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HOW GOOD ARE INPUT DEMAND MODELS USED IN PREVIOUS STUDIES NOW?

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A. INTRODUCTION

Since the late 1950s, several studies have been undertaken to estimate demand functions for farm inputs primarily to determine the quantities of resources employed and the magnitude of output forthcoming. The studies estimated the demand functions directly from observed time series market data on quantities consumed of an input, price of the input, prices of related inputs, product prices, and other relevant variables. Among notable early works are those of Zvi Griliches (1958) on fertilizer, Cromarty (1959) on tractors, Heady and Tweeten (1963) on several inputs and Schuh (1962) on farm labor. Though less frequently, similar studies have continued to be undertaken in recent times (Carman, et. al. 1977; Olson, 1979; Gunjal and Heady, 1983). However, the results of the earlier studies have come to serve as a bench-mark to which of most of the recent studies have been compared with.

Typical features of these direct estimation studies include a theoretical framework to derive basic demand relationships; modifications to the theoretically derived relationships to make them more realistic, e.g., making the models dynamic, addition of explanatory variables, and incorporation of product price expectation; and estimation of price and other elasticities. Some of these features will be reviewed briefly in the next section.

Since the early major input demand studies were undertaken, there have been fundamental changes in U.S. agriculture that may have bearing on the relevance of the estimated demand functions. These include changes in the quantities and mix of inputs; changes in relative prices and other economic variables; changes in farm structures including decrease in farm numbers and increase in farm size; expansion in farm product exports; increase in farm assets; expansion in the use of farm credits; continued development of new technology; and increased government involvement through farm commodity programs and taxation.

The concern in this study is that the fundamental changes in the agricultural environment mentioned above would have impact on the demand for farm inputs and hence, the estimation results of the previous input demand studies may not hold if the same equations were re-estimated using more recent data. This will be tested by re-estimating selected models (prefered by the authors) of selected previous studies for selected inputs using data for the period 1946-85. The results of the updated estimates will be compared with the results of the original estimates to see if the two results are different.

B. MAJOR DIRECT INPUT DEMAND ESTIMATIONS

a. Fertilizer Demand Studies

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 nutrient 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 a 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 (represented by a time trend variable) were the major determinants of fertilizer consumption.

Heady and Tweeten's book (1963), Resource Demand and Structure of Agricultural Industries, is the most comprehensive published work on farm input demand. It covers a large number of inputs including fertilizer and estimates demand functions for various regions of the country and the U.S. as a whole. 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 modified limited information maximum likelihood estimation method and using 1945-77 annual data in original observation and logarithmic forms. The results show 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 et. al. (1977). Although there are some differences in the maintained hypothesis, functional forms used, and other estimation features that make the estimated results slightly different from each other, the variables that were repeatedly found 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.

b. Farm Machinery Demand Studies

Total farm machinery demand studies are few in number but studies of farm tractor demand are numerous. As a result, the review will cover both types of machinery in order to get a better perspective. Griliches (1960) specified the demand for the stock of farm tractors and the demand for gross investment as a function of the index of price paid for tractors relative to the index of price received for crops, interest rate, the lagged value of the stock of farm machinery, wage of hired farm labor, the value of stock of horses, real proprietors' equity, prices paid for motor supplies, and a time trend variable representing slowly changing variables. Several single equation static and dynamic demand models for stock and gross investment were estimated by ordinary least squares regression in logarithmic form using data for the period 1920-57. In the demand for stocks, only the index of prices paid for tractors relative to the prices received for crops, interest rate, and the lagged stock were found to be significant. In the investment demand function, only the same three explanatory variables were significant.

Heady and Tweeten (1963) specified the aggregate gross investment demand for all farm machinery and motor vehicles as a function of the ratio of current year prices of farm machinery to the prices received for agricultural products, the ratio of the current year prices of farm machinery to hired farm labor wage, the stock of farm machinery, net farm income from farming in the previous year, the past year ratio of proprietors' equities to liabilities, the index of agricultural policy (a dummy variable), and a time trend variable. Several equations were estimated by single equation least squares (OLS) method and limited information technique using 1926-59 annual data. If we limit ourselves to the results of the OLS method, the major determinants of gross investment were current year index of the price of all farm machinery to the prices received for crops, the past year's ratio of proprietors' equities to total liabilities or the net farm income in the past year, and the time trend variable.

Gunjal and Heady (1983) estimated several gross investment models for all farm machinery, tractors, harvesting machinery, and other farm machinery for the U.S. and the regions of the country using 1950-77 annual data. They also adjusted gross investment for qualitative changes by deflating the gross investment by the farm machinery price index and estimated quality constant gross investment demand functions. They specified gross investment as a function of the ratio of the machinery price to the agricultural product price, interest rate, expected net farm income, lagged stock of farm machinery in 1967 constant dollars, and a time trend variable representing the effect of other relevant variables. The relationships were estimated by single equation least square method. All the variables other than interest rate were found to be highly significant (at the 1 percent level) and interest rate was moderately significant (at the 6 percent level).

From the review of these studies, we can see that the variables that explain the demand for stock and gross investment in farm machinery are the price of farm machinery relative to the price received for agricultural products, the interest rate, the ratio of farmers' equities to total liabilities, net farm income, and time trend variable. Other farm machinery demand studies are those of Cromarty (1959) for tractors, machinery, and trucks; Fox (1966) for tractors; Rayner and Cowling (1968) for tractors in the U.S. and U.K.; Olson (1979) for machinery; and Penson (1981) for tractors. These latter studies support the results of the first three studies reviewed above.

c. Hired Farm Labor Demand Studies

There are a large number of single equation and simultaneous equation hired farm labor demand studies. Only a few important ones will be reviewed here. Heady and Tweeten (1963) estimated several static and dynamic demand models using single equation OLS, simultaneous equation models estimated in reduced form by the Theil-Basmann technique, and autoregressive least squares method. They estimated the models in original observations and in logarithmic forms using data for the periods 1910-57, 1920-39, 1929-57, and 1940-57. The number of hired laborers used was specified as a function of the average farm wage rate, the prices received for agricultural products lagged one period, the stock of farm machinery and equipment, a time trend variable, and the lagged dependent variable. Only the farm wage rate and the lagged price received for agricultural products were found to be the principal determinants of hired labor demand. The lagged dependent variable was significant in some of the equations but was reduced when a time variable was included.

