X_{t-1}, and an error, u_t, i.e.,

$$L_t = f(P_{t-1}, X_{t-1}, u). \tag{16.11}$$

Yield per production unit, O/L, is a function of the number of production units, current price, other variables, Y, and error, w, or

$$(O/L)_t = g(P_t, L'_t, Y_t, w_t). \tag{16.12}$$

To avoid least-squares bias (correlation between L_t and w_t), the predicted value of production units, L′, from equation (16.11) is inserted in (16.12). This is equivalent to making L a predetermined rather than a current endogenous variable in the supply equation (16.12).

The variables used in these functions, not described earlier in this chapter, are:

O_{Crt} = the gross production of crops in the current year, expressed as a percent of the 1947-49 average crop output.

O_{Lkt} = the gross production of livestock in the current year, expressed as a percent of the 1947-49 average livestock output.

L_{dt} = land used for crops in the United States in the current year in millions of acres, including acreage from which one or more crops are harvested, plus acreage of crop failure and summer fallow. L'_d is the predicted values of L_d from a least-squares equation.

L_{kt} = the current number of animal units of breeding livestock in the United States, expressed as a percent of the 1947-49 average and excluding horses and mules. L'_k is the predicted L_k from a least-squares equation.

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[10] Tweeten, Luther G., and Heady, Earl O. Short-run corn supply and fertilizer demand functions based on production functions derived from experimental data; a statis analysis. Iowa Agr. Exp. Sta. Res. Bul. 507. June 1962. p. 577.

$(O/L)_{Ldt}$ = crop production per acre in the current year, expressed as a percent of the 1947-49 average.

$(O/L)_{Lkt}$ = livestock production per breeding unit in the current year, expressed as a percent of the 1947-49 average.

$(P_{Lk}/P_{Fd})_t$ = the current year index of the ratio of prices received by farmers for livestock to the price paid by farmers for feed, expressed as a percent of the 1947-49 average. When a subperiod such as 1926-41 is specified, the observations are actual values from 1926 to 1941, but zeros from 1946 to 1959.

All variables are for the United States from 1926 to 1959, excluding 1942 to 1945. Other variables are defined previously in the chapter.

Least-Squares Estimates of Crop Supply

Coefficients, standard errors and elasticities are indicated for crop output, O_{Cr}, as a function of past year prices, P_R/P_P, for two subperiods, the stock of productive assets, weather and time (Table 16.2). In (16.13) the coefficients of price are .20 for both periods and provide no basis for rejecting the null hypothesis that the response of crop output to prices has remained unchanged between the 1926-41 and 1946-59 periods. The results indicate that the short-run elasticity of crop output with respect to P_R or P_P is approximately .18.

Equation (16.14) would indicate that the marginal response of acreage to prices has increased at a linear rate since 1926. The coefficient of TP_R/P_P is significant and positive. Computed at the full-period mean of the price and time variables, the price elasticity of acreage is .055, indicating that acreage is relatively unresponsive to price changes. The long-run elasticity is the short-run elasticity divided by the adjustment coefficient .5 (1 minus the coefficient of L_{dt-1}). At twice the short-run elasticity, it is still of small magnitude.

The response of yield, $(O/L)_{Cr}$, indicated in equation (16.15), to price appears, under the particular specification, to have increased in the postwar period. The standard error of the <u>difference</u> between the coefficients of price for the two periods is .054. The difference in the coefficients is .051; hence, we have no basis for rejecting the hypothesis that the yield response to price in the two periods was equal. The elasticity of yield response to price is approximately .16 according to equation (16.15). The results indicate that the price elasticity of yield is approximately three times that of acreage (when elasticities are computed at the means of the entire period) but it is still a low quantity. The coefficient of the predicted current acreage, L'_{dt}, is negative and significant in (16.15) and suggests that greater acreage is associated with lower yields. Because of the current interaction between yield and acreage the elasticities of L_{dt} and $(O/L)_{Cr}$ with respect to price do not sum to the elasticity of crop output with respect to price. The

Table 16.2. Supply Functions for Crop Production, O_{Cr}, Cropland, L_d, and Crop Production per Acre, $(O/L)_{Cr}$, Estimated by Least Squares With U.S. Data From 1926 to 1959, Excluding 1942 to 1945*

Equation and Dependent Variable †	R^2	Constant	P_R/P_P t-1 (1926-59)	P_R/P_P t-1 (1926-41)	P_R/P_P t-1 (1946-59)	TP_R/P_P t-1	S_p t	W t	T	L_d t-1	L'_d t
(16.13) O_{Crt}											
Coefficient	.94	-48.32		.20	.20		.66	.438	.46		
Standard error				(.10)	(.07)		(.23)	(.037)	(.21)		
Elasticity				.19	.17						
(16.14) L_{dt}											
Coefficient	.77	252.48	-1.04			.030	.49		-3.10	.51	
Standard error			(.42)			(.010)	(.24)		(1.00)	(.13)	
Elasticity			.055 ‡			-- ‡					
(16.15) $(O/L)_{Crt}$											
Coefficient	.96	157.87		.156	.207		.55	.436	.35		-.50
Standard error				(.092)	(.065)		(.22)	(.066)	(.22)		(.16)
Elasticity				.150	.173						

*Composition of the variables is discussed in the text. The coefficient estimates in this and other tables may be somewhat biased by government programs reducing acreages and increasing yields and product prices.

† All equations are estimated linear in original values. Elasticities are computed at the mean of the 1926-59 period or the subperiod indicated at the top of the column.

‡ The two coefficients of P_R/P_P are combined by assuming T is at the mean for the entire period. Hence, only one estimate of elasticity is obtained.

coefficient -.5 of L'_d indicates that a 1 percent decrease in current acreage is associated with a .12 percent increase in current yields. The result is an empirical manifestation of why acreage control programs have not been as effective as intended. If the coefficient is an accurate measure of short-run acreage-yield interaction, from 10 to 15 percent more acres must be removed from production to reduce crop output a given amount than would be necessary if acreage-yield interaction were zero.

The current price variable, $(P_R/P_P)_t$, was also included in the three equations in Table 16.2, but the coefficients were insignificant in all cases. The implication is that the effect of current year price is either too small to be detected by the small sample of observations or is overshadowed by the past year price. The prices received by farmers for crops and livestock rather than prices received for crops alone are included in the functions in Table 16.2 because many crops are grown for livestock feed. For these feed crops, livestock rather than crop prices are the relevant decision variable.

Least-Squares Estimates of Livestock Supply

Table 16.3 includes the coefficients, standard errors and price elasticities for least-squares equations expressing livestock output, O_{Lk}, animal units, L_k, and livestock output per animal unit, $(O/L)_{Lk}$. According to (16.16), the elasticity of O_{Lk} with respect to past year price is approximately .14. The current year price coefficient is not significantly different from zero. Equation (16.18) provides insufficient grounds for concluding that the marginal price response in the postwar and prewar periods differs. Collinearity is less apparent, standard errors smaller, and degrees of freedom greater in equation (16.17) than in (16.18). Thus, (16.17) provides the more reliable estimate of the price elasticity .19 of livestock numbers on farms. The adjustment coefficient .25 (one minus the coefficient of L_{kt-1}) indicates that the long-run elasticity is approximately four times larger than the short-run elasticity.

The marginal response of livestock yield (livestock output per animal unit) to price increased in the postwar period according to equation (16.19). The t test for the difference between the coefficients, .161 and .274, is highly significant. It is interesting to note that the price elasticities .22 and .26 for the respective prewar and postwar periods are rather similar, however. The elasticities are computed by multiplying the price coefficients by the price-yield ratio in the respective periods. Because of marked improvements in livestock production efficiency and for other reasons, the mean of yields is much larger in the postwar period. Since relative prices have not changed appreciably, the difference in elasticities is not large despite the significant shift in marginal response between the two periods.

The insignificant coefficient of L'_k in (16.19) is consistent with the

Table 16.3. Supply Functions for Livestock Production, O_{Lk}, Animal Units, L_k, and Livestock Production per Animal Unit, $(O/L)_{Lk}$, Estimated by Least Squares With U.S. Data From 1926 to 1959, Excluding 1942 to 1945*

Equation and Dependent Variable†	R^2	Constant	P_{Lk}/P_{Fd} t (1926-59)	P_{Lk}/P_{Fd} t (1926-41)	P_{Lk}/P_{Fd} t (1946-59)	P_{Lk}/P_{Fd} t-1 (1926-59)	P_{Lk}/P_{Fd} t-1 (1926-41)	P_{Lk}/P_{Fd} t-1 (1946-59)	S_p t	W t	T	L_k t-1	L'_k t
(16.16) O_{Lkt}													
Coefficient	.99	26.39	.022			.116			1.16	.024	.68		
Standard error			(.047)			(.041)			(.13)	(.048)	(.11)		
Elasticity			.0254			.135							
(16.17) L_{kt}													
Coefficient	.86	50.80				.165				-.081		.745	
Standard error						(.033)				(.037)		(.073)	
Elasticity						.188							
(16.18) L_{kt}													
Coefficient	.87	62.96					.140	.115		-.088		.59	
Standard error							(.038)	(.050)		(.037)		(.14)	
Elasticity							.177	.116					
(16.19) $(O/L)_{Lkt}$													
Coefficient	.99	16.08		.161	.274				1.060		.887		.029
Standard error				(.020)	(.032)				(.074)		(.069)		(.123)
Elasticity				.217	.255								

*Composition of the variables is discussed in the text.

†All equations are estimated linear in original values. Elasticities are computed at the mean of the 1926-59 period or the subperiod indicated at the top of the column.

hypothesis that there is no interaction between livestock numbers and output per animal. In another formulation, not included, the coefficient was significant and negative, however. The equations in Tables 16.2 and 16.3 are not intended to provide a definitive analysis of supply response but are intended to give a brief summary of the price response for two components of aggregate supply. The results are summarized as follows: The short-run price response for all components of output is low and highly inelastic. The livestock and crop components, and especially components within these aggregates, may be more responsive than aggregate output to prices because of opportunities for substituting crops for livestock and because much feed is fed to livestock. Only the response of cropland and of livestock output per animal unit to prices increased significantly in the period studied. Computed at the means, the price elasticity of cropland is lowest and of livestock yields is highest. Current prices have little influence on crop output and livestock inventories, but have a significant effect on current livestock yields.

ADJUSTING FARM OUTPUT

The estimates from this study provide a basis for appraising the implications of various policy instruments for adjusting demand and supply in agriculture. While much of the following discussion is oriented toward farm income, we do not select income adjustment as a unique goal or choose any one policy for attaining it. Many other means and ends might be specified such as parity farm income or prices, stable income, maximum farm or national income or free markets. The analysis here is predictive, basing expected effects on past behavior, and is subject to the limitations of data and specifications.

Before appraising the effectiveness of the price mechanism for bringing needed resource adjustment, it is necessary to examine trends in supply and demand shifters. If supply is shifting to the right at a much more rapid rate than demand, a supply elasticity greater than zero still may not make the price system an effective instrument for achieving needed adjustments.

The major shift variable of aggregate commodity supply is farm technology, T', and of demand is population. Additional sources of demand expansion such as increased disposable per capita income, foreign markets and improved diets have not resulted in large shifts in the demand curve and cannot be expected to do so in the future. It is interesting to note that the two major sources of demand and supply expansion — productivity and population — have shifted the respective curves at nearly equal annual average rates, 1.7 percent, during the postwar period (Table 16.4). The U.S. population increased 28 percent and agricultural productivity increased 27 percent from 1946 to 1960. If demand expands at the same rate as productivity, T', no change in the aggregate level of conventional resources would be necessary. It

Table 16.4. Percent Increase in Aggregate Demand and Supply Shifters in the Postwar Years

Item	Percent Increase		
	(1946-53)	(1953-60)	(1946-60)
Output	11.2	16.5	29.6
Input	4.0	-1.0	3.0
Productivity	7.1	18.9	27.3
National population	12.9	13.2	27.8

is not surprising, therefore, that the aggregate input in farming increased only 3 percent from 1946 to 1960.

While for the entire period supply has shifted at nearly the same rate as demand, the shift in supply appears to be accelerating (Table 16.4). National population increased 13 percent in each subperiod, but productivity increased 7.1 percent from 1926 to 1953 and 18.9 percent from 1913 to 1960. If, as in the latter period, demand and supply increase 1.8 percent and 2.5 percent per year respectively, product prices can be expected to decline, on the average, (2.5 - 1.8)4 = 2.8 percent per year (assuming the average price flexibility of demand is -4). Maintaining price at a constant level under these circumstances would require that annual output be restrained about .7 percent through resource reduction. A short-run supply elasticity of .1 suggests that output would decline only (.1)(2.8) = .28 percent in the short run from fewer inputs, or about half the needed adjustment to maintain prices. In the analysis which follows we assume that the magnitude of demand and supply shifters are equal since: (a) some additions to productivity are caused by "random" fluctuations in weather, (b) some potential future demand shifters such as increased national income are not included and (c) the analysis is simplified by abstracting from demand and supply shifters. It is well to caution, however, that this simplification tends to bias the results by overestimating the ability of the price mechanism to increase or maintain farm income.

Improvement in agricultural prices, income and return on resources can be achieved through demand expansion or supply contraction. We focus our attention only on feasible policy alternatives. National population and farm productivity T' are not considered to be relevant policy instruments. Gains to society from greater productivity are too great to be disturbed by direct action; furthermore, the rate of productivity change is difficult to manage. Because the income elasticity of demand for farm products is low, and for other reasons, the potential for expanding the demand for agricultural products is limited. The onus of long-run agricultural adjustments falls logically on resource movements (and, consequently, output) in agriculture. The supply elasticity abstracts from the productivity index and is an indication of the output response to prices received, P_R, through resource adjustments.[11]

We first consider the implication of free markets for adjusting output, prices and income in agriculture. Some studies of this type have been made but have lacked adequate knowledge of the supply response.[12] A study of the ramifications of free markets is a major research project in itself. The principal purpose of this study is to estimate supply parameters rather than to trace the exact implication of free markets. But to illustrate the meaning of the supply elasticities found in this study and to illustrate broadly some of the adjustments that would occur, a free market model is simulated using elements of the existing situation. The assumptions of the model are: (a) current agricultural output is predetermined by past prices (supply), and current price is determined by current output (demand), (b) the average price flexibility of product demand for domestic and foreign markets in the short run at the farm level is -4.0 (price elasticity is -.25)[13], (c) that 5 to 10 percent of all agricultural output is being diverted from price-setting markets by government accumulation of surplus output, export and consumer subsidies or resource restrictions,[14] (d) that nonprice influences shifting supply to the right are offset by demand expansion, (e) that input prices in aggregate will remain stable, that existing stocks will not be

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[11] The assumption is that the aggregate output-input ratio in agriculture is unaffected by prices received, P_R. To test this hypothesis, the productivity index, T′, was regressed on relative prices, P_R/P_P, in agriculture. No significant relationship could be found, and the hypothesis was not rejected. This test does not preclude the possibility of sensitivity of T′ to changes in the relative input prices, e.g. ratios of farm labor wages to machinery price or operating input price.

[12] Brandow, G. E. Interrelations among demands for farm products and implications for control of market supply. Pa. Agr. Exp. Sta. Bul. 680. University Park. 1961; (Shepherd, Geoffrey, Paulsen, Arnold, Kutish, Francis, Kaldor, Don, Heifner, Richard, and Futrell, Gene.) Product, price and income estimates and projections for the feed livestock economy under specific control and market-clearing conditions. Iowa Agr. and Home Econ. Exp. Sta. Special Report 27. Ames. 1960; USDA. Projections of production and prices for farm products for 1960-65 according to specified assumptions. In U.S. Congress. Senate. Report from the USDA on farm price and income projections. [Ellender Report] 86th Congress, 2nd Session, Senate Document 77. pp. 3-24. U.S. Government Printing Office. Washington. 1960.

[13] A recursive model is assumed in Table 16.5. The model is equivalent to assuming that the current supply quantity (output) is a function of past prices in the supply equation linear-in logarithms. Similarly, the current price is a function of the predetermined current quantity in a single least-squares product demand equation linear in logarithms. The coefficient of the quantity variable in the demand equation is the constant price flexibility. It is not strictly correct to assume that the inverse is the price elasticity of demand. That is, the price flexibility generally is defined as the coefficient of quantity when price is the dependent variable. Price elasticity of demand generally is defined as the coefficient of price when quantity is the dependent variable. The two concepts are equivalent only if there is no error in the model or if the assumptions are correct underlying the limited information technique, which is independent of the direction of normalization. The product demand function was not estimated in this study. For a summary of several estimates of the price elasticity of demand for product aggregates in agriculture, see Brandow, op. cit., pp. 19, 50.

[14] Cf. Shepherd, et al., op. cit., p. 6; Shepherd, Geoffrey, Appraisal of the federal feed-grains programs. Iowa Agr. Sta. Res. Bul. 501. Ames. 1962. p. 359; USDA. Projections of production and prices, op. cit., p. 20.

placed on the market,[15] that prices will be determined by current output and (f) that markets for farm products (outside of government restrictions, etc.) are now in equilibrium. The estimated elasticity of aggregate supply (output) is .10 in the short run, .15 in the intermediate run. There would be obvious advantages in considering the output responses for several categories of farm output. For purposes of this study, however, it is felt that many of these advantages would be lost because of the elusive substitution possibilities among components of farm output.

The movements of farm prices, output and income are indicated in Table 16.5. The first example is based on the assumption that the government would remove farm restrictions and subsidies until farm product marketings are 5 percent above the initial level in year 1. The 5 percent increase in output decreases farm prices from the initial index of 100 to 80 in year 1, or 20 percent. Because output is greater, gross income falls by a smaller percentage, 16 percent.

Table 16.5. Simulated Adjustments of Farm Output, Price and Income to Free Markets Based on Structural Elasticities Estimated in This Study

	Year				
	0	1	2	3	4
Cumulative adjustments (percent of initial year)					
Example 1 — 5 percent increase in output					
Output, O	100.0	105.0	102.9	102.6	102.4
Prices received, P_R	100.0	80.0	88.4	89.6	90.4
Gross income	100.0	84.0	91.0	91.9	92.6
Net income:					
(a) Above operating expenses*	100.0	74.2	88.5	90.7	92.3
(b) Above production expenses†	100.0	58.4	82.1	85.7	88.3
Example 2 — 10 percent increase in output‡					
Output, O	100.0	110.0	105.6	104.9	104.5
Price, P_R	100.0	60.0	77.6	80.4	82.0
Gross income	100.0	66.0	81.9	84.3	85.7
Cumulative elasticities					
With respect to P_R					
Demand for Q_O §	0	0	.3	.4	.5
Demand for Q_H +	0	0	.1	.2	.3
Supply of O #	0	0	.10	.13	.15
With respect to Y_F					
Demand for S_p **	0	0	.02	.03	.04
Demand for Q_F ††	0	0	.1	.2	.3

*Gross income less current operating and hired-labor expenses. The indices depend on the absolute level and relationship between expenses and income — those used for the initial period are based on average actual 1958-60 relationships. The assumed price flexibility of demand -4 and other assumptions are given in the text — the excess output is assumed to be placed on the market in year 1.

†Gross income less operating and hired-labor expense; also less taxes, interest, rents and consumption of farm capital. The latter expenses are assumed to be proportional to the stock of assets, S_p.

‡Only a few quantities are presented because the estimated elasticities are not considered applicable for large adjustments.

§Based on demand functions for operating inputs, Q_O, estimated in Chapter 13. These and other elasticities assume current quantities respond to past and other prior prices.

+From demand functions for hired farm labor, Q_H, estimated in Chapter 8.

#Output supply elasticity, estimated earlier in this chapter from equations in Table 16.1.

**Based on investment functions for all productive assets, S_p, estimated in Chapter 12. Y_F is net farm income.

††Based on functions for family labor, Q_F, in Chapter 9.

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[15] Surplus stocks might be liquidated through Public Law 480 and other federal measures to remove stocks outside regular market channels.

Assuming expenses remain at current levels, net income (a) above operating expenses would fall about 25 percent and (b) above production expenses would fall over 40 percent in year 1. The supply response to low prices in year 1 becomes apparent in year 2. For each 10 percent drop in prices, farmers decrease output 1 percent. Hence, output falls from 105 in year 1 to 103 in year 2. The reduction of output and expenses in year 2 arises primarily from the reduction in operating inputs such as fertilizer, protein feed, etc. After year 2, supply adjustments depend primarily on adjustments in durable inputs. The potential long-run adjustment of output is large from durable inputs such as irrigation equipment, drainage and livestock inventories (the long-run price elasticity is .6). The annual or "marginal" adjustment is small, however, and is only .03 from year 2 to year 3. Since P_R is 88.4 in year 2, or 11.6 percent below the initial price, the output adjustment is (11.6) (.03), or .3. Output in year 3 is therefore 102.9 - .3 = 102.6. The "excess" supply is 2.6 percent, hence, P_R is (4) (2.6), or 10.4 per cent below the equilibrium or initial price in year 3 according to the assumptions in example 1. Gross income is (102.6) (89.6) or an index of 91.9 in year 3.

