DYNAMIC FACTOR DEMANDS FOR AGGREGATE SOUTHEASTERN UNITED STATES AGRICULTURE

Timothy G. Taylor and Michael J. Monson

Abstract

A four equation input demand system for aggregate Southeastern United States agriculture consistent with dynamic optimizing behavior is specified and estimated. Labor and materials are considered as variable inputs while land and capital are treated as quasi-fixed inputs. It is found that the adjustment rates for capital and land differ considerably and are interdependent. Further, the data appear consistent with the existence of an aggregate production technology and the hypothesized optimizing behavior.

Key words: dynamic duality, factor demands, quasi-fixed inputs.

The long-run nature of agriculture in the United States is underscored by such traits as "family farms," "stewardship," and a die-hard characterization of the producer. Indeed, these traits are economically visible in the heavy investment in land and capital which typifies United States agriculture. However, in spite of this long-run nature, empirical analyses of the industry based on explicit dynamic optimizing behavior are scarce, even though concerns of over-capitalization and liquidity have drawn national attention to the farm sector.

By far, the most common means of incorporating dynamic elements in the analysis of input demand has been through the use of the partial adjustment model (Askari and Cummings) or other distributed lag specifications. Although considered *ad hoc,* the partial adjustment (alias flexible accelerator) model has been rationalized on theoretical grounds. More precisely, Lucas, Treadway (1969, 1974), and Mortensen, using the cost of adjustment hypothesis, have demonstrated that under certain restrictive assumptions concerning the production technology, the partial adjustment mechanism can be considered as an approximation to the solution of a dynamic optimization problem in the neighborhood of equilibrium.

In spite of this approximate theoretical rationalization, the partial adjustment model contains several limitations (see Berndt et al., 1979 for an extensive discussion). Perhaps the most significant of these is that the adjustment rate of the quasi-fixed input is constant and independent of the degree of disequilibrium in other input markets.

The constancy of the adjustment rate results in a proportional relationship between short-run and long-run demand elasticities, with the constant of proportionality equal to the adjustment rate. The independence of the rate of adjustment with respect to disequilibrium in other input markets is a manifestation of the fact that applications of the partial adjustment model generally focus on a single input (e.g., land) ignoring other quasi-fixed or variable inputs (a notable exception is Nadiri and Rosen). Thus, interpretations of short- and long-run elasticities are necessarily clouded as the failure to explicitly incorporate the interdependence of inputs through the production technology makes it difficult to know which inputs are fixed and which are varying, and how this affects the estimated elasticities.

Recognizing these limitations, Berndt et al. and Denny et al. introduced both the interdependence of inputs and quasi-fixity into a system of input demand equations by combining static duality concepts with internal costs of adjustment. Using the assumption of quadratic costs of adjustment, these analyses obtained a system of variable input demand functions and net investment equations from the Euler equations corresponding to a dynamic objective function. This methodology, however, is generally tractable for only one (or, at most, two) quasi-fixed input(s), and critically relies on the assumption of quadratic costs of adjustment.

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Florida Agricultural Experiment Station Journal Series No. 6312.

Recently, Epstein and Epstein and Denny, drawing on the work of McLaren and Cooper, extended these notions to establish a full dynamic duality between the firm's production technology and a dual function termed the value function. This research has shown that the value function can be used in conjunction with a generalized version of Hotelling's Lemma to obtain expressions for variable input demands and optimal net investments in quasi-fixed inputs theoretically consistent with some underlying production technology and dynamic optimizing behavior. Further, dynamic duality is applicable to an arbitrary number of quasi-fixed inputs.

The objective of this analysis is to utilize dynamic duality to specify and estimate a system of variable input demands and net investment equations for aggregate Southeastern United States agriculture. Labor and intermediate materials are taken to be variable inputs, while land and capital are considered to be quasi-fixed.

