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.

[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

[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.

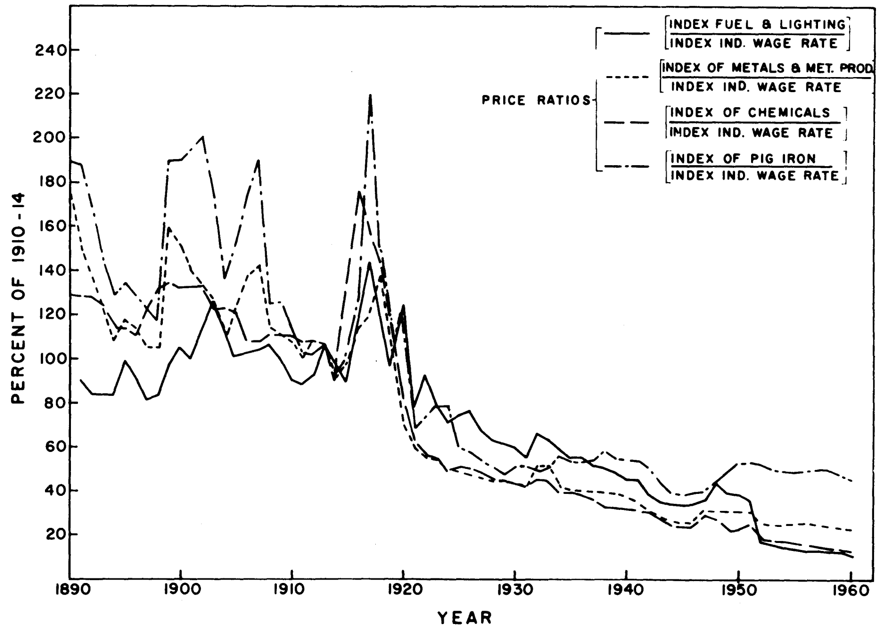

Figure 4.1. Relative prices of basic capital materials and labor, U.S., 1890-1960 (1910-14=100).