Both measures of net income also are improved, not only because gross income is higher, but also because expenses are lower in year 3. Net incomes above operating expenses and production expenses respectively are 92 and 88 percent of initial levels by year 4. The impact of declining product prices is greater for net income over production expenses because interest on mortgages, taxes and depreciation are nearly fixed costs. It is apparent that the rate of adjustment of prices, output and income toward initial levels is slowing considerably by year 4. Although prices and incomes remain considerably below initial levels, they are improving gradually. Adjustments become small, and our estimates become even less accurate; therefore the adjustments after year 4 are not illustrated.

Complete withdrawal of government restrictions and export subsidies would be expected to increase by 5 to 10 percent the quantity of farm products entering price-setting markets. Example 2 in Table 16.5 suggests the price, output and income response if the upper limit, 10 percent (of additional output) is reached. The 10 percent rise in output in year 1 depresses farm prices 40 percent and gross income 34 percent. Farm inputs have not yet responded to falling prices, and production expenses remain at the initial level in year 1 according to the assumptions of the model. Actual farm expenses currently are 65 to 70 percent of realized gross farm income. A drop of one-third in gross farm income, depicted in year 1 of example 2, would leave the average farm operator with little net income. Because net income is required for household and other expenditures, a serious farm financial crisis would result. The prices and income would be improved somewhat after several years, but price and gross income are only 82 and 86 percent, respectively, of the initial level by year 4. Example 2 is not considered realistic; the actual increase in farm marketings with free markets is expected to be around 6 or 7 percent, hence closer to example 1. If government influence in agriculture continues to grow, example 2 may become a more realistic setting, however, and points up the increasing difficulty of a government exit from agriculture as the surplus capacity grows.

Table 16.5 illustrates (a) the adjustment to free markets and (b) the interpretation of the parameters estimated in this study. The recursive nature of the adjustment process is apparent. It is not possible to conclude because the intermediate run elasticity is .15 that a 40 percent drop in P_R (from an index of 100 to 60 in example 2) will decrease output (40) (.15) = 6 percent in four years. To decrease output 6 percent, the 40 percent fall in price must be sustained each year. Because some adjustment occurred before year 4, P_R was above the year 1 index in years 2 and 3 (was less than 40 percent below the initial level). Thus, output declined to an index of 104.5 rather than to 103.4 (110 less 6 percent of 110) in example 2. These results caution that the supply elasticity may be a misleading indication of adjustment potential. Supply elasticity estimates indicate that output is decreased 6 percent in approximately 25 years by a sustained 10 percent drop in P_R. But because of the recursive nature of adjustments, indicated in Table 16.5, the initial drop in price is not sustained, but gradually rises. The result is that less adjustment is made in a given period than the supply elasticity, defined in terms of a once-for-all price change, might lead one to expect.

The benefits of a supply response greater than zero are apparent from Table 16.5. If the elasticity of supply were zero, the indices of price and income would fall to 60 and 66, respectively, in example 2 and remain at that level each year thereafter. The fact that gross income recovered nearly 30 percent from year 1 to year 4 in example 2 indicates that supply response cannot be omitted in studies of free markets without introducing large errors.

For net income above production costs per family worker to be improved, the number of workers would need to decline approximately 12 percent in example 1. In Chapter 9 a sustained 10 percent fall in relative (residual) farm income per worker was found to reduce the number of workers up to 3.5 percent in four to six years. Assuming optimistically that national employment is very high and that the elasticity of response of labor to income is .30 in four years (see Chapter 9), the decline in labor numbers is 7 percent by year 4. Thus, the fact that net income has fallen 12 percent, employment only 7 percent, suggests that per worker incomes would be considerably below initial levels by year 4. Over a longer period, income per worker would continue to improve but at a very slow rate. The example is crude, of course, and is only a very rough measure of the possible effect of free markets on per worker incomes. Like other estimates in this section, the results suggest aggregate effects, and the micro impact for individuals may run counter to the total.

One may question whether the results in Table 16.5 underestimate or overestimate the impact of free prices on incomes in agriculture. Based on the previous results, the assumption that nonprice influences shifting supply to the right will be offset by demand expansion does not seem realistic. *Rapid recent increases in farming efficiency indicate that source T' alone may exceed the expanding demand without increasing* the application of conventional inputs. Restraining the level of conventional inputs places a great strain on the price system. The input demand functions estimated in this study suggest that there are strong nonprice influences (at the farm level, but not in the national economic growth framework) which increase inputs with high production elasticities. These influences which change the over-all production function and the marginal productivity of individual resources, discussed in the foregoing chapters, are likely to continue in the future and in many instances to overshadow the "direct" price effects. Even drastic reductions in farm product prices may be unable to offset the input-increasing effects of these forces. Hence, the estimates of Table 16.5 probably present an overly optimistic view of the ability of the price system to cope with the resource and income adjustments needed in agriculture.[16]

Some implications of "direct" supports for farm prices P_R without controls or diversionary purchases are apparent from the estimated supply elasticity. By "direct" price support, we refer to an amount per unit paid by government to producers and announced prior to the production period. The output, after production, is sold in the market. This is only one, and not necessarily the most efficient or desirable, type of price support. We use it only for illustration of the recursive interrelationship of price and output reactions.

The output-increasing effect of direct price supports acts, without control of supply, against the intended purpose. Assume that direct price supports, paid per unit produced, increase P_R 10 percent. Since the short-run supply elasticity is .10, output is expected to increase by 1 percent in two years. If price flexibility is -4.0, the 1 percent increase in output is expected to decrease P_R by 4 percent. Hence, the net "real" support price is the original 10 percent increase minus 4 percent, or 6 percent. In the intermediate run, the supply elasticity is .15; hence, output should be 1.5 percent greater. The net real increase in P_R would be only 4 percent. It is apparent that because of the inelastic demand for farm products, the intended price and income benefits to farmers would, through this system of direct supports, soon be dissipated unless farm output was to be controlled.

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[16] Another source of declining net income and need for resource adjustment is the increasing prices paid by farmers for inputs. Prices of some resources (e.g. labor) increase more than others (e.g. operating inputs), but the general price trend is upward. From 1946 to 1960, prices paid by farmers for items used in production, including interest, taxes and wage rates, increased 44 percent. Rising input prices like falling output prices depress net farm income and place an additional burden on the price mechanism to bring needed adjustments.

17.

An Input-Output Analysis of Structure[1]

THE EMPIRICAL ANALYSIS of previous chapters revolved mainly around time series data extending back to 1926. Projections in Chapter 18 are for 1980 and stem from trends and certain assumptions on variable and parameter magnitudes as these relate to agricultural structure and its change. Many of these projections rest on observations over the period 1950-60, since the structure of this period is considered, for many categories of inputs, to depart greatly from that of previous decades. By 1950, U.S. agriculture was heavily mechanized. The additions to stocks of productive assets through this source, as well as its effect on demand for operating and similar inputs, had shifted from the 1930's when widespread mechanization was only beginning to gain momentum. Similarly, biological innovations such as hybrid corn were generally adopted by 1950, but provided a different input demand framework as compared to earlier decades. Of course, changes in structure are not discrete, but tend to be continuous over time. Some categories of inputs projected in Chapter 18 consider this fact and relate to observations prior to 1950 where it is obvious that change has been gradual and highly continuous.

However, since many of the projections relate back to time series observations of the 1950-59 decade when a different and "fairly mature" structure is assumed to exist, we present an alternative interpretation of resource demand and agricultural structure for 1954, a period near the midpoint of the 1950-59 decade. These interpretations or estimates are based on an input-output model emphasizing regional and commodity sectors of agriculture. Because of time limitations and inadequate data for aggregation and stratification of time series data by these sectors, it was not possible to derive comparable regression models for individual commodities and regions. Hence, we select 1954 for this analysis since it is midpoint in the decade to which many projections in Chapter 18 relate. Also, census data were not available for computing a parallel input-output model for 1959.

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[1] Harold O. Carter of the University of California is co-author of this chapter.

INPUT-OUTPUT ANALYSIS AND LIMITATIONS

An input-output model represents a particular set of assumptions about inter-sector resource structure and demand. The model itself imposes certain restrictions for the impact of economic growth on the outputs and inputs of the various sectors of the economy. An input-output model generally refers to a particular point in time and, as we have mentioned elsewhere in applications particularly to agriculture, serves more usefully for descriptive purposes than in defining changes in interrelationships among resource furnishing and using sectors over time. More particularly, it provides requirements coefficients, indicating output induced or required from the i-th sector or industry for a one-unit increase in output by the j-th sector. Because of the particular mathematical characteristics of input-output models, certain constraints are forced on the intersectoral relationships expressing interdependence in supply and demand among commodities ranging from primary inputs to consumer goods and services. Mainly, these characteristics specify that an increment of output in one sector, or in final demand, reflects demand back to input supplying sectors in the manner of a fixed mix. Substitution is not allowed between inputs drawn from different sectors in a "pure" input-output model, although substitution can be considered to take place within the aggregation of inputs used to specify or define a sector or industry.

In contrast to most of the behavioral equations and the stability conditions outlined in Chapter 3, an input-output model necessarily assumes constant marginal productivities and total production elasticities equal to unity. While input-output models computed for data at different points in time can reflect economic and technical changes, one referring to a particular period or point in time does not do so. Other limitations of input-output models in general, and those applied to agriculture particularly, could be mentioned. However, since these have been discussed elsewhere, they need not be detailed here.[2] The

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[2] For discussion of these limitations, see the following: Heady, Earl O., and Carter, Harold O. Input-output models as techniques of analysis for interregional competition. Journal of Farm Economics. Vol. 41. Dec. 1959; Heady, Earl O., and Schnittker, John A. Application of input-output models to agriculture. Journal of Farm Economics. Vol. 39. Dec. 1958; National Bureau of Economic Research. Input-Output Analysis, An Appraisal. Princeton University Press. Princeton, 1955; Carter, Harold O., and Heady, Earl O. An input-output analysis emphasizing regional and commodity sectors of agriculture. Iowa Agr. Exp. Sta. Bul. No. 469. 1959; Schnittker, John A., and Heady, Earl O. Application of input-output analysis to a regional model emphasizing agriculture. Iowa Agr. Exp. Sta. Bul. No. 454. 1959; Leontief, W., et al. Studies in the Structure of the American Economy, New York, Oxford Press, 1953; Barna, Tibor (Ed.). The Structural Interdependence of the Economy. John Wiley & Sons, Inc. New York, 1954; Morgenstern, Oskar (Ed.). Economic Activity Analysis. John Wiley & Sons, Inc. New York, N. Y. 1954; Morgenstern, Oskar. On the Accuracy of Economic Observation. Princeton University Press. 1950; Moses, L. N. Interregional input-output analysis. American Economic Review. Vol. 45. May, 1951; Peterson, G. A., and Heady, Earl O. Application of input-output analysis to a simple model emphasizing agriculture. Iowa Agr. Exp. Sta. Res. Bul. No. 427. 1955; Cameron, Burgess. The production function in Leontief models. Review Economic Studies, Vol. 20. Aug. 1952; Hurwicz, Leonid. Input-output analysis and economic structure. American Economic Review, Vol. 45. May, 1951.

empirical model presented in this chapter does, within the recognized limitations of such models, illustrate the interdependence in certain supply-demand relationships of different regional and commodity sectors of agriculture. It shows, in the restricted sense mentioned above and within the limitations of the model specification used, the "demand" or requirements for resources produced by these individual sectors as output of agricultural sectors or the final bill of goods is increased. Or, conversely, it shows the "demand" or requirements for inputs placed on other sectors as a particular commodity and regional sector of agriculture changes its output. Measured at different points over time, we would expect the technical and interdependency coefficients reflecting these parameters to change in the manner suggested by the projections of Chapter 18.

MODEL

The mathematical nature of the input-output model is summarized below. The empirical quantities presented later are based on an <u>open</u> model of the type in (17.1). In application of input-output models, the total economy is divided into a relevant number of sectors or subindustries, with each (a) requiring or purchasing resource inputs from other sectors and (b) producing intermediate resources or finished goods which are required by other sectors. If all sectors serve as both producers and consumers, the system is a "closed" model; here all sectors are assumed to be interdependent, and inputs and outputs are functionally related. In a closed model, households represent an industry with labor services as the output and consumption goods such as food, shelter, medicine, recreation, etc. as the inputs. Under the necessary input-output assumptions of constant technical ratios, this procedure implies that a man-hour of labor requires a fixed mix of consumption goods. For models where some sectors are related to other sectors but are not functionally dependent upon them, the system is <u>open</u>. Final demand (exports, government, service and household consumer goods) is autonomously determined by factors outside the system. Labor and managerial services then are considered as inputs but not as products functionally related to the household sector.

The open model used can be illustrated as:

$$
\begin{array}{lc}
(17.1) & X_1 - x_{11} - x_{12} - \dots - x_{1n} = Y_1 \\
 & X_2 - x_{21} - x_{22} - \dots - x_{2n} = Y_2 \\
 & \vdots \qquad\qquad\qquad\qquad \vdots \\
 & X_n - x_{n1} - x_{n2} - \dots - x_{nn} = Y_n
\end{array},
$$

where $X_1, X_2, \dots, X_n$ represent gross output of the various economic sectors; x_{ij} $(i, j=1, \dots, n)$ represents actual flows of resource inputs and services from sector i to sector j; and Y_i (i=1, ... , n) are the flows to final demand sectors (household consumption, investment, government, foreign trade, inventory).

The constraining assumptions made in input-output analysis are reflected in the relations between purchases or input demand of an endogenous sector (i.e., x_{ij}) and the level of output of this sector (i.e., X_j). Assuming a linear relationship (an assumption not too relevant for agriculture) the equation below follows:

$$x_{ij} = a_{ij}X_j + c_{ij} \tag{17.2}$$

where a_{ij} and c_{ij} are parameters.

In the empirical work following, the assumption is made that $c_{ij} = 0$. The a_{ij} (the input-output, technological or requirements coefficient) is derived as the ratio between x_{ij} and X_j:

$$a_{ij} = x_{ij}X_j^{-1}. \tag{17.3}$$

The input-output coefficient represents the direct requirement of sector j upon sector i per unit (dollar) of output of sector j. In this sense, it serves somewhat as a "technological reflection of demand" by sector j, per unit of its output. The x_{ij} similarly reflect the "total demand" of sector j for input from sector i in this same "technological manner." Thus, if output of an agricultural sector (j) requires \$2 million of materials from the chemical sector (i), and if total output of the agricultural sector is \$200 million, the related technical coefficient is 2/200 = .01. The agricultural sector has direct requirement or "de-mand" for .01 dollar of inputs drawn from the chemical sector for each dollar of farm sector output, the total chemical "input demand" being \$2 million.

Substituting (17.2) into (17.1) yields:

$$\begin{aligned} X_1 - a_{11}X_1 - a_{12}X_2 - \dots - a_{1n}X_n &= Y_1 \\ X_2 - a_{21}X_1 - a_{22}X_2 - \dots - a_{2n}X_n &= Y_2 \\ \vdots \qquad\qquad\qquad\qquad &\quad \vdots \\ X_n - a_{n1}X_1 - a_{n2}X_2 - \dots - a_{nn}X_n &= Y_n \end{aligned} \tag{17.4}$$

or in matrix notation:

$$X - AX = Y \tag{17.5}$$

where X is the vector of sector outputs, A is the matrix of input-output coefficients and Y is the vector of final demand quantities. Hence, with specified final demands Y_1, Y_2, ... , Y_n and constant input-output or resource requirement coefficients, equations (17.4) can be solved for the outputs $X_1, X_2, \ldots, X_n$; the resulting equations are given in (17.6). The A_{ij}'s (commonly referred to as interdependence coefficients) are elements of the inverse matrix $(I - A)^{-1}$.

$$
\begin{aligned}
X_1 &= A_{11}Y_1 + A_{12}Y_2 + \ldots + A_{1n}Y_n \\
X_2 &= A_{21}Y_1 + A_{22}Y_2 + \ldots + A_{2n}Y_n \\
&\vdots \\
X_n &= A_{n1}Y_1 + A_{n2}Y_2 + \ldots + A_{nn}Y_n
\end{aligned}
\tag{17.6}
$$

or in matrix notation

$$X = (I - A)^{-1}Y\,. \tag{17.7}$$

Equations (17.1) and (17.4) represent the descriptive component while equation (17.6) represents the analytical aspects of an input-output model. However, from the standpoint of direct resource "demand" and inter-sector structure of agriculture, the elements of matrix A are of as much interest as those of $(I - A)^{-1}$. Using the definitional equation:

$$(I - A)^{-1} = B \tag{17.8}$$

to simplify later presentation, we have interest in A to indicate all direct demand of sector j for inputs drawn from (representing the outputs) of other sectors, and B to indicate the sum total of direct and indirect demand upon a particular sector for a one-unit change delivered to final (consumer or exogenous) demand by a particular sector.

The interdependence coefficients (A_{ij}'s) represent the direct and indirect requirement or resource input demands upon sector i for a one-unit change in the amount of goods delivered to final demand by industry j. This analytical feature makes the tool pertinent to interregional relationships since the indirect as well as the direct effect of change are reflected among regions.

REGIONAL AND COMMODITY COMPONENTS OF MODEL

The empirical model used designates 10 agricultural regions and nine commodities within each of these as separate sectors. Hence, there are 90 possible agricultural sectors. The 10 regions or groupings of states are the same as those used in Chapter 7 for application of regression models in estimating fertilizer demand from time series observations. For purposes of identification in the tables which follow, the agricultural regions for aggregation are shown in Figure 17.1.

Two types of aggregation are feasible for agricultural commodity

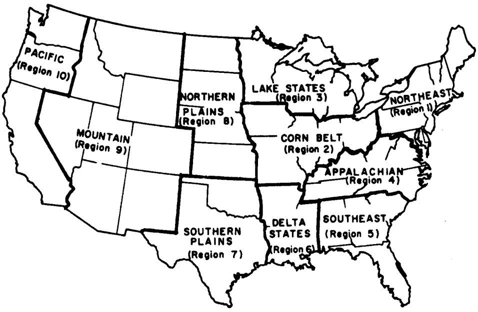

Figure 17.1. Regional sectors in input-output model.

sectors: (a) classification by products and (b) classification by enterprises. The product basis is used to conform with available data. Agricultural statistics are published, with few exceptions, on a commodity basis. Both classifications have disadvantages: for an enterprise classification, output and input composition varies to an extent that coefficients are not uniquely defined. For example, dairy farmers produce both cash and feed crops, while cash crop farmers raise some livestock. The proportions within each farm vary over time depending on relevant price relationships and individual preferences. In product groupings, large numbers of agricultural commodities are joint products. The distribution of resource inputs among commodity groups is difficult and sometimes arbitrary, since there is no given basis for allocating inputs such as machinery, building depreciation, petroleum products and similar items among individual commodities. For convenience, the commodity or product grouping is used in this study. The k-th regional sector (Figure 17.1) then has the following commodity sectors:

k.1 Livestock and livestock products — meat animals, dairy products, poultry and eggs and miscellaneous livestock products.

k.2 Feed grains — corn, oats, barley and grain sorghum.

k.3 Food grains — wheat, rice, rye and buckwheat.

k.4 Forage crops — hay, pasture, and grass and legume seeds.

k.5 Vegetables and fruit — vegetables, fruits and nuts.

k.6 Cotton — cotton lint and cottonseed.

k.7 Tobacco — unmanufactured tobacco.

k.8 Oil crops — soybeans, peanuts, flaxseed and tung nuts.

k.9 Miscellaneous agriculture — sugar crops, miscellaneous crops, forest, nursery and greenhouse products, horse and mule services, and other agricultural services.

Commodity groups are numbered 1 through 9, while k designates regions (k = 0, 1, 2, ... 10). Zero denotes a national group and 1, 2, ... 10 denote regional groups. For example, 1.1 denotes livestock (product 1) in the Northeast (region 1); livestock in the United States is denoted by 0.1. Although there are 90 possible sectors in the agricultural section of the model, cotton production is negligible in regions 1, 3 and 8, and tobacco is not produced in regions 6, 7, 8, 9 and 10. Hence, the agricultural economy is reduced to 82 sectors after deleting these 8 sectors.

