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THE DEMAND FOR FARM MACHINERY

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THE DEMAND FOR FARM MACHINERY

I. INTRODUCTION

U.S. agriculture has undergone significant changes in the past four decades. There were continued structural changes such as increase in farm size and decrease in farm numbers; large expansion in the 1970s and contraction in the early 1980s. There were also changes in the economic conditions or forces affecting agriculture such as rapid expansion in farm exports, increase in farm assets, expansion of farm credit, continuing development of new technology, and increased government involvement through farm commodity programs and taxation. These developments have a profound impact on resource organization in general and input demand in particular.

Though there are several excellent farm machinery demand studies for U.S. agriculture, most of them did not include some these developments in their analysis because the studies were undertaken during or prior to the occurrence of these developments. Therefore, the major goal of this study is to analyze the demand for farm machinery using more recent data and variables reflecting the recent developments. The analysis enables us to estimate structural coefficients and elasticities and to determine the factors that affect the demand for farm inputs. First we will look at the major historical trends in the use farm machinery, the expansion of the 1970s and contraction of

the early 1980s, and the forces that are likely to have affected
machinery demand.

A. Historical Changes in Use of Farm Machinery

U.S. agriculture has become very highly mechanized as
compared to the early 1940s. Larger, more efficient, and
increasingly specialized tractors, trucks, grain combines, corn
pickers, balers, forage harvesters, livestock equipment, and
other equipment are being used. The intensive use of farm
machinery has also enabled farmers to use less labor and more of
other purchased inputs such as fertilizers and pesticides,
thereby making agriculture more productive and efficient.

1. Trend in the Use of Farm Machinery

The trend in the number and size of major farm machinery
groups from 1945 to 1985 is presented in Table 1. Between mid-
1940s and mid-1960s, the number of tractors doubled while the
total horsepower almost tripled. As a result, the average
horsepower per tractor rose from 25.9 in 1945 to 36.8 in 1965.
The number of tractors has more or less declined since then while
the total horsepower and average horsepower have continued to
increase. The number of motor trucks also doubled between the
mid-1940s and mid-1960s, but has hardly increased since. The
number of grain combines, corn pickers and shellers, and field
forage harvesters increased by 2.8, 7.8, and 15.8 times,

Table 1

Number and Size of Principal Farm Machinery, 1945 to 1985 (Jan. 1 stock)

Year	Total Number (Thous.)	Tractors P.T.O. H.P. (mill)	Aver. H.P.	Motor Trucks (Thous)	Grain Combines (Thous)	Corn Pickers (Thous)	Pickup Balers (Thous)	Field Harvest. (Thous)
1945	2354	61	25.9	1490	375	168	42	20
1950	3394	93	27.4	2207	714	456	196	81
1955	4345	126	29.0	2675	980	688	448	202
1960	4688	153	32.6	2834	1042	792	680	291
1965	4787	176	36.8	3030	910	690	751	316
1970	4619	203	43.9	2984	790	635	708	304
1975	4469	222	49.7	3032	524	615	667	255
1980	4726	304	64.3	3344	625	701	756	293
1985	4676	311	66.5	3380	645	684	800	285

Sources: 1) Agricultural Statistics, USDA, (various years).
          2) Selected Farm Mach. Stat., Hanthon et. al. (for H.P. 1945-60).

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respectively, between mid-1940s and mid-1960s, but has more or less continuously declined since. However, the number of pickup balers increased almost 18 fold between 1945 and 1965, declined through the 1970s, but has rebounded again in the early 1980s reaching 800,000 units in 1985.

The downward trend in the number of farm machinery between the mid-1960s and 1980 was mainly due to improvements in the quality of the machinery such as size (horsepower), hydraulic linkage and other features of the machinery. However, the downward trend in the early 1980s was primarily the result of contraction in the agricultural economy.

2. Trends in the Value of Stock and Gross Investment

Table 2 presents the stock of farm machinery and gross investment for selected years from 1946 to 1985. The total value of the stock of all farm machinery on farms in nominal and real terms more than doubled in the five years between 1946 and 1950 and increased at an annual rate of 6.2 percent in nominal and 1.4 percent in real between 1950 and 1970. After a moderate growth for two decades, the stock of farm machinery accelerated between 1970 and 1980 because of favorable economic environment such as growing farm sector equity, increased availability of credit, investment tax credit, favorable real interest rates, and increased crop prices and planted acreage (Daberkow, p. 12). Hence, the value of stock more than tripled in nominal terms and

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Table 2

Stock of Farm Machinery and Gross Investment, 1946-85

Year	Bill. $	Stock Const.(1982) Bill. $ *	Annual Gross Investment Bill. $	Const.(1982) Bill. $ *	Invest. Stock Ratio
1946	4.7	24.2	1.0	5.2	.21
1950	12.3	51.5	3.2	13.4	.26
1955	16.3	59.9	2.8	10.3	.17
1960	19.0	61.5	2.8	9.1	.15
1965	22.2	65.7	4.2	12.4	.19
1970	27.5	65.5	4.9	11.7	.18
1975	57.2	96.5	8.7	14.7	.15
1980	93.1	108.6	12.8	14.9	.14
1985	87.8	78.7	7.4	6.6	.08

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

* Deflated by GNP implicit price deflator, 1982 = 100

increased over one and a half times in real terms between 1970 and 1980. However, this trend was dramatically reversed in the early 1980s and the value of stocks dropped by 1.2 percent in nominal terms and 5.6 percent in real terms annually between 1980 and 1985.

Annual gross investments in farm machinery have paralleled trends in the value of stock of farm machinery. Annual expenditures for farm machinery grew by 16 percent in nominal terms and by 2.7 percent in real terms between 1970 and 1980, but plunged by 8.4 percent in nominal and 11.1 percent in real terms annually between 1980 and 1985. The major reasons for the reversal in the trend in the early 1980s are declining farm

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equity, high real interest rates which led to reduced availability of cash to the farming sector, record debt, and lower farm income (Daberkow (1981) & Fact Book of Agriculture (1986)).

The ratio of gross investment to the value of stock of farm machinery provides the trend in the proportion of annual purchases as compared to available stock. Annual purchases were 21 percent of value of stock in 1946 and increased to 26 percent in 1950. It averaged about 17 percent between 1950 and 1970, declined to about 14 percent in the 1970s, and further declined to 8 percent by 1985. This trend is in agreement with the trend in the number of farm machinery presented earlier in Table 1. This shows that farmers are replacing machinery less frequently and making relatively less net investment as compared to their stock. Though increased farm machinery capacity, improved efficiency (e.g., due to increased average farm size), and better management practices can contribute to the decrease in the ratio, the sharp decline in the early 1980s was due to the overall contraction in farming and increased spending by farmers for repair and maintenance. The 1986 Fact Book of U.S. Agriculture indicates that during the 1970s, farmers annually spent between $0.23 and $0.33 on machinery repairs for each dollar spent on machinery purchases; but this amount increased to $0.59 by 1984.

B. Objectives of the Study

There are several excellent farm machinery demand studies that were conducted from the 1950s to the early 1980s. Most of these studies employed single equation linear regression analysis. The overall objective of this study is to extend these studies by incorporating emerging economic, policy and structural forces mentioned earlier. The specific objectives of this study are as follows:

1) Provide a brief historical background of the trends in the use of farm machinery.

2) Use neoclassical investment theory, previous input demand studies and recent agricultural literature to identify the forces or variables that determine the demand for farm machinery.

3) Briefly review the empirical framework to be used and the associated problems.

4) Specify demand functions for stock of farm machinery and gross investment incorporating the theoretical explanatory variables and the emerging forces. Estimate the demand functions using single equation (OLS) and autoregressive least squares (ALS) and report the results.

5) Compute elasticities for selected demand models and assess the magnitudes and directions over time. Compare with results of previous studies.