Schuh (1962) estimated the demand and supply of hired farm labor using simultaneous equation model and data for the period 1929-57. The quantity of hired labor demanded was specified as a function of the real farm wage, the prices received for agricultural products, the prices of other inputs, a measure of technology, a time trend variable, and the lagged dependent variable. The supply of hired labor was specified as a function of real farm wage, income earned in nonagricultural employment, the unemployment rate in the general economy, and the size of the civilian labor force. Static and dynamic models were estimated using the Theil-Basmann technique. Also a single equation least squares estimate was made in order to verify the validity of the assumption of simultaneous determination of quantity hired and the wage rate.

The statistical results show that both the static and dynamic simultaneous equation procedures were acceptable but the single equation was not because OLS consistently failed to obtain a parameter estimate for agricultural wage in the supply equation that was significantly different from zero. The major determinants of demand were the real farm wage rate, the price received, and the lagged dependent variable where applicable. The time trend variable was also significant in the static simultaneous equation model. All the variables in the supply functions were highly significant.

A similar study was made by Hammonds, et. al. (1973) for the U.S. and Oregon using 1941-69 and 1951-70 data, respectively. Simultaneous equation models were specified and estimated by two stage least squares method. The results show that the major determinants of demand were the real farm wage rate, the real price received for agricultural products, and a measure of technology. The determinants of supply were non-farm income corrected for unemployment, the unemployment rate in the general economy, and the lagged dependent variable. The real farm wage rate and a time trend were not important in the supply equations.

Olson (1979) specified the demand for hired labor as a function of the farm wage rate, the price of fuel and oil, the price of farm machinery, the prices received for farm goods, the number of family workers, the number of farms, the average farm size, the national net farm income, the variation in income, expenditure for and stock of farm machinery, and slow changing variables grouped together in a time trend variable. Several static and dynamic single equation models of demand were estimated within a system of equations using modified limited information maximum likelihood estimation procedure. The models were estimated in original observations and logarithmic forms using data from 1946 to 1977. The results show that the dynamic specification was not supported and the factors that determine demand were the farm wage rate, the price of farm machinery, the price received for farm goods, and the number of family workers.

Finally, Wang and Heady (1980) estimated the demand and supply of hired labor using single equation least squares, two stage least squares simultaneous equation method, and autoregressive two stage least squares method. The variables used and results obtained were similar to those of Hammonds, et. al. above.

C. ANALYTICAL FRAMEWORK USED IN THE DEMAND STUDIES

1. Theoretical Framework

The basic theoretical framework used or implied in the above studies are based on the short-run and long-run profit maximization model of the competitive firm. The demand functions for variable inputs were derived, at least in principle, from the short-run static profit maximization model of the competitive firm. The demand functions for quasi-fixed (durable) inputs were derived from the long-run net worth maximization model. These are briefly discussed as follows.

a. The Demand for Variable Inputs

The basic theory of resource demand is based on the static theory of the competitive firm. 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 :

1.1) $Q = f(X_1, \ldots, X_n, K)$ or $Q = F(X, K)$

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

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

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

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

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

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

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

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

The output price P, variable input price W, and quasi-fixed input price, r, are known with certainty. The variable input, X, is chosen after determining K and observing all prices by maximizing the short-run profit function :

1.7) $\text{Max } \pi = P\, F(X, K) - W X, \qquad \text{s.t.} \quad X > 0$

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

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

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

1.9) $\frac{\partial F}{\partial x_i} \cdot \frac{\partial F}{\partial x_j} = \frac{w_i}{w_j}, \qquad i \neq j$

Condition (1.8) 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 (1.8) can be solved to obtain a system of short-run input demand functions as follows:

$$1.10 \quad X^* = X^* \ (W,P,K)$$

Where X^* are levels of inputs that the firm employs to satisfy conditions 1.8 for any 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:

$$1.11) \quad Q^* = F(X^*(P,W,K) = Q^*(P,W,K)$$

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 (equ. 1.9) into the first-order necessary condition (equ. 1.8) and the supply function (equ. 1.11) into the production function (equ. 1.1) to obtain the following n+1 identities:

$$1.12 \text{ a)} \quad P \ \partial F(X^* \ (P,W,K))/ \ \partial X \equiv W$$

and $$1.12 \text{ b)} \quad X^* \equiv X^*(P,W,K)$$

1.13) $Q^*(P,W,K) = f(X^*(P,W,K)$

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;

1) $\frac{\partial X^*}{\partial W}$ 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 decrease in the demand for that input. Hence, in equation 1.10, a negative relationship is expected between X_i and W_i.

The symmetry condition,

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

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

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

2) A priori one can say nothing definite about the signs of individual $\partial X / \partial P$ since an increase in P, through its effect on output, can lead to an increase (if superior) 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 making process extend beyond the short-run in order to derive the demand function for K.

2. The Demand for Quasi-Fixed (Durable) Inputs

The short-run profit function used above allows the derivation of only the demand functions for variable inputs. In order to derive the demand functions for quasi-fixed or durable inputs, the static theory has to be modified into a dynamic decision making horizon. This can be done by using the neoclassical investment theory developed by Jorgenson (1967).

According to this theory, the demand functions for stock of durable inputs and variable inputs can be derived directly from the long-run maximization problem of the firm. In this model, the firm is assumed to maximize net worth, i.e., the present value of a stream of net revenues accruing to the firm overtime. Using Jorgenson's notations, the flow of net revenue at time t, (R(t)), is equal to income less outlay on variable inputs less outlay on durable inputs:

$$1.15)\quad R(t) = P(t)\, Q(t) - w(t)\, L(t) - q(t)\, I(t)$$

where Q, L, and I represent levels of output, variable input (labor), and gross investment in durable inputs, respectively and P, w, and q represent the corresponding prices.

