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An Integrated Investment-Supply Response Model for U.S. Agriculture

by

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Abstract

A system of dynamic investment demand and output supply equations is consistently estimated utilizing recent advances in dynamic duality theory. Results indicate that labor, capital services, and land adjust sluggishly to relative price changes. This can be construed as a form of asset fixity within aggregate U.S. agriculture.

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United States agriculture has undergone a dramatic transformation in the post-war era. This transformation, from a moderately large sector to a relatively small sector, was accompanied by constantly shifting supply and demand conditions for agricultural products. Hypothesizing that agricultural supply grew faster than demand, Schultz concluded that "the equilibriating mechanism is faced with a transfer problem, that is, the task of moving an excess supply of resources out of agriculture (p. 49)." Accordingly, this study investigates input and output adjustments evoked by changing relative prices in aggregate U.S. agriculture over the period 1947-1979.

The adjustment-cost hypothesis is invoked to explain the dynamic behavior of production. This hypothesis provides a consistent theoretical basis for explaining agricultural investment patterns. The adjustment-cost hypothesis states that firms suffer a short-run output loss when they change their stocks of quasi-fixed factors. This hypothesis is introduced into standard production function analysis by inclusion of investment as an argument in the production function; specifically, $y = f(L,K,I)$ where y is output produced by combining vectors of variable factors (L), and quasi-fixed factors (K). I denotes the vector of gross investments in quasi-fixed factors. Adjustment costs imply sluggish input adjustments because it is costly to change stocks quickly rather than slowly. There is a sizeable literature justifying the general existence of adjustment costs (Penrose; Lucas; Mortenson; and Treadway). It suffices for the purposes of this discussion to explain its relevance to agricultural investment theory.

The agricultural economics literature that appears most pertinent to adjustment costs is the extensive discussion on costs of movement during the 1960's which explained the persistence of surplus labor in U.S. agriculture in terms of costs farmers incurred when they quit farming as an occupation (Baumgartner; Gallaway; Maddox). Aspects of these costs included search costs, relocation costs, retraining costs and psychic costs. With regard to other productive factors the existence of imperfect credit markets, wealth constraints, and pecuniary diseconomies provides a sound basis for the adjustment cost model as it does in the literature on nonagricultural investment. For factors of production other than labor, there is little empirical evidence on the magnitude of these adjustment costs. Preliminary to obtaining this information, a brief review of the formal theory of investment based on adjustment costs is appropriate.

Adjustment Costs and Dynamic Duality Theory

The investment model developed in this study does not constrain any factors to be variable. Rather, a primary objective of this study is to empirically determine which factors exhibited quasi-fixity in United States agriculture. It is assumed that agricultural production is characterized by a generalized production function $f(K,I)$; $f(I)$ satisfies: $y > 0$ and $f(K,I)$ is twice continuously differentiable; $f_K(K,I) > 0$; $f_I(K,I) < 0$ if $I > 0$ and $f_I(K,I) > 0$ if $I < 0$; and $f(K,I)$ is strictly concave in K and I. These assumptions are discussed in detail in Epstein and we only comment on the assumption on f_I and f_{II}. f_I represents the marginal adjustment cost. It is assumed to be symmetric--i.e., when investment is positive some current output must be foregone ($f_I < 0$) but when investment is negative current output is augmented ($f_I > 0$). On the other hand $f_{II} < 0$ provides a sufficient condition for being able to solve for the optimal controls uniquely in terms of the shadow prices of the capital stock. The agricultural firm is assumed to maximize the discounted stream of net cash flow over an infinite time horizon:

$$\underset{I}{\text{Maximize}} \int_0^\infty e^{-rt}(f(K,I) - P^T K)dt$$

$$\text{Subject to} \quad \dot{K} = I - \delta K \text{ and } K(0) = K_0 \tag{1}$$

where r is the discount rate, P is the vector of rental prices of stocks normalized by output price, and δ is a diagonal matrix with positive depreciation rates on the diagonal. The firm is assumed to form expectations about P statically. The firm chooses quantities of investment goods that yield the highest discounted stream of net returns. If, as they typically must, actual prices diverge from expected prices, the firm revises its estimates of the future trajectory of prices. Since the investment plan is revised in every time period, only that part of the dynamic plan when t = 0 is empirically relevant. Letting J(P, K) denote the optimal value of (1), the Hamilton-Jacobi-Bellman equation then gives:

$$rJ=\text{Max}(f(K,I)-P^T K+J_K(P,K)(I-\delta K)) \tag{2}$$

Epstein has demonstrated that the value function J(P,K) is dual to f(K,I) and obeys the properties: $J > 0$; J and J_K are twice continuously differentiable; $(\delta+r)J_K+P-J_{KK}\dot{K}^* > 0$; $J_K > 0$ when $I > 0$ and $J_K < 0$ when $I < 0$; and J is convex in P; $rJ-J_K K^*$ is convex in P.

The result that $(\delta+r)J_K+P-J_{KK}\dot{K}^* > 0$ is a restatement of the equation of motion for J_K implied by the maximum principle and follows by an application of the envelope theorem to (2) along with the earlier assumption that $f_K > 0$. The statement that $J_K > 0$ when $I > 0$ and vice versa follows by the first order conditions for (2) which imply $f_I = -J_K$, whence the result. Convexity of J in P is intuitively seen by noting that the objective function in (1) is the limit of the sum of linear functions in P. The requirement that $rJ-J_K\dot{K}^*$ be convex in P follows from the integrability relationship between J and f(K,I).

The advantage of representing the restrictions implied by dynamic theory in the form of the dual function J(P,K) lies in its analytic tractability since the duality between rJ and f(K,I) implies that the technology can be recaptured by solving (Epstein):

$$f^*(K,I)=\min_{P}(rJ(P,K)+P^TK-J_K\dot{K}^*) \tag{3}$$

Optimal investment demand equations are obtained by applying the envelope theorem to (2). Differentiating with respect to P yields:

$$\dot{K}^*=J_{PK}^{-1}(rJ_p+K). \tag{4}$$

The optimal supply equation is obtained from (3) as:

$$Y^*=r[J-J_PP]-[J_K-P^TJ_{PK}]\dot{K}^*. \tag{5}$$

Equations (4) and (5) together provide a means of generating optimal investment demand and supply equations within the adjustment cost model. Upon specification of a J function, these equations can be utilized to develop an empirical model.

An Empirical Model for U.S. Agriculture:

Consider the following candidate for a value function:

$$J=A_0+[a_1^T a_2^T]\begin{bmatrix}K\\ P\end{bmatrix}+[P^T K^T]\begin{bmatrix}A & D^{-1}\\ D^{-1^T} & B\end{bmatrix}\begin{bmatrix}K\\ P\end{bmatrix} \quad (6)$$

This is the normalized, quadratic, second-order, Taylor series expansion of J in (P, K). The empirical investment demand equations can be derived by application of (4) to (6):

$$\dot{K}^*=(ru+D)K+D\{r(a_2+AP)\} \quad (7)$$

where u is the identity matrix. The supply equation is given by:

$$y=r[A_0-P^TAP+K^TAK+a_1^T K]-[a_1^T+BK]\dot{K}^* \quad (8)$$

For empirical purposes it is assumed that U.S. agricultural output can be produced using four productive factors: labor (L), capital services (K), intermediate materials (M), and land (A). Data utilized consisted of approximate divisia index numbers on land, labor, capital, intermediate materials, and output. A detailed description of methodology employed in constructing these price and quantity indices is available in Ball. A discrete approximation to $\dot{K}$ is employed and a time trend appended to each equation.

The empirical investigation involves estimation of a complete supply response system consistent with the theory developed above. That theory, however, is a firm level theory while our data is highly aggregate in nature. To reconcile this problem, conditions sufficient to insure exact linear aggregation over firms to the aggregate levelare imposed. This requires that J be affine in K, i.e., $J_{KK}=B=0$, the null matrix (Blackorby and Schworm).

The investment-demand equations (7) take the form of a multivariate flexible accelerator with constant adjustment coefficients (Nadiri and Rosen, Epstein and Denny). A purely stochastic component is appended to each equation to capture random errors in optimization. The vector of stochastic components ε is assumed to be $N(0,\Sigma)$. To estimate the system of investment demand equations together with the supply equation, the method of full information maximum likelihood is employed.