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

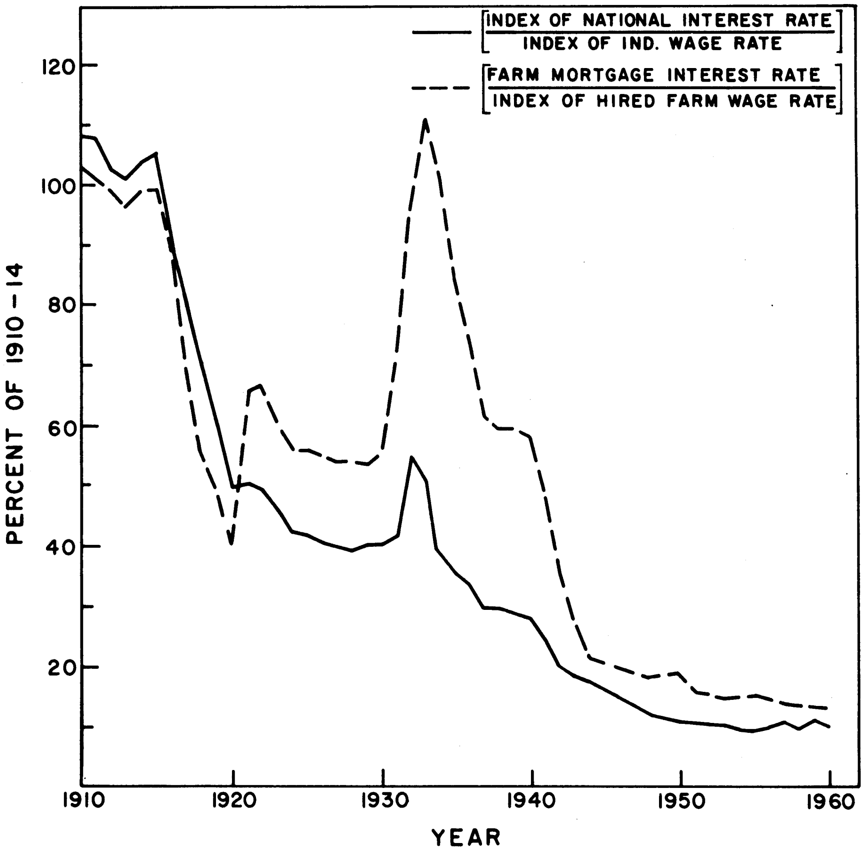

Figure 4.2. Indices of the ratio of interest rates to wage rates.

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.

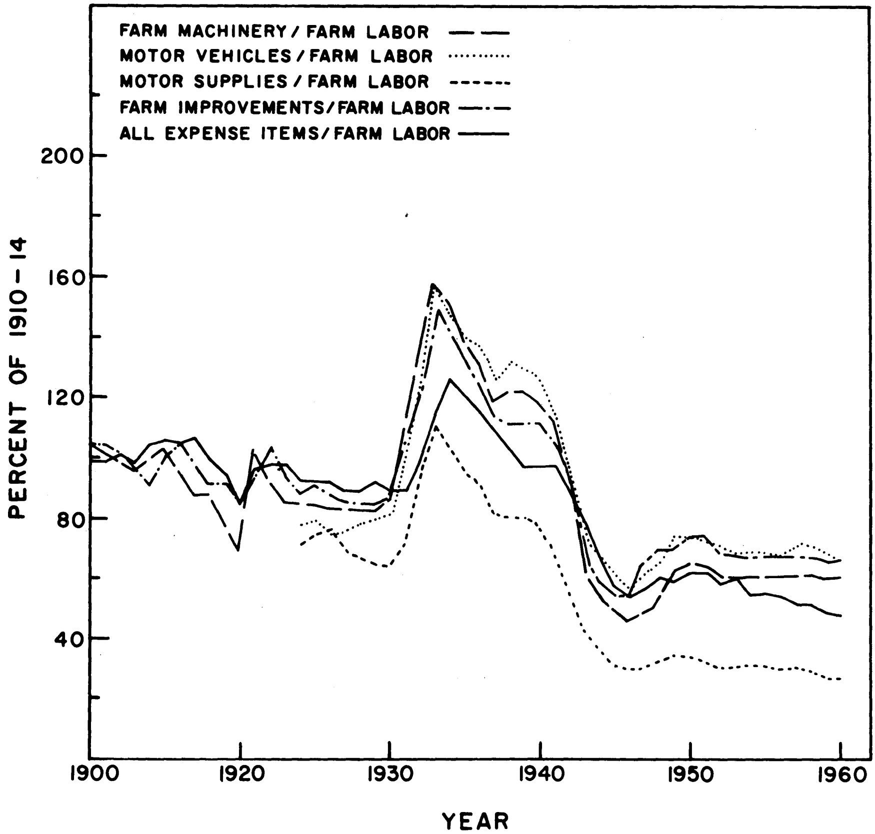

Figure 4.3. Relative prices of selected farm capital items and farm labor (ratio of price indices, 1910-14=100).

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

[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.

---

[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.

[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

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

[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

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

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

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

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.