Industry or nonfarm sectors have been aggregated on a national basis only. The major groupings of these sectors are: sectors 0.10 through 0.17 which include industries processing agricultural products; sectors 0.18 through 0.21 which are industries furnishing inputs directly to agriculture; and sector 0.22 which is an aggregation of all industries not mentioned above and furnishes inputs only indirectly to agriculture. It is obvious that the model gives greatest detail for resource requirements of one agricultural region on another agricultural sector and does not reflect requirements or "demand" for labor, either within or among agricultural sectors. The aggregations of sectors 0.10 through 0.22 can be summarized as follows:[3]

0.10 Meat and poultry processing — meat packing and prepared meats, products from poultry dressing plants and poultry products involving minor processing.

0.11 Dairy products — creamery butter, natural cheese, concentrated milk, ice cream and ices, special dairy products and fluid milk.

0.12 Grain processing — flour and meal, cereal preparations, rice cleaning and blended and prepared flours.

0.13 Prepared feeds — livestock feeds from mixers and manufacturers.

0.14 Miscellaneous food processing — miscellaneous food preparations, beverages, bakery and related products and confectionery and related products.

0.15 Vegetable and fruit processing — canned and frozen fruits and vegetables, and fruits and vegetables with minor processing.

0.16 Tobacco manufacturing — cigarettes, cigars, chewing and smoking tobacco and tobacco stemming and redrying.

0.17 Textile products — woolen and worsted manufacturing, cotton and rayon textiles, carpets, rugs and miscellaneous textile goods.

0.18 Fertilizers — fertilizer and fertilizer mixing.

0.19 Chemical products — chemicals, paints and varnishes, soap and related products, drugs and medicines and vegetables and animal oils.

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[3] Added detail on these and other points can be found in Carter and Heady, Iowa Agr. Exp. Sta. Bul. No. 469. 1959. op. cit.

0.20 Machinery and related services — tractors, farm machinery, motor vehicles and related services.

0.21 Petroleum products — gasoline, oil and grease.

0.22 All other industries — This sector includes all other products not listed above. The major products purchased by agriculture are wholesale and retail trade, transportation, veterinary services and miscellaneous supplies.

The over-all model outlined above and emphasizing regional and commodity sectors of agriculture, since previous chapters better relate agriculture to specific nonfarm sectors in terms of behavioral variables related to resource demand, gives rise to a transaction matrix with a possible order of 103. Matrices of resource requirements and interdependence coefficients of like order are possible. Because of lack of space not all data generated from the 103-order model will be presented. If we consider the flow or transactions matrix to be T and referring back to A, the matrix of input-output or per unit resource requirements, then the submatrices T^{s}_{gk} and A^{s}_{gk} can be formed where the rows in the submatrices define the requirements of the several commodity sectors in the k-th region for inputs from the commodity sectors in the g-th region. ($g, k = 1, 2, \ldots 10$.) Except for $g = k$ and for "demands" of regional agricultural sectors for resources from industrial sectors, the greatest number of these submatrices are filled with zero elements. Hence, we summarize the total intersector flow of resources and their services in the manner of Table 17.1. In the limited sense of input-output analysis, the data show the total flow of resources from the input-supplying sectors to the commodity and regional sectors of agriculture. In contrast to earlier notation, however, the rows represent the commodity and regional "demanding" sectors (j) while the columns represent the regional "supplying" sectors (i) between which flows of resources take place. (Effectively, except for aggregation of commodity supplying sectors within regions, and the deletions mentioned below, Table 17.1 represents the transform of matrix A. The commodity "supplying" sectors of agriculture have been kept separate.) The elements which define flows of inputs from agricultural sectors to processing sectors are not shown, as also is true for all elements connecting columns of industrial sectors with agricultural supplying sectors.

The data of Table 17.1 show the estimated net flow of inputs from other regional sectors, as well as industrial sectors, to a particular commodity sector within a region. Hence, for the livestock sector (row 1.1) in the Northeast, a total of $692.4 million in inputs (largely feed) flows to this sector from other sectors within the region. The Northeast (row 1.1) has $12 million in inputs drawn from the Corn Belt. Similarly, the livestock sector in each "requiring" region is estimated to have the greatest (of all sectors within a "demanding" region) requirement for inputs of "supplying" regions (usually feed and livestock

Table 17.1. Inputs Drawn by Commodity Sectors (Rows) From Various Regions and Industries (Columns); Million Dollars, 1954

Sector (j)	1.N.E.	2.C.B.	3.Lake	4.Appal.	5.S.E.	6.Delta	7.S.P.	8.N.P.	9.Moun.	10.Pac.	0.18	0.19	0.20	0.21	0.22
1.1	692.4	12.0	3.4	6.1	--	--	--	12.9	--	--	--	8.4	53.2	12.0	269.5
1.2	24.0	--	--	--	--	--	--	--	--	--	24.7	.4	75.5	11.2	38.3
1.3	11.0	--	--	--	--	--	--	--	--	--	7.3	.3	17.2	3.7	13.5
1.4	48.7	--	--	--	--	--	--	--	--	--	15.4	.5	69.9	9.9	33.6
1.5	32.8	--	--	--	--	--	--	--	--	--	29.2	16.8	69.6	12.7	57.0
1.7	1.1	--	--	--	--	--	--	--	--	--	2.4	.3	6.4	1.0	5.5
1.8	1.6	--	--	--	--	--	--	--	--	--	1.6	--	2.0	.6	2.4
1.9	39.6	--	--	--	--	--	--	--	--	--	1.0	.7	21.6	5.6	19.1
2.1	--	2688.4	--	2.1	--	--	48.3	181.3	45.0	--	--	16.0	92.6	20.9	422.4
2.2	--	82.5	--	--	--	--	--	--	--	--	138.9	1.7	422.2	70.7	688.0
2.3	--	34.4	--	--	--	--	--	--	--	--	29.5	.6	42.2	8.8	113.6
2.4	--	80.5	--	--	--	--	--	--	--	--	16.1	1.3	84.2	13.0	159.0
2.5	--	10.4	--	--	--	--	--	--	--	--	4.2	4.1	15.4	5.4	19.9
2.6	--	5.8	--	--	--	--	--	--	--	--	2.5	.2	6.2	2.3	11.6
2.7	--	.1	--	--	--	--	--	--	--	--	.8	--	.7	.2	1.5
2.8	--	41.6	--	--	--	--	--	--	--	--	5.6	.1	78.8	14.0	152.4
2.9	--	36.3	--	--	--	--	--	--	--	--	.8	.6	9.0	3.6	14.2
3.1	--	.7	1122.0	--	--	--	--	19.8	11.0	--	--	7.4	55.1	12.6	196.0
3.2	--	--	45.5	--	--	--	--	--	--	--	37.5	1.5	203.6	31.7	174.4
3.3	--	--	10.9	--	--	--	--	--	--	--	5.6	.3	15.9	3.4	21.7
3.4	--	--	51.2	--	--	--	--	--	--	--	5.7	.4	68.2	9.7	64.5
3.5	--	--	12.0	--	--	--	--	--	--	--	7.6	5.9	30.3	6.6	29.9
3.8	--	--	11.8	--	--	--	--	--	--	--	1.3	--	28.9	4.9	26.4
3.9	--	--	20.5	--	--	--	--	--	--	--	1.1	.3	19.1	4.7	14.1
4.1	--	26.9	--	583.0	--	--	10.7	--	--	--	--	5.4	40.0	9.4	131.7
4.2	--	--	--	56.1	--	--	--	--	--	--	50.8	.5	74.1	13.9	92.5
4.3	--	--	--	10.9	--	--	--	--	--	--	5.2	.4	9.4	2.3	15.7
4.4	--	--	--	56.7	--	--	--	--	--	--	18.2	.4	41.6	7.6	49.4
4.5	--	--	--	16.7	--	--	--	--	--	--	12.0	4.8	19.3	4.8	20.7
4.6	--	--	--	22.2	--	--	--	--	--	--	9.8	2.0	20.0	4.5	23.9
4.7	--	--	--	8.9	--	--	--	--	--	--	22.9	4.3	47.1	10.3	63.9
4.8	--	--	--	14.3	--	--	--	--	--	--	3.2	--	16.1	3.5	16.7
4.9	--	--	--	94.9	--	--	--	--	--	--	.7	2.7	13.3	3.4	11.3
5.1	--	--	--	--	333.0	--	5.8	--	--	--	--	4.5	18.7	4.6	94.7
5.2	--	--	--	--	43.8	--	--	--	--	--	43.1	.4	48.5	10.5	56.9
5.3	--	--	--	--	2.3	--	--	--	--	--	1.2	.1	1.4	.6	2.6
5.4	--	--	--	--	17.5	--	--	--	--	--	20.0	.2	4.8	1.0	15.1
5.5	--	--	--	--	35.3	--	--	--	--	--	36.8	9.0	42.0	9.9	50.2
5.6	--	--	--	--	42.8	--	--	--	--	--	23.4	5.6	30.9	7.2	44.0
5.7	--	--	--	--	1.6	--	--	--	--	--	4.2	1.4	6.5	1.5	11.4

5.8	--	--	--	--	18.1	--	--	--	--	--	4.2	--	14.0	3.2	12.4
5.9	--	--	--	--	63.4	--	--	--	--	--	.9	2.4	15.1	3.7	13.7
6.1	--	49.9	--	--	--	142.2	--	--	--	--	--	3.1	11.0	3.0	62.5
6.2	--	--	--	--	--	20.1	--	--	--	--	13.9	.4	25.4	6.8	33.8
6.3	--	--	--	--	--	11.2	--	--	--	--	4.6	.4	15.9	4.1	19.3
6.4	--	--	--	--	--	17.1	--	--	--	--	4.1	.2	8.5	2.3	11.9
6.5	--	--	--	--	--	5.8	--	--	--	--	3.1	1.1	4.6	1.9	8.1
6.6	--	--	--	--	--	81.5	--	--	--	--	28.6	12.2	63.6	16.6	85.6
6.8	--	--	--	--	--	11.1	--	--	--	--	.3	--	9.2	2.7	12.9
6.9	--	--	--	--	--	45.6	--	--	--	--	1.7	1.2	11.5	3.2	11.7
7.1	--	8.7	--	--	--	--	347.0	27.6	65.7	--	--	4.0	22.0	5.6	130.8
7.2	--	--	--	--	--	--	26.7	--	--	--	7.4	.5	87.5	17.4	79.1
7.3	--	--	--	--	--	--	41.1	--	--	--	4.9	.7	51.8	11.0	70.2
7.4	--	--	--	--	--	--	27.9	--	--	--	6.7	.3	19.1	3.7	18.9
7.5	--	--	--	--	--	--	6.4	--	--	--	2.5	.8	13.6	4.0	13.8
7.6	--	--	--	--	--	--	7.1	--	--	--	7.3	5.1	87.6	17.5	99.8
7.8	--	--	--	--	--	--	4.8	--	--	--	.9	--	5.3	2.0	3.5
7.9	--	--	--	--	--	--	17.2	--	--	--	1.1	1.4	4.9	1.7	8.9
8.1	--	--	--	--	--	--	24.8	1030.1	119.3	.5	--	5.4	33.2	8.1	137.5
8.2	--	--	--	--	--	--	--	58.3	--	--	16.6	1.4	215.6	36.2	237.2
8.3	--	--	--	--	--	--	--	103.8	--	--	8.3	2.1	116.4	21.3	195.9
8.4	--	--	--	--	--	--	--	91.3	--	--	3.0	.7	75.0	11.7	103.4
8.5	--	--	--	--	--	--	--	2.8	--	--	.5	.5	1.1	2.1	5.0
8.8	--	--	--	--	--	--	--	10.8	--	--	.2	.1	21.0	4.1	35.2
8.9	--	--	--	--	--	--	--	19.8	--	--	.7	.3	6.7	3.0	9.4
9.1	--	--	--	--	--	--	--	3.7	592.1	--	--	2.1	17.0	4.3	97.0
9.2	--	--	--	--	--	--	--	--	19.7	--	3.7	.9	44.6	8.1	47.7
9.3	--	--	--	--	--	--	--	--	39.8	--	1.6	2.0	47.8	9.6	82.7
9.4	--	--	--	--	--	--	--	--	46.1	--	3.9	1.6	70.2	12.2	57.7
9.5	--	--	--	--	--	--	--	--	13.4	--	3.1	2.1	22.5	5.2	23.9
9.6	--	--	--	--	--	--	--	--	19.3	--	4.5	2.9	12.7	3.0	20.6
9.8	--	--	--	--	--	--	--	--	.3	--	--	--	.5	.4	1.3
9.9	--	--	--	--	--	--	--	--	23.7	--	3.8	.8	20.4	4.4	17.0
10.1	--	--	--	--	--	--	30.8	27.7	80.1	464.8	--	3.4	17.9	4.4	149.7
10.2	--	--	--	--	--	--	--	--	--	15.2	7.3	2.3	37.9	6.6	76.5
10.3	--	--	--	--	--	--	--	--	--	20.6	7.5	2.3	23.5	4.7	71.2
10.4	--	--	--	--	--	--	--	--	--	22.3	8.7	2.4	38.4	6.1	58.5
10.5	--	--	--	--	--	--	--	--	--	65.0	20.8	19.0	123.3	22.3	131.1
10.6	--	--	--	--	--	--	--	--	--	24.5	7.9	3.1	15.1	3.2	30.5
10.8	--	--	--	--	--	--	--	--	--	.2	.4	--	.2	.4	1.2
10.9	--	--	--	--	--	--	--	--	--	14.5	5.8	3.1	22.0	4.7	25.5

for breeding and feeding purposes). Some seed inputs also flow among regions but the quantities were either too small to be presented, were impossible to estimate or were included with feed grains. The major intersector flows of inputs within agriculture are those among regions within a particular sector.

Aside from livestock, the major agricultural sectors drawing inputs from other sectors within the same region are feed grains, food grains, forage crops and cotton. Aside from livestock, and its heavier draw on inputs from other sectors within the same region and from other regions, Table 17.1 suggests the heavy dependence of agriculture on inputs from nonfarm sectors in an economy at a high stage of economic growth. The magnitude of farm inputs drawn from the industrial sectors (columns 0.18 through 0.22) completely overshadows the interregional and intraregional flow of inputs among sectors — except for feed and feeding stock for the livestock sectors. Development of policy which extends the demand for products of one region has, aside from livestock products, no important "spill over" to other regions in the sense of requiring large resource inputs drawn from farms of "outside" regions. The absolute "spill over" is much greater to the industrial sectors which furnish capital inputs to agriculture, in comparison with other sectors in the same region.

INPUT REQUIREMENT COEFFICIENTS

The number of possible technical coefficients in matrix A is 10,609; the number for the agricultural sectors on each other (the agricultural section of A) is 6,724. Hence, rather than present all of these, we present only aggregate input-output or requirements coefficients for the regional agricultural sectors. These are formed by adding the several commodity flows (the individual commodity sectors) from the g-th region to the k-th region and dividing them by the sum of commodity outputs in the k-th region. The result is a requirement or technical coefficient which shows the composite resource input flowing from the g-th region to produce a unit of output (one dollar) in the k-th region. The resource requirements of the k-th agricultural sector for inputs from two aggregate industrial sectors is repeated for comparison purposes. For identification, industrial sector I includes prepared feed, fertilizers, chemical products, machinery and related products and petroleum products. Industrial sector II includes all other resource services used by agriculture including "pure durables," operating expense items and transportation service. For purposes of clarity, and with columns added for the three aggregate industrial sectors, the matrix corresponding to Table 17.2 can be indicated as $\overline{A}$ to distinguish it from the larger and more detailed input-output matrix A from which Table 17.1 is drawn. Hence, the inverse of $\overline{A}$ is $\overline{B}$.

The elements in Table 17.1, showing estimates of the direct resource requirements of (a) the k-th region on (b) the g-th region and

Table 17.2. Matrix $\bar{A}$: Requirements Coefficients for the k-th Agricultural Region on the g-th Region and on Aggregates of Industrial Sectors, 1954*

Agricultural Regions (g) and Industrial Sectors	Agricultural Region (k)									
	1 North-east	2 Corn Belt	3 Lake States	4 Appal. States	5 South-east	6 Delta States	7 S. Plains	8 N. Plains	9 Moun. States	10 Pacific States
1	.22612	--	--	--	--	--	--	--	--	--
2	.00319	.29053	.00018	.00725	--	.02396	.00276	--	--	--
3	.00090	.00033	.30210	--	--	--	--	--	--	--
4	.00162	.00021	--	.23295	--	--	--	--	--	--
5	--	--	--	--	.20487	--	--	--	--	--
6	--	--	--	--	--	.16074	--	--	--	--
7	--	.00471	--	.00287	.00213	--	.17270	.00579	--	.00765
8	.00342	.01768	.00470	--	--	--	.00878	.30698	.00141	.00688
9	--	.00439	.00261	--	--	--	.02092	.02782	.28990	.01986
10	--	--	--	--	--	--	--	.00012	--	.15559
I†	.30137	.15573	.17937	.19690	.20392	.18759	.19868	.16707	.15950	.17423
II‡	.11664	.15432	.12506	.11483	.11053	.11815	.13538	.16874	.13370	.13502

*Elements in matrix show direct purchases from the region and nonfarm sector indicated at the left by the agricultural region indicated at the top.

†Includes sectors 0.13, 0.18, 0.19, 0.20 and 0.21 explained in the text.

‡Includes sector 0.22 explained in the text.

the two aggregate industrial sectors for 1954, indicate the magnitude of inputs which are drawn from (g) to produce a unit (dollar) of product in (k). The large direct resource requirements are for one region on itself (g = k). Even then, the requirements of agriculture on at least one of the two industrial sectors is greater than the requirements of the agricultural region on itself for the Northeast, Delta, Southern Plains and Pacific regions. When the requirements of one agricultural region on all other agricultural regions are summed, they are smaller than the sum of requirements by each agricultural region on the two aggregate industrial sectors — as expected from the discussion in Chapter 2. Even in the Corn Belt, with large "demand" for livestock and feed inputs from agricultural sectors, the sum of these requirements is only .3178, as compared to direct requirements of .3100 for the Corn Belt on aggregate industrial sectors I and II. In the Northern Plains where crop production rests less on chemicals such as fertilizer, and livestock production largely is from forage within the region, the sum of direct requirements against agricultural regions is .3407 of farm inputs per $1 of product produced while the corresponding direct input requirement on the two industrial sectors is .3358. The two figures are nearly equal for the Lake States and the Mountain States. The corresponding requirements of an agricultural region on (a) all agricultural regions and (b) the aggregate on industrial sectors are, respectively, .2353 and .4180 for the Northeast; .2052 and .3341 for the Southern Plains; .2060 and .3144 for the Southeast; .1910 and .3092 for the Pacific; and .1847 and .3057 for the Delta States.

TOTAL AND INDIRECT REQUIREMENTS

The requirement or technical coefficients serve only as estimates to indicate the direct requirements on the g-th farm region or industrial sector as output of the k-th region is increased. An <u>indirect</u> or circular "demand" for output of a particular sector also arises as output of another sector or region increases. The total of direct (Table 17.2) and indirect effects, representing the sum of "demand" for the product of a sector as output of another sector increases, can be illustrated by use of a simple two-sector model where Y_1 and Y_2 are the quantities delivered to final or consumer demand by sectors 1 and 2, X_1 and X_2 are the outputs of these two sectors and a_{ij} is the technical coefficient explained above. In addition to the direct output drawn from sector 1 as Y_1 is increased, sector 1 also needs to produce output to serve as inputs for both sectors 1 and 2, to an extent that X_1 requires some of X_2 as an input and X_2 requires some of X_1. Similarly, sector 2 must not only produce a quantity to be represented in Y_2, but also to serve as input in X_2 and X_1. Hence, sector 2 must produce, in addition to Y_2, an indirect amount equal to $a_{21}Y_1 + a_{22}Y_2$ for these "circular purposes." These additions, the indirect additions explained above, are considered to be first-round requirements or effects. Total circular or indirect requirements are derived as the sum of the second-round, third-round, fourth-round, etc., requirements. Second-round requirements for X_1 and X_2 are additional gross output generated from first-round requirements. Algebraically, second-round requirements for X_1 and X_2 are given in equations (17.9) and (17.10) respectively.

$$X_1^{(2)} = a_{11}X_1^{(1)} + a_{12}X_2^{(1)} = a_{11}(a_{11}Y_1 + a_{12}Y_2) + a_{12}(a_{21}Y_1 + a_{22}Y_2) \tag{17.9}$$

$$X_2^{(2)} = a_{21}X_1^{(1)} + a_{22}X_2^{(1)} = a_{21}(a_{11}Y_1 + a_{12}Y_2) + a_{22}(a_{21}Y_1 + a_{22}Y_2) \tag{17.10}$$

where the exponent in parentheses denotes the "round" of input requirements.