Some Hypotheses

In many instances the properties of J implied by duality cannot be easily imposed a priori and tested with ease. Convexity of J in P requires that the matrix $J_{pp} = A$ is positive semi-definite which, at a minimum, implies A is symmetric with nonnegative diagonal elements. Furthermore since (7) constitutes a multivariate system of first-order difference equations, stability of the system is of interest. Stability requires that the eigen values of $(u+ru+D)$ lie within the unit circle. Previous agricultural investment models have universally deployed the univariate flexible accelerator mechanism to investigate input adjustment (Griliches, Heady and Tweeten; Penson, Romain, and Hughes). This adjustment mechanism arbitrary imposes the assumption of independent dynamic adjustment. For this to be true D must be diagonal. When all productive factors are perfectly variable (as static theory presumes), the matrix $M = -u$. This provides another testable hypothesis. Finally, an important objective of this study is to determine which production factors were quasi-fixed. The i^{th} factor does not exhibit quasi-fixity when the following condition holds: $M_{ii} = -1$ and $M_{ij} = 0 \ \forall j \neq i$. A sequential hypothesis testing procedure is adopted when possible. Unfortunately, not all the interesting hypotheses are properly nested within each other.

Empirical Results

Estimated parameters for the system of equations are reported in Table 1. The maintained model imposed symmetry of the matrix $J_{pp} = A$. The point estimates of A, were inconsistent with positive semi-definiteness, but the diagonal elements estimated as negative are not asymptotically significantly different from zero at reasonable confidence levels. Because of the importance of convexity, an attempt was made to force the diagonal elements of the matrix A to be positive. This involved setting $A_{ii} = G_{ii}^2$ and estimating G_{ii} for those diagonal elements. The parameters G_{ii} were estimated to be practically zero. Three out of four eigenvalues of the matrix A were positive. This was inconsistent with convexity of the value function. The eigenvalues of the matrix (u+ur+D) calculated as 1.03, 0.355, 0.155, and 0.849. They are inconsistent with stability. An approximate test for the existence of adjustment costs was constructed. By the dual relations $J_K = -f_I$; if there exist no adjustment costs then J_K must be everywhere equal to zero. This requires $a_i=0$ and D=0. A likelihood ratio statistic of 210.1154 (see Table 2) resulted in a rejection of this hypothesis.

Following this, the univariate flexible accelerator hypothesis was tested. Rejection of this hypothesis suggested that interdependent input adjustments were characteristic of aggregate U.S. agriculture.

The hypothesis that all production factors were variable was also rejected. This did not preclude individual factors from being varible. Separate tests performed suggested that all production factors considered exhibited quasi-fixity over the period 1947-1979. These results support the asset fixity hypothesis that is prominent in the agricultural economic literature (Johnson and Quance).

The adjustment parameters were -0.053 for labor, -0.262 for capital, -0.631 for intermediate materials, and -0.660 for land. When all factors are at their long-run levels, only 5% of the adjustment toward the steady-state value of labor is accomplished in the first year. The corresponding adjustments during the first year were 26%, 63%, and 66% for capital, materials, and land respectively. Finally, elasticities of stocks with respect to rental prices were computed (Table 3). The surprising conclusions that emerged were the positive short-run, own-price elasticities for labor and capital. While this is not inconsistent with the adjustment-cost model (Treadway), it is somewhat difficult to rationalize. The own price elasticity of aggregate land stocks was extremely low. Short-run and long-run aggregate supply elasticities with respect to output price were 0.38 and 0.53. Long-run elasticities were different from their corresponding short-run counterparts in some respects. Most importantly, the long-run, own-price elasticity of labor is negative, but the long-run, own-price elasticity of capital services is still positive. Downward sloping, long-run derived demands are not a necessary consequence of the optimization hypothesis in the adjustment cost model. Mortensen has outlined restrictions which when combined with stability imply that the matrix $\bar{K}_p$ is symmetric negative definite. But stability has clearly been rejected in this version of the estimated model. Hence, the failure of the long-run, derived demand to slope the downward may be attributable to this factor.

Concluding Remarks

The purpose of this paper was to characterize aggregate, agricultural investment and supply response in a manner amenable to consistent empirical implementation and conceptual interpretation.