C. Machinery Included in the Study

The neoclassical investment theory discussed in the next section forms the basis for the models and explanatory variables to be included in the estimation of aggregate machinery demand functions. Separate demand functions will be estimated for total stock of farm machinery and gross investment. No attempt will be made to estimate dis-aggregated demand for separate machinery such as tractors, motor trucks, and harvesting machinery. For such analysis one can refer to Gunjal and Heady (1983), Olson (1979) and Rayner and Cowling (1968).

D. Sources of Data

Aggregate time-series data for 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.

II. EMPIRICAL FRAMEWORK

This study is primarily an extension of previous machinery demand studies and hence, essentially uses the similar empirical framework. 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 basic estimation models used in this study are single equation linear regression models.

In those models where the error structure is homoscedastic and noncorrelated, the ordinary least squares (OLS) is used. The resulting estimates from these models are best, linear and unbiased. In those models where the error structure is serially correlated, autoregressive least squares (ALS) estimation is used. In the autoregressive models, first order serial correlation error structure is assumed:

1.1) $U_t = gU_{t-1} + \in_t$, $0 < g < 1$

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

When autocorrelation is present (Durbin-Watson test), the original model is transformed using the iterative method suggested by D. Cochrane and G. H. Orcutt (1949). The method estimates g from OLS residuals and transforms the dependent and

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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 will be employed for detection.

Multicollinearity, which arises when two or more independent variables are highly correlated with each other, i.e., have an approximate linear relationship, is also a problem in such estimation. 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. What will be attempted in this study are: 1) if several coefficients have high standard errors and R^2 is high, one of the collinear variables is simply dropped if the standard errors of the remaining variables are lowered, 2) if the presence of the variables in question are supported on theoretical and other grounds, the problem will be simply 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 (t-test),

stability of relationships, and Durbin-Watson statistic or Durbin-h statistic for autocorrelation, and economic soundness of the model.

Two other empirical considerations, functional form and identification problem, are also important in such estimation. 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 criteria and desire for conformity with results of previous machinery demand studies, linear and log-linear forms are selected.

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

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

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;

1.3) $\in_i - \beta_i \, (X_i \, / \, Y_i)$

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:

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

This form provides directly estimates of elasticities since

slope and elasticities are the same, i.e.,

1.5) $\in_i \; - \; \beta_i \; - \; \dfrac{\partial \ln Y_i}{\partial \ln X_i} \; - \; \dfrac{\partial Y_i}{\partial X_i} \dfrac{X_i}{Y_i}$

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 but may not be

realistic under real world conditions. Because there are lags in

adjustment due to technology, psychological preparedness, credit

constraints, etc. and 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).

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 discussions of this problem and the related estimation and interpretation problems are provided elsewhere (Bohi (1981) and Rao & Miller (1971)).

In this study, it is assumed that the supplies of 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

several reasons: 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. On the supply side, first the supply processes of farm machinery require heavy capital investments and long lead times, which imply that production plans are geared towards future as well as current consumption levels. Second, 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, 1981). Third, farm machinery industries are mostly owned by huge machinery conglomerates whereby 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.

III. MAJOR FORCES AFFECTING THE DEMAND FOR FARM MACHINERY

Several factors determine the demand for farm machinery.
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 to simplify matters, there
are obvious overlaps between the forces suggested by the three
sources.

A. Neoclassical Investment Theory

According to Jorgenson's (1967) neoclassical investment
theory, the demand functions for stock of durable 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, i.e., R(t), is equal to income less outlay on
variable inputs less outlay on durable inputs:

1.6) $R(t) = P(t) \ Q(t) - w(t) \ L(t) - q(t) \ I(t)$

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.

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The production function, in implicit form, is:

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

where the inputs are now divided into variable and stock of durable inputs. Two restrictions apply on the production function in equation 1.6: 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,

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

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 on 1.7 and 1.8, i.e.,

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

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

1.10) $L = \{ e^{-rt} R(t) + \lambda_0 (t) F (Q, L, K)$

$+ \lambda_1 (t) (\dot{K} - I - \delta K) \} \, d(t)$

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 are equated to the time derivative of the first partial derivative with respect to the rate of change variable, i. e., $\partial f/\partial L - d/dt$ $(\partial f/\partial \dot{L})$. This doesn't present a problem when maximizing with respect to L(t) and I(t), since their rates of change do not enter (Wallis, 1980). We can derive marginal productivity conditions for variable and durable inputs from the Lagrangian function 1.10. Setting the first partial derivatives with respect to L(t) equal to zero gives the marginal productivity condition for the variable input,

1.11) $\dfrac{\partial\ Q\ (L,K)}{\partial\ L} - \dfrac{w}{P}$

The marginal productivity condition for capital services is

1.12) $\dfrac{\partial Q\ (L,K)}{\partial K} - \dfrac{c}{P}$

where

1.13) $c - (\ r + \delta\ )\ q + \dot{q},$

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 1.12 indicates that the marginal product of capital ($\partial Q\ /\ \partial K$) should be equal to the real shadow price or rental cost of capital

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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 do not 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. 1.11 and 1.12, gives factor demand functions of the general form:

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

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

where $L^*(t)$ and $K^*(t)$ 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:

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

which implies

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

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

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variable inputs are functions of the same variables less the depreciation rate.

It should be noted that the models derived above are static and do not incorporate the explanatory variables representing the emerging economic, technological and policy variables mentioned earlier. To make the models more realistic, these adjustments are made to the estimating equations presented in the next section.

B. Previous 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 proprietor's 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

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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 (discussed in detail
latter in this chapter) 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. Emerging Forces Affecting the Demand for Farm Machinery

The neoclassical investment theory suggests that the demand for farm inputs are determined by the implicit rental rate, the prices of related inputs, and the price of the product. However, review of recent agricultural literature suggest that more explanatory variables should be included in the demand functions in order to make the estimates more meaningful. The additional explanatory variables to be included in this study are addressed as emerging forces, and how they affect the demand for farm machinery are explored below.

a. Farm Product Exports

Agricultural exports, both commercial and non-commercial, 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 farm machinery can be captured by incorporating the variable in the demand equations as a demand shifter. Increases in agricultural exports are expected to increase the demand for farm inputs with a time lag.

b. 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 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 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

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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 machinery. A
positive relationship is expected between quantity demanded of
farm machinery and the debt-equity ratio.

c. Production Credit and 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

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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).

In this study, interest rate on non-mortgage credit will be used as a separate explanatory variable only in those models where the price of farm machinery is substituted for the implicit rental rate. Interest rate represents the ease with which credit is available and the cost of borrowing.

d. Government Farm Programs and Policies

i. Acreage Diversion from Crop Production

There are two major categories of government commodity programs, withholding cropland from production and support of prices and incomes. 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 acres in 1946-55, 1980 and 1981 to 78 million acres in 1983. Acreage diverted from crop production will enter machinery demand functions as a separate explanatory variable.

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.

ii. Tax Rules Affecting Machinery Demand

Taxes are one of the policy tools governments use to change the behavior of economic agents and modify the distribution of incomes and wealth. Generally farming has been accorded preferential treatment for federal taxes as compared to other sectors of the economy. The special provisions that treat agriculture more favorably than other sectors include special valuation of farms for estate taxation and deferred payments of estate taxes, liberal deductions of capital expenditures, deductibility of interest payments on business expenses, liberal interpretation of what constitutes a capital asset for capital gains treatment, and investment tax credit and accelerated depreciation provisions (Penn, 1979).

The broad effects of these provisions on the utilization of farm inputs include making investments in agriculture more attractive, altering the mix of production inputs in favor of capital inputs and land improvements, and altering the flow and timing of input purchases so that tax benefits can be gained (Penn, 1979). The impact of tax rules on the demand for farm

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machinery is extremely difficult to measure directly due to the fact that the tax benefits are realized through complex accounting procedures that allow sheltering of incomes from taxation.

