Testing Dynamic Models of the Farm Firm

Marinos E. Tsigas and Thomas W. Hertel

In this paper two models of dynamic firm behavior are fitted to a data set developed from business records of Indiana dairy farms. The parametric restrictions implied by a cost-of-adjustment model are rejected. A less restrictive, disequilibrium model is accepted; this is a model of partial and interrelated adjustment among inputs and outputs. The results suggest that adjustment in quasi-fixed inputs is slow affecting the adjustment in variable inputs and outputs.

Key words: dynamic duality, disequilibrium firm model, quasi-fixed input, dairy farm.

There is a rich tradition of research into the dynamics of agricultural supply response. Nerlove provides a valuable perspective on this work, in addition to outlining some important avenues by which the ad hoc lag structure of traditional models may be improved. These include: (*a*) incorporation of additional knowledge about the sector of interest, and (*b*) explicit treatment of the optimization process inherent in firms' supply decisions.

Examples of the first type of improvement are provided by Jarvis (beef supply); Chavas and Klemme (milk supply); and Karp, Sadeh, and Griffin (shrimp production). These authors offer detailed models of decision making in a dynamic context. There is a natural dynamic structure in each model since present and future production are related by constraints implied by population dynamics.

The second avenue of research into agricultural supply response draws heavily on behavioral restrictions implied by intertemporal optimization on the part of individual farm firms. Here, the sources of supply dynamics are not explicitly modeled. Rather they derive from the sluggish adjustment of certain quasi-fixed inputs, due to unobserved adjustment costs. The two approaches are related since the most important relationships in each model are dual to each other: the implicit rental price equations in the latter models are dual to the population dynamics equations in the former models.

Adjustment costs may be classified as either external or internal to the firm. The former are separable from the production process, while internal adjustment costs are attributable to the reduction in productivity which occurs when capital stocks are changed. This causes them to be interrelated with the production process. Adjustment costs will result in sluggish adjustment only when they are strictly convex. Any other type of adjustment costs (e.g., linear) will give rise to immediate full adjustment (Brechling). Convex adjustment costs are typically assumed to be symmetric.

The line of research which draws on restrictions implied by optimization generally has been conducted using aggregate data, aggregated across both firms and commodities (Hrubovcak and LeBlanc). In this paper, emphasis is placed on this class of models. The behavioral restrictions implied by dynamic optimization are tested against a firm-level data set. By focusing on a single type of firm—namely dairy farms—it is also possible to incorporate certain biological information into the model.

Research into the behavioral restrictions implied by intertemporal optimization, subject to adjustment costs, may be traced back to Eisner and Strotz. They derived an explicit relationship among technical parameters, the interest rate, and the speed of adjustment to

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The authors are a research associate and an associate professor, respectively, Department of Agricultural Economics, Purdue University. They thank three anonymous reviewers for their beneficial comments.

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long-run equilibrium for a single capital input. These results were generalized and refined by Lucas, Mortensen, Treadway, and others in the late 1960s and early 1970s. Interest in the long-run response to energy price shocks prompted several applications of this flexible accelerator model in the late 1970s and early 1980s (Berndt, Morrison, and Watkins). These efforts were hindered by two restrictive features of the approach: (*a*) the necessity of assuming a quadratic functional form so that the investment equation is linear in the capital stock, and (*b*) the intractability of introducing off-diagonal adjustment coefficients in the case of multiple quasi-fixed inputs.

LeBlanc and Lutton report an unsuccessful attempt to apply a cost-of-adjustment model following Treadway to Brown and Christensen's data for U.S. agriculture. As a result, they were led to the estimation of a disequilibrium model following Norsworthy and Harper where the partial adjustment mechanism is not derived from explicit economic optimizing behavior. This model introduces nonzero off-diagonal adjustment coefficients, some of which were found to be statistically significant. In a later application, Hrubovcak and LeBlanc obtained plausible results with an adjustment-cost model for U.S. agriculture with four capital assets. However, as in the work of Berndt, Morrison, and Watkins, off-diagonal adjustment coefficients in this model were restricted to be zero, thus imposing a mutually independent adjustment process for each of the capital assets.

In an effort to avoid the restrictive nature of the adjustment-cost model, recent research efforts have utilized developments in dynamic duality theory to specify a multivariate flexible accelerator model whereby behavioral restrictions may be derived for a complete matrix of adjustment coefficients (Epstein). This model is derived from a value function which defines the maximized present value of future profits. The value function may take on a wide variety of functional forms which allows the representation of a richer class of dynamic adjustment mechanisms. This more elegant model has met with mixed success in applications to aggregate data for the agricultural sector. Taylor and Monson find that it performs rather well with data from the southeastern U.S., while Vasavada rejects the dynamic duality formulation for U.S. agriculture. Vasavada and Chambers estimate the model in two steps and find that it is still not well behaved. They also reject the null hypothesis of the univariate accelerator.

