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

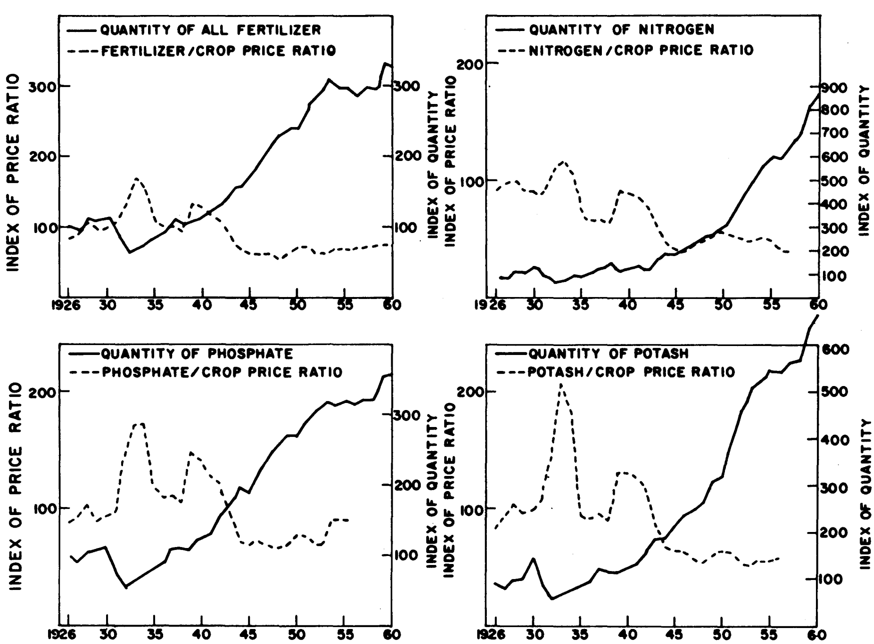

Figure 7.1. Indices of fertilizer use (tons) and fertilizer/crop price ratios for the U.S., 1926-60 (1926-30=100); including all fertilizer, nitrogen, K_2O and P_2O_5.

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

[1] Markham, J. W. The Fertilizer Industry. Vanderbilt University Press. Nashville, Tennessee. 1958.

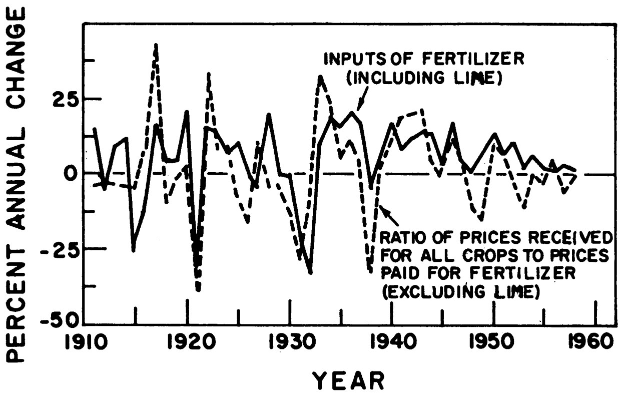

Figure 7.2. Percent annual change in fertilizer inputs and crop/fertilizer price ratio. (Source: USDA.)

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

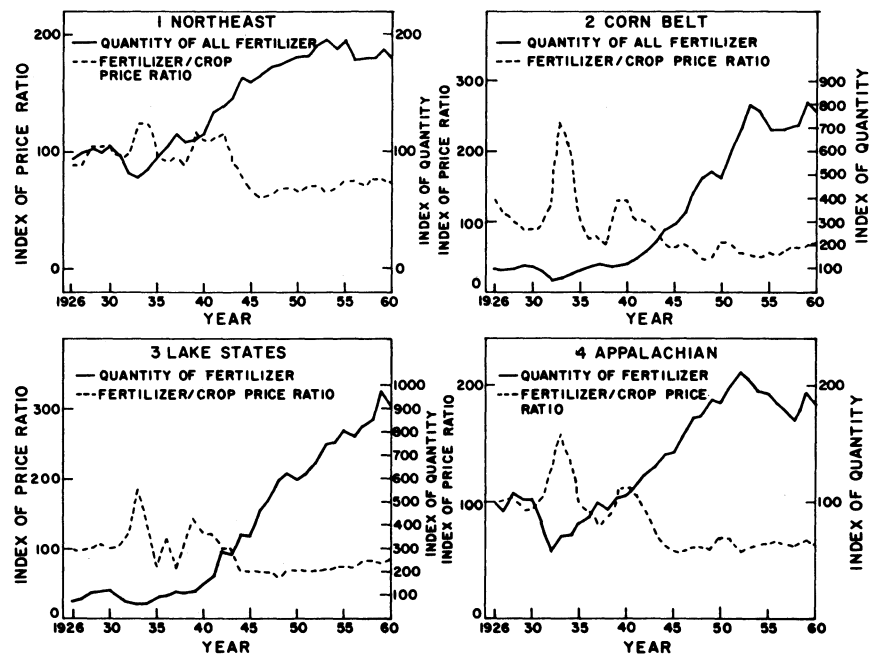

Figure 7.3. Trends in fertilizer purchases and fertilizer/crop price ratios by regions, 1926-60 (1926-30=100). (table continued)