---

[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

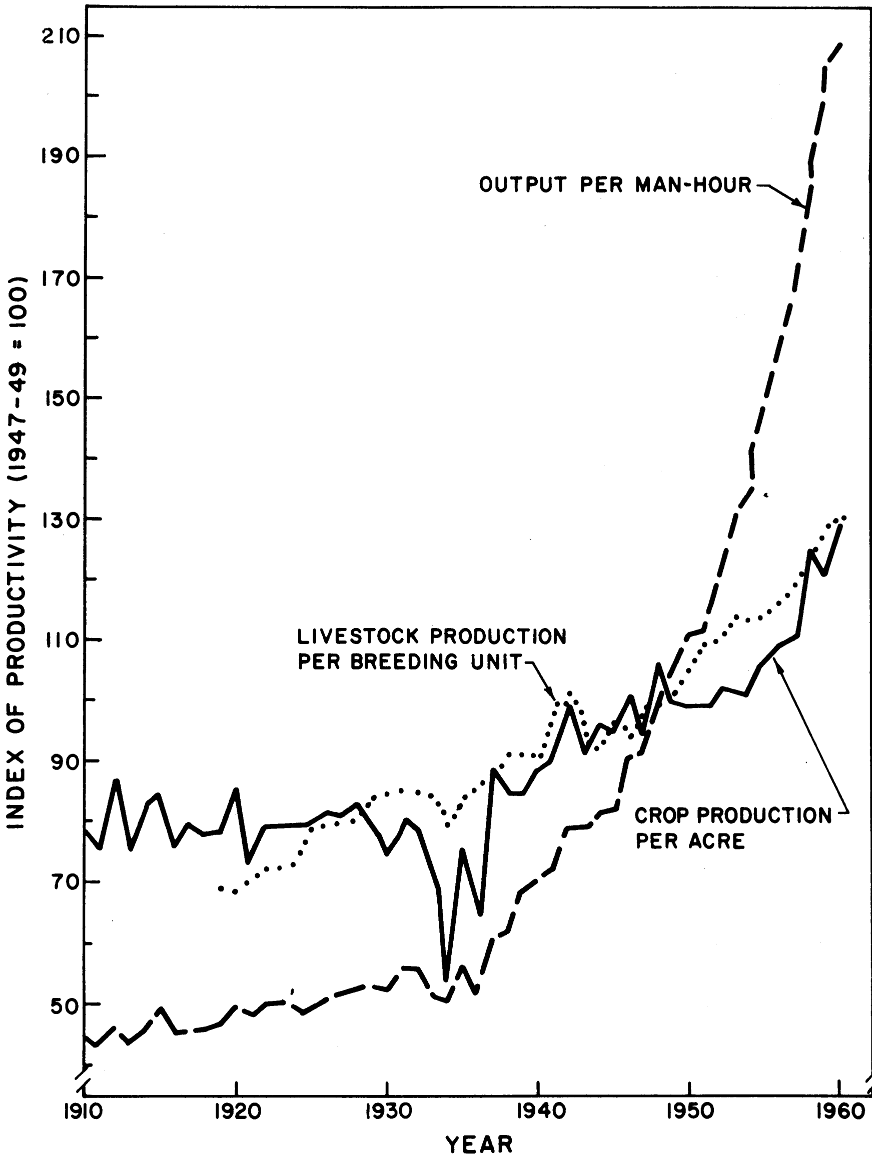

Figure 4.4. Gross transformation rates per unit of labor, land and livestock for U.S. agriculture, 1910-1960. (Source: USDA Stat. Bul. 233.)