In addition to obtaining estimates of the optimal rates of net investment in land and capital, short- and long-run price elasticities are obtained for all inputs. Furthermore, the specification used for the value function permits the testing of hypotheses concerning the degree of fixity of land and capital and the degree of interdependence in the rates of net investment in these inputs.

THEORETICAL MODEL

The central function in dynamic duality is the value function which, at time t=0, represents the maximum of the discounted present value of an infinite stream of future profits. Mathematically,

$$(1)\quad J(K_0,p,w) = \max_{L,I>0} \int_0^{\infty} e^{-rt}[F(L,K,I) - w \cdot L - p \cdot K]dt$$

$$\text{subject to: } \dot{K} = I - \delta K,\ K(0) = K_0 > 0,$$

where F(L,K,I) is a concave, twice differentiable production function relating the n-dimensional variable input vector L, m-dimensional vectors of quasi-fixed inputs K, and gross investments I to output; w and p are appropriately dimensioned vectors of the normalized (with respect to output price) rental prices of L and K; δ is a diagonal matrix of depreciation rates and r denotes the constant real rate of discount.

Apart from the usual assumptions of $F_L > 0$ and $F_K > 0$, the assumption of $F_I < 0$ is maintained. The inclusion of gross investment as an argument in the production function reflects the internal costs of adjusting quasi-fixed inputs in terms of foregone output. An additional assumption is that price expectations are static in the sense that relative prices observed in each base period are assumed to persist indefinitely. As the base period changes, expectations are altered and previous decisions are no longer optimal. Only that part of the decision corresponding to each base period is actually implemented.

This latter statement implies that, under static expectations, the value function in equation (1) can be viewed as resulting from the static optimization of a dynamic objective function. This fact can be underscored as follows. Assuming a constant real rate of discount and certain regularity conditions[1] imposed on F(L,K,I), J(K,p,w) is at a maximum in any period t if it satisfies the Hamilton-Jacobi equation for an optimal control problem such that:

$$(2)\quad rJ(K,p,w) = \max_{L,I>0} [F(L,K,I) - w \cdot L - p \cdot K + J_K(K,p,w) \cdot \dot{K}^*],$$

where $J_K(K,p,w)$ denotes the vector of shadow values corresponding to the quasi-fixed inputs and $\dot{K}^* = I^* - \delta K$ represents the optimal rate of net investment.

The significance of equation (2) is that through the Hamilton-Jacobi equation, the dynamic optimization problem in equation (1) may be transformed into a static optimization problem. In particular, equation (2) implies that the value function may be defined as the maximized value of current profit plus the discounted present value of the marginal benefit of an optimal adjustment in net investment. Thus, through the Maximum Principle, the maximizing values of L and I in equation (2) when $K = K_0$ are precisely the optimizing values of equation (1) at $t = 0$.

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[1]To avoid introducing a great deal of notation, an explicit discussion of the regularity conditions on F(L,K,I) and J(K,p,w) is omitted. The reader should see Epstein (1981, pp. 84-6) for a detailed discussion. Empirical verification of these conditions is discussed in a later section of the paper.

Utilizing equation (2), Epstein has demonstrated that the value function is dual to F(L,K,I) in the dynamic optimization problem expressed in equation (1) in that, conditional on the hypothesized optimizing behavior, properties of F(L,K,I) are manifest in the properties of J(K,p,w). Conversely, specific properties of J(K,p,w) may be related to properties on F(L,K,I). Thus, a full dynamic duality can be shown to exist between J(K,p,w) and F(L,K,I) in the sense that each function is theoretically obtainable from the other by solving the appropriate static optimization problem as expressed in the Hamilton-Jacobi equation.[2]

The static representation of the value function in equation (2) also permits derivation of factor demand functions for both variable and quasi-fixed inputs. Application of the envelope theorem by differentiating equation (2) with respect to w and p yields the system of factor demand equations:

$$(3)\ L^{*}(K,p,w) = -rJ'_{w}(K,p,w) + J_{wK}(K,p,w)\,\dot{K}^{*}$$

and

$$(4)\ \dot{K}^{*}(K,p,w) = J_{pK}^{-1}(K,p,w)(rJ'_{p} + K).$$

This generalized version of Hotelling's Lemma permits the direct derivation of a complete system of factor demand equations theoretically consistent with dynamic optimizing behavior. Further, the regularity conditions on equations (3) and (4) implied by those on the primal value function provide an empirically verifiable set of conditions on which to evaluate the theoretical consistency of the model.

