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The Effects of Interest Rates on Agricultural Machinery Investment

By Michael LeBlanc and James Hrubovcak*

Abstract

Changes in real interest rates may affect the rate of adjustment of machinery to optimal levels. This finding results from the development and application of a theoretically consistent analytical framework for examining agricultural investment in machinery. Results from duality theory on restricted variable profit functions are incorporated into a longrun dynamic optimization framework where input use is affected by external adjustment costs.

Keywords

Agricultural investment, adjustment costs, user cost of capital

Introduction

Interest in the relationship between the agricultural sector and the macroeconomy was first stimulated by the large increases in agricultural prices in 1973 identified as an important cause of general price inflation. The effects of the macroeconomy on agriculture have grown in importance as agriculture has become more "internationalized" and has received major shocks from abroad (32).¹ In addition, the most recent economic recession provides ample evidence of the importance of monetary factors and aggregate demand on secular income growth in agriculture.²

This analysis identifies and measures the effects of interest rates on agricultural machinery investment. The pivotal role of farm machinery in transforming U.S. agriculture is well known.³ Less well known, however, is how the mix of monetary and fiscal policy affects agriculture through its effect on interest rates. Identifying the relationship between the interest rate and agricultural investment takes

on added significance in light of prospects for a continued policy of tight money supply and high real interest rates.

We examine the effects of interest rates by placing the agricultural investment decision in a framework where the optimal levels of all variable and quasi-fixed inputs are determined simultaneously. Results from duality theory on restricted variable profit functions are incorporated into a dynamic optimization framework where input use is affected by external adjustment costs (8, 22, 41). Although many other approaches are possible (such as cash flow, standard neoclassical, and securities value), we use this approach because of its comparatively well-developed theoretical foundations. This "third generation" dynamic framework generates investment functions which can be approximated by a flexible accelerator structure.⁴ The speed of adjustment of quasi-fixed factors to optimal levels is endogenous and, therefore, varies through time. Short-run demand functions for variable inputs depend on input and output prices and the stocks of quasi-fixed factors and reflect the interdependence of input use.

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¹Italicized numbers in parentheses refer to items in the References at the end of this article.

²Real net cash income decreased from \$36.6 billion in 1979 to \$30.1 billion in 1983. Projections for 1984 suggest little change from 1983 (37).

³Agricultural demand for durable inputs has been studied by Griliches (12), Lamm (21), and Penson, Romain, and Hughes (29).

⁴Berndt, Morrison, and Watkins (5) categorize dynamic models as belonging to either the first generation (single-equation models using a Koyck partial adjustment framework (17)), second generation (allowing input interaction, but only a limited theoretical basis for the adjustment process), or third generation (explicitly incorporating dynamic optimization).

The attractiveness of the dynamic model used in this analysis is that it is consistent with the profit maximization hypothesis. Changes in the time discount or interest rate directly affect both the optimal level of capital stock and the rate of investment. The interest rate indirectly affects the use of variable inputs by altering the level of quasi-fixed inputs.

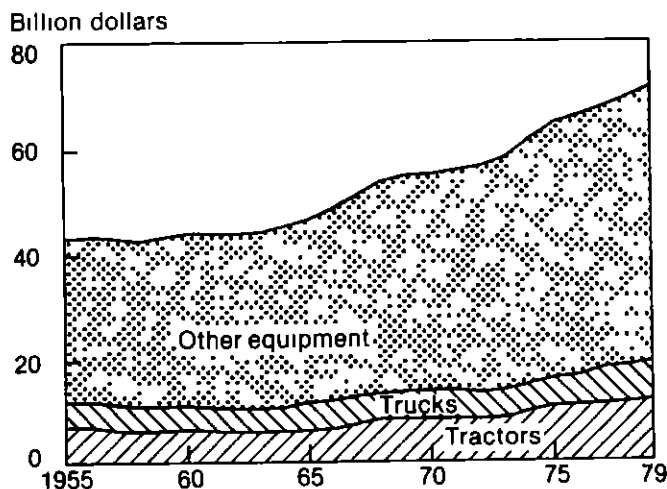
Input Use and Investment

During the last 25 years, there has been a large shift away from the use of labor and toward the use of machinery and chemicals in agriculture. The relative capital intensiveness of agriculture is evident when one compares the farm sector to the total economy. In 1979, for example, the agricultural sector used approximately twice as much physical capital per worker and three times as much physical capital per unit of production as did the economy as a whole (7).