If taxes were simply levied on pure profit, the effect of taxation on the farm firm could be captured by re-defining the net worth in equ. 1.9 as the present value of revenue less taxes (Wallis):

$$1.18) \quad PV = \int_0^k e^{-rt} (R(t) - T(t)) \, d_t$$

where T is the tax rate. In this case, taxes do not alter the profit maximizing levels of output and inputs. However, as mentioned above most agricultural taxes involve special tax provisions that affect the use of specific inputs through depreciation rates and investment tax credit and are not pure profit. For farm machinery, Conway, et. al. (1985) have proposed a modification of the implicit rental rate to capture the effects of changes in federal tax policy on farm machinery and other investments. Details of this procedure are given in Appendix I.

Their approach is directly used in this study and the implicit rental rate calculated in that study was used by permission of the authors.

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e. 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 out that investments in buildings and machinery will decrease on per acre basis as the farm size increases. He also indicates 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 non-farm 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. The increased farm size will not affect per acre employment of biological inputs. They conclude that since total cropland acreage did not show much change over the years, it will not be wrong to deduce

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that the increase in farm size does not affect total demand for biological inputs.

However, the issues of farm size, economies of scale, and related subjects are still under debate. It is hoped that the inclusion of average farm size in the demand functions of the inputs will provide additional evidence.

f. 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 farm machinery. Farm numbers will enter the machinery demand functions as a demand shifter.

g. 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., result in new production coefficients, alter the
relative prices of inputs and outputs, and contribute 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 :

$$1.19) \quad Q_t = a_t + f(X_1, X_2, \ldots, X_n)$$

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).

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However, most technical changes will increase the marginal productivity of all or of some of the inputs. If one assumes that the marginal productivity, $\partial f/\partial X_i$, increase 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;

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

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, 1970).

In both 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 non-neutral 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

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(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 decrease in the use of labor observed in U.S. agriculture are the outcomes of these phenomena.

Over time, both neutral and non-neutral technical changes will be experienced in agriculture. The outcome of this 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 non-neutral technical change. Also farm machinery are adjusted for quality changes to partly account for the effects of technical change.

h. Changes in the Quality of Farm Machinery

Though it is difficult to separate the changes in the quality of farm machinery from the other effects of technical change, it is necessary to adjust machinery for quality changes in order to avoid bias from variation in quality arising overtime. If machinery are not adjusted for quality, the effects

on the estimated demand functions would be similar to bias in the data (Heady & Dillon, 1961). Hence, prices cannot accurately reflect quantity changes if machinery qualities are also changing at the same time.

To avoid this problem, machinery have to be adjusted for quality changes over time so that the demand functions would be estimated on constant quality basis. The stock and annual purchases of farm machinery over the study period (1946-1985) vary considerably in quality due to differences in size, capacity, and efficiency of the machinery. For example, tractor units have qualitative differences such as diesel or gas engine, incorporation of hydraulics, cabin comfort, and sophistication of many other components. Qualitative changes such as horsepower, hydraulics, air conditioned cabins, etc. are usually reflected in the prices of the machinery. Previous machinery demand studies have treated the problem of qualitative changes in farm machinery in different ways. For example, Heady, Mayer and Madsen (1972) and Olson (1979) simply recognized the problem and did not account for quality changes. Cromarty (1959) measured gross investment of farm tractors simply by the number of tractors. Griliches (1960) and Rayner and Cowling (1968) constructed explicit quality indexes based on such things as horsepower and deflated the value series by an estimated constant quality price index. However, after a thorough review of these studies, Gunjal and Heady (1983) have come to the conclusion that the

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construction of an accurate and explicit quality index which will account for all the qualitative characters (often non-quantifiable) in any machinery is almost impossible, or very complicated. Instead, they proposed an implicit quality consideration, earlier employed by Heady and Tweeten (1963), which partially compensates for quality differences. This method is adopted in this study because of the ease of calculation and availability of data.

Using Gunjal and Heady's original notation, let PM_t be the current price of machinery, say tractor, paid by farmers in year t. PM_t can be viewed as composed of two parts, namely, the price of the basic machinery unit (PM_{bt}) and the price of qualitative additions to the basic unit, PM_{qt}, i.e.,

1.21) $PM_t = PM_{bt} + PM_{qt}$

If T_t is the total number of machinery purchased in year t, the total purchases of machinery in year t in current dollars is:

1.22) $PM_t \, T_t = (PM_{bt} + PM_{qt}) \, T_t$

The total purchases in 1977 constant dollars is obtained by deflating the series by an index PM_b with 1977 = 100:

$$1.23) \quad \frac{PM_t \cdot T_t}{(PM_{bt}/PM_{b77})} = \frac{(PM_{b77})}{PM_{bt}} \cdot (PM_{bt} + PM_{qt}) T_t$$

$$= PM_{b77}T_t + PM_{b77} \frac{(PM_{qt}) T_t}{PM_{bt}}$$

$$= (1 + \frac{PM_{qt}}{PM_{bt}}) PM_{b77} T_t$$

The PM_{b77} is the value of PM_b in the year 1977. The proportion of the added qualitative change is measured by the factor PM_{qt}/PM_{bt}. The direction of change in quality is obtained from the value of PM_{qt}/PM_{bt}. It could be positive, negative, or zero leading to a conclusion about quality as improvement, deterioration, or no change respectively.

From this Gunjal and Heady conclude that:

> Thus deflating (machinery) purchases in current dollars by an index of price of the basic (tractor) unit in different periods is one way of partially taking into account the qualitative changes. The machinery price index, on the other hand, reflects the index of prices of the same machinery basket based on its cost of production in different periods. Therefore, this price index is used as a proxy for the basic unit price index described in (1.23). Thus, weighing quantities by prices partially compensates for the qualitative differences, because the improved unit of machinery is weighted by a higher price.

Thus, in this study, the stock of machinery and annual gross investment will be deflated by the index of price paid by farmers for farm machinery to compensate for qualitative changes.

IV. Estimation Results

A. Definition of Variables

The stock of farm machinery on the farms include tractors, motor trucks, grain combines, shellers and balers, and other machinery. The stock of farm machinery (SM_t) is the value of the stock of all farm machinery on U.S. farms on December 31 in current dollars. This is deflated by the index of price of farm machinery to partially account for changes in the quality of machinery stock as discussed above.

Gross investment in farm machinery in each year is the expenditure farmers make for tractors, trucks, and other machinery. The value of gross investment is deflated by the index of the price of farm machinery to account for quality changes. The quality constant gross investment is used as a dependent variable in all equations.

QSM_t — The value of stock of farm machinery on U.S. farms on December 31 deflated by the index of prices paid by farmers for farm machinery.

DSM_t — The value of stock of farm machinery on U.S. farms on December 31 deflated by the producers price index.

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

The demand for the stock of farm machinery is hypothesized
to be a function of the implicit rental rate of farm machinery or
price of farm machinery as explained below, expected product
price or net farm income, debt-equity ratio, interest rate,
agricultural exports, acreage diverted from crop production
under government farm programs, farm numbers, average farm size,
the agricultural productivity index as a proxy for technical
change, and a time trend variable representing other slow
changing variables. The definitions and measurements of these
variables are as follows:

C_t — Implicit rental rate of farm machinery. This rate is
a function of prices of farm machinery, service
lives, rates of depreciation, the tax treatment of
the farm machinery, and the discount rates. Details
of how it is estimated are provided in Appendix I.
Data for this variable were provided by Hrubovak and
associates of the ERS and was used in their study of
farm investment (Conway et. al. 1988).

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).
Used as proxy for the implicit rental rate.