The production function, in implicit form, is:

1.16) $F \{ Q(t), L(t), K(t) \} = 0$

where the inputs are now divided into variable and stock of durable inputs. Two restrictions apply on the production function equation 1.11: 1) the levels of output, variable inputs, and capital services are constrained by the production function, 2) net investment is equal to gross investment less replacement investment, where replacement is proportional to capital stock. Mathematically, this relationship is,

1.17 $\dot{K}(t) = I(t) - \delta K(t)$

where $\dot{K}$ is the time derivative of the stock of capital (i.e. $\partial K/\partial t$) at time t and δ is the depreciation rate. The firm's problem is to choose time paths for variable inputs, L(t), and the stock of durable inputs, K(t), to maximize PV(0) given K(0) and L(t), K(t) > 0, subject to constraints 1.16 and 1.17, i.e.,

1.18) $PV(0) = \int_0^\infty e^{-rt} R(t)\, d(t)$

where r is the market interest rate. The Lagrangian function, dropping out the t, is

1.19) $L = \{ e^{-rt} R(t) + \lambda_0 (t) F (Q, L, K)$
$+ \lambda_1 (t) (\dot{K} - I - \delta K) \} d(t)$

where λ's are the lagrangian multipliers. The Euler necessary conditions for maximization are obtained by using calculus of variation, i.e., the first order partial derivatives as in equ. 1.8 should be equated not to zero but to the time derivative of the first partial derivative with respect to the rate of change variable, i. e., $\partial f/\partial L =$

d/dt ($\partial \dot{f}/\partial L$). This doesn't present a problem when maximizing with respect to L(t) and I(t), since their rates of change don't enter (Wallis). We can derive marginal productivity conditions for variable and durable inputs from the Lagrangian function 1.19. Setting the first partial derivatives with respect to L(t) equal to zero gives the marginal productivity condition for the variable input,

1.20) $$\frac{\partial Q(L,K)}{\partial L} = \frac{w}{P}$$

This is the same as the marginal productivity condition derived earlier in equ. 1.8 from the short-run profit function. However, the marginal productivity condition for capital services is

1.21) $$\frac{\partial Q(L,K)}{\partial K} = \frac{c}{P}$$

where

1.22) $$c = (r + \delta) q + \dot{q},$$

and is the implicit rental rate or the opportunity cost of capital service and is the function of the interest rate (r), the rate of depreciation (δ), and the price of the durable input (q). The dot over q shows a time derivative of q. Equation 1.21 indicates that the marginal product of capital ($\partial Q / \partial K$) should be equal to the real shadow price or rental cost of capital services in each time period (Gunjal, p 35). An increase in any of the determinants of c, cetris paribus, will lead to a decrease in the optimal level of capital stock. If the rates of depreciation and interest rate don't change over time, the change in the implicit rental rate will be proportional to the change in the purchase price of the durable input. In that case, the price of the durable input can be used in place of the implicit rental rate (Cowling and Metcalf, 1970).

Solving the two marginal productivity conditions, equ. 1.20 and 1.21, gives factor demand functions of the general form:

1.23) $L^*(t) = L(P(t), w(t), c(t))$

1.24) $K^*(t) = K(P(t), w(t), c(t))$

where $L^*(t)$ and $K2^*(t)$ are the optimum levels of variable input and capital stock in each time period.

The investment demand function is derived from the capital stock as follows:

1.25) $I^*(t) = \dot{K}^*(t) + \delta K^*(t)$

which implies

1.26) $I^*(t) = f(P(t), W(t), c(t), \dot{P}(t), \dot{W}(t), \dot{c}(t))$

which says that investment is a function of the price of product, the prices of related inputs, the implicit rental on capital services, and the depreciation rate. Capital stock and variable inputs are functions of the same variables less the depreciation rate.

c. <u>Limitations of the Derived Input Demand Functions</u>

The studies recognize several limitations of the derived input demand functions that limit their direct application for estimation purposes. These limitations can be summed up as follows.

First, the derived static demand functions are constrained by the assumptions of the profit maximization model. Three of the constraints are particularly important for estimation purposes:

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 model assumes that output and input prices are known and given at the time of planning production. This is only partly true because product prices are not observable at the time production decisions are made. Agricultural production decisions are based on expected rather than actual product prices; therefore, the output price has to be modified so that the expected price rather than the actual product price is used in estimation.

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, particularly so in the case of durable inputs. Thus in the estimation of the demand functions for durable inputs, some of the studies have explicitly included the interest rate paid by farmers to represent the cost and 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. To overcome the problem, some of the studies have included a proxy for technology in the estimation for demand functions.

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. As seen in the review of earlier input demand studies above, previous studies have included other relevant explanatory variables in the estimated models in order to rectify the shortcomings of the theoretical models.

2. Empirical Framework Used in the Studied

Most of the studies used single equation (e.g. fertilizer, farm machinery) and simultaneous equation (e.g. farm labor) least squares linear regression methods to estimate demand functions for various inputs. Mostly linear and log-linear functional forms were employed. The estimating models were modified to accommodate for lack perfect knowledge and lag in adjustment and that was achieved by use of partial and adaptive expectation models. These also enable estimation of short and long-run elasticities.

a. Single Equation Estimation Method

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 where only one of the input demand equations will be estimated independently.

Consider the linear relationship between the dependent variable Y and the independent variables $X_1, \ldots, X_k$ as follows:

1.27) $Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} \ldots + \beta_k X_{kt} + U_t$

where

Y_t = observable dependent variable

X_{it} = observable independent variable

U_t = unobservable error or disturbance to be estimated

β_i = unknown population parameter to be estimated

t = 1, 2,...,T observations on the variables.

In matrix form this can be written as:

1.28) $Y = X\beta + U$

The assumptions of this model are:

The relationship between Y and X is linear

1.29) $E(U) = 0$, i.e., $E(Y) = X\beta$

1.30) $E(UU') = \sigma^2 I$, i.e., each U distribution has the same variance and all disturbances are pair-wise uncorrelated and I is an identity matrix and σ^2 is the population error variance.