After peaking in 1955, the real value of the total capital stock in agriculture (land, buildings, and machinery) has remained fairly constant, ranging from a high of \$572 billion in 1955 to a low of \$528 billion in 1978. Farm machinery, however, has increased dramatically since 1955 (fig. 1). The constant dollar quantity indices for tractors, trucks, and other farm machinery have increased from \$8, \$5, and \$30 billion, respectively, in 1955 to \$12, \$7, and \$53 billion, respectively, in 1979.

Figure 1

Agricultural Machinery



The shift to a more capital-intensive agriculture sector has also had a significant effect on the use of variable inputs. While the quantity of labor has declined by approximately 3.4 percent per year since 1955, there has been a dramatic increase in the use of manufactured inputs such as fertilizers and pesticides. The use of farm chemicals has increased by about 6.6 percent per year from 1955 to 1979.

Much of this shift away from labor and toward capital and chemicals is attributable to changes in relative input and output prices. During the fifties and sixties, farmers were able to reduce costs by expanding farm size and adopting farm machinery with lower cost per unit of output rather than using higher cost labor.

Nonfarm demand for farm labor also increased farm wage rates relative to other input prices. Nominal farm labor prices increased by approximately 4 percent per year from 1955 to 1970, while machinery prices increased by only 2.9 percent per year. The nominal price of agricultural chemicals actually declined from 1955 to 1972.

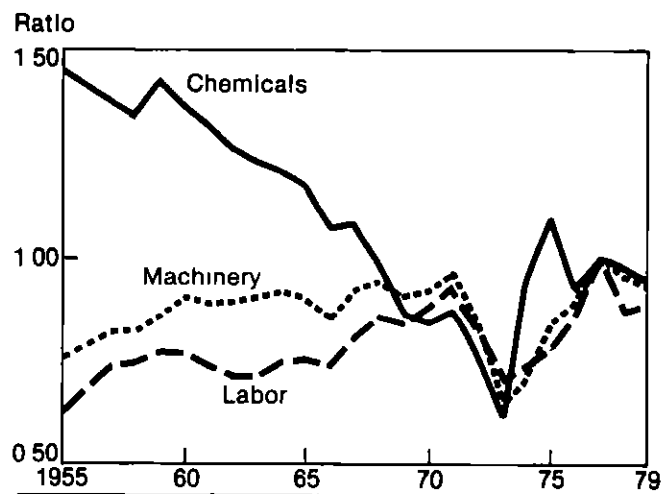
The ratio of chemical to output price fell dramatically from 1955 to 1973, whereas the ratios of both labor prices and machinery prices to output price rose slightly from 1955 to 1971 (fig. 2). The decrease in the ratio of chemical to output price increased demand for agricultural chemicals and increased the demand for complementary inputs. The increased demand for chemicals also decreased the demand for inputs (such as labor) which are substitutes for chemicals.

Stable output prices, in combination with Federal commodity programs which established minimum prices for many commodities, created an environment where farmers were encouraged to commit resources for a longer period by purchasing capital inputs.⁵ The increased demand and the resulting increase in output prices resulting from exports during the seventies also stimulated the demand for capital inputs.

⁵Just points out that the uncertainty associated with changes which may take place in Government programs may affect investment decisions and lead to allocative inefficiencies (16). However, it can be argued that the establishment of many Government programs has led to more overall price stability in the sector.