The third-round requirements (i.e., the additional gross output generated from second-round requirements) are:

$$X_1^{(3)} = a_{11}X_1^{(2)} = a_{12}X_2^{(2)} = a_{11}\Big[(a_{11}Y_1 + a_{12}Y_2) + a_{12}(a_{21}Y_1 + a_{22}Y_2)\Big] + a_{12}\Big[a_{21}(a_{11}Y_1 + a_{12}Y_2) + a_{22}(a_{21}Y_1 + a_{22}Y_2)\Big] \tag{17.11}$$

$$(17.12)\quad X_2^{(3)} = a_{21}X_1^{(2)} + a_{22}X_2^{(2)} = a_{21}\Big[a_{11}(a_{11}Y_1 + a_{12}Y_2) + a_{12}(a_{21}Y_1 + a_{22}Y_2)\Big] + a_{22}\Big[a_{21}(a_{11}Y_1 + a_{12}Y_2) + a_{22}(a_{21}Y_1 + a_{22}Y_2)\Big]$$

Continuing with this procedure, the r-th round is derived from the r-1 round as follows:

$$(17.13)\quad X_1^{(r)} = a_{11}X_1^{(r-1)} + a_{12}X_2^{(r-1)}$$

$$(17.14)\quad X_2^{(r)} = a_{21}X_1^{(r-1)} + a_{22}X_2^{(r-1)}$$

Summing rounds 1 to infinity and factoring out Y yields the final mangitudes (17.15) and (17.16),

$$(17.15)\quad X_1^r = (1 + a_{11} + a^2_{11} + a_{12}a_{21} + a^3_{11} + 2a_{11}a_{12}a_{21} + a_{12}a_{22}a_{21} + \ldots)\,Y_1 + (a_{12} + a_{11}a_{12} + a_{12}a_{22} + a^2_{11}a_{12} + a_{11}a_{12}a_{22} + a^2_{12}a_{21} + a^2_{22}a_{12} + \ldots)\,Y_2 = A_{11}Y_1 + A_{12}Y_2$$

$$(17.16)\quad X^r_2 = (a_{21} + a_{21}a_{11} + a_{22}a_{21} + a_{21}a^2_{11} + a^2_{21}a_{12} + a_{22}a_{21}a_{11} + a^2_{22}a_{21})\,Y_1 + (1 + a_{22} + a_{21}a_{12} + a^2_{22} + a_{21}a_{11}a_{12} + 2a_{21}a_{12}a_{22} + a^3_{22} + \ldots)\,Y_2 = A_{21}Y_1 + A_{22}Y_2$$

of the X_i, including the proportions represented both in the final or consumer demand, Y_i, and as inputs, x_{ij}, for the X_j. We are interested especially in the latter as part of the resource "demand" structure of agriculture. Hence, the matrix of relevant interdependency coefficients $\overline{B}$ to correspond with $\overline{A}$ for Table 17.2 is (except for two columns) provided in Table 17.3. With the direct requirements shown in Table 17.2, the sums of direct and circular requirements are shown in Table 17.3 and include the various "stages of indirect" requirements illustrated above. The elements in Table 17.3 show the gross output required in each agricultural region or industrial sector named at the left for a $1 increase in final demand for the region or sector indicated in the column and expresses both the direct and indirect effects. The services of resources used in agriculture were valued at 1954 market prices. (Since some resources in agriculture receive less than market prices, the sum of requirements exceeds the value of the unit of product.) Hence, a $1 increase in output for final demand from the agricultural processing sector (through which most of agricultural products

Table 17.3. Matrix $\overline{B}$: Interdependence Coefficients Expressing Direct and Indirect "Demands" Among Regional Agricultural Sectors, 1954

	Agricultural Regions (k)										Agricultural Processing Sector
Region (g) or Sector	1 North-east	2 Corn Belt	3 Lake States	4 Appal. States	5 South-east	6 Delta States	7 S. Plains	8 N. Plains	9 Moun. States	10 Pacific States	III ‡
1	1.29475	.00196	.00204	.00184	.00173	.00164	.00188	.00225	.00191	.00172	.06269
2	.01928	1.41862	.01014	.02263	.00897	.04851	.01390	.01025	.00886	.00825	.15302
3	.00567	.00351	1.43589	.00281	.00267	.00251	.00281	.00322	.00277	.00253	.06762
4	.00551	.00240	.00213	1.30567	.00186	.00176	.00198	.00230	.00197	.00179	.05281
5	.00230	.00165	.00174	.00162	1.25920	.00144	.00162	.00187	.00160	.00147	.03778
6	.00207	.00140	.00151	.00143	.00138	1.19280	.00142	.00158	.00137	.00127	.02317
7	.00301	.01030	.00223	.00664	.00519	.00204	1.21092	.01239	.00199	.01284	.04018
8	.01091	.03910	.01297	.00344	.00296	.00374	.01855	1.44661	.00580	.01469	.06020
9	.00267	.01208	.00746	.00190	.00168	.00178	.03793	.05879	1.41003	.03544	.04319
10	.00277	.00208	.00217	.00198	.00186	.00176	.00201	.00258	.00203	1.18609	.06265
I*	.55243	.33461	.37292	.37022	.36519	.32879	.35760	.36909	.32627	.31155	.23448
II†	.56233	.54855	.50184	.45425	.43073	.42168	.47719	.61010	.48577	.44431	.46126

*Same as sector I in Table 17.2.

† Same as sector II in Table 17.2.

‡ Includes sectors 0.10, 0.11, 0.12, 0.14, 0.15, 0.16 and 0.17 explained in text.

flow to final consuming sectors) is estimated to require (in direct, indirect and circular effects) .6033 of $1 of outputs from the 10 agricultural regions and .6957 of $1 from the two aggregate industrial sectors which supply inputs to agriculture. These figures again emphasize the structural nature of agriculture in a developed economy, with value of inputs from industrial sectors exceeding the sum of all inputs from agricultural sectors to produce $1 of processed products for final demand (with the agricultural product itself included in the latter). Over 25 percent, or $.15 of outputs induced from agricultural regions as a result of a flow of $1 of product from the agricultural processing sector to final demand comes from the Corn Belt. The corresponding figure hardly exceeds 10 percent from other individual regions.

Including the indirect effects in expressing requirements on regions and sectors for inputs further emphasizes the lack of "economic tie" between regions, with the interrelationship of an agricultural region being much more with itself and with the industrial sectors which furnish resource inputs to agriculture. In a more "universal sense" relative to all other regions, the Mountain region tends to be second to the industrial sectors in providing inputs to other regions. The inputs required from the Mountain region, with $1 of product moving to final demand from other regions, is .04 for the Southern Plains, .06 for the Northern Plains, .04 for the Pacific States. However, the Corn Belt, with movement of $1 in products to final demand, has a requirement of .04 on the Northern Plains (mainly for feeder stock), and the Delta region has a requirement of .05 on the Corn Belt (mainly for feed). Other coefficients, comparing regions with product flowing to final demand against other agricultural regions furnishing farm products as inputs for the former, equal to or exceeding .01, are almost entirely for grain as livestock feed. These are small interregional dependence coefficients and are dwarfed entirely by the magnitude of the interdependence coefficients of the k-th agricultural regions on industrial sectors in aggregate.

For the complete model, the interdependence coefficients (based on matrices A and B) are even smaller for the j-th agricultural commodity sector (in reflecting "demand" for inputs, from the i-th agricultural commodity sector) as compared to "demand" for inputs of an agricultural sector against the several industrial sectors defined earlier in the text. (Of course, comparable coefficients perhaps would require disaggregating an industrial sector such as chemicals into plant insecticides, animal medicines, etc.) On the detailed basis of agricultural commodity sectors, the requirements of a livestock sector on feed grain and forage sectors within the same region are much higher than the interdependence coefficients connecting the k-th "demanding" and the g-th "supplying" regions ($g \neq k$) in Table 17.3. Also, the coefficient of livestock of the k-th region against grain or feeder stock of the g-th region ($g \neq k$) also tends to be relatively large. The interdependence coefficients, based on the complete 103-order matrix B, are provided in Table 17.4 for the livestock sector in the k-th region against the

Table 17.4. Interdependence Coefficients of Regional (k) Livestock Sectors With Livestock and Feed Grain Sectors of Other Regions (g); From Matrix B, 1954

Region (g) and Sector	Livestock Sector by Regions (k)									
	1.N.E.	2.C.B.	3.Lake	4.Appal.	5.S.E.	6.Delta	7.S.P.	8.N.P.	9.Moun.	10.Pac.
1. 1. stock	1.0618	.0008	.0007	.0011	.0011	.0011	.0011	.0007	.0008	.0011
1. f. grain	.1297	.0012	.0010	.0023	.0026	.0027	.0025	.0010	.0013	.0026
2. 1. stock	.0034	1.0583	.0021	.0028	.0028	.0028	.0027	.0020	.0020	.0027
2. f. grain	.0336	.3808	.0083	.0387	.0201	.1143	.0270	.0077	.0010	.0206
3. 1. stock	.0031	.0015	1.0422	.0012	.0012	.0012	.0011	.0008	.0008	.0012
3. f. grain	.0056	.0020	.3254	.0033	.0037	.0038	.0035	.0015	.0019	.0037
4. 1. stock	.0037	.0008	.0004	1.0473	.0006	.0006	.0006	.0004	.0004	.0006
4. f. grain	.0012	.0003	.0002	.2561	.0003	.0003	.0003	.0002	.0002	.0003
5. 1. stock	.0004	.0003	.0002	.0004	1.0640	.0004	.0004	.0003	.0003	.0004
5. f. grain	.0010	.0004	.0003	.0067	.2557	.0007	.0007	.0003	.0004	.0003
6. 1. stock	.0003	.0002	.0002	.0003	.0003	1.0552	.0002	.0001	.0002	.0002
6. f. grain	.0009	.0003	.0003	.0006	.0007	.1288	.0006	.0003	.0003	.0007
7. 1. stock	.0010	.0110	.0007	.0094	.0079	.0007	1.0550	.0152	.0006	.0252
7. f. grain	.0033	.0027	.0010	.0034	.0035	.0025	.1620	.0031	.0012	.0061
8. 1. stock	.0075	.0383	.0100	.0010	.0010	.0010	.0009	1.0657	.0007	.0063
8. f. grain	.0096	.0142	.0051	.0050	.0057	.0057	.0310	.3225	.0067	.0243
9. 1. stock	.0014	.0142	.0069	.0014	.0012	.0008	.0689	.0787	1.1588	.0723
9. f. grain	.0009	.0017	.0009	.0006	.0007	.0006	.0075	.0081	.1172	.0078
10. 1. stock	.0015	.0005	.0005	.0008	.0008	.0008	.0007	.0008	.0005	1.0594
10. f. grain	.0013	.0005	.0004	.0001	.0011	.0011	.0010	.0004	.0005	.0657

livestock and feed grain sectors in the g-th region. (The coefficients along the diagonal exceed unity because $1 in sales not only requires this amount of livestock, but also requires inputs of breeding and feeder stock from the same area.) Again, however, the interdependence coefficient of the j-th agricultural commodity sector against the i-th sector is, except for the two sectors in Table 17.4, much smaller when the latter is an agricultural sector than when it is an industrial sector, even with the degree of aggregation considerably smaller than in 0.13 through 0.22.

SUMMARY OF SOME INPUT INTERDEPENDENCE AMONG REGIONS

In terms of the magnitude of interregional interdependence coefficients, the Northern Plains was most dependent upon other agricultural regions (Table 17.3) for inputs to service its outputs. A $1 increase in agricultural products of this region delivered to final demand generated 9.5 cents of agricultural output in other regions to serve as inputs in the former. Of this, the Mountain States accounted for 5.9 cents or 62 percent of the increase in inputs so generated. Each $1 of Northern Plains livestock products delivered outside the system generated in the Mountain States: 7.9 cents of livestock output and .8 cents of grain output (Table 17.4). Likewise, 1.5 cents of livestock in the Southern Plains was associated with each $1 of Northern Plains livestock products. A strong two-way dependence is shown between the Northern and Southern Plains. The Southern Plains required feed grains from the Northern Plains, while the Northern Plains purchased feeder animals from the Southern Plains.

Also, agriculture in the Southern Plains showed a high dependency upon other regions. A $1 delivery to final demand of livestock products in the Southern Plains required 3.1 cents from feed grains in the Northern Plains, 6.9 cents and .8 cents from livestock and grain, respectively, in the Mountain States. These individual flows, traced back through the model, indicate that an increase in output of feed grains (2.0 cents) in the Corn Belt (sector 2.1) consisted primarily of direct flows to livestock in the Southern Plains and indirect flows to prepared feeds (sector 0.13) eventually purchased in region 7. Similarly, feed grains requirement in the Northern Plains (sector 8.2) is divided into direct and indirect flows. Purchases by the Southern Plains from the Mountain States (sector 9.1) were mainly feeder cattle and sheep. Increases in forage output in the Mountain States, as reflected in aggregations and specifications of the particular model, resulted from the increased requirements of feeder animals subsequently shipped to the Southern Plains.

Each $1 of agricultural products delivered to final demand from the Pacific States generated 8 cents of agricultural output in other regions to serve as inputs in region 10. The largest tie-up is with agriculture in the Mountain States. Each $1 of livestock products (sector 10.1), delivered to final demand, directly and indirectly required 2.1 cents of feed grain from the Corn Belt (sector 2.2), 2.5 cents of livestock from the Southern Plains (sector 7.1), 7.2 cents of livestock from the Mountain States (sector 9.1) and 2.0 cents of forage crops from the Mountain States (sector 9.4). The induced output of 2.1 cents from feed grains in the Corn Belt consisted chiefly of direct feed grain shipments to prepared feeds (sector 0.13) which, in turn, were purchased for (a) livestock in region 10 and (b) feeder livestock raised in other regions and purchased in region 10.

Agriculture in the southeastern section of the United States (regions 4, 5 and 6) also is dependent upon feed grain production in the Corn Belt. A $1 delivery of livestock products from the Appalachian region to final demand requires an increase in output of 3.9 cents of feed grains in the Corn Belt (sector 2.2). A $1 delivery of livestock products in the Southeast (sector 5.1) to final demand requires 2.0 cents of feed grains in the Corn Belt (sector 2.2), as reflected in both direct and indirect or induced flows of inputs. A $1 delivery of livestock in the Delta States (sector 6.1) similarly requires 11.4 cents of feed grains in the Corn Belt (sector 2.2).

The Corn Belt again, in both direct and indirect flows of inputs, has a relatively large dependence on livestock production in the Great Plains (regions 7 and 8) and Mountain States (region 9). One dollar of livestock products in the Corn Belt delivered to final demand required livestock output of 1.1 cents in the Southern Plains (sector 7.1), 3.8 cents from livestock in the Northern Plains (sector 8.1) and 1.4 cents from livestock in the Mountain States (sector 9.1).

We also can summarize the indirect or induced outputs from agricultural regions and sectors as a result of changes in demand for the products of agricultural processing sectors (e.g., "finished" products from farms moving to consumers).[4] A $1 increase in the demand for meat and poultry products (sector 0.10) generates, under the restrictions and model limitations mentioned above, $1.09 of total gross output in agriculture and 73 cents in industries furnishing inputs to agriculture. Of this $1.09, 39.5 cents, or 35 percent of the total, is generated in the Corn Belt. In contrast, only 2.8 cents is generated in the Delta States. The majority of the increase in gross output in each region, to serve as inputs for the agricultural processing and other agricultural sectors, resulting from a $1 increase in consumption of meat and poultry products, is in livestock and feed crop sectors. Output generated in livestock and feed grain sectors of the Corn Belt (sectors 2.1 and 2.2) was 25.9 and 10.3 cents, respectively, as demand for meat and poultry products is increased by $1. Gross output of feed grains generated in the Corn Belt, required to produce the livestock generated in other regions, is greater than the total increase in livestock generated

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[4] Not all details are shown here but can be found in Carter and Heady, Iowa Agr. Exp. Sta. Bul. No. 469. 1959. op. cit.

in all regions. Most Corn Belt feed grains are consumed by livestock within the region. However, the prepared feeds industry (sector 0.13) purchases large quantities of corn from the Corn Belt that subsequently flow to livestock in other regions. Too, the Corn Belt, a surplus feed grain region, makes direct shipments of corn to deficit feed grain regions.

Gross output generated in the Northern Plains, for each $1 of meat and poultry products delivered to final demand, was 14.7 cents, second only to the Corn Belt. Correspondingly, gross output induced was 11.4 cents in the Lake States and 8.8 cents in the Northeast. As a group, the Southeast regions of the United States (regions 4, 5 and 6) generated gross output of 14.6 cents for each additional dollar of meat and poultry products delivered to final demand. The parallel increase in agricultural output was 60 cents in the Northeastern regions (regions 1, 2 and 3), 21 cents in the Great Plains (regions 7 and 8) and 13 cents in the Western States (regions 9 and 10).

The $1 change in final demand for meat and poultry products has the effect of inducing 11.0 cents of output from the machinery sector to flow as inputs to agricultural sectors. The induced output in the prepared feed industry (sector 0.13) is 9.8 cents. Output induced in the fertilizer industry, per $1 of meat and poultry products delivered to final demand, is estimated at 1.8 cents. Fertilizer use is associated with crop production, an indirect effect following from the need of livestock for grains and forages. Hence, fertilizer production is indirectly related to demand for processed meat products.

A $1 increase in final demand for dairy products (sector 0.11) generates a total of 91.6 cents of gross output in agriculture and 67.7 cents of gross output in industries providing agricultural inputs. The largest increase, or the greatest proportion of the 67.7 cents total, is generated in the dairy areas of the Lake States, Northeast and Corn Belt. The required increases in output, per $1 of dairy products delivered to final demand, are 19.3 cents in the Lake States, 18.7 cents in the Northeast and 18.3 cents in the Corn Belt. In the Northeast, 14.4 cents of the output is from the livestock sector and 1.8 cents from the feed grain sector. In contrast, 11.1 cents is from the feed grain sector and 5.1 is from the livestock sector in the Corn Belt. The increase of feed grains in the Corn Belt is entirely an indirect transaction. Feed grain flows to livestock sectors within and outside the regions and also to prepared feeds (sector 0.13). However, the majority of the increase in the livestock sectors of the Corn Belt is a direct transaction. The Pacific States show the largest increase in gross output, of the Plains and Western States, associated with a $1 increase in final demand for dairy products. Most of the required increase (6.1 cents out of 8.3 cents) is in the livestock sector rather than in feed grains. This large proportion of the total in the region results because the region is a deficit producer of feed grains.

Gross output generated in industrial sectors, from a $1 change in final demand for dairy products, was similar in magnitude to those required for changes in demand for meat and poultry products.

A $1 increase in the demand for processed grain products generated an increase in agricultural output totaling 57 cents and an increase in industry output totaling 98.2 cents.[5] These magnitudes are in contrast to the effect on agricultural and industrial output when the changes in final demand were for meat, poultry and dairy products. A $1 increase in final demand for meat and poultry products requires an increase of $1.09 of agricultural output. The corresponding increase in final demand for grain products is only about one-half that generated by meat products. The differential is related primarily to the relative degree of processing that grain products undergo before reaching the final consumer.

The product mix of the vegetables and fruit sector includes highly processed products (e.g., canned and frozen foods) and vegetables and fruit with only minor processing. The linear constraints of the model cause this mix to remain in a constant proportion for changes in demand. A $1 increase in final demand for vegetable and fruit products required an increase in gross output of 54 cents from agriculture and a total of 70 cents from industry. The largest regional increase in gross output was in the Pacific States with 19.6 cents, or approximately 40 percent, of the total increase in agricultural output. A $1 change in final demand for tobacco products generates about a 50-cent increase in total agricultural output. The Appalachian region, the primary source of raw tobacco, accounts for 38.3 cents, or about 75 percent, of the induced output.

Changes in final demand for industrial sectors which furnish inputs to agriculture have small effects on agricultural output. Approximately 10 percent of output from the agricultural input supplying industry was purchased by agriculture, while more than 40 percent was purchased by final demand sectors in the form of motor vehicles, fuel and oil, paints and varnishes, etc.