1.31) Rank of $(X) = k \leq T$, i.e., no exact linear relationship exists between two or more of the independent variables.

1.32) X is non-stochastic matrix whose values are fixed.

1.33) The U vector has a multivariate normal distribution.

Assumption 1.29, 1.30, and 1.33 can be combined into one.

1.34) $U \sim N(0, \sigma^2 I)$

Ordinary Least Squares Estimation

As indicated in Johnston (1984), Pindyck and Rubinfeld (1981), and others, the classical linear regression model (CLR), or simply the ordinary least squares (OLS) estimation technique, is the most popular and widely used single equation regression estimation method. The model is based on the principle of choosing β which minimizes the sum of the squared residuals (e'e), i.e.,

1.35) $\text{Min } (Y - X\beta)' (Y - X\beta) = e'e$

The OLS estimation β is $\hat{\beta}$, where

1.36) $\hat{\beta} = (X'X)^{-1} X'Y$

From this we get the following important results:

The OLS estimator is a linear unbiased estimator of β, i.e.

1.37) $E(\hat{\beta}) = \beta$

1.38) $Var\ (\hat{\beta}) = \sigma^2(X'X)^{-1}$

And the unbiased estimator of σ^2 is S^2 where

1.39) $S^2 = e'e/T-k$

Several violations of the CLR model were recognized. Some of these are: 1) specification error (non-linearity, wrong regressors, etc.); 2) non-zero expected disturbance; 3) disturbance having no uniform variance and correlated; 4) observation on X being stochastic; and 5) multicollinearity. Three of these problems are of practical concern in evaluating the updated estimates: specification problem, serial correlation and multicollinearity.

1.40) $Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + U_t$

but the relevant variable X_2 is excluded and the following regression equation is estimated :

1.41) $Y_t = b_0 + b_1 X_{1t} + U_t$

The effects of such mis-specification error on the estimated b_1 are given in detail in Johnston (1984), Pindyck (1981), Intriligator (1978), etc. In short, the least square estimate of equation (1.41) will yield biased estimate of the true slope parameter, i.e.,

1.42) $E\ (b_1) = b_1 + b_2\ (cov\ (X_1, X_2)\ /var\ (X_1))$

The bias will not disappear as the sample size grows, so that the omission of X_2 from the true model yields inconsistent parameter estimate as well (Pindyck). 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 equ. (1.42) but also because the disturbance variance cannot be correctly estimated.

On the other hand, the inclusion of irrelevant variables has quite different effects. Suppose the true model is equ. 1.41 but we estimate equ. (1.40). Here the inclusion of the irrelevant variable doesn't introduce any bias and no loss of consistency. Hence,

1.43) $E(b_1) = b_1$

However, the problem will lead to loss of degrees of freedom and therefore, loss of efficiency since the variance of b_1 will be larger. Yet, since the estimated $Var(b_1)$ will be an unbiased estimator of the true variance of b_1, 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 statistical problem, the exclusion of a relevant variable is. Thus, if the change in the economic environment of U.S. agriculture has impact on the demand for farm inputs, then the omission of variables representing the changed environment will contribute to inconsistent parameter estimate in the updated estimates.

The second major estimation problem recognized in the studies 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).

Assume here that the serial correlation is of the first order which is of the form:

1.44) $U_t = gU_{t-1} + \epsilon_t, \qquad 0 < g < 1$

where U_t is distributed as N $(0, \sigma^2_\epsilon)$ but not independent of the other errors over time, and ϵ_t is distributed as N $(0, \sigma^2_\epsilon)$ and is independent of other errors over time and g is an unknown parameter.

The presence of serial correlation, i.e., g significantly different from zero, is 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 D. Cochrane and G. H. Orcutt (Pindyck). The method estimates g from OLS residuals and transforms the dependent and independent variables so that the residuals from the transformed equation will be serially uncorrelated. The Durbin-Watson test is not valid when there are lagged dependent variables as regressors. In that case, the Durbin-h statistic should be employed (Pindyck).

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. In most of the studies: 1) if several coefficients had high standard errors and R^2 was high, one of the collinear variables was dropped if the standard errors of the remaining variables were lowered, 2) if the presence of the variables in question were supported on theoretical and other grounds, the problem was simply noted and nothing was done.

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

b. Simultaneous Equation Estimation Method

The simultaneous equation estimation technique enables the estimation of a complete system of equations that are related to each other. Consider two structural equations of demand and supply models for hired farm labor:

1.45) Demand: $Y_{1t} = \beta_0 + \beta_1 W_1 + \beta_2 X_1 + U_1$

1.46) Supply: $Y_{2t} = \alpha_0 + \alpha_1 W_1 + \alpha_2 X_2 + U_2$

Where Y_1, Y_2, and W_1 are endogenous variables determined within the system and X_1 and X_2 are predetermined variables. The application of OLS estimation concerns the likely correlation of U_1 with X_1 in Equ. 1.45

and U_2 with X_2 in Equ. 1.46 which lead to biased and inconsistent parameter estimates. Single equation limited information estimation techniques that can give unbiased and consistent parameter estimates are indirect least squares (ILS), instrumental variables (IV), two stage least squares (2SLS), and limited information maximum likelihood (LI/ML). Because of its ease and applicability to both just and over-identified equations, the 2SLS technique was employed in the relatively recent previous studies to estimate the structural parameters of the simultaneous equation models.

In 2SLS, a proxy or instrumental variable $\bar{W}_1$ is constructed which is highly correlated with W_1, but not with U_1 and U_2. The 2SLS technique then consists of replacing W_1 by $\bar{W}_1$, which is purged of the stochastic element and then performing an OLS regression of Y_1 on $\bar{W1}$ and X_1.