DPM_t — Real price of farm machinery. The index of price paid for farm machinery deflated by the producer price index (1967 = 100). DPM_t is used as a proxy for C_t assuming that C_t and the price of farm machinery are proportional and to allow other components of C_t as separate explanatory variables in the estimation.

DPP_t — The index of prices received by farmers for all agricultural products (1977 = 100) deflated by the consumer price index (1967 = 100)

YN_t — Net farm income in billions of current dollars.

RYN_t — Net farm income in billions of dollars deflated by the consumer price index (1967 = 100)

E_t — The ratio U.S. farmers total equities to their total outstanding liabilities for farming purposes.

FW_t — The index of wage paid for hired farm labor.

RFW_t — Real wage of hired farm labor. The index of wage paid for hired farm labor deflated by the GNP implicit price deflator.

PR_t — The index of the value of farm real estate per acre.

RPR_t — The index of real value per acre of farm real estate deflated by the producer price index, 1977 = 100. RPR_t is used as a proxy for the real price of land.

PA_t — The index of prices paid by farmers for all agricultural inputs.

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RPA_t — The index of price paid by farmers for all agricultural inputs deflated by the producer price index, 1977 = 100. Used as a proxy for the real price of all other inputs.

RZ_t — The value of agricultural exports deflated by the producer price index, 1977 = 100.

R_t — Average interest rate on non-real estate farm loans outstanding on December 31.

D_t — Acreage diverted from crop production under various government programs.

N_t — Number of farms in the U.S. on January 1 of the current year.

A_t — Average farm size of U.S. farms in acres on January 1 of the current year.

TE_t — Index of agricultural productivity (1977 = 100) representing technical change.

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

B. Demand for Stock of Farm Machinery

1. Stock Demand Models

Several single equation stock demand functions will be estimated in linear and log-linear forms. The demand for the

stock of farm machinery is hypothesized to be a function of the implicit rental rate of farm machinery, the price received for agricultural products, prices of other inputs, and other demand shifters such as agricultural exports and acreage diverted from crop production under government farm programs. The stock of farm machinery is adjusted for quality changes by weighing stock by aggregate machinery price index in order to maintain the proportionality between services and stock which forms the basis for the calculation of the implicit rental rate (Appendix I). Some of the stock demand models considered in this chapter are presented below.

Model A

This is a static demand for stock of farm machinery. The stock of farm machinery are durable inputs that provide a flow of services to the production function. The equilibrium demand for services of farm machinery at any one time is the function of the price of the machinery service (the implicit rental rate), C_t, anticipated product price (PP_t^e), and the prices of substitute and complementary inputs. These include prices of hired farm labor (FW_t), land (PR_t), and all other inputs taken together (PA_t). Hence the demand for the equilibrium level of machinery services can be specified as follows:

$$1.24) \quad S_t^* = F \ (C_t, \ PP_t^e, \ FW_t, \ PR_t, \ PA_t)$$

Assuming that the flow of machinery services is a constant proportion of the stock of farm machinery, the equilibrium stock of machinery will be determined by the same explanatory variables:

1.25) $\quad SM_t{}^* = F\ (C_t,\ PP_t^e,\ FW_t,\ PR_t,\ PA_t)$

or in linear estimating form:

1.26) $\quad SM_t^* = b_0 + b_1 C_t + b_2 PP_t^e + b_3 FW_t + b_4 PR_t$
$$+ b_5 PA_t + U_t$$

where U_t is the error term. Equation (1.26) is a simple static demand model representing Model A.

Model B

Model B is a stock adjustment model based on the assumption that farmers slowly adjust stocks to the equilibrium level because of psychological, institutional, and other reasons. Using Nerlove's distributed lag model that assumes that the greatest adjustment towards equilibrium is made in the early years, the actual adjustment of stock from the previous to the present year is some constant fraction, g, needed to bring the stock to equilibrium level at the end of the current year:

1.27) $\quad SM_t - SM_{t-1} = g\ (SM_t^* - SM_{t-1})\ ,\qquad 0 < g < 1$

or

1.28) $\quad SM_t = g\ SM_t^* + (1 - g)\ SM_{t-1}$

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Since the equilibrium stock is a function of the implicit rental rate, expected product price, and the prices of substitutes and complements, we can substitute equation (1.26) into equation (1.28) to get model B:

$$1.29) \quad SM_t = b_0g + b_1gC_t + b_2gPP_t^e + b_3gFW_t + b_4gPR_t$$
$$+ b_5gPA_t + (1 - g) SM_{t-1} + gU_t$$

This is a linear adjustment model where the adjustment coefficient, g, is a constant fraction of the disequilibrium eliminated. The coefficients b_ig are the short-run coefficients. The long-run coefficients are obtained by dividing b_ig by g.

In those models where the equations are estimated in logarithmic form, the dynamic adjustment process can be postulated as the percentage annual change in machinery stock as a fraction of the percentage difference between equilibrium stock in year t and actual stock in year t-1 (Cowling et. al.):

$$1.30) \quad SM_t / SM_{t-1} = (SM_t^*/ SM_{t-1})^g$$

Taking the logarithm of both sides and rearranging terms, we get:

$$1.31) \quad logSM_t = g \log SM_t^* + (1 - g) \log SM{t-1}$$

By substituting equation (1.25) into (1.31), we get the percentage adjustment model B:

$$1.32) \quad \log SM_t = b_0g + b_1g \log C_t + . . . + b_kg \log PA_t$$
$$+ (1 - g) \log SM_{t-1} + gU_t$$

Now the adjustment coefficient, g, is a fraction of the percentage difference between equilibrium stock in year t and the actual stock in year t-1. Thus, model B assumes that the greater the initial disequilibrium, the smaller will be the disequilibrium which is eliminated (Cowling, et. al.).

Model C

This model uses the price paid by farmers for farm machinery instead of the implicit rental rate. The implicit rental rate for farm machinery, i.e., the price of the flow of services from stock of machinery, C_t, depends on the market price of machinery, the depreciation rate, discount rate (interest rate adjusted for internal and external cost of financing), and tax considerations. If we assume that the implicit rental rate is proportional to the price of new machinery, we can substitute the price of new machinery (PM_t) for the implicit rental rate. Also, the market price of machinery and the other components of the implicit rental rate can be entered as separate explanatory variables. Model C is based on the first assumption and specified in logarithmic form as follows:

$$1.33) \quad \log SM_t = b_0g + b_1g \log PM_t + \ldots + b_kg \log PA_t$$
$$+ (1 - g) \log SM_{t-1} + gU_t$$

Other Models

Structural changes represented by farm numbers (N_t) and farm size (A_t), agricultural exports (RZ_t), acreage diverted from crop production (D_t), the ratio of farmer's equities to liabilities (E_t), net farm income (YN_t), and proxy for technology (TE_t) are incorporated into several of the above and other models to measure the influences of these variables.

These and several other models were estimated and those with theoretically and statistically acceptable results are reported in the next section.

2. Estimation Results

Machinery stock demand models were estimated by single equation least squares in linear and log-linear functional forms. Only selected equations are reported in Table 3. Many estimates were rejected for statistical problems such as low R^2, unstable coefficients, serial correlation, etc.

All the equations have high R^2, over .97 for each. OLS estimates of equ. (1.38) and (1.39) exhibited slight serial correlation problems and were estimated by autoregressive least squares method. However, the autocorrelation coefficients were not statistically significant and hence, OLS could have been used as well. The coefficients were generally evaluated at the 5 percent level, unless specifically mentioned otherwise. The implicit rental rate (C_t) and the real price of farm machinery

Table 3. Structural Coefficients for Demand for Stock of Farm Machinery.