PROJECTIONS BY INPUT-OUTPUT MODELS

Projections relating economic growth to output from various sectors to serve for final demand and inputs of various sectors have been and can be made from input-output models. They serve "best" for models with "highly aggregated sectors" where the broad composition of the sector allows a decline in one input used in production to be offset or "covered up" by an increase in another. For this reason, they serve with very limited utility for models emphasizing agriculture where great change is taking place in the relative commodity making up "food" in its composition from different regions and in the relative mix of labor and the various capital resources going into it within all regions. Given the magnitude of technical change and resource

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[5] Excluding agricultural processing sectors, as in the case of other quantities mentioned for this section.

substitutions indicated in Chapters 2 and 4 and with divergent changes in demand for various categories of inputs predicted in Chapters 7 through 16, it is obvious that interdependence or resource requirements coefficients based on an input-output model at one point in time cannot serve efficiently for projecting resource demand and structure at a distant point in time.

Recognizing this point, we provide conditional projections in Chapter 18 which recognize the great change in the structural parameters of agriculture over time. We believe these to be the more relevant types of projections for guidance of public policy, individual decisions and research and educational programming relating to the farm industry. Those from input-output models necessarily cause a "fixed structure" to prevail because of the conditions cited earlier; namely, linear homogeneous production functions, fixed mix requirements on inputs, etc. However, for individuals who (a) do not wish to accept the projections of Chapter 18, based on expected continuous change in the structural parameters of agriculture and in its behavioral interrelations with the industrial economy and (b) insist that structure of the past will be extended into the future, we have derived some projections for 1975 based on the above input-output model. These conditional projections (see Chapter 18) are compared with 1954 outputs.

The assumptions made for the projections to 1975 for the above input-output model, but not for the projections of Chapter 18, and aside from population, are those of Daly.[6] The basic assumptions for projections in this chapter are: (a) a population of 230 million (b) farm commodity exports at 1954 levels (c) price at 1953 levels and (d) final demand for sectors other than agricultural processing sectors at the 1954 level. (The latter assumption, for purposes of computational convenience, does not recognize the very small quantity of farm products flowing directly to final demand or the small indirect effect of growth in final demand for industrial nonfood products on output of agriculture which serve as inputs for industry.)

To conform with the model, to avoid confusion with the more realistic projections of Chapter 18 and to conserve space, we present only a summary of the projections and emphasize industrial sectors producing inputs for agricultural sectors.

The projected "demands" for agricultural processed goods (sectors 0.10 through 0.17) for 1975 suggest a required increase of 28 percent, over 1954, in farm output. The associated increase in outputs from industrial sectors, to serve as inputs for farm sectors, would be 6.5 percent. The latter percentage is small since industrial sectors producing inputs for agriculture distributed the very major part of their output to nonfarm sectors in 1954. (See summary in Table 17.5.)

Industries whose outputs serve directly as inputs to agriculture would be required to increase their output by 5.5 percent. Other

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[6] Daly, R. F. The long-run demand for farm products. Agricultural Economics Research. Vol. 7. Feb. 1956.

Table 17.5. Changes in Gross Output (With 1954 Conditions) Needed To Meet Projected Deliveries to Final Demand for Processing Industries in 1960 and 1975, U.S. Economy (Aggregation of Commodity Groups and Subdivisions of Industry)

National Processing Sectors	1954 to 1975	
	Absolute change	Percentage change
	(million dollars)	
0.1 Livestock and livestock products	6,145.2	33.2
0.2 Feed grains	1,817.0	28.8
0.3 Food grains	301.9	12.8
0.4 Forage crops	798.6	32.0
0.5 Vegetable and fruit	1,135.9	32.7
0.6 Cotton	272.0	8.0
0.7 Tobacco	606.0	52.9
0.8 Oil crops	94.2	8.6
0.9 Miscellaneous agriculture	363.5	17.9
Total farm output	11,534.3	28.2
I Agr. furnishing ind.*	3,991.4	5.5
II All other ind.†	9,138.5	2.4
III Agr. proc. ind.‡	20,494.2	32.2
Total ind. output	33,624.1	6.5

*Agricultural furnishing industries include sectors 0.13, 0.18, 0.19, 0.20 and 0.21.
†All other industries include sector 0.22.
‡Agricultural processing industries include sectors 0.10, 0.11, 0.12, 0.14, 0.15, 0.16 and 0.17.

industries, with only an indirect relationship to agriculture, would be required to increase output by 2.4 percent (as a result of 28 percent growth in demand for "finished or processed" agricultural commodities alone, without considering increase in final demand for the many nonfarm sectors of the economy). For the agricultural input-furnishing industries (sectors 0.13 through 0.17), the largest percentage increase in output, about 30 percent, would be required in the prepared feeds industry (sector 0.13). Most of this increase would be associated with projections in demand for livestock products (sectors 0.10 and 0.11). The second largest percentage increase in output, about 26 percent, indicated by the input-output model would be in the fertilizer industry. Practically all of the fertilizer increases are indirect demands of livestock (sectors 0.10 and 0.11) processing sectors which purchase livestock, but which in turn require crops that are fertilized. However, with the present rate at which new fertilizer practices are adopted, needed production increases in the fertilizer industry likely will be much greater than 26 percent. (See Chapter 18.)

The third largest projected increase among the agricultural furnishing industries to meet 1975 demands on the agricultural processing industries, about 6 percent, would be in the chemical industry (sector 0.19). Half of this increase is related to projected demand for fruit and vegetable products (sector 0.15). "Indirect" inputs to farm fruit and vegetable sectors of fruit sprays and dust make up a large part of the increase.

The machinery and related services sector (0.20) would have a 3.7 percent increase in volume from 1954 to 1975; however, the projected absolute change is 1,368 million (1954) dollars, the largest of any agricultural furnishing sector. An increase of 1.8 percent, or almost one-half of the total increase in sector 0.20, is related to increases in demand for meat and poultry products (sector 0.10).

Required increases in the petroleum industry (sector 0.21), i.e., gasoline, grease and oil, to meet projected 1975 final demand for agricultural processing products were 2.6 percent, or 323 million (1954) dollars. The large part of the increase in production again is related to projected changes in demand for meat and poultry products (sector 0.10).

APPLICATION OF PROJECTIONS

We have not compared interregional flows under the above projections. One limitation, in change in interregional "demand" relationships, revolves around the "fixed mix" assumption. Without examining the direct and indirect effects of changes in final demand on output in a particular sector, we can illustrate the effect of a proposed change in output in the j-th producing sector on outputs in the i-th sector (i.e., on the amount of output in the i-th sector necessary to serve as an input in the j-th sector). Suppose that j refers to livestock production in one region and i refers to feed grain production in another. Then a_{ij} indicates the additional amount of grain needed to be produced in the i-th region, to allow a unit increase in output by the j-th region. This interpretation would be entirely correct if j obtained grain inputs only from i. However, at the time for which data apply, j may have obtained part of its requirement from i and part from other regions. If sector j is to increase livestock output, input-output models suppose that its incremental feed imports are met by flows of grain from crop regions in proportion to the a_{ij}'s. If region j has been importing feed grain from regions g and k, the model assumes increase in livestock production in j to be forthcoming from incremental imports in the ratio $a_{gj}a_{kj}^{-1}$ from the two grain-producing regions, regardless of the level to which livestock production and feed imports in j are increased. "Fixed mix" projections might approach reality for small regional changes. But for larger regional shifts, the allocation of grain imports from deficit regions to surplus regions could not be expected to correspond to the pattern of the past.

These projections for other sectors can serve the person who wishes to concentrate on a nostalgic structure of agriculture, who imagines that the relative share of farming in the national economy and that the relative labor and capital employment of agriculture will remain unchanged so that educational and policy programs can retain their historic pattern. We prefer a "heads out of the sand approach," however, and turn to the conditional projections in Chapter 18 where we try, although imperfectly, to account better for changes in structural variables and parameters. The reader is welcome to accept either set or type of projections, or others lying between them. Other input-output models can be computed at later dates and can serve, in comparison with the one above, to indicate direction and magnitude of change in agricultural structure. Because of economic development and technological change, shifts in factor prices and consumer expenditure patterns, low aggregate supply elasticities for some agricultural resources (especially land) and production functions which do not impose conditions of constant returns and technical complementarity among resources, models computed for the future will show a continuous shift in interdependence coefficients. This direction is expected, given the momentum of change in magnitudes in variables and parameters summarized in Chapters 1 through 4. Hence, we now turn to projections which are more realistic in allowing this change in structure.

18.

Prospective Resource Structure and Organization in 1980

MOST PERSONS with a close interest in agriculture would like answers to the question, "What will be the level and rate of change in demand for various farm resources during the next two decades?" Such information would be useful for firms supplying inputs to agriculture. This knowledge also is relevant for educational units and rural institutions and enterprises associated with agriculture. Somewhat similarly, the future structure and organization of agriculture will suggest guidelines for farm policy. The magnitudes of production, demand and supply elasticities largely will determine whether agriculture can adjust to the forces of economic growth without severe income sacrifice in an unrestricted market framework. But remedial policies to correct income and other inequities cannot be formulated in terms of farm variables alone. The appropriate policies also depend on values of farmers and consumers, and on national rates of employment and growth. The long-run projections made in this chapter are intended to provide useful background information for decisions which must be made in a national and internal environment favoring change in the structure and organization of agriculture.

STRUCTURE AND FORECASTS

The structural equations estimated in earlier chapters are less useful for making long-run than short-run forecasts, and are used sparingly for the analysis which follows. Other quantities, methods and judgments also must be employed to evaluate the upcoming structure of agriculture. If we had been able to include all relevant variables relating to future structural changes in specifications of resource demand and supply functions, the task of projection might have been simple. However, numerous variables falling outside the realm of time series measurement will have important bearing on the future resource employment pattern and structure of agriculture.

Some of these variables, generally instrumental variables which will be determined by the public and policymakers, will take on much larger magnitudes than in the past. One example is education and vocational guidance in rural areas. The more intensive emphasis being placed on gearing these social activities to economic change will likely have greater impact in agricultural labor supply quantities and elasticities with respect to commodity prices and farm and nonfarm labor returns than did concentration and investment in vocational agriculture and 4-H activities in the past. Similarly, the nature and extent of public investment and programs in creating new knowledge of technology and farm resource productivities will have tremendous influence on farm resource demand and structure. These variables will be determined by the public "outside the system" of measurable variables available in time series analyses. They will, however, have an important impact on the types and quantities of resources employed in agriculture.

Action programs relating to production control, price supports, surplus disposal and even aids in international development which affect exports of U.S. farm products will have some impact on the resource structure and organization of agriculture. The number and sizes of farms, the magnitude of the farm population and labor force, the amounts and proportions of durable and operating inputs will be affected by these numerous institutional, social or instrumental variables. Similarly, the acreage devoted to food and fiber crops, or the conventional mix of these, as compared to the acreage devoted to recreation and forestry, will be partly determined by these variables whose magnitude or nature are (a) decided largely outside of the market mechanism and (b) not expressed statistically as time series observations.

Even a particular and major set of variables which are, *ex post*, reflected in time series statistics will greatly affect the resource structure and organization of agriculture but cannot themselves be predicted with great certainty. Here we refer to those variables relating to the rate of national economic growth. Even if we had been able to formulate and quantitatively derive a general-equilibrium and simultaneous-equation model of agriculture reflecting all relevant supply and demand relationships of the industry, and to link these appropriately to the structural relationships of the dominating nonfarm income wage and employment variables, our projections might be inaccurate because we cannot be certain of national growth rates over the 1960 to 1980 period.

TYPES AND PURPOSES OF PROJECTIONS

Numerous types of forecasts are possible. The most desirable for public decisions, policy formulations and private choices would be a set of *unconditional long-run forecasts* predicting the magnitude of the dependent variables, all predetermined and instrumental variables, and those "purely dependent variables of agricultural structure."[1]

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[1] *Cf.* Ferber, R., and Verdoon, P. J. Research Methods in Economics and Business. Macmillan. New York. 1962. Chap. 10.

Obviously, the relatively simple models of previous chapters do not allow this complete set of unconditional forecasts. The procedure in previous chapters was to make conditional short-run forecasts where we assumed certain magnitudes for the independent variables, or those which were considered to be predetermined relative to the particular variables being projected. In all projections it becomes almost impossible to differentiate entirely between conditional forecasts and judgment forecasts in the sense that assumptions must be made if complete models cannot be formulated and estimated for unconditional forecasts. This is due to paucity of data and the high intercorrelation of variables constituting the structural system of agriculture.

Long-run projections must be interpreted in respect to their intended purpose. One objective of long-run projections might be to answer the question, "If quantities continue recent trends, what will be their level in 1980?"

A second estimate of future quantities might be based on input requirements necessary to meet expected demand for farm output. These requirements might be based on the "fairly predictable" magnitudes: population and per capita food consumption in 1980. If productivity also could be predicted with accuracy, the resource requirements then could be computed in relation to output needs.

A third approach is to estimate the most efficient input level and combination for producing the output that would clear markets at prices providing satisfactory returns on farm resources.

The respective approaches might be broadly characterized as "what is likely to be," "what needs to be" and "what optimally ought to be." The last two approaches have normative elements; the first is basically positivistic. The methods obviously are related and cannot be entirely separated.

Normative considerations, based on values of the public relating to structure of agriculture, have had some effect on parameters of the past (although our simple models and specifications were only sensitive enough to measure these indirectly) and will likely do so in the future. For example, society may decide that the number of farms projected for the future is too small, and enact legislation which more nearly preserves Jeffersonian concepts and restrains growth in farm size. In this case, prediction of farm numbers and population from past trends would be above the target.

On the other hand, educational and vocational guidance in rural areas may be intensified in preparing farm youth for more rapid growth in off-farm employment. In this case, our projections of farm numbers and sizes may fall below the target. But in any case, normative considerations and value judgement will affect the magnitude of instrumental or policy variables and the parameters which attach to "purely structural variables."

But just as the quantitative analyst who relies only on positivistic analysis and predictions encounters discomfort because of the above changes, individuals who expect certain policy restraints and institutions to preserve or attain a particular farm structure also are likely to be frustrated. Agriculture is now such a small portion of the national economy, and the forces of economic growth fall too strongly on it, to allow a purely normative specification of structure. The pull of factor prices under economic development mentioned in earlier chapters serves as an illustration. Unless farmers organize more completely to raise bargaining power, the issue of what agriculture ought to be will be determined increasingly by the dominant nonfarm society. At the moment, public indecision on agricultural policy and farm structure arises because conflict in concept of "what ought to be" has not yet been reconciled among the various groups with economic and value positions relating to agriculture.

All three approaches outlined above are used in projecting the organization of resources to 1980. The method used in the following section is related to normative concept of what ought to be for maximum economic efficiency. However, we prefer to present the projection in terms of what could be and do not imply what should be. Even though a given organization represents an economic optimum, it may not be optimum from a sociological or political standpoint. The section is followed by a more positivistic estimate of what the combination and level of resources is likely to be in 1980.

POTENTIAL IN STRUCTURE AND ORGANIZATION

Under high employment in the national economy and the absence of war, rates of change in respect to labor force and farm numbers and sizes will be largely maintained in relative magnitude. There are several bases for this assumption: (a) the institutional and policy forces mentioned previously and related to greater intensity and modernized direction of education and vocational guidance for rural youth, (b) the growing economic literacy among farm and related publics which give them increased understanding of the national economy and its interaction with the farm sectors under growth, (c) the great likelihood that the agricultural extension service will bring even greater knowledge and basis for decision to farm communities and (d) the growing competition and commercialization of agriculture under existing and prospective technology and resource prices.

The potential for change is still great. Referring back to the proportion of low-income persons in agriculture (Chapter 2), it is obvious that the number of families and the size of the farm labor force, especially in the low-income sector, must decline by a continued large proportion if real per capita incomes are to be raised near the level of nonfarm sectors. The potential also is great for change in the distribution of total farms and their contributions to the nation's food supply function. Converting data related to Table 2.5 to a 1954 price basis and including all farms, change in number of farms of different sales volume from 1939-59 is given in Table 18.1. Farms with less

Table 18.1. Number of Farms Classified by Economic Class (1000 farms)
(Value of Sales at 1954 Constant Prices)

Value of Sales	1939	1949	1959*
Under $2,500	4,185	3,295	1,638
$2,500 to 4,999	1,015	882	618
$5,000 to 9,999	585	721	654
$10,000 and over	312	484	795
($2,500 and over)	1,912	2,087	2,067
($5,000 and over)	897	1,165	1,448
All farms	6,097	5,382	3,705

*Would include approximately 232,000 additional farms with sales of less than $2,500, if definition of a farm had been the same in 1959 as in earlier years.

than $5,000 in sales (61 percent of all farms) had only 13 percent of the nation's total farm sales in 1959. The slack capacity or underemployment of labor and machine resources on farms with sales of $5,000 and over (39 percent of all farms) which produce 87 percent of national sales, could easily take over this 13 percent share. Under these conditions only 1.4 million farms would exist. But the decline could go much deeper, with the certainty that remaining farms could produce the nation's food supply and current exports at low price and with some surplus.

If the farms with less than $10,000 in sales were organized to produce the same sales volume per farm as those with over this amount in 1959, the following changes would be possible. The 2.2 million farms (with sales of less than $10,000) producing the 29.1 percent of sales could be reduced to 322,000, if they produced the same volume as farms with $10,000 and greater sales in 1959. Adding the 795,000 of the latter group with the 322,000, it is obvious that 1.1 million farms already could produce the 1959 level of output. With the 50 million acre reduction in cropland projected by the USDA for 1980[2] and with the projected trend in per acre and animal yields, based on already existing knowledge as indicated by studies such as those of Rogers and Barton,[3] these 1.1 million farms could readily produce the nation's 1980 food supply.

However, considering the degree of unexploited cost economies

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[2] Land and Water Policy Committee. USDA. A land and water resource policy for the United States. (Mimeo.) Washington, D.C. 1962.

[3] Barton, G. T., and Rogers, R. O. Farm output, past changes and projected needs. USDA Agr. Inf. Bul. No. 162. 1958; Rogers, R. O., and Barton, G. T. Our farm production potential, 1975. USDA Agr. Inf. Bul. No. 233. 1959; Barton, G. T., and Daly, R. F. Prospects for agriculture in a growing economy. In Center for Agricultural and Economic Development. Problems and Policies of American Agriculture. Iowa State University Press. Ames. 1959. Also see Shrader, W. D., and Riecken, F. F. Potentials for increasing production in the Corn Belt. In Center for Agricultural and Economic Development. Dynamics of Land Use — Needed Adjustments. Iowa State University Press. Ames. 1961.

currently existing on model-sized farms,[4] with some measure of underemployed labor on these same units, the number of farms to produce the 1980 food supply, with scale of operation approaching but still short of minimum cost, is around .75 million. (If all commercial farms declined at the 1954-59 rate in each subsequent census period, the number of commercial farms would be 680,000 in 1979.) If a like number of part-time and residential units were to exist, producing only a trivial portion of the nation's farm sales, the potential number of all farms is only 1.5 million. The potential labor force associated with this number is only 3.5 million persons, at the level of productivity existing on farms with sales over $10,000 in 1959. The potential in labor force could go as low as 2.8 million, if only farms providing $10,000 or more in sales were to exist.

Associated with this potential would be a considerable increase in farm operating inputs and a shift of nonreal estate capital inputs to a greater proportion of operating items and a smaller proportion of durable inputs. If the potential number of farms for 1959 had existed, input of durable capital might have been somewhat less than the 1959 actual figure. However, in terms of 1980 potential in farm numbers and sizes discussed above, the potential in durable inputs would increase somewhat over the 1959 level, but not nearly in the magnitude of potential operating inputs.

These figures revolve around the potential structure of agriculture explained above. They are conservative potentials, with the full potential being for an even smaller number of farms. It is toward these potentials which actual trends migrate. Hence, we now turn to selected long-run projections, estimated in the simplified conditional forecast and positive framework discussed earlier.