In dynamic simultaneous equation estimation with independent errors, the 2SLS is asymptotically efficient. However, it is not a consistent estimator when the error terms are correlated because the lagged endogenous variables are correlated with the residuals. If the errors are positively correlated, the coefficient of the lagged dependent variable will be upward biased and as a result, the corresponding adjustment coefficient will be downward biased and the associated long run elasticities will be inflated. Also, the usual formula of the covariance matrix of the 2SLS estimator will be a biased estimator of the asymptotic covariance matrix of the estimator parameter, hence, the t and F statistics are biased (Wang and Heady). In this case, the presence of autocorrelation is detected by the use of Durbin-h statistics. The problem is corrected by the use of autocorrelated 2SLS (A2SLS) (Fair, 1980). The A2SLS is a consistent estimator, it is an efficient estimator in a class of limited information estimators if each equation has the same autocorrelation coefficient. The small sample properties of A2SLS have been studied by means of Monte Carlo study (Wang and Heady); and the results suggest that it performs reasonably well in the dynamic simultaneous equation model with alternative assumptions of error structure.

3. Other Empirical Considerations

a. 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 (1984), Tomek and Robinson (1981)). Based on these and other cosiderations, two functional forms were used in the studies. These are linear and log-linear.

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

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

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 ;

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

where 1.49) $\beta_i = \partial Y_i / \partial X_i$

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 studies the elasticities were estimated at the mean of the observations.

The log-linear functional form is as follows: :

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

This form directly provides estimates of elasticities since slope and elasticities are the same, i.e.,

$$1.51) \quad \epsilon_i = \beta_i = \frac{\partial \ln Y_i}{\partial \ln X_i} = \frac{\partial Y_i}{\partial X_i} \frac{X_i}{Y_i}$$

It should be noted that 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. and as a result the 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).

b. Identification Problem

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).

To overcome the problem, it was explicitly or implicitly assumed that the supplies of the inputs estimated by single equation least squares, e.g., fertilizer and farm machinery, are perfectly elastic. This means that price determines the point of use along the demand curve, but shifts in demand don't affect price. This assumption is realistic for five reasons: 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 a 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 and farm machinery 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, fertilizer and farm machinery industries are mostly owned by huge, petroleum, chemical, and machinery conglomerates whereby fertilizer and farm machinery are small fractions of operations of these conglomerates. As a result the industries can maintain short-run supply prices when demand fluctuates, thus absorbing loses 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.

In the simultaneous equation estimation of the demand and supply of an input, e.g., hired farm labor, the equations were identified by the order condition for identification through the use of zero restrictions. This condition requires that the number of excluded exogenous variables be greater than or equal to the number of included endogenous variables less one.

D. Update of Selected Demand Estimates

Selected models of fertilizer, farm machinery and hired farm labor of selected previous farm input demand studies were updated using the original specifications, measurements, and estimations and relatively more recent data. Since some of the durable input demand studies were undertaken before Jorgenson's theory discussed above was published, some of the estimating equations may not neatly conform to the theoretical derivations. The definitions of variables and the results of the updated estimates are presented below.

1. Definitions of Variables

a. Dependent Variables

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.

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

QG_t = U.S. farmers' total expenditure for all farm machinery deflated by the index of prices paid by farmers for farm machinery.

DG_t = quantity of all farm machinery purchased by farmers deflated by CPI

LH_t = hired farm workers employed, estimated by USDA and measured in numbers (thousands)

b. Independent Variables

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.

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

RPF_t = fertilizer price index deflated by the general wholesale price index for the current year

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.

YG_t = cash receipt from farming, including government payments

PR_t = the index of average per acre value of farm real estate

AT_t = total crop acreage

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

RPM_t = the ratio of the index of price paid by farmers for farm machinery to the index of price received for agricultural products in the same year (1977 = 100).

$RRPM_t$ = ratio of index of current price for all farm machinery to index of price received by farmers for agricultural products lagged one period

HPM_t = the current year index of the ratio of the price of all farm machinery to hired labor wage

DSM_t = the value of stock of farm machinery in constant (1967) dollars.

SM_t = the value of the stock of farm machinery on U.S. farms by the wholesale price index

YN^E = declining three year arithmetic average of U.S. net farm income, i.e., $YN^E = 1/2YN_{t-1} + 1/3YN_{t-2} + 1/6YN_{t-3}$

E_t = the ratio U.S. farmers total equities to their total outstanding liabilities for farming purposes.

RFW_t = real wage of hired farm labor. The index of wage paid for hired farm labor deflated by the CPI

PFW_t = wage of hired farm labor deflated by the index of price paid by farmers for production expenses

MPP_t = index of prices received by farmers deflated by the index of farm machinery price.

UN_t = percent civilian unemployment rate in the general economy.

RLW_t = average hourly wage rate of non-farm civilian labor force adjusted for unemployment and deflated by CPI, 1967 = 100 (Wang & Heady) as follows:

a) $K_t = LW_t\ (1 - 5.\ UN_t)$

b) $KK_t = K_t/\ K1977\ .\ 100$

c) $RLW_t = KK_t/CPI\ 1967{=}100$

Where LW_t is the average hourly wage of non-agricultural workers, UN_t stands for the unemployment rate in the general economy, and CPI is the consumer price index. As indicated by Wang and Heady (1980), the variable RLW_t reflects the appeal of the real wage earned adjusted for employment opportunities in the non-farm sector. This formulation is based on the assumption that when the unemployment rate reaches 20 percent in the economy, there are no off-farm employment opportunities. And as a result, RLW_t has a zero effect on the supply of labor.

CLW_t = LW_t $(1-UN_t)$/CPI 1967=100

DPP_t = the index of prices received by farmers for all agricultural products (1977=100) deflated by the the index of prices paid by farmers

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.

2. Updates of Selected Fertilizer Demand Estimates

Selected estimates of fertilizer demand functions from the studies by Griliches (1958), Heady and Yeh (1959), and Heady and Tweeten (1963) were updated using data for the period 1946-85. The results are presented in Table 1. 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 total plant nutrient used (QN_t) and in the other two, it was total fertilizer material used (QF_t). The independent variables used were real price paid for plant nutrients (RPN_t), lagged price paid for fertilizer material (PF_{t-1}), real price paid for fertilizer material (RPF_t), price received for crops

Table 1. Updated Estimates of Selected Previous Fertilizer Demand Studies.