Figure 2

Input/Output Price Ratio



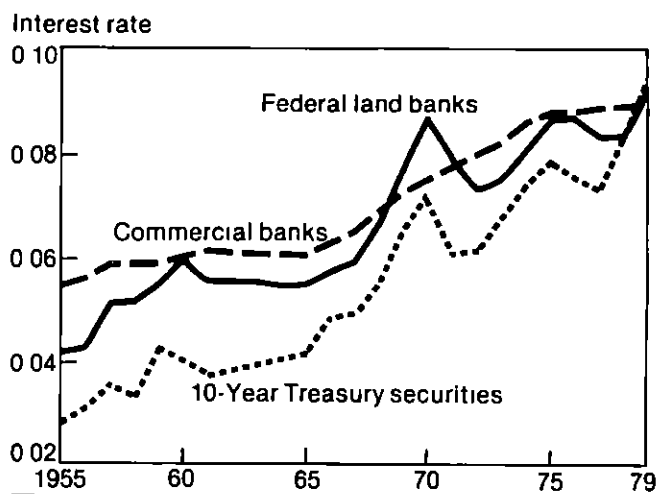
The increased demand for farm capital has stimulated the demand for credit. Total real farm debt (1972 dollars), excluding farm households and Commodity Credit Corporation loans, increased from \$21 billion in 1955 to \$72 billion in 1979 (37). The interest rates that agricultural borrowers pay are closely related to interest rates in the general economy because loanable funds are obtained from the same sources (fig. 3). The Farm Credit System (FCS), comprised of Federal Land Banks (FLB's), Production Credit Associations (PCA's), and Federal Intermediate Credit Banks (FICB's), held \$37 billion of nominal farm debt in 1979. FCS obtains loanable funds through the sale of securities in U.S. financial markets. Like any other banking organization, FCS typically boosts interest rates in the presence of tight monetary policies or increases in the nonfarm demand for funds. However, because FCS banks use average cost pricing (rates based on the average interest rate on all their outstanding bonds) rather than the more typical marginal cost pricing, interest rates on new loans tend to lag behind those of other lenders when interest rates rise.

Theoretical Model

During the sixties and early seventies, economists attempted to derive aggregate dynamic relationships

Figure 3

Nominal Interest Rates



from rational optimizing behavior.⁶ In these analyses, the neoclassical view of frictionless market response was replaced by one where information is costly and irreversibilities exist. This framework was used to examine search behavior (1, 33), transaction costs (3, 31), and the formation of expectations (6, 24). Although Barro (3) and Rothschild (31) examined adjustment behavior, their focus only on transaction costs led to results where firms adjust fully once a threshold is exceeded. Such an adjustment process, applied without other considerations, contradicted most empirical observations which suggest a gradual adjustment process.

Because the accelerator model has proved a valuable econometric tool, economists have sought a theoretical framework for the partial adjustment or accelerator model since Nerlove's early applied work (25, 27). Many economists recognized this gap in economic theory where an elaborate theoretical structure, which existed for determining the level of an input, was combined with an *ad hoc* theory of adjustment. Eisner and Strotz developed a more

⁶Examples of these early attempts include the work of Eisner and Strotz (8) on the determinants of business investment completed under the auspices of the Commission on Money and Credit and a compendium of articles published in *Microeconomic Foundations of Employment and Inflation Theory* (30).

rigorous theory of adjustment by casting the firm in a dynamic optimization framework (18) The present value or net worth maximized by the firm depends on the optimal level of inputs selected by the firm and on the adjustment of the current capital stock to the optimal level

More recently, Lucas (22), Gould (11), and Treadway (36) have extended the work of Eisner and Strotz Although the models differ in their complexity, all have the same underlying structure postulated by Eisner and Strotz Each specifies an objective function incorporating factor adjustment costs and a production function. The firm is assumed to maximize net worth over a given time period Adjustment costs are interpreted either as foregone profits due to shortrun rising supply prices in the capital-supplying industry or as increasing costs associated with integrating new equipment into production (reorganizing production and training workers) These costs vary with the speed of capital adjustments The models also assume that the values of the expected input and output prices do not change This static or stationary expectations assumption is required if the dynamic optimization problem is to be well defined (28) ⁷ Because expectations are static, the firm adjusts to a fixed target considered to be the longrun equilibrium of neo-classical theory Given these assumptions, a firm maximizing its present value changes capital stock in a manner similar to that suggested by the accelerator model

Following Berndt, Fuss, and Waverman (4) and Berndt, Morrison, and Watkins (5), we can derive the optimal adjustment paths for the quasi-fixed inputs by incorporating a shortrun restricted profit function into a longrun dynamic optimization framework The assumptions of competitive input and output markets are maintained In addition, the model assumes that these competitive real prices are known with certainty and remain stationary over time ⁸

⁷This assumption could probably be relaxed if an alternative approach to the formation of expectations were allowed For a comparison of a subjective Bayesian concept of rational expectations, see Swamy, Barth, and Tinsley (34)

⁸Nerlove (28) discusses how expectations can be incorporated into an adjustment cost model, however, his approach is empirically intractable