The use of dynamic duality via the value function not only permits the derivation of input demand systems consistent with dynamic optimizing behavior, it also permits the theoretical rationalization of many commonly used adjustment models. An example of particular interest in agricultural applications is the partial adjustment or, more generally, flexible accelerator model. Epstein (p. 89) has demonstrated that if the value function takes the general form:

$$(5)\ J(K,p,w) = g(K,w) + h(p,w) + p'(rI - M)^{-1}K,$$

where g(K,w) and h(p,w) are arbitrary functions, the net investment equations [equation (4) above] may be expressed as:

$$(6)\ \dot{K}^{*} = M(K - \overline{K}(p, w)),$$

with M representing the adjustment matrix of the accelerator mechanism. The precise functional forms for L^{*} and long-run equilibrium capital stocks, $\overline{K}$, are determined by choice of the g(•) and h(•). For only one quasi-fixed input, equation (6) collapses to the partial adjustment model with adjustment matrix M becoming a scalar measuring the rate of adjustment. For more than one quasi-fixed input, this model corresponds to the multivariate flexible accelerator.

EMPIRICAL MODEL

Given a functional specification for the value function which has the potential to satisfy the requisite regularity conditions either locally or globally, demand equations for variable and quasi-fixed inputs can be obtained by application of the generalized version of Hotelling's Lemma. It should be noted that, as in static duality, the value function can in principle be directly estimated as a single equation. However, most specifications will involve a sufficiently large number of parameters to make single equation estimation problematical for most data sets.

It has become a somewhat standard operating procedure in static duality applications to choose a flexible functional form to represent the objective function. In the application of dynamic duality, however, the notion of flexibility in terms of a second order Taylor series approximation to some true underlying function is not adequate. The reason for this is that, in the dynamic setting, third order properties are of significance. Thus, any truly flexible function would necessarily have to involve approximations to the third order which, for most data sets, would involve too many parameters to render estimation feasible.

In the present analysis, the specification of J(K,p,w) is taken to be a form quadratic in quasi-fixed inputs and log-quadratic in normalized prices. Although this specification is

[2]The dual minimization problem corresponding to equation (2) is given by:

$$F(L,K,I) = \min_{p,w>0} [rJ(K,p,w) + w \cdot L + p \cdot K - J_{K}(K,p,w)\dot{K}^{*}].$$

not flexible in the conventional sense, it permits the derivation of a system of factor demand equations, potentially consistent with the necessary theoretical regularity conditions, while minimizing the degree of nonlinearity in the estimation equations. The precise form of the value function as applied to two quasi-fixed inputs, capital (C) and land (A), and two variable inputs, labor (L) and materials (M), is given by:

$$(7)\ J(K,p,w) = a_0 + [a'b'c']\begin{bmatrix} K \\ \log p \\ \log w \end{bmatrix} + \tfrac{1}{2}[K'\ \log p'\ \log w'] \bullet \begin{bmatrix} A & O & O \\ O & B & D \\ I & D' & C \end{bmatrix}\begin{bmatrix} K \\ \log p \\ \log w \end{bmatrix} + K'G^{-1}p + K'Nw + p'G^{-1}ST + w'VT,$$

where $K = [C, A]'$, is the vector of quasi-fixed inputs capital and land, $\log p = [\log p_c \log p_a]'$ and $\log w = [\log w_L \log w_m]'$ denote the normalized price vectors for quasi-fixed and variable inputs, respectively, and T denotes a trend variable approximating disembodied technical change. Model parameters are defined by $a = (a_j)$, $b = (b_j)$, $c = (c_i)$, $i,j = 1,2$; $A = [a_{ij}]$, $B = [b_{ij}]$, $C = [c_{ij}]$, $D = [d_{ij}]$, $G^{-1} = [g^{ij}]$, $N = [n_{ij}]$, $i,j = 1,2$ and $V = (v_i)$, $S = (s_j)$, $i,j = 1,2$. In addition, symmetry restrictions of the form $a_{ij} = a_{ji}$, $b_{ij} = b_{ji}$ and $c_{ij} = c_{ji}\ \forall\ i \neq j$ are maintained.

