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THE DEMAND FOR FERTILIZER

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There has been a large increase in the amount of fertilizer used in the past forty years. Between 1946 and 1981, the total quantity of fertilizer material used increased over three times and the total quantity of the three principal plant nutrients (N, K_2O, P_2O_5) increased more than seven-fold (Table 1). However, after 1981 the use of all fertilizers declined due to the overall contraction experienced in the agricultural sector. The total consumption of total fertilizer material increased from 16.1 million tons in 1946 to 52.8 million tons in 1980 but declined to 49.0 million tons in 1985. Total plant nutrient consumption increased from 3.3 million tons in 1946 to 23.1 million tons in 1980 and declined to 21.7 million tons in 1985. The increase up to 1980 in the use of total fertilizer used was due to the use of more fertilizer per acre since total crop acres have not changed much during the period. The dramatic increase up to 1980 in the use of fertilizer plant nutrients was due both to increases in the quantity of total fertilizer used and to improvements in the quality of the fertilizers as shown by the steady increases in average plant nutrient contents. The decline in the use of fertilizers in the early 1980s was due to a decline in cropland acreage and a reduction in the per acre application rate.

A similar pattern can be seen in expenditures (Table 2). Farmers' total expenditures for plant nutrients increased from $571 million in 1946

Table 1

Quantities of Fertilizers Used, 1946-85
(Quantities in '000 tons)

Year	Total Fertilizer Total Qty	Total Fertilizer Lbs/acre	Plant Nutrients Total Qty	Plant Nutrients Lbs/acre	Plant Nutrient % of Total Fert.
1946	16,087	98	3,286	20	20.4
1950	19,758	117	4,058	24	20.6
1955	22,194	132	6,109	36	27.5
1960	25,571	161	7,463	46	29.2
1965	31,836	212	10,987	72	34.5
1970	39,588	267	16,068	107	40.6
1975	42,484	259	17,572	106	41.4
1980	52,787	310	23,083	133	43.7
1985	49,008	295	21,656	128	44.2

Source: Agricultural Statistics, USDA, (various years).

Table 2

Expenditures and Unit Prices of Fertilizers

Year	Total Expen. for Fertil. Million $	Total Expend. 1982 Constant Mill. $*	Price/ton of Fertil. $	Price/ton of Nutr. in Cons. 1982 $*
1946	571	2,943	35	896
1950	868	3,632	44	895
1955	1,106	4,066	50	666
1960	1,252	4,052	49	543
1965	1,877	5,553	59	505
1970	2,340	5,571	59	347
1975	6,506	10,971	153	624
1980	9,067	10,580	172	458
1985	6,928	6,213	141	287

* = Deflated by implicit GNP deflator, 1982 = 100

Source: Economic Indicators of the Farm Sector, National Financial Summary, USDA, (various years).

to $9,067 million in 1980 but declined to $6,928 million in 1985 (nominal dollars). In constant 1982 dollars, farmers' expenditures increased from $2,943 million in 1946 to $10,580 million in 1980 and declined to $6,213 million in 1985. Thus, while the quantity of plant nutrients used increased about six times between 1946 and 1980, the expenditures in real terms increased only about three times in the same period due to the decline in the real price of plant nutrients during this period.

The nominal price of fertilizer gradually increased from 1946 to the early 1970s but made a three fold jump between 1970 and 1975 due to the generally high inflation rate and the sudden increase in the price of oil. However, it declined in the early 1980s due to the decrease in fertilizer demand and the ease in the rate of inflation and energy prices. On the other hand, the real price of fertilizer decreased continuously up to the early 1970s, then almost doubled between 1970 and 1975, and dramatically declined in the early 1980s. The decline in the real price of plant nutrients prior to the inflation of the 1970s was generally attributed to the increase in the quality of fertilizer, increased competition from abroad, and efficiency in production and raw material acquisition. However, the decline in the early 1980s seems mainly due to reduced demand on the part of farmers.

These changes in demand are what sparked this current study. Several excellent farm input demand studies were conducted from the 1950s to the early 1980s, but they were done before the changes that occurred in the 1980s. The overall objective of this study is to extend these studies by incorporating emerging economic, policy and structural forces and estimate the demand functions of fertilizer. Also, selected models from previous demand studies will be updated using data for the period 1946-85 and compared with the results of the current study. Elasticities for selected demand models will be estimated and compared with previous estimates to assess changes in magnitude and direction over time.

MAJOR FORCES AFFECTING THE DEMAND FOR FERTILIZER

Several forces or factors determine the demand for fertilizer. Three major sources will be used to identify these forces: (1) economic theory, (2) previous input demand studies, and (3) recent agricultural economics literature. Though the division of these sources is helpful, there are obvious overlaps between the forces suggested by the three sources.

Forces Suggested by Economic Theory

The static theory of the competitive firm provides a good starting point for identifying the factors that determine the demand for variable inputs. A producer's (firm's) demand for production inputs is derived from the demand for its final products. Assuming that the production function (technology) and prices are given, a system of input demand functions can be derived from the first order conditions for profit maximization. The derivation also suitably extends to total demand, the summation of individual demand, since producers are assumed to be identical under perfect competition.

Consider a firm producing one output, Q, and using variable inputs, $X_1, \ldots, X_n$, and a stock of quasi-fixed input, K. The firm's production function can be represented as:

$$(1) \quad Q = f(X_1, \ldots, X_n, K) \quad \text{or} \quad Q = F(X, K)$$

This is a physical relationship portraying the level of output, the marginal and average productivities of the factors of production, and the marginal rate of substitution between pairs of factors. The marginal products are:

(2) $\partial F(X,K) / \partial X > 0$

(3) $\partial F(X,K) / \partial K > 0$

The production function is strictly concave, which implies the law of diminishing returns, i.e.,

(4) $\partial^2 F(X,K) / \partial^2 X < 0$

(5) $\partial^2 F(X,K) / \partial^2 K < 0$

(6) $\partial^2 F(X,K) / \partial^2 X \cdot \partial^2 F(X,K)/\partial^2 K$

$- \partial F(X,K)/\partial X \cdot \partial F(X,K)/\partial K > 0$

Assuming the output price P, variable input price W, and quasi-fixed input price, r, are known with certainty, the variable input, X, is chosen by maximizing the short-run profit function:

(7) $\text{Max } \pi = P*F(X,K) - WX - rK, \; X > 0$

Where π is the profit function and the rest are as defined above. The first order necessary condition for profit maximization is:

(8) $P*\partial F(X,K) / \partial X = W$

The satisfaction of this condition also satisfies the cost minimization condition:

(9) $\frac{\partial F}{\partial x_i} \bullet \frac{\partial F}{\partial x_j} = \frac{w_i}{w_j}, \; i \neq j$

Condition (8) says that the firm should hire current inputs up to the point where the value of the marginal product from employing one unit of a factor must equal its own price. Assuming the sufficient second order conditions hold, equation (8) can be solved to obtain a system of short-run input demand functions as follows:

(10) $X^* = X^* (W,P,K)$

Where X^* are levels of inputs that the firm employs to satisfy condition (8) for any set of prices. The X are homogeneous of degree zero, thus proportional changes in input and output prices do not change input or output levels.

By inserting the input demand functions back into the production function, the output supply function can be obtained from which the optimum level of output can be obtained as a function of output price, input wages, and the quasi-fixed factor:

(11) $Q^* = F(X^*(P,W,K)) = Q^*(P,W,K)$

Since the input demand functions are homogeneous of degree zero, so is the output supply function (Intriligator, 1971). The response of the optimal levels of input X^* and output Q^* to changes in W, P, and K can be obtained by first inserting the input demand function (9) into the first-order necessary condition (8) and the supply function (11) into the production function (1) to obtain the following n+1 identities:

(12a) $P\partial F(X^*(P,W,K)) / \partial X \equiv W$ and

(12b) $X^* = X^*(P,W,K)$

(13) $Q^*(P,W,K) \equiv f(X^*(P,W,K))$

The sensitivities of X^* and Q^* are obtained by differentiating these identities with respect to the n+1 parameters P, W, and K. Details of the derivations can be found in Intriligator(1971). The results on the input side are twofold. First,

$\frac{\partial X^*}{\partial W}$ is negative definite and symmetric matrix.