Equ.	Data Period	Est. Method	Depend. Var.	C	C_t	RPM_t	DPP_{t-1}	QSM_{t-1}	E_{t-1}	YN_{t-1}	R_t	PR_t	RPR_t
1.34	1946-85	OLS,O	QSM_t	.004	-.012* (.002)		.00006* (.00003)	.799* (.048)					.00001* (.000006)
1.35	>>	>>	>>	.008	-.015* (.003)		.00004 (.00005)	.840* (.058)	.0005* (.0003)				.00003* (.00001)
1.36	>>	OLS,L	>>	-2.19	-.097* (.019)			.795* (.048)			-.011 (.046)		.070 (.048)
1.37	>>	OLS,L	>>	-5.640	-.108* (.024)			.765* (.032)	.023 (.078)				.162* (.052)
1.38	>>	AR(1),L	>>	-0.852		-.210* (.034)		.747* (.049)			-.054 (.070)	.188* (.043)	
1.39	>>	>>	>>	-.541		-.197* (.039)		.745* (.057)		.007 (.019)		.183* (.047)	
1.40	>>	OLS,L	>>	1.310		-.207* (.035)		.805* (.042)			-.071* (.034)		.133* (.033)

* - Significant at 5% level.
** - Significant at 10% level.

The numbers in parentheses are the standard errors

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Table 3. Continued.

	FW$_t$	RFW$_t$	PA$_t$	RPA$_t$	RZ$_{t-1}$	D$_t$	N$_t$	A$_t$	TE$_t$	T	AR(1)	R^2	$\bar{R}^2$	dW	h	g
1.34		.00008 (.00006)										.976	.973	2.11	-.33	.20
1.35						-.00001 (.00001)		-.00004 (.00003)				.979	.974	2.47	-1.57	.16
1.36				.313* (.149)	.009 (.030)	-.004 (.004)	-.025 (.062)					.984	.980	2.40	-1.31	.20
1.37							.291 (.196)			.362 (.373)		.979	.975	1.93	.23	.23
1.38	-.010 (.076)		-.200* (.076)			-.002** (.001)				.124 (.295)	-.016 (.013)	.98	.98	2.81	-2.65	.25
1.39			-.217* (.071)			-.001** (.001)		.111 (.241)		.128 (.365)	.020 (.013)	.985	.979	2.76	2.54	.25
1.40									.056 (.103)	.089 (.174)		.982	.978	1.98	.07	.19

(RPM_t) have negative coefficients as expected and are significant. The coefficient of C_t is lower than that of RPM_t in absolute terms because of the positive impact of investment allowance and other tax provisions incorporated into C_t.

The expected product price (DPP_{t-1}) is positive and significant in equ. (1.34) and insignificant in equ. (1.35). The adjustment coefficient, g, is about 0.20, suggesting that farmers adjust about 20 percent of the actual stock of farm machinery in the first year in response to changes in prices and other variables. The total adjustment would take over 10 years.

The lagged ratio of farmers equities to their outstanding liabilities (E_{t-1}) is positive and significant in equ. (1.35) and insignificant in (1.37). Similar results were obtained in other unreported equations. Since there is high collinearity between E_{t-1} and N_t, multi-collinearity could be the problem that rendered E_{t-1} insignificant in equ. (1.37). The net farm income (YN_{t-1}) is positive but insignificant. This agrees with the results of Cromarty (1959), but doesn't agree with those of Heady and Tweeten (1963), Olson (1979), and Gunjal and Heady (1983) who found positive and significant coefficients.

The interest rate on non-mortgage loans (R_t) is negative and significant in equ. (1.40). It is not significant in equ. (1.36) and (1.38). However, since R_t is highly collinear with PR_t, FW_t, and PA_t, there could be multicollinearity problem and hence, it is difficult to separate the effects of these variables.

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However, the negative relationship suggests that as interest rate increases, farmers demand for stock of machinery will decrease. Both the deflated and undeflated values of real estate per acre are positive and highly significant except in equ. (1.36), implying a substitute relationship between stock of machinery and farm real estate/land. The coefficient of the wage of hired labor is positive in equ. (1.34) and negative in equ. (1.38) and both are insignificant, implying that farm wages are not important determinants of stock. Similar results were obtained in several unreported models.

Of the remaining explanatory variables only the price of all other inputs (PA_t) and acreage diverted from crop production (D_t) have the expected signs, i.e., negative and are mostly significant. The coefficient of average farm size (A_t) is negative in equ. (1.35) and positive in equ. (1.39) and both are insignificant, suggesting that farm size does not have impact on the demand for stock of machinery. The time trend variable (T) has positive coefficients but is not significant. The agricultural productivity index (TE_t) is positive and insignificant. The insignificance of TE_t is not unrealistic because of the correction of the stock of machinery for quality changes which will account for most of the effects of technical change on farm machinery.

3.   Stock Demand Elasticities

Elasticities were calculated for those variables whose coefficients had the expected signs and were statistically significant in Table 3. The results are presented in Table 4. The elasticity of QSM_t with respect to C_t is between -.050 and -.108 in the short-run and between -.249 and -.473 in the long-run, calculated at the means for equ. (1.34) and (1.35). It ranges between -.191 and -.207 in the short-run and between -.944 and -1.062 in the long-run with respect to RPM_t. This implies that other things being equal, if C_t increases by 10 percent, the demand for stock of farm machinery will decline by 1/2 to 1 percent in the short-run and by about 2 1/2 percent to 4 1/2 percent in the long-run. And if RPM_t increases by 10 percent, the demand for stock would decline by about 2 percent in the short-run and by 10 percent in the long-run. Thus favorable income tax treatment of farm assets and favorable credit terms embodied in C_t have reduced the response of stock demand by 50 to 75 percent than would otherwise be.

The elasticity of stock of farm machinery with respect to the expected price for agricultural products (DPP_{t-1}) is between 0.046 and 0.068 in the short-run and between 0.288 and 0.332 in the long-run. Thus, other things being equal, a 10 percent increase in the expected product price would increase the demand for stock of farm machinery by about 1/2 percent in the short-run and by about 3 percent in the long-run. With respect to the real

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Table 4. Elasticities of Demand for Stock of Farm Machinery, 1946-85*.

Equation	Short-Run					Long-Run[1]					
	C_t	RPM_t	DPP_{t-1}	RPR_t	RPA_t	C_t	RPM_t	DPP_t	RPR_t	RPA_t	g
1.34*	-.050	--	.068	.045	--	-.249	--	.332	.220	--	.201
1.35*	-.063	--	.046	.105	--	-.394	--	.288	.656	--	.160
1.36	-.097	--	--	.070	.313	-.473	--	--	.341	1.527	.205
1.37	-.108	--	--	.162	--	-.460	--	--	.689	--	.235
1.38	--	-.210	--	--	--	--	-.830	--	--	--	.253
1.39	--	-.197	--	--	--	--	-.773	--	--	--	.255
1.40	--	-.207	--	.133	--	--	-1.062	--	.682	--	.195

* Elasticities are calculated at the mean of the observations.

(1) Long-run elasticities are obtained by dividing the short-run elasticity by the adjustment coefficient.

price of land, the stock demand elasticity is between 0.045 and 0.133 in the short-run and between .220 and .689 in the long-run. The response in the long-run is about five times that of the short-run but still inelastic.

Finally, the elasticity of QMS_t with respect to the real price of other inputs (RPA_t) is .331 in the short-run and 1.527 in the long-run. Hence, ceteris paribus, a 10 percent increase in the price of all other farm inputs would increase demand for stock of machinery by 3 percent in the short run and by 15 percent in the long-run. Thus, the stock of farm machinery has an elastic response only with respect to the real price of other inputs. The implications of these results are discussed later in this section.