One of the problems with these tests of Epstein's multivariate flexible accelerator is that, while the model is based on a theory of the individual firm, the data employed are highly aggregated. Thus, it seems logical to test the model using firm-level data. In this paper we use panel data. This has several benefits. Panel data tend to contain a large number of observations and suffer less from simultaneity and multicollinearity than do aggregate time-series data. As a result, bias is likely to be reduced and efficiency is likely to be increased.

The panel data used in this paper is based on a collection of Indiana farm business records. We test several alternative dynamic models of interrelated investment and supply against this data set. The Epstein model, based on dynamic duality, is rejected. A somewhat less restrictive model, combining attractive features of the Nadiri-Rosen and Norsworthy-Harper approaches, is accepted at a .025 level of probability.

Specification of the Basic Model

The basic flexible accelerator model for a single, quasi-fixed asset may be written as:

$$K_t - K_{t-1} = \lambda(K_t^* - K_{t-1}),$$

or alternatively:

$$K_t = (1 - \lambda)K_{t-1} + \lambda K_t^*, \tag{1}$$

where K_t^* is the fully adjusted level of capital stock, which depends on prices and other exogenous variables. K_{t-1} and K_t are the beginning- and end-of-period capital stocks, and λ represents the speed of adjustment towards K_t^*. While ad hoc models tend to treat λ as a constant, Eisner and Strotz demonstrated how λ may be expected to depend on a combination of technical parameters as well as the interest rate. Adding the other asset and netput equations gives rise to:

$$\begin{bmatrix} K_t \\ L_t \end{bmatrix} = \begin{bmatrix} B_0 \\ C_0 \end{bmatrix} + \begin{bmatrix} B_1 & B_2 & B_3 & B_4 \\ C_1 & C_2 & C_3 & C_4 \end{bmatrix} \begin{bmatrix} K_{t-1} \\ P_t \\ W_t \\ Z_t \end{bmatrix}, \tag{2}$$

where matrices have the following dimensions and represent:

K_t (2 × 1), end-of-period capital stocks;
K_{t-1} (2 × 1), beginning-of-period capital stocks;
L_t (5 × 1), netput quantities;
P_t (2 × 1), implicit rental prices;
W_t (5 × 1), netput prices; and
Z_t (2 × 1), exogenous factors.

Equations (1) and (2) imply that $B_1 = I - \lambda_1$, and $C_1 = -\lambda_2$, where the dimension of B_1 and λ_1 is 2 × 2, the dimension of C_1 and λ_2 is 5 × 2, and I is the identity matrix. Matrices λ_1 and λ_2 are the adjustment coefficient matrices, and they show the effect of disequilibrium in capital stocks ($K_t^* - K_{t-1}$) on adjustment in capital stocks and netputs ($K_t - K_{t-1}$ and $L_t - L_{t-1}$), respectively. The diagonal elements of B_2 and C_3 are the own-price response coefficients in the capital stock and netput equations.

Data

The major source of data was the Purdue Farm Accounting Project (Indiana Cooperative Extension Service) which provided an economical and readily obtainable source of information about 16 Indiana crop-dairy farms over the years 1971–82.

The sample used in this study is not a random sample of commercial Indiana farms. Thus, inferences must be made with caution. However, Mueller concludes that "differences between record keeping farms and a representative sample of all farms are essentially differences in the quantity of basic resources, particularly land and capital, utilized by the farm operators . . . and, given basic resources, managerial ability is not greatly different on record keeping farms and survey farms" (p. 292). Unfortunately, in order to estimate the dynamic adjustment process, we were forced to select farms which participated in the project over a long period. This necessarily excluded newcomers and dropouts. These two kinds of farms are probably different from those in the sample, and they may make an aggregate time series exhibit different characteristics than this sample.

The quality of this panel data is good. Recall error has been minimized, since the survey was not retrospective and farmers recorded information as events happened. In addition, the standardized format of the accounting records as well as the supervision of field agents have contributed to increased accuracy of the data.

The variables distinguished in this study are presented in table 1. (More details about data development are available in Tsigas.) Rather than using reported beginning-period inventory values for machinery and real estate, a version of the perpetual inventory method has been employed (Usher). According to this method, the present net capital stock of an input is equal to the sum of previous investment expenditures times the fraction of each investment remaining:

$$K_t = (1 - \delta)^{t-T} K_T + \sum_{T \le s \le t} (1 - \delta)^{t-s-1}(I_s/p_s), \text{ or}$$

$$K_t = (1 - \delta)K_{t-1} + (1 - \delta)(I_{t-1}/p_{t-1}),$$

where K_t is beginning-of-period stock valued at constant dollars, K_T is the initial value of capital, I_s is gross investment expenditures for period s, δ is the rate of decline in the value of services provided by the asset, and p_s is a price index which deflates current dollars.