ESTIMATED RESOURCE ORGANIZATION IN 1980

The following estimates of resource quantities, efficiency, farm size and numbers are intended to reflect what the 1980 resource organization is likely to be, based on past trends, judgments, and on structural relationships analyzed earlier. The approach basically is positivistic, but again we emphasize that the various approaches are

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[4] For example, see the following indications of cost economies not exhausted on farms of the most typical or modal size in major producing areas: Heady, Earl O., and Krenz, R. W. Farm size and cost relationships in relation to recent machine technology. An analysis of potential farm change by static and game theoretic models. Iowa Agr. Exp. Sta. Bul. No. 504. 1960; Heady, Earl O., et al. Farm size adjustments in Iowa and cost economies in crop production for farms of different sizes. Iowa Agr. Exp. Sta. Bul. No. 428. 1954; Fellows, Irving. Economies of scale in dairy farming. Connecticut Agr. Exp. Sta. Bul. No. 285. 1956; Barker, Randolph A., and Heady, Earl O. Economy of innovations in dairy farming to increase resource returns. Iowa Agr. Exp. Sta. Bul. No. 478. 1961; Scoville, O. J. Farm size and costs in Nebraska. USDA Tech. Bul. No. 931. 1952; Hurd, Edgar B. Wheat-pea farming in Washington and Idaho, 1935-53. USDA Circular No. 954. 1955.

related. Data show that trends in input quantities tend to be consistent with criteria of economic efficiency, although the adjustment to the optimum is slow for many resources, as is apparent from foregoing chapters. The projections which follow are based on the assumption that these optimizing forces will continue to operate in the future about as in the past. Of course, this "normal" rate and direction of adjustment could be upset by a major change in government programs, war, depression, extended drought, discovery of radical new technology, etc. We abstract from such phenomena and attempt to measure what, based on available information, is likely to be the 1980 resource organization, not what could be or should be the organization. Basically the projections are extensions of past trends, particularly those of the 1950's. It follows that with such "naive" techniques, projections are likely to be realized only if the future basic economic structure, or the rate of change in structure, does not deviate markedly from the past.

We make the judgment (assumption) that national growth rates and public policies from 1960 to 1980 may change but will be somewhat comparable to those of the previous 20 years. Projections depend on a somewhat unpredictable foreign demand. To accommodate the volatile export market, two levels of exports are assumed. This procedure of projecting two estimates is used in other instances also, where trends are unstable.

The 1980 projections of resource quantities, efficiency, farm size and numbers in this chapter supplement the many short-run projections made throughout the book. While the short-run predictions made in earlier chapters were structural, the long-run predictions are based generously on "naive" techniques. The structural equations of earlier chapters, providing the basis for short-run projections from prices, technology and other explanatory variables, are not well suited for long-run estimates and are used sparingly.[5] Structural equations are rigid, and predictands are a function of predictors related by fixed and single-valued elasticities or marginal coefficients. While constant coefficients and linear approximations are adequate in the short period analyzed and for short-run extensions, they cannot be expected to hold for long periods in the future. Furthermore, many of the structural equations contain lagged dependent variables. These equations generally predict with great accuracy in the short run, but errors accumulate and accurate estimates cannot be expected for long-run extensions.

Finally, distant projections from structural equations must be based on assumed levels of prices and other independent variables chosen because they are truly exogenous (or predetermined) and economically relevant, not because they are easily predicted in the future. Consequently, the error in predicting the explanatory variables, coupled with other complications, often may result in less reliable forecasts from structural equations than from simple extensions of the

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[5] Structural models should be kept up to date and extrapolations ordinarily should not be carried more than two years into the future according to Klein, Lawrence R. A Textbook of Econometrics. Row, Peterson and Company. Evanston, Illinois. 1953. p. 265.

predicted trend. Some direct long-run predictions are made from preceding structural equations, but uses of the equations mainly are indirect. In many instances, results from earlier chapters are necessary in establishing judgments or assumptions of future quantities, since simple past trends are inconsistent or too volatile for useful forecasts.

The subsequent extrapolations are based essentially on past trends, the assumption being that the underlying structural change will not be large. The naive, simple extensions of past trends are supplemented with estimates based on requirements. In some instances, requirements are quite highly predictable, e.g. from a stable trend in population, low price and income elasticities for food and a somewhat fixed per capita consumption. Given resource productivity and fixed output requirements, resource quantities thus are "set." We would expect deviations from these resource levels to be corrected by the price system, although substitutions within the input aggregate might be notable.

Past trends are extended, in most instances, from 1950-60 data. This period was selected because much of the instability in quantities and prices caused by the Depression and World War II was dampened or dissipated by then, giving a more stable and predictable trend. Also, there are advantages in extending recent trends in a farm structure that has changed greatly in the recent decades.

Four algebraic forms for extrapolating the quantity, Q_i, with time, T, are (18.1) to (18.4).

$$Q_i = a + bT \tag{18.1}$$

$$Q_i = a + b\sqrt{T} \tag{18.2}$$

$$\log Q_i = \log a + bT \tag{18.3}$$

$$\log Q_i = \log a + b \log T \tag{18.4}$$

The simple linear equation (18.1) forces a constant absolute annual change, b, in Q_i and can be useful for projecting a rising trend. But it is less useful for extending a quantity which decreases, since a negative input is not meaningful. The square root function (18.2) rises or falls at a decreasing rate, and therefore gives a more "conservative" projection than (18.1). Exponential equation (18.3) forces a constant percentage rise or fall in Q_i. The equation is useful for extending "biological quantities" such as labor or population; but also, it does not become negative over an extended time period. The constant percentage change implies growing absolute increments with a rising trend and declining absolute quantity decrements with a falling trend. Equation (18.4), similar to (18.3) since Q_i does not become negative, allows more flexible rates of change than (18.3).

AGGREGATE OUTPUT, INPUT AND PRODUCTIVITY

Output requirements projected to 1980 range from 48 billion to 52 billion 1947-49 dollars (Figure 18.1). The higher requirement, based on a 1980 national population of 260 million, is from (18.3) using 1950-60 data. The estimate is 44 percent above the 1960 level, and is based on a predicted 1.75 percent annual rate of population growth.[6] Per

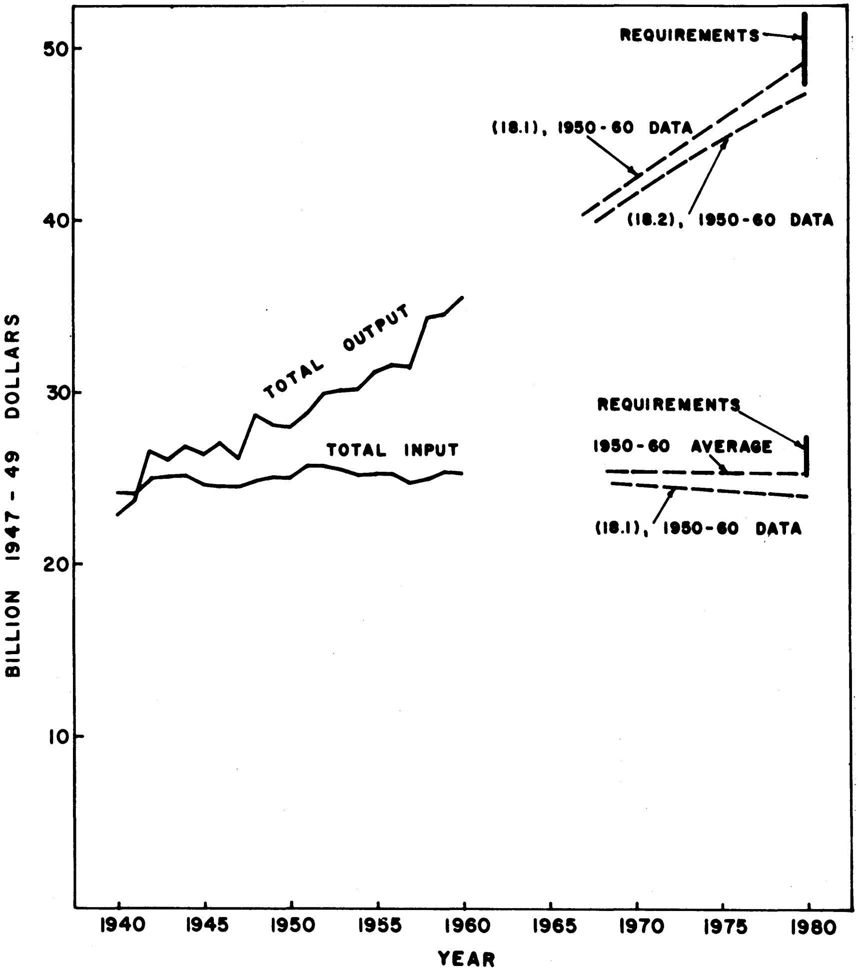

Figure 18.1. Aggregate farm output, input and productivity for 1940 to 1960, and projected to 1980. (1940-60 estimates from: USDA Stat. Bul. 233. Revised 1961; and USDA Tech. Bul. 1238. 1961.)

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[6] Other population estimates for 1980 are in: Koffsky, Nathan M. Potential demand for farm products. In Iowa State Center for Agricultural and Economic Development. Dynamics of Land Use — Needed Adjustments. Chap. 3. Iowa State University Press. Ames. 1961.

capita disposable income is projected to grow about 2 percent per year, and to be 50 percent higher in 1980 than in 1960.[7] Assuming that the aggregate income demand elasticity for food will be only .10 in 1980, the large increment in income per capita alone increases farm output requirements only 5 percent. The higher output requirement is based on the rather optimistic assumption, for this prediction, that exports will be 22 percent above the 1960 level. For 1980, net addition to all farm commodity stock is set at 500 million 1947-49 dollars, considerably below the 1960 level. The resulting sum, $52 billion of farm output, is 50 percent over the 1960 value and is slightly over one USDA estimate.[8]

The lower projected output requirement in Figure 18.1 is based on a U.S. population of 255 million in 1980, exports 22 percent below the 1960 level, and other assumptions given above. The lower requirement of 48 billion 1947-49 dollars of farm output in 1980 is 35 percent greater than the 1960 farm output.

Input requirements are based on a linear extension of the 1950-60 trend in resource productivity corrected for weather (Figure 18.2).[9] The predicted 1960 productivity index is 170 (1947-49=100) and is 35 percent greater than the index in 1960. The indices of livestock production per animal unit and crop production per acre are also predicted to be nearly 170.[10] This projection is a simple extension by (18.2) of the 1950-60 index of livestock efficiency and is a linear projection of crop production per acre after removing weather effects. The total percentage increase is least for livestock efficiency because the 1960 value is greatest.

Based on output requirements and on predicted productivity in Figure 18.2, the aggregate resource requirements for 1980 are between 25 and 27.5 billion 1947-49 dollars. Figure 18.1 suggests that these output and input requirements are approximately met by extending 1950-60 trends. The nearly 50 billion dollar output indicated by a linear extension of the trend is approximately the mid-range of projected requirements. To meet requirements, it may be necessary to reverse the 1950-60 downward trend in aggregate inputs according to Figure 18.1. If the productivity measure is correct, the level of inputs need not change appreciably, however, and the current aggregate level of inputs may be nearly adequate to meet needs of 1980. Of course, major changes within the aggregate of output and input must occur. Changes

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[7] See also Knowles, James W. Growth prospects for the American economy. In Iowa State Center for Agricultural and Economic Development. Dynamics of Land Use — Needed Adjustments, op. cit., Chap. 2.

[8] USDA. Land and Water Policy Committee. Land and water resources — a policy guide. Washington, D.C. 1962.

[9] Weather index from Stallings, James L. Weather indexes. Journal of Farm Economics. 42:180-86. 1960. The index of weather was set at the 1950-60 mean, 104.5 with 1947-49=100.

[10] Alternative and somewhat lower projected annual increments in crop yields are presented in Barton and Rogers. Farm output, past changes and projected needs, op. cit., p. 43. See also footnote 19 of this chapter.

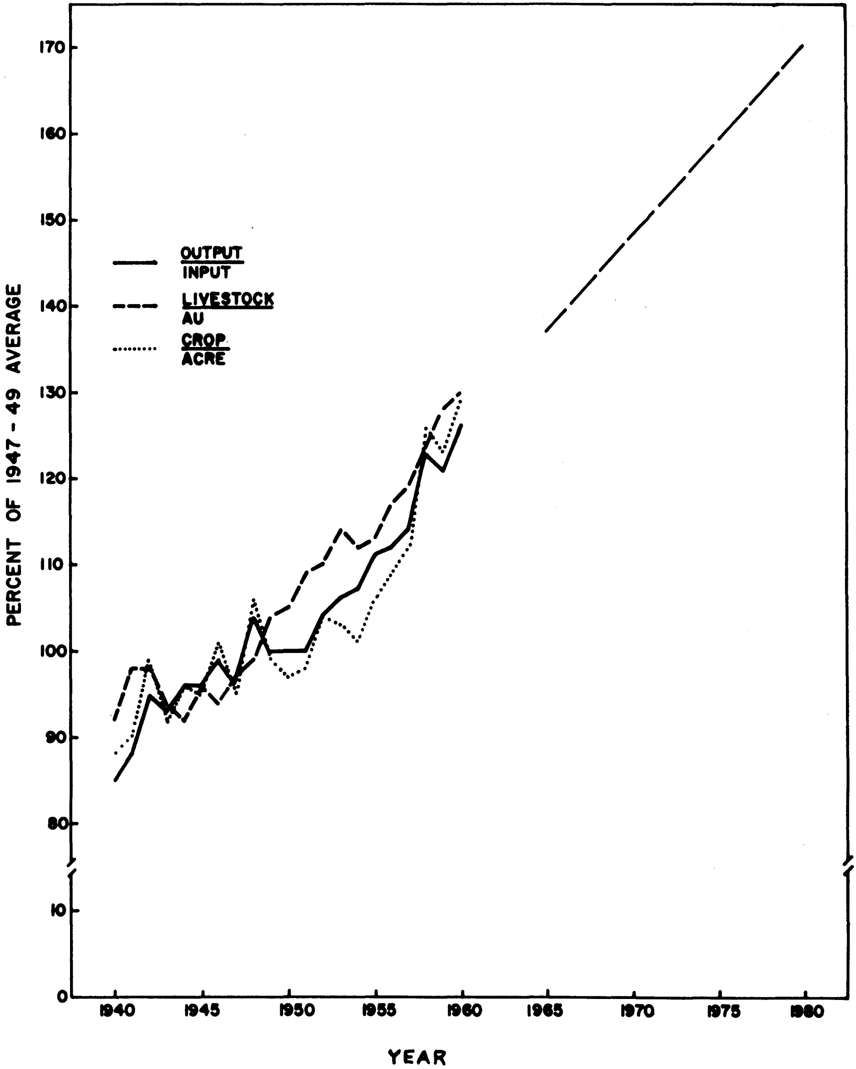

Figure 18.2. Aggregate output per input, livestock output per animal unit and crop output per cropland acre from 1940 to 1960, and projected to 1980. (1940-60 estimates from: USDA Stat. Bul. 233. Revised 1961.)

within the output category are discussed elsewhere.[11] In the following section we discuss changes within the input category.

Output O in 1980 is predicted from the supply equation (18.5) (cf. equation (16.3)) to be 48.2 billion 1947-49 dollars.

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[11] Koffsky, op. cit., p. 45.

$$(18.5)\quad O_t = -12{,}710 + \underset{(8.6)}{32.0}(P_R/P_P)_{t-1} + \underset{(32.3)}{123.1}\, S_{pt} + \underset{(19.6)}{259.0}\, T'$$

$$R^2 = .99$$

The "parity" or commodity/input price ratio P_R/P_P is set at the 1955-59 average, the stock of productive assets at 117.1 billion 1947-49 dollars (see Table 18.2) and the productivity index T′ at 170 (Figure 18.2). Standard errors are in parentheses below the coefficients. The predicted output, $48.2 billion, is about the minimum requirement in Figure 18.1. A slight increase in S_P of T′ could greatly affect output, but it may be noted that since a one-unit increase in the short-run price index P_R/P_P raises output only 32 million 1947-49 dollars, a large adjustment in prices is predicted to be required for raising output by (say) one billion dollars in the short run.

RESOURCE PROJECTIONS

For farm output requirements to be realized with only a small increase in total input, major changes must continue to occur in farming specialization, management, institutions and especially within the aggregate input category. These latter changes generally represent continued substitution of the more productive for the less productive inputs. In fact, for the 1980 productivity projections to be realized, it is essential that these substitutions do occur. Tendencies for continued increase in levels of the more productive resources are apparent in the following projections to 1980 of labor, durables, operating inputs and various components of these resource categories.

Farm Labor in 1980

Extending 1950-60 trends by (18.3) and (18.4), sizeable reductions in farm population and labor force are forecast for 1980 (Figure 18.3). In the two decades after 1960, hired labor is predicted to decline 30 to 35 percent, family labor 45 to 55 percent. These ranges are not confidence intervals, based on probabilities, but are only point estimates from the trend extension. The 1980 point estimates are extended smoothly backward in Figure 18.3, but these extensions have no meaning for (say) 1965 and may not be consistent with projections for that year in foregoing chapters. The projections suggest that the farm labor force will decline from 7.1 million in 1960 to 4 million in 1980, a 44 percent decline. More than 3.1 million farm workers would have to find jobs in other industries, however, because of net additions to the farm labor force by an excess of births over deaths.

In an alternative procedure, we estimate the number of workers required in 1980 to be 3.6 million. This result is based on the compound

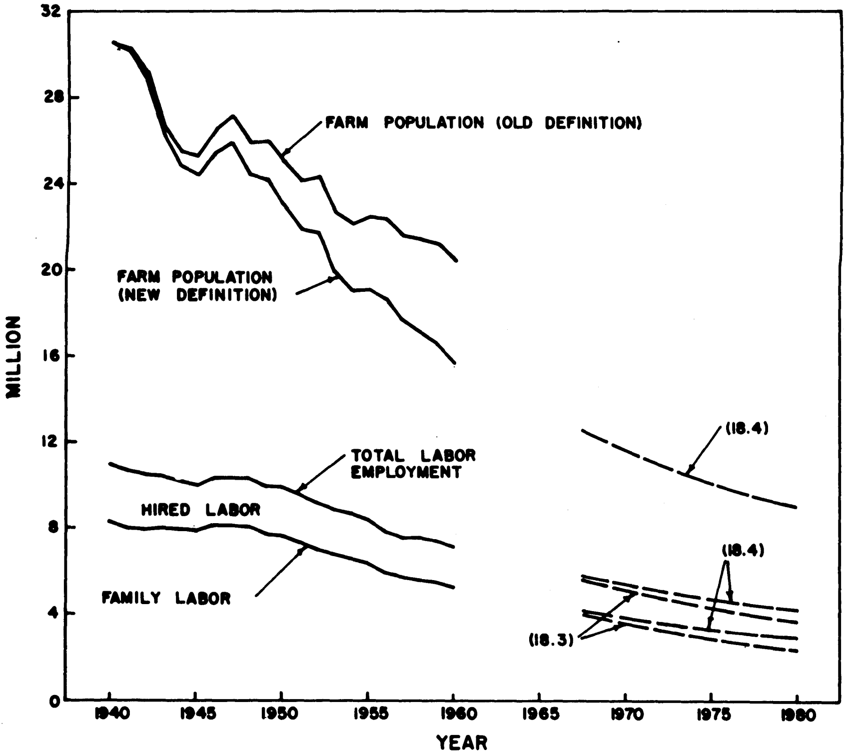

Figure 18.3. Projections of farm population and employment to 1980. (1940-60 data from: Economic report of the President. 1961; and USDA. The farm income situation. July 1962.)

interest formula assuming annual increases in output and output per man-hour to be 1.8 and 5 percent, respectively.[12] The "required" labor force, assuming the same ratio of man-hour requirements to labor force in 1980 as in 1960, is 49 percent below the 1960 number and is a slightly greater decline than projected from employment trends. The results suggest that for labor efficiency in agriculture to increase at the rapid rates experienced in the past, sizeable numbers of farm workers will need to find employment outside agriculture. To reduce the labor force by 44 percent in 20 years, annual employment must decline by an average of nearly 2 percent per year. According to

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[12] The number of man-hours, M_{80}, required in 1980 is given as

$$M_{80} = M_{60}(1 + r_0)^n(1 - r_m)^n$$

where M_{60} is man-hours required in 1960, r_0 is the rate of increase in output and r_m is rate of increase in labor efficiency. The time, n, is 20 years. This procedure, based on the compound interest model, was used by Johnson to project man-hour requirements to 1975. Cf. Johnson, Stanley S. A Quantitative Analysis of Demand for and Supply of Farm Labor. Unpublished Ph.D. Thesis. Library, Iowa State University. Ames. 1961.