Study	Data Period	Est. Method	Depend. Var.	C	RPN_t	PF_{t-1}	RPF_t	PC_{t-1}	RPC_{t-1}	YG_{t-1}	QN_{t-1}	QF_{t-1}	PR_{t-1}	AT	T	R^2	dW	h
1.52 Griliches (1958)-Original (Model 3)	1911-56	OLS,L	QN	.13	-.54*						.77*					.98	-	-
					(.07)						(.13)							
1.52′ Update, Original (Model 3)	1946-85	>>	>>	1.011	-.27*						.93*					.99	1.88	.38
					(.11)						(.02)							
1.53 Heady & Tweeten (1963)-Original (Model 7.9)	1926-60	>>	QF	4.60		-1.40*		.21				.39*	.01		.002	.99	-	-
						(.36)		(.28)				(.17)	(.20)		(.004)			
1.53′ Update, Original	1946-85	>>	>>	2.10		-.18**		.04				.49*	.09		.79*	.98	1.99	1.49
						(.09)		(.11)				(.16)	(.09)		(.41)			
1.54 Heady and Yeh (1959)-Original (Model 3.3)	1926-56	>>	QF	10.68			-.49*			.64*				-1.08	.08*	.99	-	-
							(.20)			(.05)				(.62)	(.02)			
1.54′ Update, Original	1946-85	>>	>>	6.99			-.46*			.45*				2.92*	-3.96*	.97	1.87	-
							(.13)			(.10)				(.55)	(1.14)			

OLS, L = Estimated in logarithmic form.
dw = Durbin-Watson statistic.
h = Durbin-h statistic.
* = Significant at the 5 percent level.
** = Significant at the 10 percent level.
Numbers in parenthesis are the standard errors.

lagged one period (PR_{t-1}), total cash receipt from farming (YG_t), price paid for land lagged one period (PR_{t-1}), total crop acreage (AT_t), and a time trend variable (T). Griliches model is a simple dynamic model where the total quantity of plant nutrient used is a function of real price of plant nutrient and the lagged quantity of plant nutrients used. Heady and Tweeten's model is also dynamic with QF_t as a dependent variable and includes several explanatory variables. Heady and Yeh's model is static with QF_t as a dependent variable. All the original and the updated estimates have high R^2, though this value should not be taken seriously because the presence of the lagged dependent variable introduces serial correlation into the equation and the time trend variable picks up the effects of other explanatory variables.

In all the three estimates, all the corresponding coefficients in the original and the updated estimates have similar signs except for that of total crop acreage (AT_t) and the time trend variable (T) in the Heady and Yeh's model. In the original estimate, total crop acreage had a negative (-1.08) and insignificant 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, total cropland has a positive and significant coefficient of 2.92 implying an opposite relationship. On the other hand, the time trend variable was positive and significant in the original estimate but negative and insignificant in the updated estimate. A negative sign for the time trend variable implies that the use of fertilizer declined over time, which is contrary to the actually observed general trend.

Table 2. Updated Estimates of Selected Previous Gross Investment in Farm Machinery Studies.

Equ.	Study	Data Period	Est. Method	Dept. Var.	C	RPM_t	$RRPM_t$	HPM_t	QG_{t-1}	DSM_{t-1}	SM_t	YN^E	E_{t-1}	R_t	TE_t	T	AR(1)	R^2	dW	h
1.55	Heady & Tweeten (Model 11.4)	1926-59	OLS,O	QG_t	766.78	-8.82*		.41					126.01*			27.24*		.97	1.38	
	(S.E.)					(1.77)		(1.30)					(20.87)			(7.56)				
1.55′	Update	1946-85	>>	>>	71.16	-2.99*		1.61**					1.44*			-.94*		.93	.73	
	(S.E.)					(.84)		(.89)					(.48)			(.20)				
1.55″	Update	>>	AR(1)	>>	70.70	-3.01*		1.64**					1.45*			-.94*	-.001	.93	.74	
	(S.E.)					(.90)		(.98)					(.49)			(.20)	(.013)			
1.56	Heady & Tweeten (Model 11.9)	1926-59	OLS,O	>>	771.38	-7.63*			.15				99.83*			23.33*		.97	1.43	
	(S.E.)					(1.33)			(.12)				(27.95)			(6.17)				
1.56′	Update	1946-85	>>	>>	52.87	-1.11*			.44*				.65*			-.61*		.95	1.02	4.11
	(S.E.)					(.45)			(.11)				(.33)			(.19)				
1.56″	Update	>>	AR(1)	>>	42.33	-.94*			.57*				.71*			-.54*	-.05	.96	1.41	
	(S.E.)					(.44)			(.13)				(.32)			(.21)	(.04)			
1.57	Heady, Mayer & Madsen	1924-65	OLS,O	DG_t	-3910.75		-1.19				.03*		132.59*		33.32*	29.39*		.90	1.33	
	(t)						(.44)				(1.26)		(3.47)		(3.13)	(1.91)				
1.57′	Update	1946-85	OLS,O	DG_t	-8418.38		-296.51				-64.65*		-290.97*		-40.56	376.73*				
	(t)						(1.63)				(3.09)		(2.58)		(1.19)	(4.58)		.47	.61	
1.57″	>>	>>	AR(1)	>>	-8426.61		-296.51				-64.68*		-291.14*		-40.57	376.92*	.00001			
							(1.60)				(3.01)		(2.51)		(1.18)	(4.39)	(.01)	.47	.61	
1.58	Gunjal & Heady	1950-77	OLS,O	QG_t	10939	-19883*				-.19*		.135*		1080**		249.60*				
	(t)					(2.35)				(4.20)		(2.57)		(1.62)		(3.56)		.74		
1.58′	Update	1946-85	>>	>>	5.91	-1.14*				.01		.01		-.09		.17*				
	(t)					(5.39)				(.57)		(.66)		(.30)		(2.68)		.75	.70	
1.58″	>>	>>	AR(1)	>>	66.57	-1.22**				-.10		-.02		-.92		.31	.75*	.96	1.97	
	(t)					(1.80)				(.77)		(.42)		(.94)		(.77)	(6.23)			

OLS, O = Estimated linear form.
dW = Durbin-Watson statistic.
h = Durbin-h statistic.
SE = Numbers in parenthesis are the standard errors.
t = Numbers in parenthesis are the t values.
* = Significant at the 5 percent level.
** = Significant at the 10 percent level.