In the usual Marshallian framework, the relative fixity of inputs slows the adjustment to a new equilibrium position Immediate adjustment is prevented because certain inputs cannot be changed until a given period of time has elapsed after the original decision to alter the inputs is made If uncertainty is excluded, then the reason for slower rather than faster adjustment is that it costs the firm more to adjust production more rapidly Following Eisner and Strotz, production factors are characterized as being more or less fixed as a function of the cost of varying the input sooner rather than later (8) We assumed that quasi-fixed inputs can be varied at a cost $C(\dot{K})$ where \dot{K} equals dK/dt That is:

$$\dot{K} = I - \delta K \quad (1)$$

where I is the gross addition to the stock of the quasi-fixed factor and δ is the rate of exponential depreciation The normalized cost of adjustment is defined as

$$C(\dot{K}) = qI + qD(\dot{K}) \quad (2)$$

where q is the purchase price of the asset divided by output price, $D(\dot{K})$ is a twice-differentiable function, and $D''(\dot{K}) > 0$ Adjustment costs at the initial time $t = 0$ are

$$C(0) = q\delta K \quad (3)$$

This formulation assures constant marginal costs of replacement with increasing marginal costs of net change Costs are expressed in units of the asset price of the quasi-fixed factors

Net receipts, $R(t)$, can, therefore, be written as.

$$R(t) = P[G(W, K) - C(\dot{K})] \quad (4)$$

where P is the unit price of output, $G(W, K)$ is the Unit-Output-Price (UOP) restricted profit function, W is a vector of normalized (output price) input prices, and K is a quasi-fixed capital input ⁹ If the

⁹The restricted profit function represents the locus of shortrun maximized profit of a firm as a function of output price, input prices, and quantities of fixed factors (19, 20) The UOP profit function, therefore, is nonincreasing and convex in W (normalized input prices) and nondecreasing in P and K (40) The quasi fixed input, K , may be vector valued and represent more than one quasi fixed input

firm requires a rate of return, r , a weighted average of the rate of return to equity and the cost of external financing, then the present value of net receipts at time $t = 0$ is:

$$V(0) = \int_0^{\infty} e^{-rt} R(t) dt \quad (5)$$

The firm's longrun dynamic problem is to choose time paths for variable inputs, $X(t)$, and the quasi-fixed input, $K(t)$ to maximize $V(0)$ given $K(0)$ and $X(t)$, $K(t) > 0$. Because G assumes shortrun optimizing behavior conditional on P , W , and K , the optimization problem facing the firm is to find, among all the possible $G(W, P)$ combinations, the time paths of $X(t)$ and $K(t)$ that maximize the present value of net receipts.

One can obtain a solution to (5) by using either the Euler equation or Pontryagin's maximum principle. If static price expectations are assumed and profits and adjustment costs are normalized on output price, then the Hamiltonian necessary for applying the maximum principle is.

$$H(X, K, \dot{K}, y, t) = e^{-rt} [G(W, K(t)) - C(\dot{K}(t))] + y\dot{K}(t) \quad (6)$$

where y is a costate variable, the dynamic equivalent of a Lagrangian multiplier of static optimization problems. Costate variables generally vary through time and are assumed to be nonzero continuous functions of time (14). Necessary conditions for the maximization of H require:

$$G'(W, K) - u - rC'(\dot{K}) + C''(\dot{K})\ddot{K} = 0 \quad (7)$$

where u is the normalized user cost of capital.

These necessary conditions are assumed sufficient to obtain a maximum. That is, the marginal profit associated with the quasi-fixed input equals its marginal cost of adjustment. Equation (7) has a stationary solution $K^*(P, W, r)$ which is obtained by setting $\dot{K} = \ddot{K} = 0$:

$$G'(X^*(K^*), K^*) - u - rC'(0) = 0 \quad (8)$$

The variable K^* is the steady-state or longrun profit-maximizing demand for the quasi-fixed factor obtained by solving equation (8).