Negative definite means that the elements along the principal diagonal are negative, i.e., $\partial X_i/\partial W_i < 0$, $i = 1, \ldots, n$, which means that the input demand curves always slope downward. Thus an increase in the price of an input will lead to a decrease in the demand for that input. Hence, in equation 10, a negative relationship is expected between X_i and W_i.

The symmetry condition,

$$(14) \qquad \frac{\partial X_i^*(P,W,K)}{\partial W_j} = \frac{\partial X_j^*(P,W,K)}{\partial W_i}$$

shows that the effect of change of W_j on the demand for X_i^* is the same as the effect of change of W_i on the demand for X_j^*. However, the maximization model does not imply whether the signs of

$\dfrac{\partial X^{i*}}{\partial W_j}$, $i \neq j$, will be positive or negative.

The second result of the differentiation of equations 12 and 13 has to do with the signs. A priori one can say nothing definite about the signs of individual $\partial X_i/\partial P$ since an increase in P, through its effect on output, can lead to an increase (if it's a superior input) or decrease (if inferior) in the use of the inputs. What can be ruled out is that all cannot be negative simultaneously. However, one can generally assume that all inputs are superior and expect a positive relationship between X_i and P.

In the above model, the level of the stock of quasi-fixed input, K, is fixed in the short run. However, K can be varied in the long-run and hence, the model has to be modified to allow the decision process to extend beyond the short-run in order to derive the demand function for K, but that is beyond the need of this paper.

Limitations of the above Theories

The static theory of profit maximization presented above is a good starting point for the understanding of the basic forces that determine the demand for fertilizer. However, static input demand functions estimated strictly from the above derivations may not be satisfactory for several reasons. First, the derived static demand functions are constrained by the assumptions of the profit maximization model. Three of the constraints are particularly important here:

1) The model assumes that producers make immediate adjustments to quantity demanded in response to changes in relative prices, unhindered by market information and/or supply lags. This is unrealistic because producers may not be able to make instantaneous adjustments due to physical, psychological, technological and institutional factors. Hence, several time periods may elapse before full adjustments are made in response to a new set of relative prices and other factors. This is addressed by using dynamic demand models as discussed in the next section.

2) The assumption that output and input prices are known and given at the time of planning production should also be questioned because product prices are not observable at the time production decisions are made. Agricultural production decisions are based on expected rather than actual prices; therefore, the output price has to be modified so that the expected price rather than the actual product price is used.

3) The unconstrained profit maximization model implies that capital funds required for production purposes are unlimited. This assumption is also unrealistic because most farmers have to borrow from commercial banks and government credit institutions in order to finance the purchases of

production inputs. Thus, credit limits are reasonable constraints to be placed in the optimization model. The interest rate paid by farmers on nonmortgage loans is used to represent the ease with which credit can be obtained.

The second reason that static input demand functions are unsatisfactory is that the derived functions are "vague in that the constraints on the production process are unknown and regarded as given and constant during the period of analysis" (Bohi, 1981). For example, the models assume that technology is known and fixed, some inputs are of limited availability in the short-run, and some inputs are indivisible or lumpy because of the lack of continuous technology (Bohi, 1981). Though these constraints may be necessary to simplify the models, they may not be realistic in the analysis of demand involving dated data. For example, technology can be changed and some fixed inputs can be increased or decreased over time. Because of the limitation of data and the need for simplifying the analysis, only changes in technology will be considered in the analysis.

The third reason for dissatisfaction is that, the input demand functions derived from the theoretical models don't include explanatory variables other than input and product prices. However, as seen in earlier input demand studies and recent agricultural literature (reviewed in the next section), factors such as exports, wealth of farmers, acreage diverted from crop production, taxes, and changes in farm numbers and sizes could affect the demand for farm inputs.

Therefore to make the demand functions more realistic and meet the objectives of the study, the derived theoretical models have to be modified. These modifications, however, don't change the basic estimation methods used in previous input demand studies, which form the basis for this study.

Forces Identified in Previous Input Demand Studies

Several resource demand studies have identified and measured the forces that determine the demand for fertilizer. Though these studies mainly used explanatory variables suggested by economic theory, they have also incorporated additional explanatory variables that were believed to determine the demand for farm inputs. The findings of selected studies on fertilizer will be reviewed briefly in this section. The primary focus of this review is to identify the major determinants of the demand for fertilizer. However, in order to provide a better picture of the studies, the estimation procedures and related matters will be mentioned briefly also.

One of the pioneering fertilizer demand studies is that of Griliches (1958). He specified the quantity of fertilizer plant nutrient consumed per acre as a function of the real price of fertilizer, (i.e., price paid per plant nutrient unit relative to price received for crops), the price of other factors of production, and the lagged quantity of fertilizer plant nutrient consumption. The inclusion of the lagged dependent variable was based on the grounds that farmers will take more than one time period to adjust their fertilizer application to changed price ratios, in accordance with Nerlove's (1958) distributed lag scheme. Griliches estimated several U.S. and regional models in logarithmic form using ordinary least squares (OLS) method and annual data covering the periods 1911-56 and 1931-56. The major conclusions drawn from the study were that the demand for fertilizer plant nutrients was determined by the real price of fertilizer relative to crop price and the lagged quantity of fertilizer nutrient. The dynamic model specification was also found to be appropriate.

Heady and Yeh (1959) specified the total tonnage of commercial fertilizer consumed as function of real price of fertilizer (deflated by the general wholesale price index), the real average crop price lagged one period, cash receipts from farming lagged one period, cash receipts from crops and government payments lagged one period, total acreage of cropland, and time as proxy for technical and knowledge change. The relationships were estimated in logarithmic form using the OLS method and annual data for the period 1926-56, excluding the years 1944-50 on the grounds that supply was short and rationing was in effect during that period. The results indicate that the real price of fertilizer, the real average crop price or cash receipt from farming, and technology were the major determinants of fertilizer consumption.

Heady and Tweeten's book (1963), <u>Resource Demand and Structure of Agricultural Industries</u>, is the most comprehensive published work on farm input demand. It covers a large number of inputs including fertilizer and estimates demand functions for the U.S. as a whole and for various regions of the country. Over 50 aggregate U.S. fertilizer demand models for total fertilizer, total plant nutrients, and individual plant nutrient consumption were estimated. A large number of explanatory variables were used and estimated in log linear form using data for the period 1926-60. In the static models, the major determinants of fertilizer demand were the price of fertilizer, the price received for crops, the price of land, and a time trend variable representing technological change. In the dynamic models, the lagged quantity of fertilizer was important in addition to the variables in the static model.

Another comprehensive and relatively recent resource demand study that includes fertilizer is that of Olson (1979). He specified the demand for fertilizer and lime as a function of its own price, the price of seed and pesticides relative to the prices received for crops, the number and sizes of farms, the ratio of farmers' equity to outstanding debt, national net farm income, the variation between expected and actual net farm income, and other slowly changing variables represented by a time trend variable. The equations were estimated as single equations within a system of equations using the modified limited information maximum likelihood estimation method and using 1945-77 annual data in original observation and logarithmic forms. The results show that the price of fertilizer relative to price received for crops, the price of seed relative to price received for crops, the debt-equity ratio, and time representing slowly changing variables were the major determinants of demand.

Other fertilizer demand studies that used similar approaches and explanatory variables were those of Griliches (1959), Marhatta (1976), and Carman and Heaton (1977). Although there are some differences in the maintained hypotheses, functional forms used, and other estimation features that make the estimated results slightly different from each other, the variables that were found repeatedly to determine the demand for fertilizer were the real price of fertilizer, the price received for crops, lagged quantity of fertilizer used, and a time trend variable.