Utilizing the generalized version of Hotelling's Lemma, the demand equations for variable inputs labor and materials, $L^*(K,p,w) = [L^*, M^*]'$ are given as:

$$(8)\ L^*(K,p,w) = -r\hat{w}^{-1}(c + D \log p + C \log w) - rVT - rNK + N\dot{K}^*(K,p,w),$$

where $\hat{w}$ denotes a diagonal matrix of normalized variable input prices. The presence of beginning period capital stocks and the optimal rates of net investments indicate that, while variable inputs adjust to equilibrium levels instantaneously, the adjustments are conditioned by both K and $\dot{K}^*$.

In similar fashion, utilizing equation (4) yields the optimal net investment equation for land and capital, $\dot{K}^*(K,p,w) = [\dot{C}^*, \dot{A}^*]'$,

$$(9)\ \dot{K}^*(K,p,w) = G[r\hat{p}^{-1}(b + B \log p + D' \log w)] + rST + (r + G)K,$$

where $\hat{p}$ denotes a diagonal matrix of the normalized rental prices of quasi-fixed inputs, and $G = [g_{ij}]$, $i,j = 1,2$ denotes the inverse of G^{-1} in equation (7). The presence of K in equation (9) indicates that, as in the case of variable input adjustments, the rate of net investment is conditioned by the beginning period levels of the quasi-fixed inputs. It should also be noted that the premultiplication of the bracketed expression in equation (9) by G yields expressions which are nonlinear in parameters.

A comparison of the form of the value function in equation (7) with that of equation (5) indicates that the optimal net investment equations are consistent with the multivariate flexible accelerator. An advantage of using dynamic duality is that the accelerator mechanism may be expressed in terms of the parameters of the value function. Specifically, equation (9) can be rewritten as:

$$(10)\ \dot{K}^*(K,p,w) = M(K - \bar{K}(p,w)),$$

where the adjustment matrix M is given by

$$(11)\ M = rI + G$$

and the long-run demand equations for the quasi-fixed inputs $\bar{K}(p,w) = [\bar{C}, \bar{A}]'$ are defined by:

$$(12)\ \bar{K}(p,w) = -(I + rG^{-1})[r\hat{p}^{-1}(b + B \log p + D' \log w + rST)].$$

Note that use of logarithms in the specification of J(K,p,w) yields long-run steady state demand functions for land and capital which are loglinear in prices.

The form of the adjustment matrix in equation (11) permits direct testing of hypotheses in terms of nested parameter restrictions. In particular, the hypotheses of: (1) independent rates of adjustment: $g_{12} = g_{21} = 0$, and (2) instantaneous adjustment of quasi-fixed inputs: $r + g_{11} = r + g_{22} = 1$, $g_{12} = g_{21} = 0$, can be tested. Independent rates of adjustment indicate that the rate of adjustment to long-run equilibrium of each quasi-fixed input is independent of the level of the other quasi-fixed input. For example, net investment in land in any time period would not depend on the level of capital stock in that period. Instantaneous adjustment would occur when current levels of quasi-fixed inputs adjusted to equilibrium levels within one time period.

DATA AND EMPIRICAL RESULTS

The primary data used for estimation were quantity and price indexes for the quasi-fixed inputs, capital and land, and variable inputs, labor and materials corresponding to aggregate Southeastern United States agriculture over the 1949 to 1981 period.[3] The primary data sources were the *State Income and Balance Sheet Statistics* and *Farm Productivity and Efficiency Statistics* published annually by the Economic Research Service, USDA.