C. Gross Investment in Farm Machinery

1. Estimation Models

Model E

Farm machinery are durable goods and because of this, one purchases current and future services from these machines. As a result of this, the demand for gross investment follows a dynamic process involving current and past stocks. Let's define net investment or change in stock ($SM_t - SM_{t-1}$) as the expenditure to expand existing stock and gross investment (G_t) as equal to net investment plus replacement investment (D_t) where

replacement investment is the expenditure required to restore

losses in productive capacity of the existing capital stock:

1.41) $G_t = SM_t - SM_{t-1} + D_t$

Assuming D_t is directly proportional to the stock of capital

at the end of the previous period, i.e.,

1.42) $D_t = dSM_{t-1}$

where d_t is the depreciation rate, then an investment demand

function can be obtained by substituting equ. (1.24), (1.27), and

(1.42) into equ. (1.41) to form model E:

1.43) $G_t = A_og + A_1gC_t + A_2gDPP_t^e + \ldots + (d-g)SM_{t-1} + gU_t$

or

1.44) $G_t = b_0 + b_1C_t + b_2DPP_t^e + \ldots + b_kSM_{t-1} + V_t$

The b_i's in equ. (1.44) are the structural coefficients and

b_k or $(d-g)$ is the measure of net machinery stock adjustment

speed. The impact of SM_{t-1} on G_t, i.e., b_k can be positive or

negative depending on whether d or g is larger. Because the

impact of lagged stock on net investment is negative while its

impact on replacement demand is positive. Therefore, the actual

sign of b_k is indeterminate, a priori (Griliches, 1960).

However, b_k needs to be negative in order to reach the desired

stock levels in a finite time period (Gunjal & Heady).

It is not possible to determine the long-run coefficient, A_i,

directly from equ. (1.43) because the values of d and g are not

known. In this case Heady and Tweeten have suggested to use the g from equ. (1.48) below to determine the long run coefficient. They also suggest that a previous estimate of the rate of depreciation, d, can be used to approximate (d-g).

Model F

Model F is an adjustment model developed by Nerlove (1958) and is based on the assumption that farmers are subjectively certain of current decision variables but slowly adjust due to psychological, institutional, technological, and other reasons. For many inputs, rapid adjustment is made towards equilibrium level of purchases in the early years and adjustment rate becomes small as equilibrium is approached. In this model, the actual adjustment in purchases in year t is a constant proportion, g, of the difference between desired or equilibrium level of purchases in the current year, G^*_t, and the actual purchases during the past year (Heady and Tweeten, 1963):

1.45) $G_t - G_{t-1} = g (G_t^* - G_{t-1})$

or

1.46) $G_t = gG_t^* + (1-g) G_{t-1}$

If we assume the equilibrium rate is a function of the implicit rental rate, the product price, expected net farm income, farm wages (FW_t), and a time trend variable, we can define the equilibrium level of demand as follows:

1.47) $\quad G_t^* = b_0 + b_1 C_t + b_2 PP_t + b_3 YN_{t-1} + b_4 FW_t + b_5 T + U_t$

Then by substituting the right hand side of equ. (1.47) into equ. (1.46) for G^*, we get model F:

1.48) $\quad G_t = b_0 g + b_1 g C_t + b_2 g PP_t + b_3 g YN_{t-1} + b_4 g FW_t$
$$+ b_5 g T + (1-g) G_{t-1} + g U_t$$

The $b_i g$ are short-run coefficients and by dividing by g we get the long-run coefficients. Because the error structure is not so complicated, model F can be satisfactorily calculated by OLS.

Model G

This is an adjustment model based on Griliches' (1960) proposal which rests on the importance of machinery as an input in the production process. The equilibrium machinery input is identified as the stock of machinery and hence, the actual adjustment in machinery inventory in the current year is some proportion, g, of the equilibrium or desired change in inventories or stocks:

1.49) $\quad SM_{t+1} - SM_t = g(SM_{t+1}^* - SM_t)$

where SM_t is the stock of machinery on January 1 of year t and SM_{t+1}^* is the desired or equilibrium stock on January 1 of year t+1. Assuming depreciation, d, is a constant proportion of the

beginning year stock, the end of year stock equals investment
plus undepreciated carryover from last year:

1.50) $SM_{t+1} = G_t + (1-d)SM_t$

Rewriting identity (equ 1.50) we get:

1.51) $G_t = (SM_{t+1} - SM_t) + dSM_t$

Assuming the desired level of stock is a function of the
same variables as G_t in equ. (1.47), we get:

1.52) $SM^*_{t+1} = b_0 + b_1C_t + b_2PP_t + b_3YN_{t-1} + b_4FW_t$
$$+ b_5T + U_t$$

By substituting equ. (1.52) into (1.49) and the resulting
expression into equ. (1.46), the investment model G is formed:

1.53) $G_t = b_0g + b_1gC_t + b_2gPP_t + b_3gYN_{t-1} + b_4gFW_t$
$$+ b_5gT + (d-g)SM_t + gU_t$$

Again as in model E, g is approximated by the value
obtained in equ. (1.48).

Several other models explaining different investment
behavior can be formulated to approximate farmers' decision
processes. As would be seen in the next section, most of the
above models were modified in the process of calculation in order
to get satisfactory statistical results.

2. Estimation Results

Table 5 presents the structural coefficients for the demand for gross investment in farm machinery. Equ. (1.55), (1.57), (1.58) and (1.60) were estimated in linear and the rest in log-linear forms. Equ. (1.54) to (1.56) represent Model F, equ. (1.57) to (1.59) represent Model E, and equ. (1.60) represents Model G. Several other variants of these models were also estimated, but most were not reported because of serious statistical problems. The total variance in total farm machinery demand explained by the explanatory variables (R^2) ranges from 85 to 92 percent. No serious autocorrelation was encountered as evidenced by the Durbin-Watson and Durbin-h statistics. Hence, all equations were estimated by ordinary least squares.

The coefficients of implicit rental rate of farm machinery (C_t) are negative and highly significant. The coefficients of the real price of farm machinery (RPM_t) are also negative and highly significant. These results indicate that as the rental rate or the real price of farm machinery increase, farmers purchase less farm machinery, i.e., a negatively sloping demand curve. The price of agricultural products (DPP_t) has positive impact on total farm machinery demand, but the coefficient is statistically insignificant (equ. 1.54). The coefficients associated with the lagged and current stock of farm machinery, i.e., DSM_{t-1} and DSM_t respectively, are the differences between the depreciation rate (d) and the adjustment coefficient (g).

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Table 5. Structural Coefficients for Gross Investment in Farm Machinery.

Equ.	Data Period	Est. Method	Depend. Var.	c	C_t	RPM_t	DPP_t	QG_{t-1}	DSM_{t-1}	DSM_t	RYN_{t-1}	E_{t-1}	R_t
1.54	1946-85	OLS,L	QG_t	-6.16	-.37* (.08)		.38 (.34)	.40 (.70)			-.11 (.07)		
1.55	>>	OLS,O	>>	-5.32		-.69* (.16)		.31* (.09)				.16 (.11)	-.41* (.20)
1.56	>>	OLS,L	>>	8.98	-.36* (.08)			.40* (.08)					
1.57	>>	OLS,O	>>	-24.29	-13.88* (1.68)				.09 (.08)			.25* (.11)	
1.58	>>	OLS,O	>>	-15.89	-13.36* (1.86)				-.06 (.05)		-.03 (.05)	.19* (.09)	
1.59	>>	OLS,L	>>	-5.38		-.76* (.24)			.09 (.17)		.06 (.09)		.76* (.15)
1.60	>>	OLS,O	>>	-15.90	-12.94* (2.12)					-.03 (.06)	-.02 (.05)	.17** (.09)	

* = significant at the 5% level.
** = significant at the 10% level.
The numbers in parentheses are the standard errors.

Table 5. Continued.