Other Emerging Forces Affecting the Demand for Farm Inputs

The above theoretical frameworks suggest that the demand for farm inputs is determined by the price of the input or the implicit rental rate in the case of quasi-fixed input, the prices of related inputs, and the price of the product. However, the limitations of the basic theoretical models, previous input demand studies, and recent agricultural literature suggest that more explanatory variables should be included in the demand functions in order to make them more meaningful. The additional variables to be included in this study and how they affect the demand for farm inputs are explored below.

Farm Product Exports. Agricultural exports, both commercial and noncommercial, have increased considerably over the decades. In nominal dollars, the value of agricultural exports from the U.S. increased from $2,857 million in 1946 to $43,780 million in 1981 but declined to $31,187 million in 1985. After adjusting for inflation, the value of exports increased three-fold between 1946 and 1981. This increase can be viewed as a phenomenon arising from external shocks that shift the demand curve for agricultural products. This kind of shift in the 1970s led to increased product prices in the short-run and to increased output in the long-run. To meet the growing demand, farmers increased their productive capacity and used more variable inputs. The impact of agricultural exports on the demand for fertilizer can be captured by incorporating the variable in the demand equations. Increases in exports are expected to increase the demand for farm inputs with a time lag.

Increased Wealth of Farmers. There was a gradual increase in the wealth of farmers up to the early 1970s, a sharp increase in the 1970s, and a marked decline in the early 1980s. Since most of the wealth of farmers is in the form of land, the fluctuation largely followed changes in farmland values. Changes in the wealth of farmers have an impact on the demand for farm inputs, particularly capital inputs. Increase in liquid farm assets such as cash and bonds will directly provide the funds required for investments and the purchase of other inputs. Also, an increase in asset values will increase the willingness of lending institutions to extend credit for the purchase of inputs.

Increased asset value can also be a measure of the farm firm's ability to withstand unfavorable outcomes. If a farm's equity is high, a relatively small financial loss may cause little concern; whereas if the equity is low, the same loss may increase liabilities above the value of owned assets and cause bankruptcy. The ratio of the farmer's debt to outstanding liabilities is a measure of this influence on input demand both psychologically for the farmer and actually for outside credit sources (Heady & Tweeten, 1963).

The debt-equity ratio can also serve as a proxy variable to measure past incomes. Favorable past incomes contribute to the increases in equity which will have a delayed or lagged influence on investment. Income generated through capital gains on durable assets during inflationary periods also increases equity and, hence, increases funds available for investment. Therefore, the debt-equity ratio will be used to represent the influences of wealth on the demand for farm inputs. A positive relationship is expected between quantity demanded of an input and the debt-equity ratio.

Production Credit and the Interest Rate. There has been considerable expansion in the use of credit for the purchase of farm inputs. Total farm debt increased from $8.3 billion in 1946 to $207 billion in 1983, but declined to $188 billion in 1985. Interest payments on these debts increased from $402 million in 1946 to $18.7 billion in 1985, becoming the single most important farm expense and surpassing the expenditures for fertilizer, livestock and poultry, feed purchased, and hired labor.

The increased availability of credit allows farmers to purchase more inputs than they would be able to do otherwise. On the other hand, increases in interest rates increase the cost of borrowing and that would lead to reduced use of inputs. This is because producers will equate the marginal value product of the input to the cost of the input plus the cost of credit used to buy the inputs (Heady and Dillon, 1961).

However, there are considerable debates as to the role of real balances on aggregate production functions and agricultural production functions. Also, there are no investigations as to the role of interest rates in the demand for variable inputs (Kimble et al.). Traditionally, the interest rate was used as an explanatory variable only in the analysis of the demand for durable inputs. It seems that the first attempt to include interest rate (credit) in the demand for variable inputs was made by Kimble et al. (1988). They suggested that operating and mortgage credit can enter the production function as nonphysical inputs and estimated several variable input demand functions incorporating interest rate as a separate explanatory variable. They found that the majority of the inputs are substitutes with operating credit and complements with mortgage credit.

In this study, the interest rate on nonmortgage credit will be used to represent the ease with which credit is available and the cost of borrowing. It should be noted that the introduction of an interest rate in the fertilizer demand functions implies a relaxation of the assumption of no credit constraint in the profit maximization model.

Government Farm Programs. There are two major categories of government commodity programs: withholding cropland from production and support of prices and incomes. The price and income support programs include direct price support programs; commodity storage, handling, disposal and surplus removal; international commodity agreements; special food assistance programs; and marketing orders and agreements. Most of these programs are more or less concerned with supply management and are directly or indirectly reflected in the product prices and farm incomes and need not be represented independently in the input demand functions. However, acreage diversion directly places a constraint on the production function by limiting the availability of land. That leads to the reduction of other complementary factors of production. The size of cropland withheld from production ranged from zero in 1946-55, 1980 and 1981 to 78 million acres in 1983. Acreage diverted from crop production will enter the demand functions as a separate explanatory variable.

Technical Change. The processes and effects of technological change have been addressed at length elsewhere (Binswanger, Hayami & Ruttan, Kislev and Peterson). In short, technological change in the form of new and/or better quality machinery, fertilizers, pesticides, hybrid seeds, better trained labor, livestock disease controlling drugs, etc., results in new production coefficients, alters the relative prices of inputs and outputs, and contributes to increased production efficiency. Increased efficiency results in the shift of the production function upward at every level of input. Technical change can be incorporated into the production function by relaxing the assumption of known and fixed technology and by dating the production function and the inputs.

If the production surface is lifted upward parallel to itself with no change in its shape, then the marginal productivity and marginal rates would remain unchanged. Mathematically, this simple parallel shift in the isoquant can be represented by the following production function:

(15) $Q_t = a_t + f(X_1, X_2, \ldots, X_n)$

If the extra output, $a_t - a_{t-1}$, can be sold at the same price as before, there would be no change in the use of inputs or remunerations and the owners will receive large residual profits. This is a neutral technical change with respect to the relative use of factors of production (Brown, 1970).

However, most technical changes will increase the marginal productivity of all or some of the inputs. If one assumes that the marginal productivity, $\partial f/\partial X_i$, increases in the same proportion, say κ, the relative marginal productivity, and hence the marginal rate of substitution will remain the same. In that case, technical change can simply be accounted for by renumbering the isoquants, say, from q to κq. This kind of neutral technical change can be represented by the production function:

(16) $Q_t = a_t f(X_1, X_2, \ldots, X_n)$

Under this condition, for any given factor price, the relative use of factors will be left unaltered by the technical change, if output advances at the same rate as a_t (Brown).

In both of the above types of neutral technical change, the effect of technology can be captured by the use of a smooth linear or exponential time trend variable in the production function. The derived input demand function will also have the time trend variable as a working approximation for technical change.

The type of technical change observed in U.S. agriculture is, however, the nonneutral type whereby some marginal productivities are affected more than others (Binswanger, Hayami and Ruttan, Kislev and Peterson). In that case, the functional form of f_t (shape of the isoquant), or its parameters, or both can be affected. That introduces changes in relative factor use (substitution) even without changes in relative factor prices. Hence, the use of factors whose marginal productivities have increased relative to others will increase as farms minimize costs. In actuality, both the marginal productivity and relative prices have changed over time. Thus, the increase in the use of farm machinery and fertilizer and the decrease in the use of labor are the outcomes of these phenomena.

Over time, both neutral and nonneutral technical changes will be experienced in agriculture. The outcome is that the production function and the associated input demand functions will be affected accordingly. However, as indicated in some studies (e.g., Tomek, 1981), it is difficult to isolate and measure the impacts of technical change from that of other forces affecting the production function. To circumvent the problem, the agricultural productivity index is chosen as a proxy for both neutral and nonneutral technical change.

Changes in the Qualities of Inputs. Though it is difficult to separate the changes in the quality of inputs from the other effects of technical change, it is necessary to adjust inputs for quality in order to avoid bias from variation in quality arising overtime. If inputs are not adjusted for quality, the effects on the estimated demand functions would be similar to bias in the data (Heady & Dillon). Hence, prices cannot accurately reflect quantity changes if input qualities are also changing at the same time. To avoid this problem, the demand for plant nutrients will be estimated as well as the demand for total fertilizer material.