Since no time series data on input prices at the regional level were available, implicit price indexes were obtained by applying Fisher's weak factor reversal test[4] to the quantity indexes and corresponding expenditure data. Calculation of price indexes in this manner ensures consistency in the data in that in each time period the product of the price and quantity index for each input is equal to the ratio of current expenditures to expenditures in the index base period.

Labor input was measured by the index of total hours of farm work. The price of labor was obtained using this index and expenditures on wages and perquisites. The materials input represents an aggregate of seed, feed, fertilizer, agricultural chemicals, and other inputs. Price data corresponding to this input were obtained using corresponding expenditure data. Land was measured by an index of total acres in the southeast region. The price of land was calculated using this quantity index and data on the total value of farm real estate. Capital input was defined by the index of farm machinery. Since capital expenditure and consumption data below the national level are not available prior to 1970, the user cost of capital was calculated using the quantity index in conjunction with data on depreciation in terms of current replacement cost and expenditures for operation and repairs.

In order to normalize input prices, a regional output price index was generated from the regional index of total output and the combined value of cash receipts, government payments, net inventory change, and value of farm consumption. Output price was lagged one period to reflect the fact that current price is not generally observed by producers when production and investment decisions are made.

Following the usual convention, equations (8) and (9) were appended with disturbance terms to reflect errors in optimizing behavior. Estimation was accomplished using iterated nonlinear three stage least squares (N3SLS). The iterated N3SLS estimator has been shown by Berndt et al. (1974) to be a minimum distance estimator. Although the system is nonlinear in parameters, it is linear in variables. Thus, as noted by Hausman, the iterated N3SLS estimator is asymptotically equivalent to full information maximum likelihood (FIML) and therefore yields consistent and asymptotically efficient parameter estimates.

The estimated parameters of the unrestricted system using a real discount rate of 0.05 are presented in Table 1.[5] Fifteen of the 26 estimated parameters are at least two times their corresponding asymptotic standard er-

TABLE 1. ITERATED THREE STAGE LEAST SQUARES STRUCTURAL PARAMETER ESTIMATES FOR SOUTHEASTERN UNITED STATES AGRICULTURE, 1949-1981

Parameter	Estimate	Asymptotic standard error
c_1	−742.299	207.33
c_2	−245.572	583.76
d_{11}	−65.549	106.19
d_{12}	119.912	54.71
d_{21}	141.872	116.58
d_{22}	−96.433	54.72
c_{11}	−145.522	95.68
c_{12}	−244.564	77.07
c_{22}	498.082	573.63
n_{11}	2.450	0.77
n_{12}	−1.547	2.34
n_{21}	1.089	0.27
n_{22}	−0.494	0.46
b_1	1,956.687	438.96
b_2	−522.000	160.16
b_{11}	2,590.470	413.24
b_{12}	−261.900	147.27
b_{22}	−123.602	75.85
g_{11}	−0.604	0.15
g_{12}	0.548	0.23
g_{21}	−0.024	0.01
g_{22}	−0.229	0.05
v_1	−17.383	1.62
v_2	−24.055	7.40
s_1	19.280	5.63
s_2	4.280	0.62

[3]The southeastern region is composed of the states of Alabama, Florida, Georgia, and South Carolina.

[4]Let Q_{it} and P_{it} denote the quantity and price indexes corresponding to the i^{th} input, and denote expenditures on the i^{th} input by E_{it}. These indexes satisfy Fisher's weak factor reversal test if $P_{it}Q_{it} = E_{it}/E_{io}$ where E_{io} denotes expenditures in the index base period. If only Q_{it} and E_{it} are known, an implicit price index can be defined by: $\tilde{P}_{it} = (E_{it}/E_{io})/Q_{it}$. See Diewert for a discussion of this concept.