Another notable difference between the original and the updated estimates is that the magnitude of some of the coefficients, which are also elasticities, greatly differ. In Griliches' original estimate, the coefficient of QN_{t-1} was 0.77, which gives an adjustment coefficient of 0.23. In the updated estimates, the coefficient of QN_{t-1} increased to 0.93 and the adjustment coefficient declined to only .07, which is very low. 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, the coefficient of the lagged price of fertilizer was -1.40 and significant, which is elastic. However, in the updated estimate, it was only -.18, which is highly inelastic. Also, the coefficient of the time trend variable was .002 and insignificant in the original estimate, but that increased to .79 and became significant in the updated estimate.

Overall, the above results show that the coefficients of the updated estimates differ from those of the original estimates both in magnitude and in some cases, in sign. The results also indicate that fertilizer has become more price inelastic over time.

3. Update of Selected Gross Investment Estimates

Selected estimates of gross investment functions from studies by Heady and Tweeten (1963), Heady, Mayer, and Madsen (1972) and Gunjal and Heady (1983) were updated using data for the period 1946-85. The results of the original and the updated estimates are presented in Table 2. All the updated estimates had serial correlation problem as evidenced by the dw and h-statistics and were re-estimated by autoregressive least squares method. However, the coefficients of AR(1) were insignificant in all the equations except in equ. 1.58'' and hence, the OLS estimation would have been appropriate in those cases.

In the updated estimate of Heady and Tweeten's equ. 1.55 and 1.56, the R^2 are high and the coefficients of RPM_t and E_{t-1} have the same signs and are significant as in the original estimates. The coefficient of the time trend variable changed from positive to negative but is significant as in the original estimate. The sign of the time trend variable in the updated estimate is also consistent with the declining trend of investment in farm machinery observed in recent periods. IN equ. 1.56 the magnitude of the coefficient of the lagged dependent variable was .15 and not significant but in the updated estimates equ. 1.56' and 1.56'', it became about three times larger than that of the original estimate and significant. The updated estimate of Heady, Mayer, and Madsen's equ. 1.57' and 1.57'' have R^2 of .47 each, which is very low as compared to the original R_2 of .90. Also, the coefficients of three of the explanatory variables have different signs from those in the original estimate. The real price of farm machinery ($RRPM_t$) has the expected sign but is not significant both in the original estimate and the updated estimate. The coefficient of the debt-equity ratio (E_{t-1}) changed from positive to negative, which is opposite to what is expected. The estimation of this model by autoregressive least squares did not improve the results. Overall, the update of this model did not perform well statistically or theoretically.

Equation 1.58 was used by Gunjal and Heady to estimate a quality constant gross investment demand for farm machinery. In the original estimate, the R^2 was .74 and all the variables except R_t, were statistically significant at the 5 percent level. The updated estimate by OLS exhibited serial correlation problem and was re-estimated by autoregressive least squares method. The coefficient of AR(1) was highly significant and there was a marked difference in the magnitudes of the coefficients. Also, the R^2 increased from .75 in the OLS update to .96 in the autoregressive least squares update. However, the coefficients of all the explanatory variables other than that of the real price of machinery (RPM_t) were insignificant and the real price of farm machinery was significant only at the 10 percent level. Thus, this model also did not perform well with the new data.

Overall, only the updated estimates of Heady and Tweeten's two models performed somewhat better both statistically and theoretically. The other models did not perform well with the data. In general, the basic statistical estimation procedures are sound but the model specifications are not compatible with the new data.

4. Update of Selected Hired Farm Labor Demand Estimates

Selected estimates of selected previous hired farm labor demand studies were updated using data for the period 1946-85. The results of the original and the updated estimates are presented in Table 3. In Heady and Tweeten's equ. 1.59, the R^2 was .98 in the original and .94 in the updated estimate. The real farm wage (PFW_t) was negative and significant in the original, but in the updated estimate it is still negative but not significant. The coefficients of the lagged dependent variables are

Table 3. Updated Estimates of Selected Previous Hired Farm Labor Demand Studies.

Equ.	Study	Data Period	Est. Method	Dept. Var.	C	RFW_t	PFW_t	DPP_t	MPP_t	LH_{t-1}	RLW_t	CLW_t	UN_t	TE_t	T	R^2	dW	h
1.59	Heady & Tweeten (Model 8.9)	1910-57	OLS,O	LH	27.89		-.10* (.06)		.05 (.03)	.83* (.07)					.18 (.12)	.98		
1.59′	Update	1946-85	>>	>>	164.00		-1.31 (8.39)		1239.82 (896.74)	.81* (.13)					.11 (6.52)	.94	2.09	-.48
1.60	Heady & Tweeten (Model 8.12)	1910-57	>>	>>	23.86		-.05 (.06)	.05 (.06)		.85* (.07)					-.24* (.11)	.98		
1.60′	Update	1946-85	>>	>>	2020.61		-586.82 (452.05)	2.51* (1.24)		.49* (.15)					-14.03* (6.93)	.95	2.04	-.36
1.61	Hammonds D	1941-69	2SLS,O	>>	1927.77	-16.99* (4.00)		8.35* (3.50)		.19 (.9)				4.70** (1.4)				
	S	>>	>>	>>	1112.09	4.88 (1.00)				.70* (3.1)		-24.95* (4.1)	24.70* (1.9)		5.67 (.9)			
1.61′	Update D	1946-85	>>	>>	218.40	-3.01 (9.21)		194.66 (206.78)		.83* (.16)				-.67 (3.07)			2.05	-.86
	S	>>	>>	>>	1282.21	10.24 (11.16)				.69* (.14)		-40.34 (44.96)	6032.61* (1405.76)		22.19* (5.56)		2.41	
1.62	Wang & Heady D (Model 24&25)	1941-73	2SLS,O	>>	1968.78	-16.85* (7.77)		7.73* (3.76)		.21 (.34)				4.39 (4.80)			.47	
	S	>>	>>	>>	88.11	5.00** (2.99)				.98* (.10)	-5.91* (1.11)				-7.00* (3.50)		1.94	
1.62′	Update D	1946-85	>>	>>	301.21	-4.90 (9.25)		207.26 (207.37)		.80* (.16)				-.35 (3.08)			1.98	
	S	>	>>	>>	442.09	6.85 (13.70)				.88* (.16)	-1.00 (3.13)				-7.92 (5.73)		2.05	