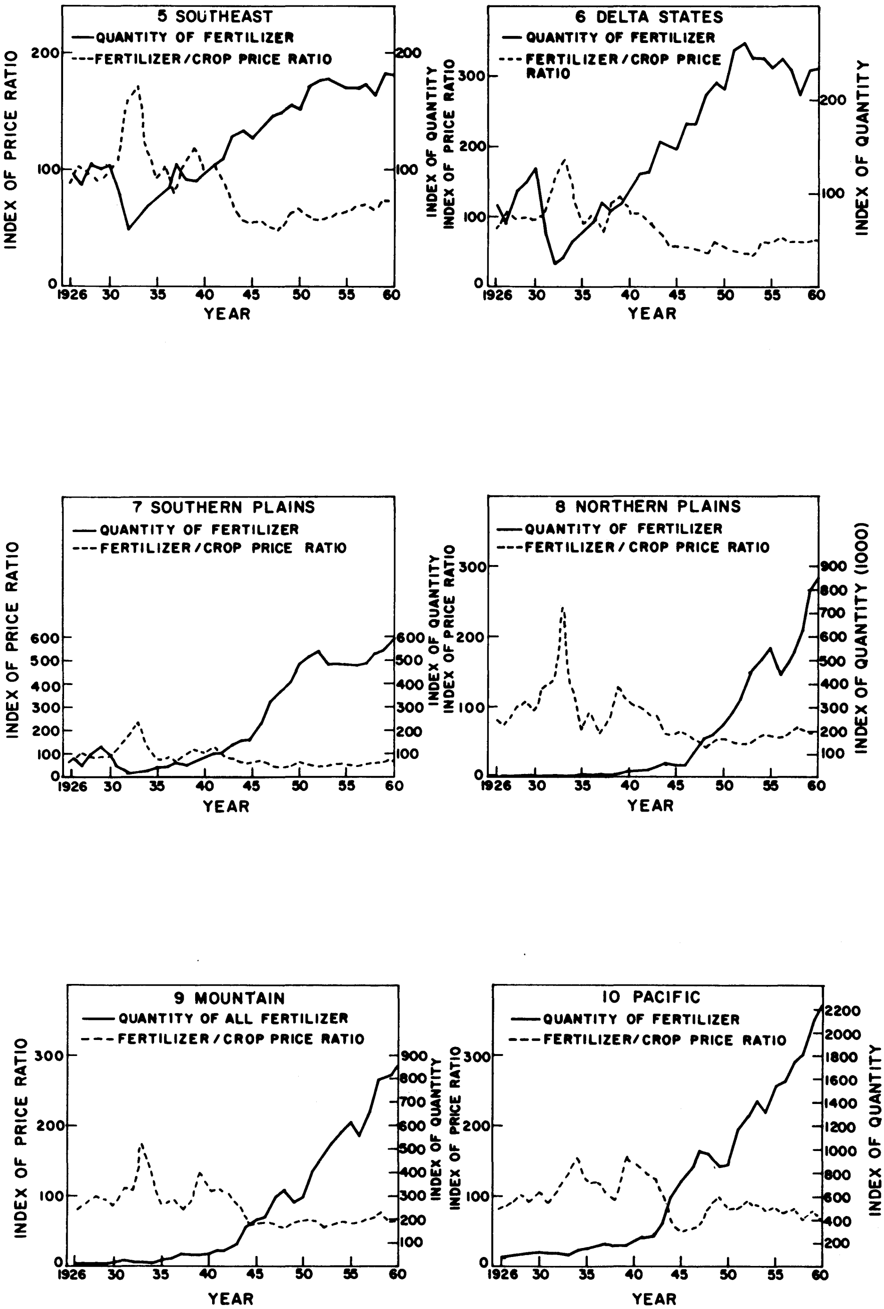

Figure 7.3. (continued

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

[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

[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.