Increase in Farm Sizes. One of the major structural changes that has occurred in U.S. agriculture is change in farm size. Average farm size increased from 193 acres in 1946 to 446 acres in 1985. The effects of changes in farm size on the demand for farm inputs have gained increased attention in recent years. Olson (1979) found that investments in buildings and machinery will decrease on a per acre basis as the farm size increases. Also that the demand for farm machinery and buildings may not increase proportionately as the farm size increases through purchase and rent because farmers sometimes have more machinery capacity than they presently require, thus enabling them to farm more land without additional machinery.

On the other hand, Kislev and Peterson (1982) found that the ratio of the opportunity cost of farm labor to the price of farm machinery services determines the size of the farm operation by influencing the machine-labor ratio. They argue that an increase in nonfarm wages will increase the opportunity cost of labor in agriculture, raise the ratio of wages to machine cost, increase capital-labor ratio, and with the assumption of constant labor per farm, cause an increase in farm size. They also conclude that since total cropland acreage did not show much change over the years, it will not be wrong to deduce that the increase in farm size does not affect either per acre employment or total demand for biological inputs.

However, the issues of farm size, economies of scale, and related subjects are still under debate. The inclusion of average farm size in the demand function may provide additional evidence of size effects.

Decrease in Farm Numbers. Farm numbers have declined from 5.9 million in 1946 to 2.3 million in 1985, but the decline was not uniform during this period. Farm numbers declined at an annual rate of 2.0 percent between 1946 and 1973 but slowed down to 0.9 percent thereafter. Despite the decrease in the number of farms, total acreage in farms changed little, from 1145 million acres in 1946 to 1014 million acres in 1985. Also, the number of crop acres remained fairly constant during the same period. That was because as the number of farms decreased, the remaining farms increased their holdings and raised the average farm size. As a result, total farm input use didn't decline but the demand for some inputs, particularly labor, declined partly because of the displacement of owner-operators and hired labor as farms were consolidated. Thus, it is difficult to tell a priori the impact of farm numbers on the demand for fertilizer. Farm numbers will enter the demand functions as a demand shifter.

EMPIRICAL FRAMEWORK

As stated in the objectives, this study is primarily an extension of previous input demand studies and hence, essentially uses the same empirical framework employed in the previous studies. The major difference from the earlier studies will be the incorporation of additional explanatory variables and refinement of the estimation methods whenever alternatives are available. The single equation model will be used to estimate the demand functions for fertilizer. However, in the update of some of the results of the previous studies, the same models and estimation techniques used in the original studies will be used directly.

Estimation Problems

Since the major objective of the study is to see if certain emerging economic, policy, and structural variables determine the demand for fertilizer, the estimation process involves the estimation of several models in an effort to obtain better models. In doing so, some relevant variables may be excluded or irrelevant variables may be included in some of the models.

The exclusion of relevant variables introduces specification bias into the estimated coefficients which does not disappear as the sample size grows, so that the omission of relevant variables yields inconsistent parameter estimates as well (Pindyck, p. 129). The only case where the bias will completely disappear is when the Cov $(X_1,X_2) = 0$. The mis-specification destroys the conventional best linear unbiased estimator (b.l.u.e.) property of the OLS estimators and also undermines the conventional inference procedures. The inference is undermined not only because of the bias in the coefficients but also because the disturbance variance cannot be correctly estimated.

On the other hand, the inclusion of irrelevant variables has quite different effects. The inclusion of the irrelevant variable doesn't introduce any bias and no loss of consistency. However, the problem will lead to loss of degrees of freedom and therefore, loss of efficiency since the variance of the coefficients will be larger. Yet, since the estimated variance will be an unbiased estimator of the true variance, this suggests that the loss of efficiency will be accounted for when the standard error of the regression is calculated and hence, conventional inference procedures are valid. Thus, while the inclusion of an irrelevant variable is not a serious problem, the exclusion of a relevant variable needs serious consideration.

Another major estimation problem of concern is serial correlation, which arises when the disturbances of the linear regression model are correlated, making the coefficients of the OLS estimate inefficient, although still unbiased and consistent. In the case of positive serial correlation, the regression will be unbiased, but the standard error of the regression will be biased downward, leading to the conclusion that the parameter estimates are more precise than they actually are (Pindyck, p. 153). The presence of serial correlation will be tested by the use of the Durbin-Watson statistics. When the problem is present, the original model is transformed using the iterative method suggested by Cochrane and Orcutt (1949). The Durbin-Watson test is not valid when there are lagged dependent variables as regressors. In that case, the Durbin-h statistic will be employed (Durbin, 1970).

The third major estimation problem is multicollinearity, which arises when two or more independent variables are highly correlated with each other, i.e., they have an approximate linear relationship. The effect of this problem is that the estimated variance of the coefficients of the collinear variables will become very large, though the OLS estimates will remain unbiased and b.l.u.e. and R^2 is still valid. This will reduce the reliance that can be placed on the coefficients and make interpretation difficult. There is no single criteria for detecting the problem and no single solution. Two avenues will be followed for dealing with the multicollinearity in this study. First, if several coefficients have high standard errors and R^2 is high, one of the collinear variables will be dropped if the standard errors of the remaining variables are lowered. Second, if the presence of the variables in question are supported on theoretical and other grounds, the problem will be noted and nothing will be done.

Overall, the estimated models will be evaluated on the basis of the coefficient of determination (R^2), expected signs of the coefficients, significance of the coefficients, stability of relationships, Durbin-Watson statistic or Durbin-h statistic for autocorrelation, and economic soundness of the model.

Functional Forms

The choice of functional forms can be based on criteria such as 1) consistency with the regression method and the underlying production function, 2) ease of estimation including fewness of the estimated coefficients, 3) consistency with maintained hypothesis as to the way in which demand is related to the explanatory variables, 4) conformity with the data as evidenced in the statistical results (t test, R^2, DW-statistic, etc.) and 5) the reasonableness of the implied elasticities (Griffin et al., 1984; Tomek and Robinson, 1981). Though these criteria are important in the selection of functional forms, the functional forms used in previous input demand studies are maintained in this study for reasons explained earlier. These functional forms are linear and log-linear.

The linear form is the simplest functional form where the explanatory variables appear as additive elements:

(17) $Y_{it} = \beta_0 + \beta_1 X_{1t} + \ldots + \beta_k X_{kt} + U_t$

where the β_i are the slopes and are constant over the entire range of the data. The elasticity of demand implied by the form is:

(18) $\epsilon_i = \beta_i \ (X_i \ / \ Y_i)$

where $\beta_i = \partial Y_i / \partial X_i$. Thus for each one unit change in X, Y will change by β_i. The elasticity can be estimated at any price and input level, it is variable. In most of the previous studies the elasticities were estimated at the mean of the observations.

The log-linear functional form is as follows:

(19) $\ln Y_{it} = b_o + b_1 \ln X_{1t} + \ldots\ldots + b_k \ln X_{kt} + U_t$

This form provides direct estimates of elasticities since the slopes and elasticities are the same, i.e.,

(20) $$\epsilon_i = \beta_i = \frac{\partial \ln Y_i}{\partial \ln X_i} = \frac{\partial Y_i}{\partial X_i} \frac{X_i}{Y_i}$$

This functional form places some undesirable restrictions on the estimated elasticities. First, it implies that the elasticities will remain constant (while the slope is not constant) over any range of values which the explanatory variables take on; this is contrary to a variable elasticity suggested by economic theory (Bohi, 1981). Second, it imposes a symmetry condition, i.e., the adjustment to quantity demanded whether price increases or decreases is the same. This is in line with the results of the static theory discussed above but may not be realistic under real world conditions. Because there are lags in adjustment due to technology, psychological preparedness, credit constraints, etc., quantities may not be adjusted at the same rate when prices increase and decrease. Third, demand functions of this form are consistent with profit maximization only if the production function is log-linear. This would require that the elasticities of substitution among inputs in production be constant and equal (Bohi, 1981). Though these restrictions may seem stringent, the major concern which is constant elasticity is not necessarily good or bad, rather, the point is that the implications of the mathematical properties of the function relative to the logic of the behavioral and economic relations must be recognized (Tomek and Robinson, 1981).