These results are linked to the partial adjustment or flexible accelerator literature because the short-run demand for the quasi-fixed factor can be generated from equations (7) and (8) as an approximate solution in the neighborhood of $K^*(t)$ (22). The approximate solution is the linear differential system:

$$\dot{K} = B(K^*(t) - K(t)) \quad (9)$$

For a single capital input, the B matrix reduces to:

$$B = -0.5(r - [r^2 - 4H''(K^*)/C''(0)]^{0.5}) \quad (10)$$

Unlike most applications of the partial adjustment model, this derivation allows the adjustment coefficient, B , to depend on economic forces: the discount rate, the cost of adjustment, the production relationship embodied in the profit function, and the profit-maximizing behavior of the firm.¹⁰ For example, an increase in the discount rate resulting from an increase in the rate of return to equity or an increase in the cost of external financing decreases the rate of adjustment and delays the addition of new capital stock. This result is observable if equation (10) is differentiated with respect to the discount rate:

$$\partial B / \partial r = -0.5(1 - r/[r^2 - 4H''(K^*)/C''(0)]^{0.5}) \quad (11)$$

Because $H''(K^*) < 0$ is required for the uniqueness of K^* (4), $C''(0) > 0$ is true by assumption, and $0 < B < 1$ is required for stability of the adjustment process, the derivative $\partial B / \partial r < 0$. It is also apparent from equation (10) that as $C''(0)$ tends toward infinity, the adjustment coefficient tends toward zero (no adjustment) and, as $C''(0)$ tends toward zero, the adjustment coefficient tends toward 1 (complete, instantaneous adjustment).

The rate of adjustment of the i th capital good will generally depend on the difference between desired and actual stock for all capital goods. Therefore, the simplest form of the accelerator, equation (9), does not generalize easily. Lucas shows, however, that a

¹⁰See Nerlove (26) for a review of partial adjustment models and their application to agricultural problems

sufficient condition for B to be a diagonal matrix is that the stock of the i th capital good demanded is independent of the prices and stocks of other capital goods (22). This is a strong assumption, but is necessary if one is to extend this theoretical framework to multiple capital inputs while maintaining a structure that can be estimated as a closed functional form

The Empirical Model

Before the theoretical framework can be estimated, the adjustment equation must first be expressed as a difference equation, and functional forms for the profit and cost of adjustment functions must be selected. One can respecify the accelerator equation in a discrete form by first assuming that shortrun production is conditional on capital stocks at the beginning of the period. Therefore, capital stock adjustments during the period do not affect production until the following period. Second, the adjustment relationship specified in equation (9) can be replaced by.

$$K(t) - K(t-1) = B(K^*(t) - K(t-1)) \quad (12)$$

Quadratic approximations are used for both the profit function and adjustment cost function. We use a quadratic UOP profit function because its structure facilitates estimating the model without placing *a priori* restrictions on the elasticities of substitution (9). The quadratic structure generates linear input demand functions and simple expressions for demand and substitution elasticities. Furthermore, the optimal paths for capital are globally rather than locally valid because the underlying differential equations are linear (35). The UOP profit function with Hicks' neutral technological change is specified as a quadratic function of normalized variable input prices and the level of capital available at the beginning of the current period is

$$\begin{aligned} \pi = & b + aT + \sum_{i=1}^n b_i W_i + b_k K \\ & + 0.5 \left(\sum_{i=1}^n b_{ii} W_i^2 + b_{kk} K^2 \right) \\ & + 0.5 \sum_{i=1}^n \sum_{j \neq i}^n b_{ij} W_i W_j + \sum_{i=1}^n b_{ik} W_i K \end{aligned} \quad (13)$$

where b is the intercept, a is the parameter associated with the technological shift variable (T), b_i is associated with the normalized price of the i th variable input, b_k is associated with the capital stock, b_{ij} is associated with the product of the normalized prices of the i th and j th variable inputs, and b_{ik} is associated with the cross-product effects of the normalized price of the i th variable input and the capital stock.

Although there is no reason to expect that a quadratic adjustment cost function is correct in all circumstances, Gould found it to be a good approximation (11). A quadratic approximation to the cost of adjustment is:

$$C(\dot{K}) = qI + q(0.5d\dot{K}^2) \quad (14)$$

where $D(0) = 0$

All that remain for completion of the empirical model are deriving the optimal level of capital stock and describing the adjustment process where current levels of capital move toward optimal levels. It is hypothesized that adjustment costs are external to the shortrun maximization decision. One can derive the necessary conditions for optimal capital adjustment by applying equation (7). The resulting equation:

$$\begin{aligned} b_k + b_{kk} K + \sum_{i=1}^n b_{ik} W_i - u - r q d K \\ + d \dot{K} + q d \ddot{K} = 0 \end{aligned} \quad (15)$$

is a second-order differential equation where $u = q(r + \delta)$ is the normalized user cost associated with the quasi-fixed factor. One can obtain the steady state solution by setting $\dot{K} = \ddot{K} = 0$:

$$K^* = -(b_k + \sum_{i=1}^n b_{ik} W_i - u) / b_{kk} \quad (16)$$

where K^* is the optimal level of the capital stock.