Table 18.2. Projected U.S. Stocks of Productive Farm Assets to January 1, 1980
(Billion 1947-49 Dollars)*

Asset	Actual			Projected	Percent Increase	Source of Projection
	1940	1950	1960	1980	(1960-80)	
Real estate†	58.2	63.4	71.1	74.0	4	Based on 30% increase in buildings and improvements nearly offset by a 4% decline in cropland used for crops.
Livestock	12.9	13.1	14.8	17.2	16	Based on 52% rise in livestock production and a 31% increase in production per breeding unit.
Machinery	4.1	8.6	10.2	11.5	13	Linear extension of 1952-60 trend.
Other	8.1	10.8	11.9	14.4	23	Average 23% increase in cash for operating purposes and in feed inventories.
Total of above	83.3	95.9	107.8	117.1	9	
Total				127.8	19	Extending 1950-60 annual data by equation (18.2)

*1940 to 1960 data from USDA Agr. Inf. Buls. 214 and 247. 1959 and 1961. The above data for 1940 to 1960 are unrevised. The unrevised asset totals for 1960 and 1961 are 107.8 and 107.6; the revised data for the same years are 108.1 and 108.0.

†Does not include the farm dwelling.

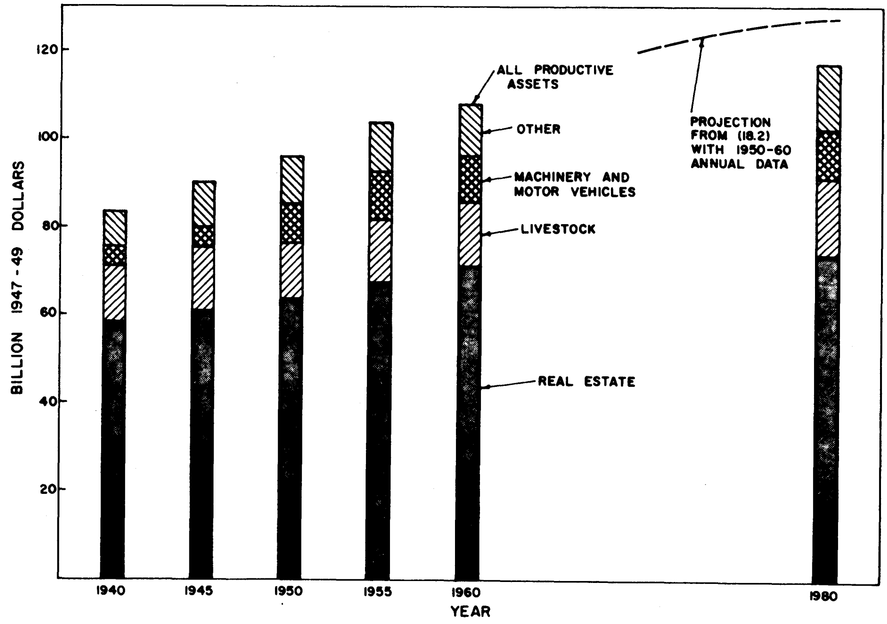

Figure 18.4. Projections of productive farm assets to 1980. (1940-60 data from: USDA Agr. Inf. Bul. 247. 1961.)

Chapters 8 and 9, whether these projections are realized or not depends not only on what happens inside agriculture (adoption of labor-saving machinery, farm consolidation, etc.) but also on what happens outside agriculture (level of national unemployment, aggregate demand, etc.). Judging from the low income and price elasticities in Chapters 8 and 9, modest efforts through farm programs to raise farm income will not materially impede labor mobility and upset the trends indicated.

Since the farm population measured by the old definition often is used and differs considerably in trend and numbers from the population based on the new definition, both estimates are included in Figure 18.3. The former and revised estimates of 1960 farm population (including Alaska and Hawaii) are 20.5 and 15.6 million, respectively, and hence differ by about five million. Projecting the revised 1950-60 series by equation (18.4), the farm population in 1980 is estimated to be nine million. The drop is 43 percent from 1960 and is comparable to the percentage decline projected for all farm labor. The estimate provides the basis for expecting a striking reduction in the proportion of the total national population on farms. The percentage dropped from 23 in 1940 to 9 in 1960, and if Figure 18.3 projections are realized, less than 4 percent of the U.S. population will live on farms in 1980. The smaller proportion of the farm population in farming has important political and policy implications. Since farm income as a percentage of the U.S. income can also be expected to decline, important economic implications are anticipated, particularly for the declining influence of a change in farm income on national income and economic outlook.

Farm Production Assets in 1980

Realization in 1980 of the lower levels of projected stocks, in Table 18.2 and Figure 18.4, would signify a considerable departure from the past trends. The three main categories (real estate, livestock and machinery) are expected to grow respectively only 4, 16 and 13 percent — considerably below their past rate and the projected future output rate.

The 1980 stock of real estate, 74 billion 1947-49 dollars, is based on the assumption that crop output requirements will be 34 percent greater. But the projected increase in yield per acre of cropland used for crops compensates for the larger requirements, and 4 percent fewer cropland acres and physical land resources are expected to be needed. An estimated 30 percent rise in irrigation, building and other land improvements, however, is predicted to offset the reduced land requirements and increase the total physical volume of real estate assets.

The projected 16 percent increase in livestock assets is based on an anticipated 52 percent increase in livestock output between 1960 and 1980. Assets need not grow as rapidly as output because livestock production per breeding unit is predicted to be slightly more than 30 percent greater in 1980 than in 1960 (see Figure 18.2).

The increase in machinery stock is predicted to be less in the two decades following 1960 than in the single decade preceding 1960. The 1980 estimate, 11.5 billion 1947-49 dollars, is 13 percent greater than in 1960 and implies an annual increase of less than 1 percent. The projection is based on trends in machinery stocks and is consistent with the short-run projections from the structural analysis in Chapter 11. The result also suggests a "mature" agricultural economy in terms of machinery. A large amount of new machinery will continue to be purchased not only to replace worn-out machines but also to substitute for machines which are inadequate for large holdings. This will offer sizeable opportunities for machinery to replace labor, despite the rather small increment in machinery assets.

The major components of "other" assets in Table 18.2 and Figure 18.4 are cash held for productive purposes and feed inventories. The categories are projected to increase appreciably because of the large increase in operating inputs for which cash resources are necessary. Feed inventories also are expected to rise appreciably because of larger livestock inventories and production. Feed efficiency (pounds of feed per pound of livestock production), as an average for the nation and in light of higher feeding levels which cause diminishing feed productivity for some classes of livestock, has not increased in the past at a rapid rate. It has been predicted to increase only one-half of 1 percent per year in the 20 years preceding 1980.[13] Cash for production, feed inventories and additional items classified as "other" assets are projected to increase 23 percent, or from a total of 11.9 to 14.4 billion 1947-49 dollars between 1960 and 1980.

Figure 18.4 illustrates the trends in Table 18.1. Real estate continues to be the major asset but its relative importance is declining. Machinery stocks grew rapidly from 1940 to 1955 but, as discussed above, that trend is not expected to continue. The physical land component only of the real estate resource, excluding building, irrigation, drainage and other improvements, would show a static or falling trend. The figure illustrates the declining rate of increase in growth of assets. The projection, to the extent realistic, signals an important shift to an even greater emphasis on operating inputs purchased from the nonfarm sector, and relatively less emphasis on durables as well as labor.

Using 1950-60 data and equation (18.2), nearly $128 billion of assets are projected for 1980. Because of the structural considerations underlying the lower projections, we believe it is more valid than the simple trend extension. Nevertheless, the upper estimate potentially can be reached, and should be regarded as the upper limit of productive assets under the most favorable growth conditions. The component parts of total productive assets would need to be adjusted upward accordingly.

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[13] Jennings, Ralph D. Consumption of feed by livestock, 1909-56. USDA Prod. Res. Report No. 21. Washington, D.C. 1958. p. 46.

Operating Inputs

Extensions of past trends in Figure 18.5 indicate major increases in the use of fertilizer and other operating inputs by 1980. A large share of the rising productivity of agriculture undoubtedly will come

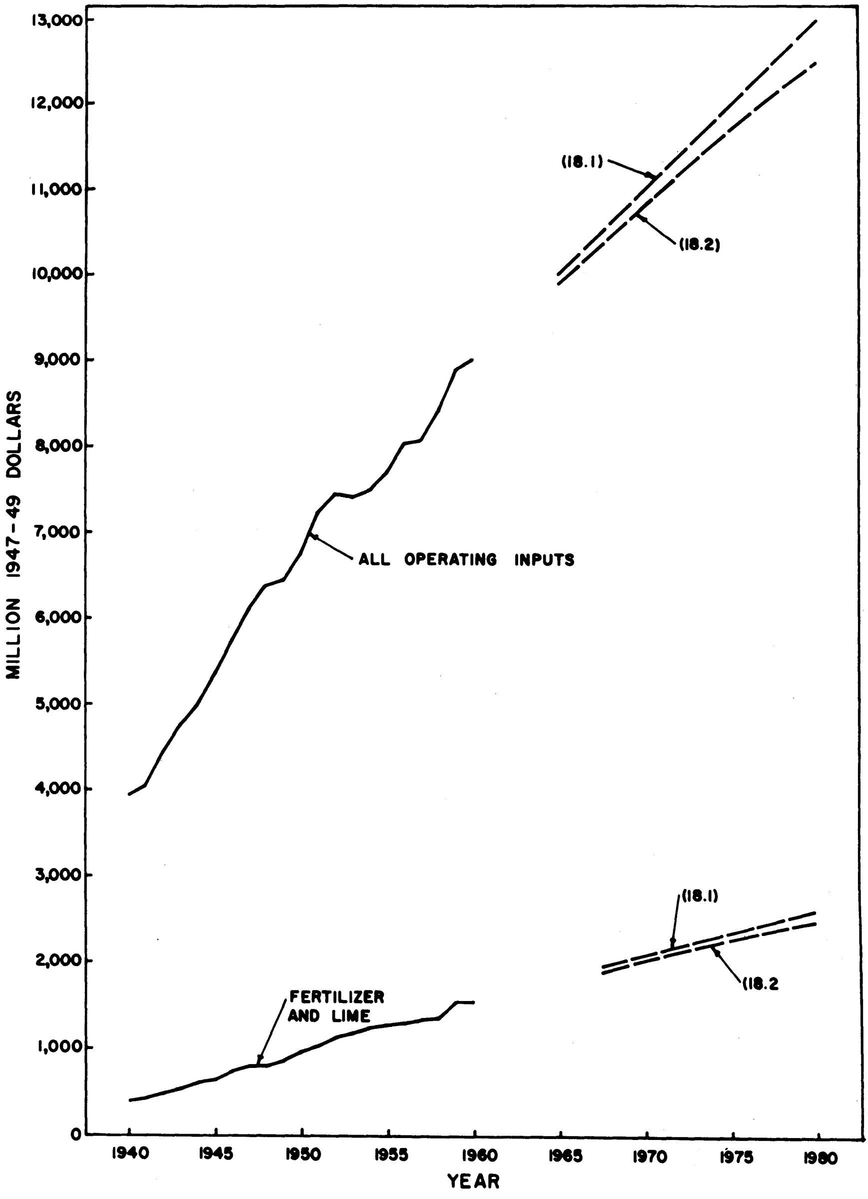

Figure 18.5. Projected purchases of fertilizer and lime, and of all operating inputs to 1980.

from these resources, because their per unit productivity is much higher than that of the resources they replace. Operating inputs include not only fertilizer and lime, but also feed, seed and chemicals furnished by the nonfarm sector. Especially important are high protein concentrates, weedicides, insecticides and hybrid seeds.

All operating inputs will total 12 to 13 billion 1947-49 dollars by 1980 if projections from (18.1) and (18.2) are realized. The rise is slightly more than 40 percent over the 1960 total of $9 billion. A structural equation (18.6) (see Chapter 13) provides a somewhat similar estimate of 1980 inputs.

$$Q_{Ot} = -\ 7551 - \underset{(1.5)}{11.8}(P_O/P_R)_{t-1} + \underset{(11.9)}{112.6}\ S_{pt} + \underset{(10.2)}{95.0}\ T \qquad R^2 = .99 \tag{18.6}$$

The extrapolated 1980 quantity of operating inputs, Q_O, from the equation is 11.8 billion 1947-49 dollars. To make the prediction, the ratio of operating input prices to all commodity prices is set at the 1955-59 average, the stock of productive assets is set at $117.1 billion (see Table 18.2) and T is 80. As stated earlier, however, the extrapolations from structural equations such as (18.6) have many limitations, and the higher estimates in Figure 18.5 are considered more realistic. It should be recognized that operating input prices have fallen, and future decrements would result in even larger projections from (18.6).

Fertilizer and lime purchases for 1980 are projected to be $2.5 to $2.7 billion. These estimates are 60 to 70 percent over 1960 purchases, or somewhat greater than the 40 percent increase estimated for all operating inputs (Figure 18.5).

Fertilizer requirements for 1980 may be computed approximately as follows: Crop production was 24 billion 1947-49 dollars in 1960, and projected 1980 requirements are $32 billion, an $8 billion increment. Assuming that 50 percent of the crop increment comes from added fertilizer,[14] the output imputed to fertilizer is 4 billion constant dollars. If we interpret an average ratio 2.5 of costs to returns as the "productivity,"[15] the additional output would require (4/2.5) = 1.6 billion constant dollars more fertilizer in 1980. An alternative estimate of fertilizer requirements, based on a study by Ibach and Lindberg,[16] suggests

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[14] From 1919-21 to 1938-40, fertilizer was responsible for more than one-fourth of the increased crop production per acre and from 1951-52 to 1955 for more than two-thirds according to Durost, D. D., and Barton, Glen T. Changing sources of farm output. USDA Prod. Report No. 36. Washington, D.C. 1960. pp. 26, 27.

[15] The average U.S. marginal return from corn per dollar spent on fertilizer in 1954 was 3.06 according to Ibach, D. B. Substituting fertilizer for land in growing corn. USDA Agricultural Research Service. ARS 43-63. 1957. p. 5. Estimates ranged from 3.78 in the Corn Belt to 1.38 in the Northern Plains. In his concluding statement on page 15, he states that fewer acres would be required in 1975 than in 1943 and 1944 if fertilizer were applied on the 1954 acreage at a marginal return-cost ratio of 2.5.

[16] Ibach, D. B., and Lindberg, R. C. The economic position of fertilizer use in the United States. USDA Agr. Inf. Bul. No. 202. Washington, D.C. 1958. pp. 7-13.

40 percent of additional crop output attributable to fertilizer and a rate of return around 2.0. The requirements therefore would be (.4)(8) = 3.2 divided by 2.0 = 1.6, the same requirement as above. The 100 percent increase in fertilizer requirements indicated by these approximate computations is somewhat greater than the 60 to 70 percent increase projected from the 1950-60 trend. The findings show that fertilizer use reasonably could be over 3 billion 1947-49 dollars by 1980; and the \$2.5 to \$2.6 billion forecast by equations (18.1) and (18.2) may be a conservative estimate.

The additional tons of fertilizer in 1980 will be either for "widening" use to acres not previously fertilized or "deepening" use on acres already fertilized. Table 18.3 gives a brief summary of some past trends and future potentials in percentage of acres fertilized and in applications per acre. In the short period from 1947 to 1954, the percentage of acres fertilized rose markedly for all the crops listed. If the potentials for 1980 are realized, few opportunities will exist to widen fertilizer use to more corn and cotton acres. Despite large gains in the proportion fertilized of close growing crops (mainly small grains) and hay and pasture from 1947 to 1954, the potential for 1980 is indicated to be only 40 to 50 percent because of limiting price and productivity ratios.

Only 30 percent of all land in crops and pasture was fertilized in 1954, but an estimated 52 percent potentially will be fertilized in 1980. The proportion of acres suitable for use of commercial nutrients will be augmented by extension of irrigation and by depletion of virgin soil resources. More intensive crop rotations and introduction of new varieties and techniques encourage use of fertilizers until the marginal

Table 18.3. Percent of Acres Fertilized for 1947 and 1954, and Projected for 1980, and Average Rates of Fertilizer Applied per Acre in 1947 and 1954*

Crops	Percent of Acres Fertilized			Average Rates (lbs.) per Acre Fertilized‡					
				N		P_2O_5		K_2O	
	1947	1954	1980†	1947	1954	1947	1954	1947	1954
Intertilled crops	43	50	75	19	34	33	35	19	30
Corn	44	60	90	10	27	23	28	12	25
Cotton	45	58	85	25	49	28	31	17	25
Close-growing crops	18	29	40-50	11	19	24	27	11	19
Hay and pasture	7	12	40	4	14	55	40	10	28
All crops and pasture	23	30	52	15	27	33	34	16	27

*1947 and 1954 data from USDA Stat. Bul. No. 216. 1957. In some instances, 1947 and 1954 data are not strictly comparable.

†Potentials, based on past trends and on estimates, by Ibach, D. B. Potentials of agricultural production. In Iowa State Center for Agricultural and Economic Development. Dynamics of Land Use — Needed Adjustments. Iowa State University Press. Ames. 1961. p. 134.

‡Data not considered adequate for 1980 projections.

Table 18.4. Projected U.S. Annual Inputs in 1980: Productive Operating and Labor Inputs, Durable Services, Output-Input Ratios and Total Output (Million 1947-49 Dollars)*

	Actual			Projected			Source of Projections	
				1980		Percent change 1960-80	Extension from 1950-60 data by equation:	Other basis:
	1940	1950	1960	High	Low			
Labor (based on man-hour requirements)	13,631	10,081	6,866	3,600		-48	(18.4)	
					3,000	-56	(18.3)	
Real estate (services)	3,485	3,651	3,750	3,900		4	(18.2)	
					3,750	0		30% increase in buildings and improvements, 4.2% decrease in soil, slight decrease in grazing
Fertilizer and lime	393	977	1,561	2,600		67	(18.1)	
					2,500	60	(18.2)	
Power and machinery	2,305	4,689	5,558	6,800		22	(18.2)	
					6,300	13		Extension by (18.1) of 1952-60 trend
Livestock and feed †	1,151	1,279	1,526	1,930		26	(18.2)	
					1,860	22		Output requirements: assuming 30% increase in livestock output per animal unit, 5% increase in livestock feed conversion rate
Aggregate nonfarm ‡	1,296	2,073	3,112	4,900		57	(18.1) & (18.2) average	
					4,400	41		Based on above estimate with 10% improvement in efficiency of purchased feed, seed and livestock
Taxes and interest on operating inputs	1,088	1,158	1,611	2,400		49	(18.2) for taxes, (18.1) for interest on operating inputs	
					2,190	36	(18.2) for operating inputs, 10% below "high" for taxes	
Miscellaneous inputs §	831	1,131	1,307	1,600		22	(18.1)	
					1,550	19	(18.2)	
Total inputs	24,181	25,040	25,292	27,730		10		Sum of high estimates
					25,550	1		Sum of low estimates
Output-input ratio	.94	1.12	1.40	1.9	1.9	35	(18.1) and removing the influence of weather	
Total output	22,825	27,958	35,454	52,000		47		
					48,000	35		

*Data based on Loomis, R. A., and Barton, G. T., Productivity of agriculture, United States, 1870-1958. USDA Tech. Bul. 1238. 1961. Also, U.S. Stat. Bul. 233. Revised 1961.

† Interest and other costs for holding livestock and feed inventories.

‡ Includes purchased feed, seed and livestock, but excluding interfarm sales.

§ Miscellaneous inputs include dairy supplies, blacksmith repairs, hardware items, etc. (see Chapter 14).

product is more nearly in line with real nutrient price (which also may decline). Various agencies will continue to inform farmers of the value of fertilizers.

Input Summary

The estimates in Table 18.4 and graphically presented in Figure 18.6 are based on the input breakdown used by the USDA to measure all annual inputs in farming. The inputs of durables are measured as the services required to maintain them at current levels in the years indicated. The projections in the table generally are consistent with those discussed for individual inputs, but in some instances a different concept is used. For example, the table contains man-hour labor requirements rather than the farm employment estimates of Figure 18.3. The projected labor requirements are 48 to 56 percent below 1960 requirements. Since labor is the only declining input and total inputs remain nearly constant or increase slightly, it is apparent that the major organizational change predicted is the continued gross substitution of capital for labor. Real estate inputs are expected to increase slightly, if at all. Improvements in real estate are predicted to increase up to 30 percent, but land input per se may be lower in 1980.

The two input categories projected to increase by the greatest percentage are fertilizer and lime and aggregate nonfarm inputs. Based on the above estimates of fertilizer requirements, the 60 to 67 percent increase depicted in Table 18.4 may be conservative. Aggregate nonfarm inputs include feed, seed and livestock inputs furnished by the nonfarm sector. Not only is the percentage rise appreciable, but also it is noteworthy that the quantity of these inputs is projected to be greater than quantities of labor and real estate inputs by 1980. This result again emphasizes the continued shift from resources originating in the farm sector to resources produced by the nonfarm sector. Based on the rising demand for operating inputs and increasing taxes apparent from the 1940 to 1960 data in Table 18.4, these inputs are projected to be from 36 to 49 percent greater in 1980 than in 1960.