Identification Problems

The input demand functions derived from the theoretical framework are systems of demand equations which are required to be estimated together. In this study, a partial equilibrium framework will be used whereby the fertilizer demand equations will be estimated independently as a single equation. In single equation direct least squares estimation, there is the basic question of whether the estimated demand equation is actually a demand or a supply function. This question arises because the observations on price and quantity corresponding to unknown demand and supply curves at different points in time correspond to points on the demand and supply curves. The statistical problem is how to identify a demand curve from a collection of such points. In depth discussion of this problem and the related estimation and interpretation problems are discussed elsewhere (Bohi (1981) and Rao & Miller (1971)).

In this study, it is assumed that the supply of fertilizer is perfectly elastic. This means that price determines the point of use along the demand curve, but shifts in demand do not affect price. This assumption is realistic for five reasons: one on the demand side and four on the supply side. First, on the demand side, farmers are small and scattered producers and hence, don't have enough bargaining power to affect the prices of the inputs they buy. Second, on the supply side, the production of fertilizer requires the development of natural gas, phosphorus, potassium, and sulfur mines which depend on long history of past prices and expectations about future prices; they are marginally affected by changes in current prices. Third, the supply processes of fertilizer also require heavy capital investments and long lead times, which imply that production plans are geared towards future as well as current consumption levels. Fourth, at any point in time, there may exist positive unused capacity that may fluctuate to accommodate changes in consumption without a corresponding fluctuation in prices (Bohi). Fifth, the fertilizer industry is mostly owned by large conglomerates where fertilizer is a small fraction of their operations. As a result the industries can maintain short-run supply prices when demand fluctuates, thus absorbing losses when demand decreases and accumulating profit when demand increases. These facts are enough to support the assumption of perfectly elastic supply curves and hence, ignore the supply side of the problem and estimate demand separately. If this assumption is true, the estimated price elasticities will not be biased.

DATA

Aggregate time-series data for the U.S. agriculture will be utilized. The data will cover the period 1946 to 1985. The major sources of data are various USDA publications and other sources based on USDA information. Some of these sources are Agricultural Statistics, Economic Indicators of the Farm Sector, 1986 Fact Book of U.S. Agriculture, and Statistical Abstract of the United States.

DEFINITION OF VARIABLES

The dependent variables are:

QF_t = the total quantity (tons) of fertilizer material used by U.S. farmers.

QN_t = the total quantity (tons) of fertilizer plant nutrients, i.e., nitrogen (N), potassium (K_2O), and phosphorus (P_2O_5), used by U.S. farmers.

The independent variables are:

PF_t = the index of the prices paid by farmers for fertilizer, 1977 = 100.

PPF_t = the ratio of the index of prices paid by farmers for fertilizer to the index of price received for crops, 1977 = 100.

RPF_t = the index of the prices paid by farmers for fertilizer deflated by the producer price index, 1977 = 100.

RPN_t = the ratio of the expenditure per ton of fertilizer plant nutrient (total fertilizer expenditure divided by quantity of plant nutrient) to the index of prices received for crops.

CPN_t = the index of prices paid by farmers for fertilizers deflated by the producer price index, 1977 = 100.

PC_t = the index of prices received by farmers for crops, 1977 = 100.

RPC_t = the index of prices received by farmers for crops deflated by the producer price index, 1977 = 100.

PPR_t = the ratio of the index of average per acre value of farm real estate to the index of prices received for crops.

RPR_t = the ratio of the index of the average per acre value of farm real estate (December 31) deflated by the producer price index, 1977 = 100.

PA_t = the index of prices paid by farmers for all agricultural inputs, 1977 = 100.

RPA_t = the index of the prices paid by farmers for all agricultural inputs deflated by the producer price index, 1977 = 100.

FW_t = the index of wage paid for hired farm labor.

RZ_t = the value of agricultural exports in million of dollars deflated by the producer price index, 1977 = 100.

R_t = average interest rate on non-real estate loans outstanding on December 31.

D_t = acreage diverted from crop production under various government farm programs.

N_t = the number of farms in the U.S.

A_t = average farm size of U.S. farms in acres.

DE_t = average debt-equity ratio of U.S. farms.

TE_t = the index of technical change represented by the index of agricultural productivity, 1977 = 100.

T = time represented by last two digits of the current year, representing slow changing variables not accounted for directly by the other variables.

Fertilizer Demand Models

Several alternative models depicting farmers' decision-making processes are specified to form the basis for estimation. Based on statistical results and other considerations as discussed earlier, these models will be modified as needed and only those with good results will be reported.

Model A. This is a static demand model based on the theory of the competitive firm. The quantity of fertilizer demanded is hypothesized to be a function of (1) the price of fertilizer relative to the price received for crops, and (2) the prices of substitutes and complements (i.e., land, labor, and all other inputs taken together) relative to the price received for crops.

(21) $$QF_t = B_0 + B_1\ PPF_t + B_2\ PPR_t + B_3\ (FW / PC)_t + B_4\ (PA / PC)_t + U_t$$

Where QF is the quantity of fertilizer demanded, PPF_t is the index of the price of fertilizer deflated by the index of price received for crops, PC_t is the price of crop, PPR_t is the index of the price of land (real estate) deflated by the index of price received for crops, FW_t is the price of labor, PA_t is the price of all other inputs, and U_t is the error term. This model assumes demand is homogeneous of degree zero in factor prices and that only changes in relative prices, not absolute prices, affect demand behavior.

Model B. Even though price changes may be equal, when the permanent portion of one price change (say the numerator) is perceived to be larger than the permanent portion of another price (say the denominator), relative prices will not be appropriate and it will not be easy to estimate separate elasticities. Thus, the constant price ratio implied by model A may not be realistic since prices do not change in the same proportion most of the time. Therefore, to overcome this problem, model B is specified with each price entering as an independent variable:

(22) $QF = B_0 + B_1PF_t + \ldots + B_5PA_t + U_t$

Model C. Model C is a simple adaptive expectation model whereby farmers base their fertilizer purchases on expected rather than actual crop prices. This model will also enable the calculation of short-run and long-run elasticities as well. Consider a simple demand model where quantity demanded is based on expected crop price and all other explanatory variables are momentarily left out:

(23) $QF_t = B_0 + B_1PC^e{}_t + E_t$

Where $PC^e{}_t$ is the expected crop price. Since $PC^e{}_t$ is not observable, suppose expectations are a weighted average of present and expectations in the previous period plus a prediction error:

(24) $PC^e{}_t = PC^e{}_{t-1} + g\ (PC_t - PC^e t\text{-}1) + U_t$

where $0 \leq g \leq 1$. If $g = 0$, expectations do not change; if $g = 1$, expected prices are always the same as present prices. Since these are extremes, g is expected to lie between 0 and 1. From equation (23) we get:

(25) $PC^e{}_t = (QF_t - B_o - E_t) / B_1$ and thus,

(26) $PC^e{}_{t-1} = (QF_{t-1} - B_o - Et\text{-}1) / B_1$

Substituting (25) and (26) into (24) and simplifying, we get Model C:

(27) $QF_t = gB_o + gB_1PC_t + (1 - g)\ QF_{t-1} + [E_t - (1 - g)$

$E_{t-1} + B_1U_t]$

This estimating equation is of the autoregressive form with a moving average type error process.

The total number of periods (e.g., years) required for a given percentage total adjustment to take place can be calculated from the model using the following formula:

$$n = \frac{\log P}{\log (1\text{-}g)}$$

where P is the proportion of adjustment remaining (e.g., .05 if 5 percent remains) and n is the number of years after which P remains (Hammond, 1974). This dynamic model provides short-run and long-run elasticities.