Several important results have emerged but paramount amongst them is the statistical result that aggregate production factors do tend to sluggishly adjust to price changes. Our results suggest that the greatest adjustment lags occur in agricultural labor and capital markets with the shortest lags being in land and intermediate materials markets. These findings, are consistent with the oft-stated belief in the early 1960's that an important element of the solution of the "farm problem" was to expedite the transfer of surplus labor out of agriculture.

Of course, the empirical analysis is not without flaws. Most importantly, the maintained model is only capable of generating a multivariate flexible accelerator representation of optimal investment behavior. Furthermore, the estimated model does not satisfy all the regularity conditions implied by the adjustment-cost model. While failure to meet curvature conditions is not unique to this study, it is a cause of concern and suggests that further research with alternative functional specifications would pay rich dividends.

Table 1. Estimated Parameters of Maintained Model Under Consistent Aggregation: Normalized Quadratic Value Function

Parameter	Estimated Value	Standard Error
A_0	-0.0072	0.0040
C_1	-0.1404	0.2913
C_2	-0.2620	0.1403
C_3	0.2703	0.2169
C_4	0.1858	0.0404
A_{11}	-1.1968	1.0945
A_{12}	0.0284	0.4156
A_{13}	-0.5778	0.2337
A_{14}	0.0949	0.1216
A_{22}	-0.4681	0.2674
A_{23}	-0.0105	0.1857
A_{24}	-0.0262	0.0712
A_{33}	1.0145	0.2883
A_{34}	-0.0430	0.0926
A_{44}	0.1025	0.0631
τ_1	0.0039	0.0097
τ_2	0.0438	0.0186
τ_3	0.0495	0.0235
τ_4	-0.0134	0.0040
τ_5	0.2224	0.1119
M_{11}	-0.0538	0.1037
M_{12}	-0.0027	0.2428
M_{13}	0.2132	0.2456
M_{14}	0.2874	0.9014
M_{21}	0.0503	0.0372
M_{22}	-0.2628	0.0943
M_{23}	0.3304	0.0905
M_{24}	0.6904	0.3247
M_{31}	0.1158	0.0721
M_{32}	0.2037	0.1852
M_{33}	-0.6317	0.1862
M_{34}	-0.6618	0.6778
M_{41}	-0.0276	0.0146
M_{42}	0.0874	0.0418
M_{43}	-0.0332	0.0371
M_{44}	-0.6603	0.1261
a_{11}	5.6382	6.4535
a_{12}	3.2627	5.8703
a_{13}	2.6766	4.6469
a_{14}	-0.2217	7.8394

1=Labor 2=Capital 3=Intermediate Materials 4=Land 5=Output

τ_i = 1,5 are technical change coefficients

Table 2: Hypothesis Tests on Complete System of Equations Derived from a Normalized Quadratic Value Function

Hypothesis	Log Likelihood Function	$-2\ln \lambda$	Degrees of Freedom
Maintained Model	598.47	--	--
No Adjustment Costs	493.41	120.11	20
Univariate Flexible Accelerator	583.22	30.50	12
All Factors of Production Variable	520.82	155.30	16
Labor Variable	578.80	39.34	4
Capital Variable	581.66	33.62	4
Intermediate Materials Variable	592.60	11.73	4
Land Variable	592.60	11.72	4

Table 3: Short and Long Run Elasticities of Stocks with Respect to Prices: Normalized Quadratic Value Function

Short-Run Elasticities

Stocks \ Prices	Labor	Capital	Intermediate Materials	Land	Output
Labor	0.0185	-0.0035	0.0823	0.0012	-0.0986
Capital	-0.0485	0.0530	0.1059	0.0185	-0.1289
Intermediate Materials	0.0404	-0.0173	-0.2180	-0.0057	0.2007
Land	-0.0046	-0.0079	0.0054	-0.0232	0.0303
Output	0.8429	0.3807	-1.3185	-0.1359	0.3828

Long-Run Elasticities

Stocks \ Prices	Labor	Capital	Intermediate Materials	Land	Output
Labor	-0.5066	-0.1981	0.1983	0.0308	0.4755
Capital	-0.6859	0.1160	-0.1100	0.0542	0.6257
Intermediate Materials	-0.1258	-0.0476	-0.3398	0.0294	0.4839
Land	-0.0768	0.0152	0.0093	-0.0308	0.0831
Output	0.3570	0.4023	-1.1088	-0.0346	0.5362

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