[5]The system was also estimated using real discount rates of 0.03 and 0.07. Estimated elasticities and adjustment rates appear to be very stable over the range of discount rates considered. This finding is consistent with the findings of Epstein and Denny.

rors. Given the nonlinear and simultaneous nature of the system, it is difficult to evaluate the theoretical consistency of the model solely by viewing the structural parameter estimates. However, this can be accomplished by numerically evaluating the appropriate regularity conditions.

For all inputs, the short- and long-run own price derivatives are negative at each data point. Thus, the appropriate monotonicity conditions are satisfied. The existence and uniqueness of long-run equilibrium (steady state) levels of capital, $\bar{C}(p,w)$, and land, $\bar{A}(p,w)$, are satisfied as estimated values for $\bar{C}(p,w)$ and $\bar{A}(p,w)$ and are positive at all data points. Furthermore, the stability of these long-run equilibrium demands is ensured as the implied adjustment matrix $\hat{M} = rI + \hat{G}$ is nonsingular and negative definite.

In contrast to static dual profit maximization, convexity of the value function in prices is, in general, not sufficient to verify the necessary curvature properties on the implied production technology. However, if the value function is such the $J_K(K,p,w)$ is linear in normalized prices, as is the case for the present specification, convexity is sufficient for the existence of these curvature requirements. Evaluation of the eigenvalues for the Hessian matrix of the value function indicated that convexity was obtained at 30 of the 33 data points. While it is disappointing that convexity was not obtained for all data points, it is encouraging that the nonconvexities corresponded to the 1949 to 1951 period.

The adjustment matrix implied by the estimated parameters indicates that the rates of adjustment to long-run equilibrium for capital and land are considerably different. The estimated rate of adjustment for capital was 0.554 while the adjustment rate for land was estimated to be 0.179. This implies that about 55 percent of the optimal net investment in capital will occur in the first year in response to a change in relative prices given an equilibrium level of land. Conversely, only about 18 percent of the optimal investment in land will occur within 1 year given an equilibrium level of capital.

The hypotheses of independent rates of adjustment and instantaneous rates of adjustment are nested within the unrestricted model. Independent rates of adjustment imply that the rate of adjustment of one quasi-fixed input is independent of the degree of disequilibrium in the level of the remaining quasi-fixed input. Instantaneous rates of adjustment imply that quasi-fixed inputs completely adjust to long-run equilibrium levels in one period. In essence, this hypothesis is actually a test of the dynamic structure of the model as instantaneous adjustment implies that supposedly quasi-fixed inputs are actually freely variable inputs.

The results of sequential testing of these hypotheses are presented in Table 2. As can be seen, both the hypotheses of independent rates of adjustment and instantaneous adjustment are rejected. The second hypothesis (H^2) is, in fact, implicitly rejected since the testing sequence is terminated upon the first rejection of a null hypothesis. This partially explains the rather substantial magnitude of the test statistic for the second hypothesis.

One particularly attractive aspect of the explicit recognition of dynamic optimization is the clear distinction between the short-run, where quasi-fixed inputs partially adjust to relative price changes along the optimal investment paths, and the long-run, where quasi-fixed inputs are fully adjusted to their equilibrium levels. Table 3 presents the short-run uncompensated price elasticities for various intervals of the 1949 to 1981 periods.

All short-run own price elasticities are negative and, with the exception of labor during the 1949-65 period, are inelastic. The elastic nature of labor demand during this period is somewhat consistent with some recent findings by Antle. It can also be noted that the own, as well as cross-price, elasticities are generally trended. This trending is consistent with the findings of Epstein and Denny and

TABLE 2. SEQUENTIAL HYPOTHESIS TESTS FOR INSTANTANEOUS AND INTERDEPENDENT RATES OF ADJUSTMENT FOR CAPITAL AND LAND

Hypothesis	Test statistic[a]	Critical value
H_0^1 : Independent rates of adjustment: $(g_{12} = g_{21} = 0)$	9.500	$\chi^2_{2,0.025} = 7.378$
H_a^1 : Unrestricted model		
H_0^2 : Instantaneous adjustment: $(g_{11} + r = g_{22} + r = 1,$ $g_{12} = g_{21} = 0)$	954.569	$\chi^2_{3,0.025} = 9.348$
H_a^2 : Independent rates of adjustment		