<u>Model D</u>. This is a naive product price expectation model where the expected price is simply assumed to be equal to last year's price:

(28) $PC_t{}^e = PC_{t-1}$

Then the demand for fertilizer becomes a function of lagged crop price:

(29) $QF_t = B_o + B_1PF_t + B_2PC_{t-1} + U_t$

<u>Model E</u>. This is a simple Nerlove (1958) partial adjustment model. The partial adjustment hypothesized can be stated as follows. Suppose the long-run equilibrium quantity of fertilizer demanded, $QF_t{}^*$, is a function of the price of fertilizer, PF_t, and an error term is U_t:

(30) $QF_t{}^* = Bo + B_1PF_t + U_t$

The desired level, QF_t^*, may not be attained instantaneously and hence, the observable QF_t may only reflect a partial adjustment from current to long-run equilibrium level. The adjustment is assumed to follow a stochastic partial adjustment process formulated by Nerlove:

$$(31) \quad QF_t - QF_{t-1} = g(QF_t^* - QF_{t-1}) + E_t , \qquad 0 < g < 1$$

where g is the partial adjustment coefficient and E_t is a stationary time series. By substituting equation (30) into (31), model E is obtained in which all variables are observable:

$$(32) \quad QF_t = gB_o + gB_1PF_t + (1 - g)\ QF_{t-1} + U_t$$

In all the above models the quantity of fertilizer, QF_t, will be substituted by the quantity of fertilizer plant nutrient, QN_t, to estimate quality constant fertilizer demand functions. Explanatory variables such as interest rate, exports, farm size, farm numbers, and technology are incorporated into the above basic models.

ESTIMATION RESULTS

Several single equation models were specified for total fertilizer tonnage and total quantity of principal plant nutrients. The equations were estimated by OLS except where serial correlation was detected, at which time the equations were estimated by autoregressive least squares method. Model specifications are not reported which did not conform to expected signs, did not explain variation well, and/or had other poor properties.

The Demand for Total Fertilizer Material

The first two functions were estimated with the data in original form. The first function was a short-run static demand model (Model A) which explained fertilizer material demand by the fertilizer/crop price ratio, the ratio of real estate price to price received for crops, and a time trend variable (Equation 33, Table 3). All the variables have the expected signs and are significant ($p \leq .05$). The adjusted R^2 is .95. A simple dynamic model estimated with the real price received for crops in the past year is entered as a separate explanatory variable (Model E), has an adjusted R^2 of .95 also and all the coefficients have the expected signs (34). In this model, the real price of fertilizer, the lagged dependent variable, and the real value of real estate are significant ($p \leq .05$), but the real price received for crops is not significant ($p > .10$).

Five functions were estimated in logarithmic form and include several of the emerging explanatory variables discussed earlier. The adjusted R^2 were high (i.e., .97 and .98) in these equations. The real price of fertilizer (RPF_t) has negative coefficients as expected and all were significant at the 5 percent level except for one which was significant at the 10 percent level. The real price received for crops lagged one period had a positive coefficient as expected, suggesting that the demand for fertilizer increases with increases in the price received for crops, but only three of the five are significant (equations 36, 37, and 39).

The coefficient of the real value of farm real estate was positive and not significant, suggesting that fertilizer and land are not good substitutes (39). The real price of all farm inputs, which was used as a proxy for the price of all other inputs, was positive and significant ($p \leq .05$), showing a substitute relation between fertilizer and all other farm inputs taken together (35, 38, and 39). Also, the nonreal estate interest rate coefficient was negative as expected but not statistically significant

($p > .10$; equation 37). This implies that even though credit is complementary to fertilizer in the production process, it is not an important determinant of total fertilizer material demand. The coefficients of the real value of lagged agricultural exports (37 and 38), acreage diverted from crop production (36), and farm numbers (35 and 39) had the expected signs but were insignificant ($p > .10$).

The average farm size was positive and significant ($p \geq .05$; equations 35, 38, and 39) suggesting that fertilizer use increases as farm size increases. Since managers of large farms usually have better management skills, more capital, access to productive credit because of the larger land they can offer as collateral, more benefits from government payments, relatively lower cost of production, etc, we assume they will use more fertilizer per acre as the farm size increases. However, since average farm size has grown steadily larger, it is also partly capturing slow changes which were to be explained by the time trend variable. In models without average farm size, the time trend coefficient was significant ($p \leq .05$; equations 36 and 37); but when average farm size was introduced the time trend coefficient was not significant ($p > .10$; equations 38 and 39).

Technical change (represented by the agricultural productivity index) and time (representing slowly changing variables not accounted for by the other variables) have positive coefficients but only time is significant ($p \leq .05$; equations 36 and 37). When these two variables don't appear together in the same equation, the time variable will also pick the effects of technical change and other slowly changing variables as well. Thus it is difficult to interpret the coefficient of time in those cases. Also, as noted above, the slow increase in average farm size apparently overrides the slow changes in technical change and time causing those coefficients not to be significant ($p > .10$).

The coefficient of the lagged dependent variable QF_{t-1}, (i.e., 1-g from Model E) varies from .21 (equation 39) to .65 (equation 34); however, not all were significant ($p \leq .05$). Hence, the adjustment coefficient, g, is between .35 and .79 which indicates that 35 to 79 percent of the total long-run adjustment to the desired level is made in the short-run. However, the large difference in the values of g is an indication of lack of stability in some of the equations.

The wealth of farms as measured by the debt-equity ratio was not significant ($P > .20$) in functions estimated but not reported. Wealth may be more important in explaining behavior of individual farmers rather than farmers' aggregate behavior over time.

Overall, the results indicate that the major determinants of total fertilizer consumption were the real price of fertilizer, the real price received for crops in the past year, the real price of farm real estate, the real price of other inputs, and either average farm size or time. Both of the function forms (linear in actual observation and linear in the logarithms of the observations) performed well. The best model in terms of significant coefficients and expected signs was equation 36.

The Demand for Fertilizer Plant Nutrients

Since farmers are interested in the nutrient content of fertilizers rather than the total bulk, the demand for plant nutrients is more meaningful to analyze. Also, using the nutrient quantities gives the quality-constant demand function for fertilizer. The models used were the same as those for total fertilizer, i.e., A to E described above.

All the equations were estimated in log-linear form and had an adjusted R^2 of .99 (Table 4). Because of the presence of serial correlation, equations 40 and 41 were estimated by autoregressive least squares method. The first function estimated was a simple, static model (Model A), except for the inclusion of the time trend variable (equation 40). In this function the coefficients of the price of fertilizer (relative to the price of crops) and time had the expected signs and were significant ($p \leq .05$); however, the coefficient of the price of land (relative to the price of crops) had the expected sign but was not significant ($p > .10$). Thus, there was no strong evidence to suggest that fertilizer plant nutrients and land are substitutes for each other. When the relative prices were replaced by the separate real prices (Model B), similar results were obtained (equation 41). The coefficients of the real price of plant nutrients and the price received for crops (lagged one period) had the expected signs and were significant ($p \leq .05$). The coefficient of the real price of land was positive but not significant ($p > .10$), again implying that they were not good substitutes.

Several dynamic models were estimated which also incorporated several of the emerging forces affecting agriculture (equations 42 through 46). In all the equations the coefficients of the relative and real prices of fertilizer (RPN and CPN) had negative signs and were significant ($p \leq .05$). The relative and real prices of land (PPR and RPR) had positive coefficients but was significant ($p \leq .10$) only in equation 46. This again suggested that fertilizer plant nutrients and land were not good substitutes. The coefficient of the real price of all other inputs (RPA_t) was positive and significant ($p \leq .05$), showing that plant nutrients and all other inputs were substitutes.