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

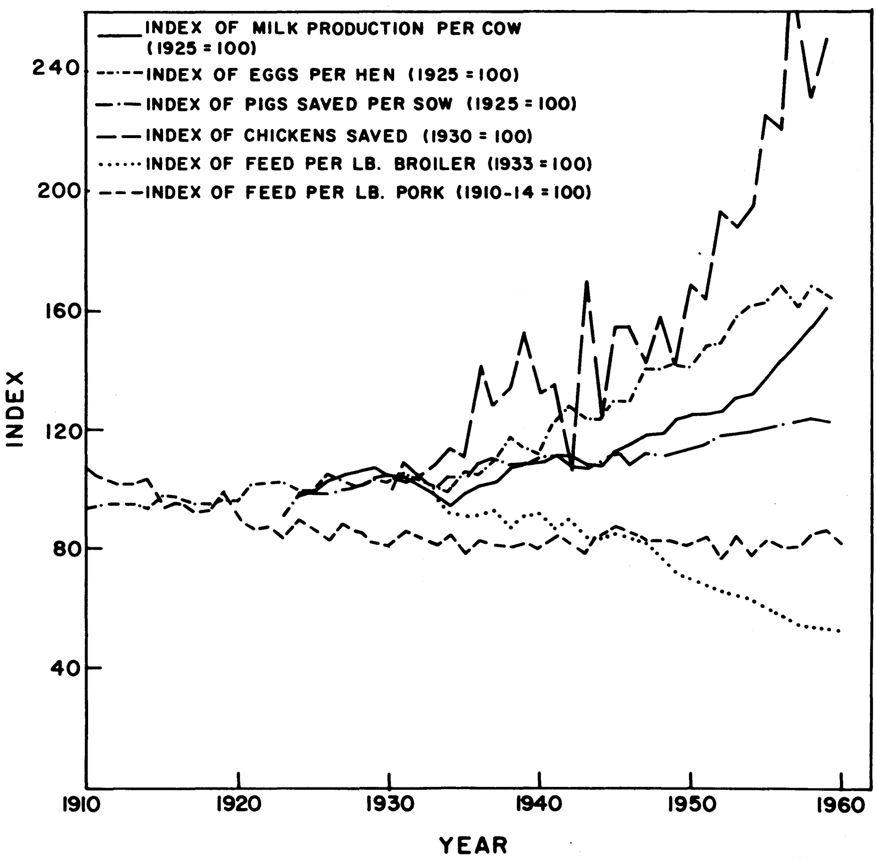

Figure 4.5. Output per animal and bird, and feed per pound of broilers and pork. (Source: Agricultural Statistics.)

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.

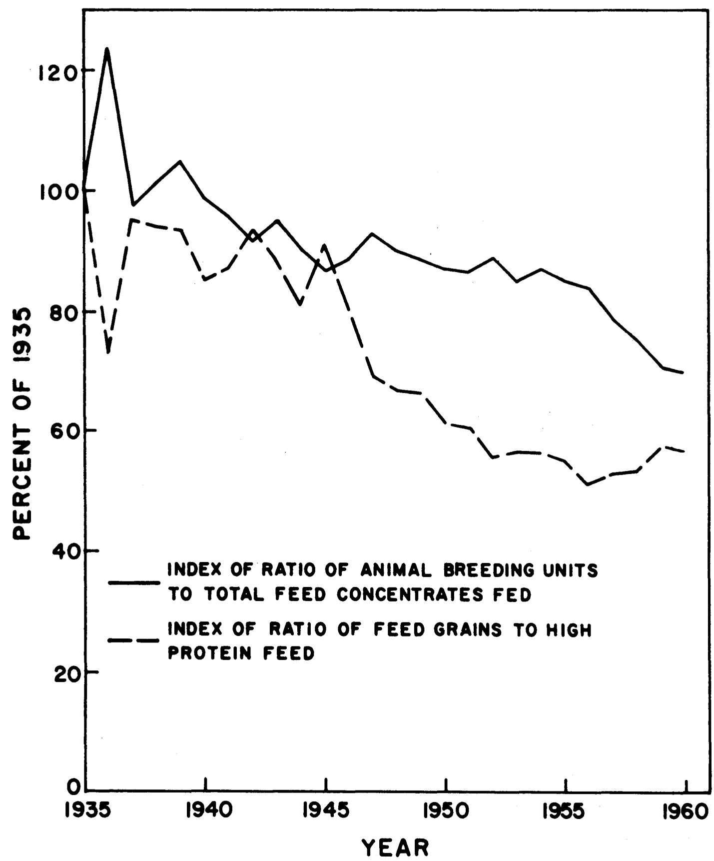

Figure 4.6. Ratios of animal units to feed and of feed grains to high protein feed, 1935-60 with 1935=100. (Source: USDA.)

[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).

[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.