The adjustment equation is therefore:

$$B = -0.5(r - [r^2 - 4b_{kk}/qd]^{0.5}) \quad (17)$$

Equations (16) and (17) are substituted into equation (12) to form:

$$K(t) - K(t-1) = -0.5(r - [r^2 - 4b_{kk}/qd]^{0.5})$$

$$(-(b_k + \sum_{i=1}^n b_{ik} W_i - u)/b_{kk} - K(t-1)) \quad (18)$$

Data

The analysis uses aggregate time series data for 1955 through 1979. A detailed description of the data is available in Ball (2). The data were aggregated by use of a discrete Tornquist approximation of a Divisia index. Ball computed Tornquist price indices first and then computed implicit quantity indices by dividing value (revenue or expenditures) by the Tornquist price index.

Ball formulated labor data to account for differences in the productivity of different types of workers and changes in quality due to education. For capital, the separation of price and quantity components of outlays is based on the correspondence between the value of an asset and the discounted value of its services (13, 15). The service price depends on the asset price, the rate of return, and the rate of replacement. The effect of income taxes on the service price of capital is not considered because of the difficulty of deriving a marginal tax rate for agriculture where a significant proportion of firms are either sole proprietorships (76 percent) or partnerships (13 percent) (38).¹¹ We separated outlays on capital into price and quantity components by combining the rate of return with the other components of the service price. The discount rate is assumed to be a weighted average of the longrun real interest rate (external financing) and the longrun real return to equity (internal financing). Weights were computed from 1969 and 1979 Farm Finance Survey data (38, 39). Interest rates for external financing were computed from rates charged by Federal Land Banks on new farm loans. The longrun rate of return to equity is based on Melichar (23) and Gertel (10).

Analysis

We estimated a flexible accelerator model of the form given by equation (18) with an appended classical error term for 1955 through 1978. Because the accelerator model is nonlinear in its parameters, we used a nonlinear maximum likelihood estimator.

Regressors include the ratio of input to output price for four classes of variable inputs (labor, chemicals, intermediate inputs, and energy), real discount rate, user cost of capital, and normalized price of machinery. The table shows the estimated value for each parameter and its associated asymptotic standard error and t-statistic. The R^2 statistic is 0.57. The estimated parameters generate a plausible model structure. Increases in the user cost of capital decrease investment. Increases in the normalized prices of labor, chemicals, and energy increase investment. Increases in the normalized price of intermediate inputs decrease investment. The model is dynamically stable in the sense that the estimated magnitude of the adjustment coefficient lies between zero and unity.

A plot reveals much greater variability in the observed data than the predicted data (fig. 4). The model predicts better in the latter half of the sample data and accurately captures the large increase in investment in 1973. The model predicts the first half of the sample less accurately than the second, although it generally predicts changes in the direction of investment.

Changes in interest rates affect investment in two ways. First, changes in the interest rate work through the user cost of capital to affect the optimal level of capital stock. Second, interest rates also affect the rate of adjustment of machinery to optimal levels.

Estimated parameters and associated statistics

| Coefficient | Value | Asymptotic standard error | Asymptotic t-statistic |
|-------------|------------|---------------------------|------------------------|
| b_k | 80,299.40 | 4,227.87 | 19.0 |
| b_{lk} | 28,166.70 | 1,178.45 | 23.9 |
| b_{ck} | 51,827.20 | 3,661.43 | 14.2 |
| b_{fk} | -48,061.40 | -9,928.38 | 4.8 |
| b_{ek} | 65,391.10 | 5,602.68 | 11.7 |
| b_{kk} | -96 | -27 | 3.6 |
| d | 642.04 | 184.61 | 3.5 |