[a] The test statistic utilized is $T^0 = n(S^0 - S)$ where S^0 denotes the minimized distance of the residual vector under the null hypothesis. S is similarly defined for the unrestricted model and n is the sample size. Under the null hypothesis $T^0 \sim \chi^2$ with degrees of freedom equal to the number of independent restrictions (Gallant and Jorgenson).

TABLE 3. SHORT-RUN AVERAGE UNCOMPENSATED INPUT DEMAND ELASTICITIES FOR SOUTHEASTERN UNITED STATES AGRICULTURE FOR VARIOUS SUBPERIODS, 1949-1981

Input	Period	Elasticity with respect to price of: Labor	Materials	Capital	Land
Labor	1949-55	−6.270	0.346	0.090	−0.169
	1956-60	−2.539	0.288	0.075	−0.141
	1961-65	−1.216	0.246	0.064	−0.120
	1966-70	−0.444	0.194	0.051	−0.095
	1971-75	−0.347	0.125	0.030	−0.061
	1976-81	-0.327	0.098	0.025	−0.047
Materials	1949-55	0.259	−0.169	0.151	0.102
	1956-60	0.200	−0.229	−0.117	0.079
	1961-65	0.172	−0.293	−0.101	0.067
	1966-70	0.154	−0.363	−0.091	0.060
	1971-75	0.115	−0.311	−0.068	0.045
	1976-81	0.109	−0.352	−0.065	0.043
Capital	1949-55	0.063	−0.088	−0.366	0.072
	1956-60	0.046	−0.064	−0.201	0.053
	1961-65	0.042	−0.059	−0.161	0.049
	1966-70	0.036	−0.050	−0.078	0.041
	1971-75	0.035	−0.049	−0.132	0.040
	1976-81	0.026	−0.037	−0.041	0.030
Land	1949-55	−0.033	0.025	0.029	−0.076
	1956-60	−0.023	0.017	0.020	−0.057
	1961-65	−0.018	0.014	0.016	−0.046
	1966-70	−0.015	0.011	0.013	−0.037
	1971-75	−0.013	0.010	0.011	−0.029
	1976-81	−0.010	0.008	0.009	−0.023

is a manifestation of the growth in Southeastern United States agriculture over the sample period.

The short-run gross substitute/complement relationships implied by the estimated cross-price elasticities are generally consistent with prior expectations. Labor appears to be a substitute for materials and capital and seems to exhibit a complementary relationship with land. This latter relationship is consistent with the labor intensive crops (e.g. vegetables and orchard crops) which are of major importance in the region. Materials are estimated to behave as a complement to capital and as a substitute for land. Finally, capital and land are short-run substitutes.

The long-run elasticities in Table 4 indicate that all own price elasticities are negative. Further, a comparison with Table 3 indicates that the Le Chatilier principle which states that long-run own price elasticities should be at least as large as the corresponding short-run elasticities is satisfied. In general, the long-run own price elasticities for labor, capital, and land are strictly greater than their short-run counterparts, while the short- and long-run own price elasticities are approximately equal for intermediate materials.

The long-run gross substitute/complement relationships implied by the cross-price elasticities are consistent with those found in the shortrun. Labor is estimated to substitute with materials and capital and exhibits a complementary relationship with land. Materials behave as a long-run complement for capital and substitute for land. Land and capital behave as long-run substitutes.