	RPR_t	RFW_t	RPA_t	RZ_{t-1}	D_t	N_t	A_t	TE_t	T	R^2	$\bar{R}^2$	dW	h	g
1.54	.24** (.14)	.35 (.32)	1.14 (1.01)						-.34 (.55)	.94	.92	2.13	.46	.60
1.55			.28* (.11)	.0003* (.0001)	.003 (.01)			.01 (.03)		.90	.87	1.79	.81	.69
1.56	.21 (.16)		2.02* (.61)	-.002 (.11)		-1.10 (1.08)	-.10 (.99)		-1.86 (1.22)	.93	.92	2.28	-1.03	.60
1.57			.52* (.10)	-.003 (.07)		.001 (.0007)				.88	.86	1.64		
1.58			.57* (.10)	.0002* (.0001)				.04 (.03)		.88	.86	1.74		
1.59	.76* (.15)		1.48* (.77)						.10 (.60)	.90	.88	1.33		
1.60			.56* (.11)	.0002* (.0001)				.04 (.03)		.88	.85	1.70		

However, it is not possible to determine the values of d and g from the coefficients and they need to be estimated indirectly from other estimates as discussed earlier. In equ. (1.58) and (1.60) the variables have negative sign and are not significant, suggesting that the desired stock will be reached in a finite time interval. However, it is positive and insignificant in equ. (1.57) and (1.59). Since the coefficients are insignificant, i.e., not statistically different from zero, d and g are almost equal in size. These results are similar to the findings of Heady and Tweeten (1963), Olson (1979), and Gunjal and Heady (1983).

The lagged net farm income (RYN_{t-1}) has an unexpected negative sign in three out of four equations and is insignificant in all the equations. Hence, the lagged net farm income is not an important determinant of gross investment. The lagged ratio of farmers' equities to their outstanding liabilities (E_{t-1}) is positive as expected and two of the coefficients are statistically significant at the 5 percent level and one at the 10 percent level.

Because of the inclusion of the cost of internal and external financing in the calculation of the implicit rental rate of farm machinery, interest rate (R_t) was not used as a separate explanatory variable in those equations where the implicit rental rate was used as the price for services of farm machinery. However, in equ. (1.55) and (1.59) where the index of price of

farm machinery was used, interest rate appears as a separate explanatory variable. In both equations, R_t has the expected negative sign and is highly significant, indicating that as interest rates increase, farmers decrease the purchase of farm machinery.

The value (price) of farm real estate (RPR_t) has a strong positive impact on machinery purchases as indicated by the positive and highly significant coefficients. As the price of farm real estate goes up, not only do farmers substitute machinery for land, they will also have increased asset value that will increase their ability to borrow more to finance additional machinery purchases. The real wage paid for hired labor (RFW_t) is positive, indicating a substitute relationship, but the coefficient is not significant.

The real price paid for all other farm inputs (RPA_t) is a major determinant of machinery purchases. RPA_t is positive in all equations and the coefficients are significant except in equ. (1.54). Thus as the price of all other inputs goes up, farmers will substitute farm machinery for all other inputs.

The lagged real value of agricultural exports (RZ_{t-1}) positively influences the demand for purchases of farm machinery. RZ_{t-1} is positive and significant except in equ. (1.56). On the other hand, acreage diverted from crop production under various government farm programs (D_t) is positive in equ. (1.55) and negative in equ. (1.57). The coefficients are statistically

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insignificant, implying that acreage diverted has almost no influence on machinery purchases. A possible explanation for this result is that acreage diversion is announced for each crop year and farmers may not invest in machinery based on a decision variable which they cannot make a good expectation about.

The number of farms (N_t) and average farm size (A_t) representing changes in farm structures, appear in equ. (1.56) and (1.57). The number of farms is negative and insignificant in equ. (1.56) and positive and significant at the 10 percent level in equ. (1.57). Farm size is negative and insignificant, indicating that farm size doesn't increase the efficiency of farm machinery. Heady and Tweeten (1963) and Olson (1979) also obtained a negative and insignificant coefficient for A_t. However, since farm number and farm size are inversely related, a decisively positive coefficient should have been obtained for N_t.

The agricultural productivity index (TE_t), i.e., the output-input ratio, used as a proxy for part of technical change not accounted for by adjusting machinery for qualitative changes, is positive in equ. (1.55) and (1.58) and negative in equ. (1.60) and all are insignificant. This shows that most technological change in farm machinery is in the form of qualitative change and hence, the additional explanatory variable is not required to represent technical change. The time trend variable (T) represents slow changing variables such as diffusion of knowledge about acceptance of machinery use, other aspects of technology

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not accounted for by adjustment for quality changes (since TE_t and T do not appear in the same equation), etc. not accounted for elsewhere. It has a negative sign in equ. (1.54) and (1.56) and a positive sign in equ. (1.59) and all are statistically insignificant. The insignificance of the time trend variable agrees with the results of Griliches (1960) and Olson (1979) but the sign is different. On the basis of statistical significance and economic soundness, equ. 1.55 is the best model.

3. Elasticities of Gross Investment

The elasticities of gross investment with respect to major explanatory variables are presented in Table 6. The elasticities were calculated at mean of the observations for models estimated in linear form. For those models estimated in logarithmic form, the short-run elasticities are directly the coefficients of the variables and were directly taken from Table 5. The long-run elasticities in equ. (1.54), (1.55), and (1.51) were calculated by dividing the short-run elasticities by their respective adjustment coefficients. The remaining long-run elasticities were similarly calculated by using the adjustment coefficient obtained from equ. (1.54) for reasons explained earlier.

The elasticity of annual machinery purchases with respect to the implicit rental rate of farm machinery is between -0.32 and -.39 in the short-run and between -0.53 and -0.65 in the

Table 6. Elasticities of Demand for Gross Investment in Farm Machinery With Respect to Important Variables.

Equation	Short-Run							Long-Run*							
	C_t	RPM_t	E_{t-1}	R_t	RPR_t	RPA_t	RZ_{t-1}	C_t	RPM_t	E_{t-1}	R_t	RPR_t	RPA_t	RZ_{t-1}	g^*
1.54	-.37				.24	1.14		-.62				0.40	1.90		.60
1.55		-.65	.28	-.32		1.59	.25		-.94	.41	-.46		2.30	.36	.69
1.56	-.36				.21	2.02	-.002	-.60				0.35	3.37	-.003	.60
1.57	-.34		.44			2.95		-.57		.73			4.92		.60
1.58	-.39		.34			3.23	.17	-.65		.57			5.38	.28	.60
1.59		-.76		-.76	.76	1.48			-1.27		-1.27	1.27	2.47		.60
1.60	-.32		.30			3.18	.17	-.53		.50			5.30	.28	.60

* Based on 1-g = 0.40 from equations 1.54 and 1.56 as discussed in conjunction with Model E.

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long-run. Thus, gross investment is inelastic with respect to the implicit rental rate in the short-run, with a 10 percent increase in the rental rate leading to only about 3 1/2 percent decrease in gross investment. It is also inelastic in the long-run with 10 percent increase in the implicit rental rate leading to about 6 percent decrease in purchases, double that of the short-run. The short-run investment elasticity with respect to the real price of farm machinery (the price of machinery deflated by the price received for agricultural products) is between -.65 and -.76, which is close to the ranges of -0.71 and -1.50 obtained by Heady and Tweeten (1963) using 1926-59 data (excluding 1942-47) and -.29 to -1.00 obtained by Olson (1979) using 1945-77 data. The long-run elasticity with respect to the real price of machinery is between -0.94 and -1.27 which is about unit elasticity. Gross investment is less inelastic with respect to the real price of machinery than to the implicit rental rate because of the absence of the dampening effect of taxes in the former.