The nonreal estate interest rate had negative and significant ($p \leq .05$) coefficients that ranged between -.14 and -.30. The real value of agricultural exports lagged one period was positive but not significant ($p > .10$). Thus, while exports have generally a positive influence on plant nutrient demand, they were not an important determinant of fertilizer demand. The coefficients of acreage diverted from crop production under government farm programs were negative, showing that acreage diversion reduces the demand for plant nutrients and were also significant ($p \leq .05$) in three equations (equations 42, 43, and 46) but not in equation 45.

The two variables representing changes in farm structure (i.e., farm numbers and average farm size) had positive coefficients. However, the coefficient of farm numbers was very small and not significant ($p > .10$) while that of average farm size was large and significant ($p < .05$). This implies that increases in average farm size increased the demand for fertilizer but decreases in farm numbers had no significant influence on nutrient demand. The coefficient of the index of technical change was positive and significant ($p \leq .10$) and so was that of time ($p \leq .05$). But when the two variables were used in the same equation (not reported here), their coefficients became negative and insignificant due to high correlation between the two variables. Thus, there was generally a strong upward trend in demand associated with technology (productivity) and time, but the model cannot explain neither the difference between the two variables nor the recent decrease in demand following the contraction of the early 1980s.

Again, the wealth of farmers as measured by the debt-equity ratio was not significant ($p > .20$) in functions estimated but not reported. This is the same result noted in the previous section on demand for total fertilizer material. As noted before, wealth may be more important in explaining behavior of individual farmers rather than farmers' aggregate behavior over time.

In conclusion, the major determinants of fertilizer plant nutrient demand were the real price of plant nutrients, real price received for crops (lagged one period), real price of other inputs, the interest rate on nonreal estate loans, acreage diverted from crop production, average farm size, technology, and other slow changing variables represented by the time trend. The best model in terms of correct signs and significance ($p \leq .05$) is equation 43 which uses the relative price of plant nutrients, the interest rate on nonreal estate loans, acreage diverted from crop production, average farm size, and the lagged quantity of nutrients.

DEMAND ELASTICITIES OF FERTILIZER PLANT NUTRIENTS

The short-run and long-run elasticities and the adjustment coefficients were calculated from the fertilizer plant nutrient demand models. Since all equations were estimated in logarithmic form, the coefficients are direct elasticities and are constant for the entire time period.

In the static models (equations 40 and 41; Table 5), the short-run elasticity with respect to price of plant nutrients was -.34 for the price relative to the crop price (RPN) and -.54 for the deflated (or constant) price (CPN). This implies that an increase in the price of fertilizer plant nutrient or drop in the price received from crops by 10 percent is associated with a fall in fertilizer demand by 3 percent. However, an increase of 10 percent in the deflated price is associated with a fall in fertilizer demand of 5.4 percent. But in the more realistic dynamic demand models (equations 42, 43, 44, and 45), the short-run elasticity with respect to RPN was from -.40 to -.46 and CPN from -.32 to -.41, all of which are inelastic.

Estimates of the long-run elasticities with respect to RPN and CPN are from -.82 to -.86 and from -.57 to -1.08, respectively, which are again inelastic. The short-run elasticity is roughly about half of the long-run elasticity. This implies that 50 percent of the adjustment in use towards equilibrium is made within the first year and the balance in the rest of the adjustment period, which is about four and a half years.

The short-run elasticity of demand with respect to the price received for crops in the previous year is .51 in the static model and ranges from .26 to .35 in the dynamic models. The long-run elasticity ranges from .46 to -.92. Thus, ceteris paribus, a ten percent fall in the real price received for crops would cause about 3 to 4 percent fall in nutrient demand in the short-run and 5 to 9 percent fall in the long-run.

The demand elasticity with respect to interest rate charged for non-real estate loans ranges from -.14 to -.29 in the short-run and from -.29 to -.76 in the long-run, both of which are inelastic. Thus, other things being equal, an increase in the interest rate of 10 percent would decrease fertilizer plant nutrient demand by 1 to 3 percent in the short-run and by 3 to 8 percent in the long-run.

It is interesting to note that in all the dynamic models, both the short-run and the long-run elasticities with respect to prices and interest rate are inelastic. This shows that the demand for plant nutrients is relatively less responsive to price changes and factors that affect prices. The implication of this is that large increases in the price of fertilizer do not lead to dramatic cutbacks in the demand for fertilizer. Also fertilizer demand is inelastic to price received from crops suggesting that government price support programs such as high loan rates do not produce the same proportion of impact on fertilizer demand.

UPDATES OF SELECTED PREVIOUS FERTILIZER DEMAND ESTIMATES

Selected estimates from the studies by Griliches (1958), Heady and Yeh (1959), and Heady and Tweeten (1963) were updated using data for the period 1946-85. Heady and Yeh's demand model is static and the other two are dynamic and all were estimated in logarithmic form using least squares regression. The dependent variable in Griliches' estimate was the quantity of total plant nutrients and in the other two, it was total fertilizer. The independent variables used were price paid for fertilizer or plant nutrients, price received for crops, cash receipts from farming, price of land, total crop acreage, and time. Except for receipts from farming and total crop acreage, all the other variables were used earlier in this study. The major difference between these three studies and the present study is the inclusion of additional explanatory variables such as interest rate, exports, acreage diverted from crop production, agricultural productivity, farm numbers, and farm size.

In all three studies, all the corresponding variables in the original and the updated estimates have similar signs except for that of total crop acreage (AT_t) and time (T) in the Heady and Yeh's model (Table 6). In the original estimate (equation 51), total crop acreage had a negative and insignificant ($p > .10$) coefficient suggesting that the quantity of fertilizer demanded and the total crop acreage are not strongly related. The negative sign suggests a substitute relation between crop land and fertilizer. However, in the updated estimate (equation 52), total cropland has a positive and significant ($p \leq .05$) coefficient implying an opposite relationship. On the other hand, time was positive and significant ($p \leq .05$) in the original estimate but negative in the update. A negative sign for time is contrary to the finding of the current study and the other previous studies and leads one to suspect a specification problem with the model.

Another notable difference between the original estimates and the updates is that the magnitude of some of the coefficients, which are also elasticities, greatly differ. In Griliches' original estimate (equation 47), the coefficient of the lagged quantity of nutrients (QN_{t-1}) was 0.77, which gives an adjustment coefficient of 0.23. In the update (equation 48), the coefficient of QN_{t-1} was 0.93 and the adjustment coefficient was only .07, which is very low compared with results of the current study and the other updated estimates. This would lead one to suspect a specification bias of left-out variables in that QN_{t-1} might have picked up the effect of the left-out variables.

In Heady and Tweeten's original estimate (equation 49), the coefficient of the price of fertilizer was -1.40 and significant ($p \leq .05$), which is elastic. However, in the updated estimate (equation 50), it was only -.18, which is inelastic and closer to the results of the current estimates. Also, the coefficient of time was .002 and not significant ($p > .10$) in the original estimate, but had increased to .79 in the update and was significant ($p \leq .05$).

Overall, the results of the updated estimates of Griliches and Heady and Tweeten's models are close to the results reported earlier in this study. The models performed well in terms of magnitude of R^2 and expected signs of coefficients. Heady and Yeh's static demand model is less satisfactory in comparison with the other two due to a wrong sign of the time trend variable and large coefficients for total crop acreage and the time trend variable.

SUMMARY

The estimated demand equations for total fertilizer and fertilizer plant nutrients show that some of the emerging economic, policy, and structural forces do affect the demand for fertilizers. The major forces that determine the demand for total fertilizer materials are the price variables suggested by economic theory, average farm size and time. The prices of fertilizer, the price received for crops, and the price of land (real estate), explain 92 percent of the variability in total fertilizer demand. The inclusion of the other explanatory variables increased the R^2 to 97 percent. The non-real estate interest rate, agricultural exports, acreage diverted from crop production, and farm numbers were not statistically significant ($p > .10$) in explaining the demand for total materials.