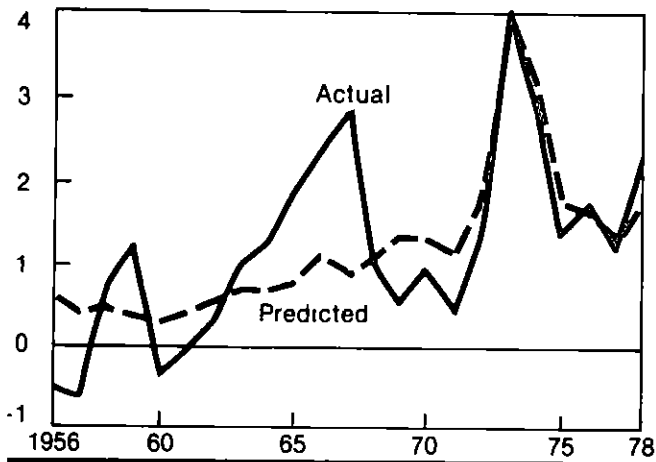
Note: Coefficient symbols are defined as follows: b_k is the intercept term for the optimal level of capital, b_{ik} is the coefficient associated with the i th normalized input price, l is labor, c is chemicals, f is intermediate materials, e is energy, k is machinery, d is the adjustment cost coefficient, and b_{kk} is the denominator of the optimal stock equation (18).

¹¹Shares are based on total operator farm assets.

Figure 4

Predicted and Observed Net Investment

Billions of 1977 dollars



Recall from equation (16) that the optimal level of machinery is a function of the ratio of variable input to output prices and the user cost of capital. In its most detailed form, equation (16) is written

$$K^* = -(b_k + \sum_{i=1}^n b_{ik} (\hat{W}_i/P) - (\hat{Q}/P)(r + \delta))/b_{kk} \quad (19)$$

where b_k , b_{ik} , and b_{kk} are parameters, \hat{W}_i is the price of the i th variable input, P is the price of aggregate output, \hat{Q} is the purchase price of farm equipment, r is the real discount rate, and δ is the rate of economic depreciation. The effects of the interest rate on the optimal capital stock is given by the derivative $\partial K^*/\partial \eta = (\hat{Q}/P)r'(\eta)/b_{kk}$ where $r'(\eta)$ is the rate of change of the discount rate with respect to the interest rate and η is the interest rate. We computed the derivative by substituting historical values for \hat{Q} , P , and \hat{W}_i . The derivative varies from about 0.41 in 1955 to 0.52 in 1977. A 1-percentage point change, from 0.04 to 0.05 for example, reduces the optimal capital stock by about half a million dollars. Although the response of the optimal capital stock to changes in the interest rate is highly inelastic, less than -0.01 in 1978, its sensitivity does increase through time.

Although interest rates do not significantly affect the optimal level of farm machinery, they do affect the rate of adjustment of machinery to optimal

levels. The estimated adjustment rate from 1955 through 1971 staggered from 0.03 to 0.02 as real interest rates and the ratio of machinery prices to output prices increased (fig. 5).¹² Adjustment rates increased significantly between 1971 and 1974. In 1974, the estimated adjustment rate reached 0.045. This abrupt increase resulted from a sharp decrease in the real interest rate (discount rate) and a decrease in the normalized machinery price. The large increase in investment during the period has been attributed to the large increase in agricultural income.¹³ Investment increased either because cash flow problems were reduced or farmers sought to avoid taxes by taking advantage of tax credits and accelerated depreciation tax provisions. Results from this analysis suggest a possible alternative explanation. Namely, the increase in investment can be attributed to an increase in the cost of foregone profits.

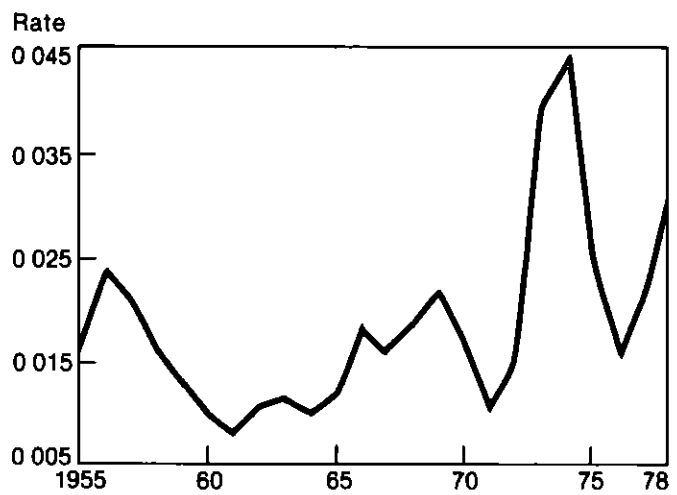
The results also indicate that the ratio of machinery price to output price is a relatively more important determinant of the adjustment rate than the real interest rate. The average machinery price elasticity of adjustment, $(\partial B/\partial q)(q/B)$, of -1.03 is considerably