The effects of technical change were incorporated into the value function as a linear trend component. Thus, technical change is implicitly assumed to be disembodied. The estimated parameters for technical change were all positive implying that technical change has stimulated the use of all inputs. This is, perhaps, not surprising given the rebirth of agriculture in the Southeast over the past quarter century. The relative magnitudes of the estimated parameters, however, indicate that technical change has been material-using relative to labor. Given that a significant component of the materials input is agricultural chemicals, this result is consistent with the increased usage of such factors in current production practices. Finally, for the quasi-fixed inputs, the relative values of the estimated technical change parameters indicate that technical change has been capital-using relative to land, a conclusion consistent with previous studies.

TABLE 4. LONG-RUN AVERAGE UNCOMPENSATED INPUT DEMAND ELASTICITIES FOR SOUTHEASTERN UNITED STATES AGRICULTURE FOR VARIOUS SUBPERIODS, 1949-1981

Input	Period	Elasticity with respect to price of: Labor	Materials	Capital	Land
Labor	1949-55	−6.433	0.365	0.149	−0.210
	1956-60	−2.574	0.303	0.132	−0.181
	1961-65	−1.255	0.265	0.123	−0.163
	1966-70	−0.468	0.213	0.100	−0.138
	1971-75	−0.385	0.151	0.106	−0.109
	1976-81	−0.344	0.114	0.071	−0.088
Materials	1949-55	0.258	−0.154	−0.022	0.028
	1956-60	0.190	−0.215	−0.041	0.031
	1961-65	0.168	−0.287	−0.049	0.037
	1966-70	0.153	−0.361	−0.062	0.040
	1971-75	0.116	−0.317	−0.037	0.030
	1976-81	0.109	−0.351	−0.048	0.031
Capital	1949-55	0.133	−0.413	−3.806	0.998
	1956-60	0.067	−0.208	−1.562	0.502
	1961-65	0.043	−0.134	−0.945	0.323
	1966-70	0.300	−0.094	−0.475	0.226
	1971-75	0.250	−0.078	−0.526	0.188
	1976-81	0.184	−0.057	−0.237	0.138
Land	1949-55	−0.177	0.144	0.418	−0.577
	1956-60	−0.143	0.116	0.338	−0.509
	1961-65	-0.118	0.096	0.278	−0.434
	1966-70	−0.097	0.079	0.229	−0.367
	1971-75	−0.086	0.069	0.202	−0.293
	1976-81	−0.067	0.054	0.158	−0.244

CONCLUSIONS

Perhaps the most significant conclusion of this analysis is the apparent validity of the application of dynamic duality to the aggregate analysis of input demand in Southeastern United States agriculture. The estimated model generally satisfies all of the necessary regularity conditions indicating that the data measuring this aggregate behavior are consistent with the existence of a well-defined aggregate production technology and dynamic profit maximizing behavior.

This is a significant conclusion in that dual production theory, whether static or dynamic, is very rigorous in its adherence to the theoretical notions of a production technology and the existence of optimizing behavior as the *modus operandi*. This theory, however, is rooted at the level of the firm. That such theory is empirically applicable at a more aggregate level of analysis makes the implicit assumption that aggregate production relationships can be analyzed as if they were a single firm considerably more palatable.

The empirical results provide a strong indication that not only are land and capital quasi-fixed in that they are slow in realizing equilibrium adjustments to relative price variations, but also that the rates of adjustment are interdependent. This finding has rather significant implications regarding empirical analyses which assume either or both of these inputs are freely variable. Furthermore, the interdependence of the adjustment rates of capital and land appear to cast some doubt as to the validity of single equation acreage response models using the partial adjustment mechanism, as this interdependence is not taken into account.

Finally, it is interesting to note that Chambers and Vasavada, using a similar specification for aggregate United States agriculture estimated the rate of adjustment for capital to be about 0.06 and the adjustment rate for land to be 0.70. These estimates differ substantially from those obtained for Southeastern United States agriculture. These differences have potentially significant policy implications. Significant regional differences in the adjustment rates in capital and land imply that the attainment of policy goals should be pursued on a regional basis. If such regional differences dissipate in analyses conducted at the aggregate U.S. level, the attainment of policy goals on the basis of national initiatives utilizing such analysis may prove ineffective.

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