In the case of fertilizer plant nutrients, the non-real estate interest rate, acreage diverted from crop production, average farm size, the index of technical change, and time had the expected signs and were significant ($p \leq .05$) in addition to the price variables suggested by theory. On the other hand, agricultural exports and farm numbers were not statistically significant ($p > .10$). These results generally agree with the original and updated estimates of the selected previous fertilizer demand estimates. However, the updates of previous studies show that on a purely statistical basis, simple models with price variables and time give as good results as those models with additional explanatory variables. In fact, the inclusion of several of the emerging forces in a single equation demand model did not generally give good results because many of the variables were highly correlated with each other, thus making the separation of their effects difficult.

A direct comparison of the fertilizer price elasticities of demand is difficult because of the slight differences in the estimation techniques, the time periods covered, and the choice of dependent variable (total fertilizer material or total plant nutrients). The earlier studies (Griliches, Rauser and Moriak, and Heady and Yeh) obtained short-run price elasticities ranging from -.49 to -.69 and long-run price elasticities ranging from -1.71 to -2.0. However, Olson (1979) estimated short-run elasticities (for those models estimated in log-linear form) of -.40 to -.44 and a long-run elasticity of -.56. The comparable figures found in this study are -.34 to -.46 in the short-run and -.57 to -1.08 in the long-run, which are much closer to the results found by Olson. Thus, fertilizer demand is generally inelastic with respect to its own price in the short-run and has not radically changed over time. On the contrary, the long-run elasticity has dramatically changed from elastic to inelastic due to increases in the coefficient of adjustment. Thus, because of the quick adjustment, the long-run elasticity is not much different from the short-run elasticity. The updates of selected previous fertilizer demand estimates gave smaller (i.e., more inelastic) short-run price elasticities as compared to the original estimates.

Table 3. Estimated Demand Functions for Total Fertilizer Material.

Eqn.	Est. Method	C	RPF_t	PPF_t	RPC_{t-1}	QF_{t-1}	RPR_t	PPR_t	RPA_t	R_t	RZ_{t-1}	D_t	N_t	A_t	TE_t	T	Adj. R^2	dW	h	g
33	OLS,O	6801.96		-14553.04*				1688.49*								767.75	.95	1.4		
				(3748.83)				(717.26)								(107.62)				
34	OLS,O	15002.06	-188.52**		25.15	.65*	37.54*										.95	2.2	-1.09	.35
			(106.33)		(76.22)	(.12)	(16.32)													
35	OLS,L	-6.59	-.23**		.15	.32*			1.02*				.33	1.05*	.25		.98	2.4	-2.58	.68
			(.13)		(.13)	(.14)			(.36)				(.53)	(.50)	(.23)					
36	OLS,L	1.39	-.30*		.30*	.38*						-.004				1.21*	.97	1.8	12.40	.62
			(.13)		(.13)	(.16)						(.003)				(.36)				
37	OLS,L	.82	-.30*		.30*	.41*				-.11	.03					1.24*	.97	2.1	-8.6	.59
			(.14)		(.15)	(.16)				(.10)	(.07)					(.41)				
38	OLS,L	-.73	-.23*		.12	.28**			.89*		.04			.84*	.10	-.11	.98	2.4	-5.71	.72
			(.13)		(.15)	(.16)			(.39)		(.07)			(.32)	(.24)	(.70)				
39	OLS,L	-16.76	-.34*		.30**	.21	.13		.74**				1.09	1.38*	.30	.78	.97	2.1	-4.75	.79
			(.15)		(.17)	(.16)	(.10)		(.40)				(.76)	(.54)	(.25)	(.80)				

* = Significant at 5% level (two tail test)
** = Significant at 10% level (two tail test)

The numbers in parentheses are the standard errors
dW = Durbin-Watson statistic
h = Durbin-h statistic
g = adjustment coefficient
O = original observation
L = logarithms

Table 4. Estimated Demand Functions for Total Plant Nutrients.

Eqn.	Est. Method	C	RPN_t	CPN_t	RPC_{t-1}	QN_{t-1}	RPR_t	PPR_t	RPA_t	R_t	RZ_{t-1}	D_t	N_t	A_t	TE_t	T	AR(1)	Adj. R^2	dW	h	g
40	AR(1),L	-1.92	-.34*					1.03								2.77*	.87*	.99	1.79		
			(.11)					(1.52)								(.76)	(.11)				
41	AR(1),L	9.47		-.54*	.51*		.22										.94*	.99	2.11		
				(.14)	(.17)		(.16)										(.02)				
42	OLS,L	-2.48	-.46*			.48*				-.23*	.08	-.01*	.01	1.29**				.99	2.02	-.09	.52
			(.12)			(.11)				(.10)	(.08)	(.002)	(.72)	(.69)							
43	OLS,L	-2.08	-.40*			.51*				-.14*		-.01*		1.27*				.99	1.91	.39	.49
			(.10)			(.11)				(.07)		(.002)		(.28)							
44	OLS,L	-3.81		-.41*	.35*	.62*	.12		.82*	-.29*						1.13*		.99	2.02	-.10	.38
				(.16)	(.17)	(.12)	(.10)		(.42)	(.09)						(.49)					
45	OLS,L	-4.63		-.32*	.26**	.44			.87*			-.003		1.22*				.99	1.84	.78	.56
				(.14)	(.15)	(.12)			(.39)			(.002)		(.31)							
46	OLS,L	1.21	-.43*			.77*		.16**		-.30*		-.02*			.43**			.99	1.80	.75	.23
			(.13)			(.09)		(.10)		(.11)		(.01)			(.23)						

1) The numbers in parentheses are the standard errors.
2) * indicates coefficient is significant at the 5 percent level.
3) dW is the Durbin-Watson statistics for autocorrelation.
4) h is the Durbin-h statistics for autocorrelation.
5) O = estimated in original observation.
6) L = estimated in logarithms of variables.
7) AR(1) is first order autoregressive least square estimation.
8) g = adjustment coefficient.

Table 5

Short-Run and Long-Run Elasticities for Plant Nutrient Demand

	Short-Run				Long-Run					
Eqn.	RPN_t	CPN_t	RPC_{t-1}	R_t	RPN_t	CPN_t	RPC_{t-1}	R_t	g	n
40	-.34									
41		-.54	.51							
42	-.46			-.23	-.88			-.44	.52	4.5
43	-.40			-.14	-.82			-.29	.49	4.5
44		-.41	.35	-.29		-1.08	.92	-.76	.38	6.2
45		-.32	.26			- .57	.46		.56	4.1

g = adjustment coefficient

n = number of years required to complete 95% of the adjustment

Table 6. Update of Previous Fertilizer Demand Estimates.

Eqn. & Study	Data Period	Est. Method	Depend. Var.	C	RPN_t	PF_{t-1}	RPF_t	PC_{t-1}	RPC_{t-1}	YG_{t-1}[a]	QN_{t-1}	QF_{t-1}	PR_{t-1}	AT[b]	T	R^2	dw	h
47 Griliches (1958)-Original (Model 3)	1911-56	OLS,L	QN	.13	-.54* (.07)						.77* (.13)					.98	-	-
48 Update, Original (Model 3)	1946-85	OLS,L	QN	1.011	-.27* (.11)						.93* (.02)					.99	1.88	.38
49 Heady & Tweeten (1963)-Original (Model 7.9)	1926-60	OLS,L	QF	4.60		-1.40* (.36)		.21 (.28)				.39* (.17)	.01 (.20)		.002 (.004)	.99	-	-
50 Update, Original	1946-85	OLS,L	QF	2.10		-.18* (.09)		.04 (.11)				.49* (.16)	.09 (.09)		.79* (.41)	.98	1.99	1.49
51 Heady and Yen (1959)-Original (Model 3.3)	1926-56	OLS,L	QF	10.68			-.49* (.20)			.64* (.05)				-1.08 (.62)	.08* (.02)	.99	-	-
52 Update, Original	1946-85	OLS,L	QF	6.99			-.46* (.13)			.45* (.10)				2.92* (.55)	-3.96* (1.14)	.97	1.82	-

[a] YG_{t-1} = cash receipt from farming, including government payments, lagged one period.
[b] AT = total crop acreage.
Numbers in parentheses are the standard errors.

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