Inputs in the miscellaneous category are expected to total 1550 to 1600 million 1947-49 dollars by 1980. The projected increase is less than for other inputs because some items, such as hardware and blacksmith repairs, are either obsolete or strong complements of other inputs which increase slowly. Other miscellaneous items, such as telephone expenses, are related to the number of farm dwellings which are expected to decline by 1980.

The respective high and low input projections total 27.7 and 25.5 billion 1947-49 dollars. The estimates suggest an increase in aggregate inputs of only 10 percent or less between 1960 and 1980. If this small increase in inputs is to meet output requirements (see Figure 18.1), it is essential that the substitution of fertilizer, protein feeds, etc. for labor and land continue at a rapid rate. That these input

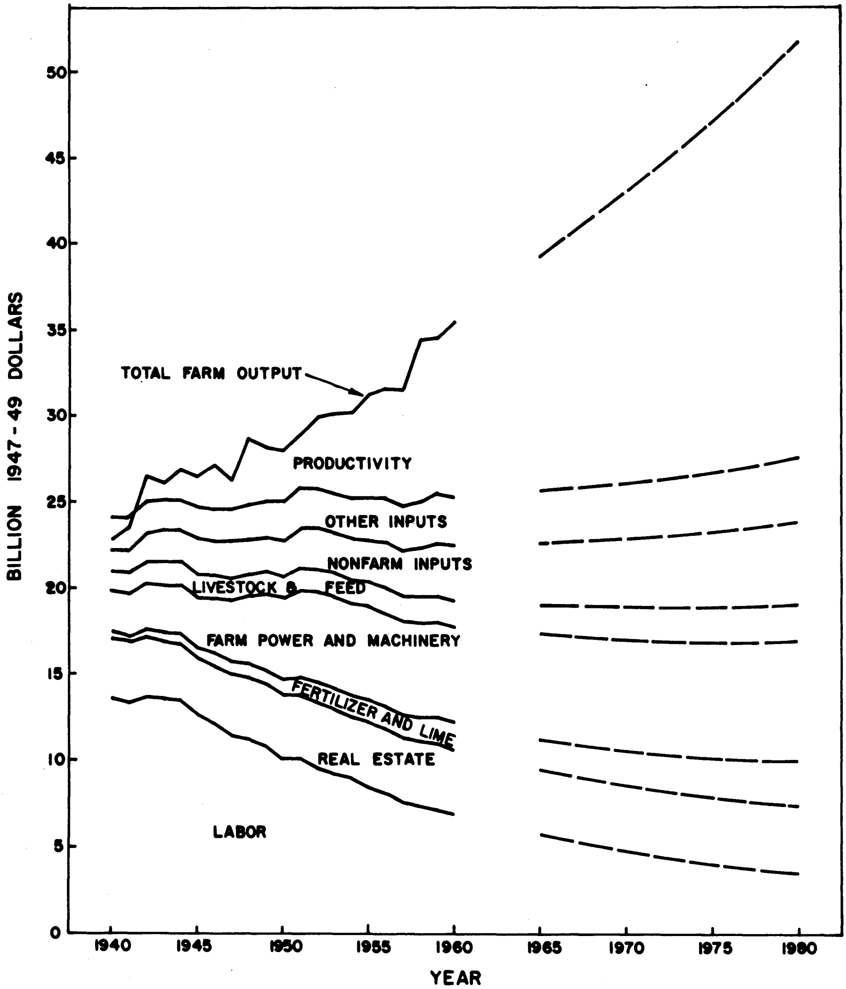

Figure 18.6. Cumulative trends in farm inputs, output and productivity from 1940 to 1960, and projected to 1980. (See "high" estimate, Table 18.4.)

projections are in line with future commodity requirements is apparent from output projections. Assuming a 35 percent increase in the productivity ratio (see Figure 18.2), the projected input levels meet the high and low output requirements given earlier in Figure 18.1. The input estimates generally are conservative, and there need be no doubt that farm resources will be adequate to fill needs in 1980. While the results are not sufficiently precise for exact inferences, the tendency for too many resources and overcapacity in agriculture may very possibly persist to 1980.

The results from Table 18.4 illustrated in Figure 18.6 are not intended to show that resources in agriculture will be adjusted optimally in 1980. For example, the 1980 output could be produced with even fewer labor resources. Too, even small deviations from the projection could disadvantage agriculture from an income standpoint. The estimate of 1980 fertilizer input may be conservative; a projection of 3200 million 1947-49 dollars may not be unrealistic. Assuming the added fertilizer input is $600 million over the high estimate and that one unit of fertilizer raises output by two units, 1980 output would be more than 53 billion 1947-49 dollars. Furthermore, Figure 18.6 shows that gains from efficiency are large, and an increase in productivity of 50 percent rather than 35 percent would result in an output of over $58 billion if inputs are $28 billion. Such outputs undoubtedly would greatly exceed requirements and would not clear markets at prices giving satisfactory returns on labor and other farm resources. The productivity increase would dictate the need for even larger decrements in resources, particularly labor, than anticipated, and our projections in Table 18.3 would not be realistic. These examples of deviations from resource projections are included to show that small errors could distort the measure of resource adjustments needed between 1960 and 1980.

FARM SIZE AND NUMBERS

Trends and projections of farm numbers and cropland used for crops per farm are presented in Figure 18.7.[17] The trend in farm numbers appears to have stabilized after 1950 and, therefore, 1950 to 1960 data are extended to 1980 by (18.3) and (18.4). The projected number of all farms is 2.3 million by equation (18.4), and slightly less than 2 million by the exponential equation (18.3). The decline from 1960 — 51 to 42 percent — is consistent with the farm labor and population decline in Figure 18.2, as would be expected.

Cropland acres per farm are projected on the basis of cropland requirements and the foregoing estimates of farm numbers. Crop production requirements are projected to be 32.4 billion 1947-49 dollars in 1980.[18] Given these requirements and a 40 percent increase in yield per acre, 341 million cropland acres used for crops are required in 1980, or 4 percent less than the 356 million crop acres in 1960.[19] If

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[17] The new classification of farm numbers is used in Figure 18.7. The 1960 classification requires a place to have 10 or more acres in land and to sell at least $50 of products annually. A smaller place can qualify by selling $250 of products. In the 1950's, a qualified farm needed only three or more acres and at least $150 of products sold or produced. "Old" estimates indicate 4.54 million farms in 1960, "new" estimates 3.95 million (about .6 million less).

[18] Largely based on estimates from: USDA. Land and water resources, op. cit., p. 37.

[19] Using 1950-60 data in equation (18.1) and correcting for weather, the 1980 crop yield index is projected to be 172. The yield index (1947-49=100) was 123 in 1959, 129 in 1960; hence the 1980 projection is 40 and 33 percent greater. The report: Land and water resources, ibid., p. 38, predicts a 56 percent increase in crop production per harvested acre and a 35 percent increase in pasture production per acre from 1959 to 1980. Yield per

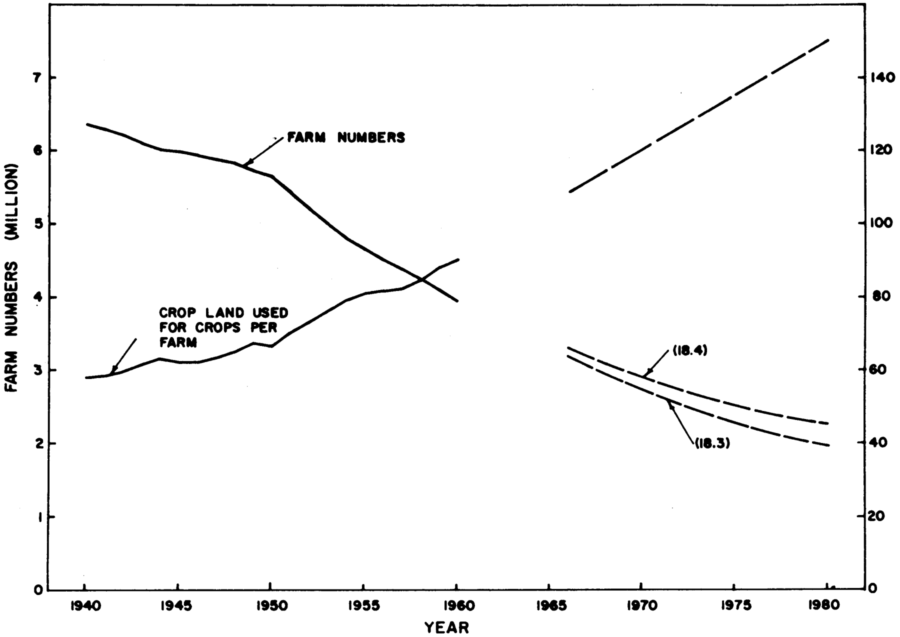

Figure 18.7. Projected farm size and numbers to 1980. (1940-60 data from: USDA. The farm income situation. July 1962; and USDA Stat. Bul. 233. Revised 1961.)

341 million acres are required in 1980 and if there are 2.3 million farms (the higher projection from (18.4) in Figure 18.7), then the average farm will have 150 acres used for crops.

The projected two-thirds increase in acres per farm over 1960 indicates considerable potential for improving input efficiency with larger units. Opportunities will exist to substitute machinery for labor by replacing depreciated stocks with new, larger machines adaptable to larger acreages. This substitution of larger machines for smaller ones need not appreciably increase stock if the new machines are

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harvested acre is expected to increase faster than yield per cropacre; nevertheless, our estimated 40 percent 1959-80 increase seems low. Our 1980 estimates were adjusted accordingly to a 47 percent increment over 1959, a 40 percent increment over 1960. This increase is predicted by equation (18.2) from 1950-60 observations without correcting for weather.

The report: Land and water resources, ibid., p. 38, projects land requirements (million acres) as follows:

	1959	1980
Total cropland used for crops	359	326
Soil improvement and idle cropland	33	11
Cropland used for pasture	66	70
Total cropland	458	407

The estimates suggest that 33 million fewer cropland acres used for crops and 51 million fewer acres of all cropland will be required in 1980 than in 1959.

Table 18.5. Percentage of All Farm Numbers in Specified Acreage and Sales Categories[*]

Item	Actual			Projected
	1939	1949	1959	1980
Sales[†]				
under $2500	69	61	48	24
$2500-$10,000	26	30	33	30
over $10,000	5	9	20	46
Acreage				
under 100	59	56	49	39
over 100	41	44	51	61
Total	100	100	100	100

[*] 1939 to 1959 original data from: Statistical Abstract of the United States. 1961. The definition of a farm changed some; corrections are made accordingly. However, no correction was made for the estimated 2.5 percent more farms that would have been included in 1939 had a later definition been used.

[†] Corrected for changes in dollar values in earlier years. No correction was made in 1959 because the index of prices received by farmers was nearly the same in 1954 and 1959.

introduced only at the rate necessary to replace worn-out and obsolete equipment. But larger machines do permit one family to farm a larger acreage and to produce more output per unit of labor; hence, machinery investment will continue to offer opportunities for movement of labor from agriculture.

In Table 18.5 and Figure 18.8, all farms are classified by sales volume and acreage. The total number of farms from 1939 to 1959 differs somewhat from estimates in Figure 18.7 because of slight differences in concepts. The data in Figure 18.8 for earlier years were revised slightly to correct for changes in the value of the dollar. This adjustment was not considered necessary between 1954 and 1959 because prices received by farmers were nearly equal in the two years. Inflation between 1959 and 1980 will place more farms in groups with higher sales volumes, but the projections in Figure 18.8 are intended to measure farm numbers from real or constant-dollar sales, not from inflated values.

Extension by equations (18.1) to (18.4) of the 1939 to 1959 trend using observations for the years included in Figure 18.8 resulted in considerable instability in 1980 projections. Those presented are based on extensions from equation (18.4) adjusted to the total farm numbers, 2.3 million, projected by (18.4) in Figure 18.7. The results also are similar to an average of the estimates from the four types of equations. Despite this "check," the projections by sales and acreage should be regarded as first attempts and considered cautiously, pending further verification.

If the estimates in Table 18.4 are correct, the relative proportion of farms over and under 100 acres will reverse between 1939 and 1980. In the former year nearly three-fifths of all farms were under 100

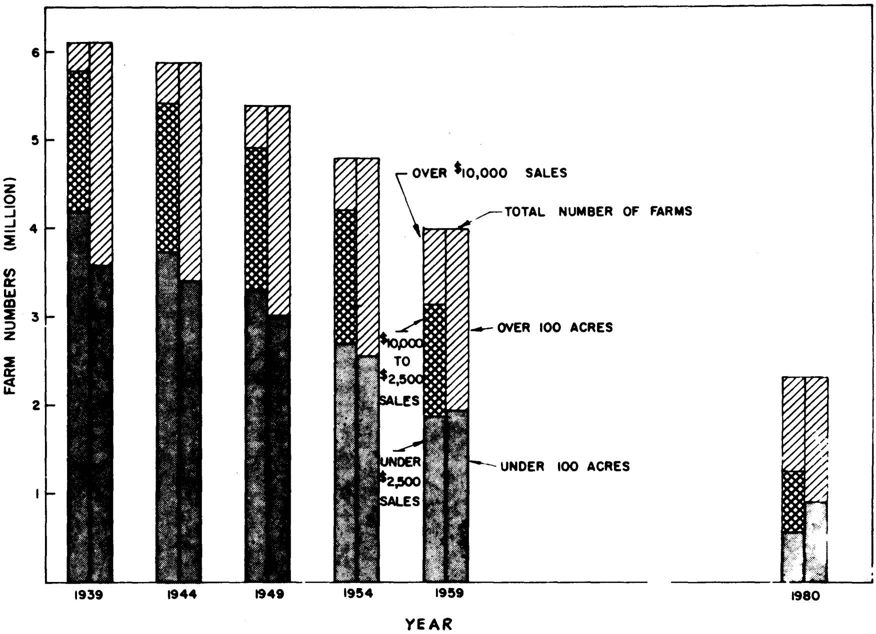

Figure 18.8. Projected farm numbers by acreage and sales volume to 1980. (1939-59 data from: Statistical Abstract of the United States. 1961.)

acres, and by 1980 three-fifths of all farms are predicted to be over 100 acres. The percentage change in the number of farms in each category is predicted to be nearly the same from 1959 to 1980 as from 1939 to 1959.

The most notable change in classification by sales is the shift in farms from the lowest to the highest category. The proportion in the middle $2500 to $10,000 category remains almost unchanged. In 1939 nearly 70 percent of all farms had sales under $2500. By 1959 the percentage in this group had dropped to 48 and by 1980 the projected percentage is 24. The proportion of farms with annual sales of over $10,000 increased from 5 percent in 1939 to 20 percent in 1959. Almost half of all farms will have sales over $10,000 by 1980 if our projections are correct. The results indicate that a major adjustment toward adequate units will have been made by 1980. The figures are somewhat misleading however, because increasing production expenses will reduce the proportion of cash income available to pay living costs by 1980 out of a given sales volume.

Having one-fourth of all farms in the lowest sales category by 1980 need not necessarily imply a great low-income problem. Many farmers in this group will be retired, work off farms or have various other sources of income. Hence, many of the 550 thousand farmers in this group may have adequate incomes despite the low receipts from farm sources.

Based on Figure 18.8, the trend is likely to persist for the majority of farm output to originate from fewer farms. The more than one million farms predicted to sell more than $10,000 undoubtedly will be responsible for a large portion indeed of all farm output in 1980. Sizeable investment and managerial skill will be demanded by these large farms. Whether these demands will be satisfied within the family farm structure remains to be seen. Much depends on the credit structure, managerial support provided by the Extension Service, and the institutional structure existing in 1980.

SOME CONCLUDING COMMENTS

The changes in the organization of farm resources depicted in the foregoing pages portend major shifts in the political and sociological as well as economic aspects of farm life. The projected $30,000 investment per farm worker, larger acreage and high proportion of purchased inputs all signal an increasingly commercialized agriculture. (The capital required per worker is stated in 1947-49 dollars and would be very much larger if expressed in 1960 dollars.) The diminution in labor inputs from 56 percent of total inputs to a projected 11 to 13 percent in 1980 is an integral part of the shifting emphasis to more purchased inputs. Some of the sociological characteristics of the "farm way of life" undoubtedly will disappear and the nostalgia of farm fundamentalism will become less intense. These changes also will be associated with increasing demand for management skills, a credit framework and other institutional arrangements (e.g. laws, corporate laws, leasing arrangements, purchase contracts) to service the changing farm organization. The direction taken in these institutional and other arrangements will be very important.

The impact of a given excess production and consequent low income may be even greater in 1980 than in 1960. The fact that family labor inputs have comprised a major portion of inputs in the past allowed this noncash item to absorb the variation in returns. While farmers sometimes grumbled, they at least were usually able to remain in farming by accepting lower labor returns if the income setbacks were not too severe. But if increasing cash costs are combined with inflexible procedures to adjust expenses between favorable and unfavorable years, the pressures for a more equitable market structure may be severe. Furthermore, the projected decline in farm population and numbers to 9 and 2.3 million respectively in 1980 will make efforts to improve bargaining power more feasible. Hence, the potential for reorganization of farming to obtain greater bargaining power will be much greater in 1980 than is true of the 1960's. Efforts in this direction may also be prompted by farmer reactions to a public indifferent to the economic disadvantage of agriculture.

Despite lags in redistricting of political units as population shifts, agriculture will undoubtedly lose a large amount of political influence between 1960 and 1980 as the farm population drops to as little as 4 percent of the total population. The declining political influence is expected to reduce the number of program alternatives available to farmers. Generally, the political shift is expected to remove alternatives requiring large government outlays and eventually to reduce alternatives to two: strict controls or free markets. Because of the large capital input relative to labor input, the appeal for farm programs also will tend to be based increasingly on a reasonable return to capital on well-organized farms, as well as an equitable labor income.

With national growth in capital and efficiency, total agricultural income also will continue to decline in proportion to national income. The consequence is that economic conditions in farming will have less and less influence on national business conditions and economic growth. Hence, economic planners and policymakers can more nearly design programs disregarding the contribution of agriculture to aggregate demand and national economic health. This condition, combined with declining political influence, will tend to shift the public focus from farm problems to other areas. The above considerations suggest, then, not only a change in farm organization but also a shift in political, sociological and institutional framework for agriculture. While indicating that conditions in agriculture may be determined to a larger extent by nonfarm political and economic forces, this does not mean that the destiny of agriculture must necessarily follow this positivistic trend. The reverse may be true — these forces may prompt agriculture to re-examine its enterprise creed and concepts of distributive and commutative justice. This re-examination, in an environment of the future farm organization (size, numbers) more conducive to marketing controls, followed by proper action could make the economic fortunes of agriculture increasingly <u>internal</u> rather than <u>external</u>. Furthermore, the small portion of the national food budget going to farmers might make the public somewhat indifferent to monopolistic tendencies of farm organizations raising farm commodity prices.

The projections in this chapter and the descriptive and structure analysis of previous chapters reflect both the cause and effect of economic growth. Given exogenous price and technology variables, the organization of agriculture, i.e. income, expenses, farm size and efficiency, is determined largely by resource supply and demand elasticities (coefficients). A principal goal of this study has been to estimate the magnitude of these parameters, both in the short run and long run. Estimates of these parameters allow prediction of variables such as resource prices and quantities. Although the estimates are largely based on single equations, the analysis in Chapter 16 shows how the individual equations expressing prices and quantities can be integrated to express total and per worker incomes and other concepts. The structural parameters are intended to be useful to such integrated studies, and also can be used in partial studies to determine the implications of a change in any one explanatory variable on resource employment, etc., in farming. The analyses are far from perfect, of course, and must be interpreted in terms of the reliability of methods and data discussed in the appropriate sections.

The structural parameters depend fundamentally on the technical know-how and values and goals of farmers. Through education, research and other means, the parameters continually are being altered. While this may be disconcerting to the statistician, it can bring large benefits to farmers and society.

As demonstrated throughout the book, our estimates can be used to gauge the future direction that economic forces are moving agriculture. Since the estimates are structural and not simply predictive, it is hoped that the parameter estimates can also be used to gauge the impact of policy variables or instruments on resource quantities, output, farm size, etc. If used properly within the framework of restrictions cited here, these estimates can be useful for determining which, if any, programs are needed to bring the agricultural input, output and returns in line with national needs.

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