The elasticity of machinery purchases with respect to non-mortgage interest rate is between -.32 and -.76 in the short-run and between -.46 and -1.27 in the long-run. This indicates that an increase in non-mortgage interest rate by 10 percent will decrease machinery purchases by about 3 to 8 percent in the short-run and by about 5 to 13 percent in the long-run. Thus, in the long-run interest rate has almost as much influence on

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machinery purchases as changes in the real prices of farm machinery.

Gross investment elasticity with respect to farm land (real estate) values is between 0.21 and 0.76 in the short-run and between 0.36 and 1.27 in the long-run. With respect to real price paid for all other farm inputs, it is between 1.14 and 3.23 in the short-run and between 1.90 and 5.38 in the long-run. Thus, the demand for gross investment with respect to price of all other inputs is quite elastic, both in the short and long-run. Thus a 10 percent increase in the price of all other inputs will increase purchases of farm machinery by about 11 to 32 percent in the short-run and by about 19 to 54 percent in the long-run.

The lagged ratio of farmers equities to their outstanding liabilities is positively associated with the demand for total farm machinery. A 10 percent increase in E_{t-1} will lead to about 3 to 4 percent increase in the purchase of farm machinery in the short-run and by about 4 to 7 percent in the long-run.

Finally, the responsiveness of machinery purchases with respect to value of agricultural exports is comparatively impressive. If the result of equ. (1.56) is ignored due to a wrong sign and insignificant coefficient, the elasticity becomes between .17 and 0.25 in the short-run and between 0.28 and 0.36 in the long-run. Thus, a 10 percent increase in agricultural

exports will increase machinery purchases by about 2 percent in
the short-run and by over 3 percent in the long-run.

V. Summary and Conclusions

The estimation results in Table 3 show that the stock of
farm machinery is determined by the implicit rental rate or the
real price of machinery, the real price of land/real estate, and
the real price of other inputs. The results are inconclusive for
the price received for agricultural products, the debt-equity
ratio, interest rate, and acreage diverted from crop production.
The lagged net farm income, the wage of hired labor, agricultural
exports, average farm size, farm numbers, the index of technical
change, and the time trend variable were statistically
insignificant. Thus, the emerging forces have either
inconclusive results or are not important in determining the
demand for stocks. The lagged stock of machinery was the single
most important determinant of stock demand in all the estimates.

The short-run elasticity of stock with respect to the
implicit rental rate is between -.050 and -.108, which is quite
low. The long-run elasticity with respect to the same variable
is between -.249 and -.473 which is also low. The short-run real
price elasticity is between -.197 and -.210, almost four times
that of the implicit rental rate. This is close to the price
elasticity of .25 estimated by Griliches (1960) for tractors. It
should be noted that the favorable income tax treatment of
machinery, embodied in the implicit rental rate, insulates the
stock from responding to changes in prices. The long-run price
elasticity is between -.773 and -1.062 and the adjustment

coefficient is about .20, suggesting that total adjustment will take a long time.

The demand for gross investment is not sluggish like that for stocks and responds to several explanatory variables because it varies more than stock and hence, there is more to explain. Gross investment is determined by the implicit rental rate or the real price of machinery, the debt-equity ratio, the real price of land/real estate, the real price of other inputs, interest rate, and the lagged real agricultural exports. The real price received for agricultural products, lagged and current stocks, acreage diverted from crop production, farm numbers, average farm size, the index of technical change, and a time trend variable were not statistically significant. The insignificance of the index of technical change seems to be due to the correction of machinery for quality improvements.

The short-run investment elasticity is between -.32 and -.39 with respect to the implicit rental rate and between -.65 and -.76 with respect to the real price of machinery. The long-run elasticity is between -.53 and -.65 with respect to the implicit rental rate and between -.94 and -1.27 with respect to the real price of machinery. Again, the effects of favorable tax treatment on gross investment are quite evident from the differences in the elasticities of the implicit rental and the real price of machinery.

These results show that the stock of machinery responds only to few variables and its response is much smaller than that of gross investment. On the other hand, gross investment responds to more variables including some of the emerging forces.

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We developed a formula for implicit rental rates from the equality between the purchase price of the asset and the present value of the future rents generated by the asset (4). Assuming constant new asset price expectations and allowing for alternative depreciation patterns, the basic relationship is:

$$q_i = \int_0^{L_i} e^{-rt} u_i n_i(t) dt \qquad i = 1, 2, \ldots, m, \qquad (28)$$

where q_i is the purchase price of the ith asset when new, L_i is the service life, u_i is the rental rate expressed in terms of an undepreciated unit of capital, $n_i(t)$ is the capacity of the asset available in year t of its service life, and r is the discount rate.

Equation (28) ignores all tax considerations. When capital income is subject to an income tax, the term on the right side of equation (28) is modified to include the effects of the tax. The modified term includes the present value of the rents generated by the asset, and the present value of the tax savings produced by the investment tax credit and the tax depreciation deductions. Assuming the firm's marginal tax rate remains constant at T, equation (28) respecified to accommodate the tax system becomes:

$$q_i = (1 - T)u_i N_i + \theta_i q_i + T(1 - h\theta_i)Z_i q_i \qquad i = 1, 2, \ldots, m, \quad (29)$$

where $(1 - T)u_i N_i$ is the present value of the future rents, $\theta_i q_i$ is the present value of the investment tax credit, and $T(1 - h\theta_i)Z_i q_i$ is the present value of the future tax depreciation deductions.

If price expectations and the marginal tax rate are constant, the rental rate remains constant over the life of the asset. The productive capacity of the asset, however, declines over the life of the asset so that:

$$N_i = \int_0^{L_i} e^{-rt} n_i(t) dt \qquad i = 1, 2, \ldots, m, \qquad (30)$$

where r is the discount rate, the real after-tax of return required by the firm.

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*Directly adopted from Conway, et. al. (1985)

Although the firm pay taxes on the rents generated by each asset, the firm can deduct the decline in the value of the asset as an expense. If the present value of the depreciation deductions claimed for tax purposes is equal to the true decline in capacity for each asset, the tax system does not distort the asset mix.

If $z_i(t)$ is the fraction of the price of the ith asset deducted from income in year t of the assets tax life (M_i), the present value of the tax depreciation is TZ_iq_i, where:

$$Z_i = \int_0^{M_i} e^{-(r+p)}z_i(t)\ dt \qquad i = 1,2,\ldots,m, \qquad (31)$$

and p is the rate of inflation. However, in years when the tax depreciation base declined by the amount of the investment tax credit, the real value of the tax depreciation deduction is $T(1 - h\theta_i)Z_iq_i$, where h is the percentage of the credit which reduces the depreciation base.

In addition to the depreciation deductions, firms may also be eligible to claim an investment tax credit. If firms claim the credit at the end of the first year of the asset's service life, the present value of the credit is θ_iq_i, where:

$$\theta_i = e^{-(r+p)}\theta_i \qquad i = 1,2,\ldots,m. \qquad (32)$$

A more realistic rendering of the discount rate shows it as a weighted average of the longrun real after-tax interest rate (external financing) and the longrun real after-tax return to equity (internal financing). Because nominal interest charges are deductible from taxable income, the real cost of external or debt financing (r_d) is:

$$r_d = [r_n(1-T) - p]/(1 + p), \qquad (33)$$

where r_n is the nominal interest rate. After combining the real costs of both equity and debt financing, the real cost of the capital or real after-tax discount rate is:

$$r = fr_d + (1 - f)r_e, \qquad (34)$$

where f is the fraction debt financed, r_d is the real after-tax cost of debt financing, and r_e is the real after-tax return to equity (26).

Given the market price of the asset, equation (27) is rewritten as:

$$u_i = q_i[1 - \theta_i - T(1 - h\theta_i)Z_i]/N_i(1 - T) \qquad i = 1,2,\ldots,m, \quad (35)$$

which is the real rental rate the firm must charge to earn the required real after-tax rate of return.