[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.

$$(7.1)\quad \log F_n = \underset{}{4.965} - \underset{(.431)}{1.531} \log Z_f + \underset{(.230)}{.704} \log Z_c + \underset{(.131)}{.371} \log Z_d - \underset{(.996)}{.171} \log C + \underset{(.003)}{.008} \log T$$

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.

[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

Table 7.4. Short-Run and Long-Run Elasticities for Distributed Lag Models of National Fertilizer Demand

Equation	Short-Run Elasticity			Long-Run Elasticity		
	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

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.

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

Equation	R^2	Log of Constant	Regression Coefficients							
			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	-.439			.0105	
					(.086)	(.114)			(.0012)	
(7.15)	.986	3.64	-1.491	.106			-.008		.0007	.413
			(.366)	(.268)			(.192)		(.0038)	(.172)
(7.16)	.983	3.34			-.637	-.346		-.269	.0091	.262
					(.146)	(.267)		(.544)	(.0022)	(.174)
(7.17)	.982	2.69			-.637	-.246			.0085	.255
					(.144)	(.171)			(.0018)	(.171)
(7.18)	.966	.85			-.305					.862
					(.152)					(.079)
(7.19)	.981	1.78			-.640		.145		.0089	.335
					(.196)		(.250)		(.0025)	(.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

[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

Equation	R^2	Log of Constant	Regression Coefficients						
			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

Equation	R^2	Log of Constant	Regression Coefficients						
			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

Equation	R^2	Log of Constant	Regression Coefficients						
			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	.956		.634	.019		.182
			(.621)	(.331)		(.188)	(.005)		(1.43)
(7.39)	.973	7.37	-1.875	.661			.016		
			(.654)	(.342)			(.005)		
(7.40)	.982	5.79			-1.113	.661	.022		
					(.115)	(.174)	(.001)		
(7.41)	.971	6.90			-1.060		.023		
					(.142)		(.002)		
(7.42)	.983	4.78	-1.448	.764		.475	.015	.124	
			(.575)	(.476)		(.340)	(.009)	(.218)	
(7.43)	.980	7.26	-2.138	-.036		.001		.458	
			(.454)	(.194)		(.230)		(.124)	
(7.44)	.981	5.97	-1.663	.264			.006	.379	
			(.565)	(.320)			(.006)	(.122)	
(7.45)	.980	7.26	-2.138	-.036				.458	
			(.388)	(.186)				(.101)	
(7.46)	.979	4.53			-.736		.014	.364	
					(.168)		(.003)	(.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.

[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 $-.79 \pm .19$. 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

[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.

[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

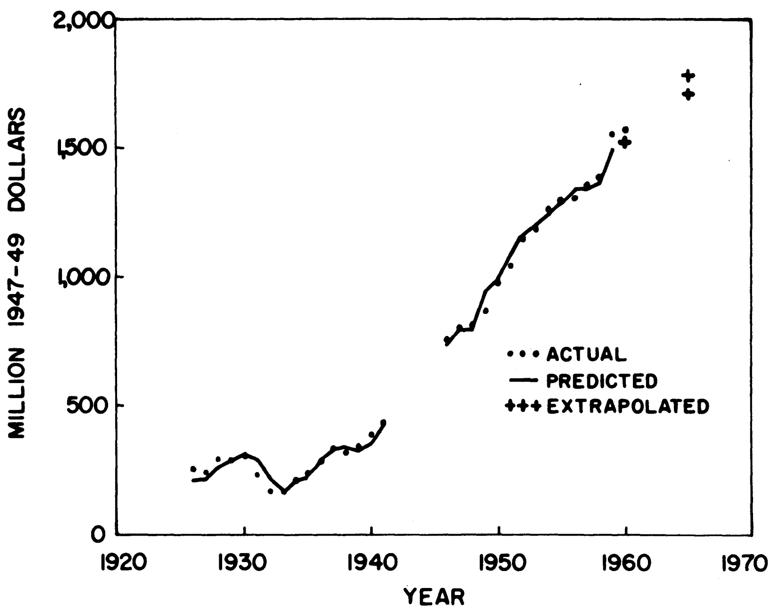

Figure 7.4. Trends in price-weighted purchases of fertilizer and lime from 1926 to 1960 (predicted and projected estimates from equation 7.50).

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

[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

[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' b	Log Z_r' s	Log Z_c b	Log Z_c s	Log R* b	Log R* s	Log C b	Log C s	Log T b	Log T 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

[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

[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

Region	R^2	Log of Constant	Log Z_r		Log T		Log R*		Log $Y_{i,t-1}$	
			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

[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		Log Z_c		Log Z_d		Log T	
			b	s	b	s	b	s	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

[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.