dW = Durbin-Watson statistic.
h = Durbin-h statistic.
* = Significant at 5 percent level.
** = Significant at 10 percent level.
Numbers in parenthesis are the standard errors.

almost equal in magnitude and significant in both the original and the updated estimates. The time trend variable is not significant both in the original and the updated estimates. Also, this result is not in agreement with the generally declining trend in hired farm labor utilization observed over the period 1946-85.

In Heady and Tweeten's equ. 1.60 of the same study, the R^2 declined from .98 in the original to .95 in the updated estimate. The farm wage rate deflated by the price paid index, PFW_t, was negative and not significant in both the original and the updated estimates. However, the magnitude of the coefficient has become very large in the updated estimate. All the other variables have similar signs for the coefficients. The average price received by farmers, DPP_t, has small and insignificant coefficient in the original estimate but large and significant in the updated estimate. Also the coefficient of the lagged dependent variable has become smaller and but still insignificant. The time trend variable has a negative sign and is significant both in the original and the updated estimate and this agrees with the declining trend in the use of hired farm labor.

In the simultaneous equation model of Hammonds, et. al. (equ. 1.61), estimated by 2SLS, all the corresponding variables other than the index of technology in the demand equation, have the same signs in the original and the updated estimates and there was no serial correlation problem. The real farm wage (RFW_t) and the real price received by farmers (DPP_t) were significant at the 5 percent level in the original estimate and both are not significant in the updated estimate. The lagged dependent variable was not significant in the original but significant in the updated estimate. Also, the magnitude of the lagged dependent variable increased over four-fold in the update, thus substantially decreasing the adjustment coefficient. There are two major concerns with this model. First, the lagged dependent variable was not significant in the original estimate and hence, a dynamic model wouldn't have been appropriate in the first place. Second, all the explanatory variables other than the lagged dependent variable were insignificant in the update, which implies that the demand for hired labor is determined only by demand in the past period. These latter problem seems to be the result of multicollinearity arising from high collinearity between the lagged dependent variable and the price variables and this severely limit the usefulness of the model.

Finally, in Wang and Heady's equ. 1.62 all the demand coefficients other than those of the index of technical change (TE_t) have similar signs both in the original and the updated estimates. The sign of TE_t changed from positive in the original estimate to negative in the updated estimate, although it was not significant in both. In the original demand estimate, RFW_t and DPP_t were significant but in the updated estimate, only LH_{t-1} was significant. Again this lack of significance of the coefficients of the updated estimate is suspected to be due to the same problems discussed above in conjunction with Hammonds' model.

The updating of the above four hired labor demand models leads to the following two generalizations. First, of the four models updated above, only Heady and Tweeten's equ. 1.60 performed well in terms of high R^2, correct signs of coefficients, and significance of three out of four coefficients. In two of the remaining three models, only the lagged dependent variable was significant. Second, the adjustment coefficient of the updated estimates varied from .17 in Hammonds' model to .51 in Heady and Tweeten's equ. 1.60, thus giving widely differing adjustment speeds.

E. SUMMARY AND CONCLUSIONS

Several studies have been undertaken in the past four decades to analyze the demand for farm inputs in U.S. agriculture. Most of these studies were conceptually based on microeconomic theory of the competitive firm and greatly utilized the judgement and experience of the researchers. These studies employed traditional time series regression method to estimate the demand functions of individual farm inputs. The explanatory variables used were those suggested by economic theory and others believed to be important by the researchers at the time of undertaking the studies. However, as U.S. agriculture changes structurally, becomes more commercialized, and increasingly integrated into the national and international economy, it is critical to assess the results of the past studies that are being used as benchmarks to see if they are still relevant under the changing environment. The objective of this study is to see if the results of the previous input demand estimates still hold under the changing farm environment.

As seen above, the selected input demand studies used single equation models for fertilizer and farm machinery and estimated by ordinary least squares. Simultaneous equation models were employed in the analysis of the demand and supply of hired farm labor and estimated by two stage least squares. The single equation OLS and the simultaneous equation 2SLS equations were estimated in linear and log-linear functional forms.

The selected updated estimates generally produced poor results. In the case of the demand for fertilizer, all of the updated estimates gave high R^2 (.97 to .99), but the signs of the coefficients were different from the original estimates for several variables. Also there were changes in the magnitude and significance of the coefficients. The own price elasticity of fertilizer has become more inelastic overtime as well. In the case of gross investment in farm machinery and hired farm labor, the results were also generally poor, i.e., very low R^2, insignificant coefficients with unexpected signs (and also different from the original estimates), and unstable coefficients were encountered.

In conclusion, the direct estimation of demand functions for farm inputs from observed market time series data provides good estimates of demand relationships in agriculture. However the U.S. agriculture is very dynamic and continuously undergoing changes. These changes lead to the obsolescence of the estimated demand functions over time. As seen in the updated estimates, the signs, magnitudes and significance of the coefficients have changed considerably. Therefore, in order to understand the changing relationships in agriculture, up-to-date estimates of demand and supply relationships are needed. Updating of previous estimates with new data will not provide satisfactory results. Hence, new estimates with appropriate model specifications that can reflect the changing economic relationships are required.

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