¹²The average interest elasticity of adjustment, $(\partial B/\partial r)(r/B)$, is -0.014. The largest (absolute value) elasticity is in 1971 (-0.03) and the smallest is in 1974 (-0.01).

¹³Real net cash income jumped from \$32.6 billion in 1971 to \$38.3, \$49.9, and \$45.5 billion in 1972, 1973, and 1974 (37).

Figure 5

Rate of Adjustment



larger than the average interest elasticity, -0.014 ¹⁴. When interest rates are held constant and the ratio of machinery to output price is allowed to vary between 0.05 and 1.5, the adjustment rate ranges between 0.045 and 0.03. An increase in the price ratio indicates a higher machinery price relative to output price and acts as a brake on investment.

The composite effect of interest rates on net investment in farm equipment working through the adjustment coefficient and the user cost of capital is small. Although the weight of our results suggests little effect, a more cautious interpretation is that our results may not support an elastic investment response to changes in interest rates. Evidence regarding the effect of the interest rate on investment for other sectors is generally inconclusive. Eisner and Strotz, in their detailed review of investment studies, state: "The interest rate has occasionally been found to be negatively related to capital expenditures, but such findings are not general. Coefficients are frequently uncertain, or, more important, so small in relation to the variations of the interest rates which have been allowed to occur as to deny that variable much historical role in influencing the rate of investment" (8). Finally, the results suggest the primary determinant of net investment in this analysis is the ratio of input to output prices. Increases in the input/output price ratios for labor, chemicals, and energy stimulate the substitution of capital and motivate investment. This effect can result from either an increase in input prices or a decrease in output prices.

Conclusions

We have developed and applied a consistent theoretical framework for examining agricultural machinery investment. We incorporated results from duality theory on restricted profit functions into an optimal control framework and derived the necessary conditions for determining the optimal paths of quasi-fixed inputs using Pontryagin's maximum principle. Although strong assumptions are made about expectations, the final dynamic modeling system is a consistent theoretical framework.

Unlike other analyses, the adjustment coefficients developed here depend on economic variables (discount rate, output price, capital price, and adjustment cost) and are, therefore, not fixed through time.

One can draw three general conclusions from this analysis. First, changes in interest rates have a minor direct effect on the optimal level of agricultural machinery. Second, although the interest rate has little effect on the optimal level of machinery, it does affect investment by altering the rate of adjustment. Higher interest rates, *ceteris paribus*, delay investment because discounted profits are lower. Third, the ratio of machinery to output price also has a significant effect on the adjustment rate. Moreover, the adjustment rate is more sensitive to changes in this input/output price ratio than to the interest rate.

The dynamic theory offered in this analysis assumes static expectations. Future work needs to develop a theory where economic agents optimize their behavior in response to dynamic conditions and the formation of expectations are endogenously determined. A second limitation is that the theory uses an interequilibrium framework. That is, a firm moves from an initial to a final equilibrium position as a result of some change in external circumstances. Unfortunately, such a phenomenon can never be observed. Instead, the adjustment path must be derived from the observed data, thereby making the task of estimating meaningful parameters problematic. Finally, this analysis focuses on a subset of the total capital stock by making an important separability assumption. Preliminary work suggests, however, a more complete model specification may be limited econometrically by available data.

Although the effect of interest rates on investment is an important link between the macroeconomy and agriculture, it is only one of many that merit investigation. The effects of macroeconomic variables on investment in land and inventories, aggregate farm demand, and the formation of price expectations are also important. As contemporary events indicate, national and international economic phenomena have an increasingly important effect on the profitability and behavior of American agriculture.

¹⁴The machinery price elasticity data show about as much variation as the interest elasticity series.

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