Application of the perpetual inventory method requires a relatively long series of investment expenditures. Since this data was not available, K_{1971} was equated to the reported value of the asset. For all other years, the perpetual inventory method was applied to compute K_t. Reported beginning-period inventory values could have been used, but they depend on accounting depreciation, which may not reflect the actual pattern of economic depreciation.

This method of estimating capital stocks assumes that assets depreciate at a geometric rate which has been criticized by Penson, Romain, and Hughes who have concluded that, for tractors, "the geometric depreciation pattern . . . represents the poorest proxy for the capacity depreciation patterns suggested by engineering considerations" (p. 635). Yet Hulten and Wykoff have found that "depreciation is accelerated relative to straight-line and can be reasonably well approximated by geometric depreciation" (p. 112). Thus, although geometric depreciation is not unanimously supported, it is adopted here as a working hypothesis. The perpetual inventory method was used to determine stock values for machinery and real estate. The stock value of the livestock asset was equated to the reported estimate of the number of breeding animals.

A rental price series for machinery was computed based on the Hall-Jorgenson equation which assumes static price expectations, geo-

Table 1. Definition of Quantity Variables

Quantity Variable[a]	Name	Definition	Units[b]
$K_1(P_1)$	Machinery	End-of-period stock of machinery and equipment	1970 dollars[c]
$K_2(P_2)$	Dairy Herd	End-of-period stock of dairy cows	Number of cows[c]
$L_1(W_1)$	Crops	Total crop production	Index (Index)
$L_2(W_2)$	Milk	Dairy production	Index (Index)
$L_3(W_3)$	Crop inputs	Crop operating inputs	1971 dollars (Index)
$L_4(W_4)$	Hired Labor	Hired labor	1971 dollars (Index)
$L_5(W_5)$	Livestock Inputs	Livestock operating inputs	Index (Index)
$L_6(W_6)$	Other Inputs	Other operating inputs	1971 dollars (Index)
Z_1	Real Estate	Beginning-of-period stock of land and farm buildings	Index
Z_2	Farm Labor	Operator's and unpaid family labor	Hours

[a] Corresponding price variables in parentheses. Netput quantities are nonnegative for outputs (i.e., $L_i \geq 0$ for $i = 1, 2$), and nonpositive for inputs (i.e., $L_i \leq 0$ for $i = 3, 4, 5, 6$). All other quantity and price variables take on nonnegative values.

[b] Corresponding price units in parentheses.

[c] Rental prices are in terms of one 1971 dollar of asset price.

metric depreciation, and debt financing (Hall and Jorgenson; Coen). A formula developed by Durst and Jeremias was modified to compute a rental price series for the dairy herd.[1]

Estimation and Hypothesis Testing

The most commonly employed behavioral assumption for dynamic models of the firm is that producers maximize the discounted sum of future profits over an infinite horizon. Furthermore, if their technology implies that capital stocks are costly to adjust, and if they have static expectations about prices, there is a value function which defines the maximized present value of future profits at any point in time (Epstein).

For a constant discount rate this value function may be approximated by:

$$(3)\quad J(Z_t, K_{t-1}, P_t, W_t) = a_0 + [a_1^T\ a_2^T\ a_3^T\ a_4^T]\begin{bmatrix} K_{t-1} \\ P_t \\ W_t \\ Z_t \end{bmatrix} + \tfrac{1}{2}[K_{t-1}^T\ P_t^T\ W_t^T\ Z_t^T]\begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{21} & A_{22} & A_{23} & A_{24} \\ A_{31} & A_{32} & A_{33} & A_{34} \\ A_{41} & A_{42} & A_{43} & A_{44} \end{bmatrix}\begin{bmatrix} K_{t-1} \\ P_t \\ W_t \\ Z_t \end{bmatrix},$$

where a_j and A_{ij} are parameter matrices, superscript T denotes transposition, $A_{ii} = A_{ii}^T$, and $A_{ij} = A_{ji}^T$. Application of an intertemporal analogue of Hotelling's lemma allows derivation of optimal investment demand and netput supply functions from knowledge of the optimal value function alone. Given (3), this gives rise to equation (4) (see below), where r is a diagonal matrix with the real discount rate on the diagonal, superscript -1 denotes inversion, and I is an identity matrix.[2] From (4), the system of net investment equations is obtained

$$K_t - K_{t-1} = (r + A_{21}^{-1})[K_{t-1} + r(rA_{21} + I)^{-1}(a_2 + A_{22}P + A_{23}W + A_{24}Z)],$$

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[1] Further details about the development of rental price data are available in an unpublished appendix which may be obtained from the authors.

[2] The real discount rate (r) was assumed to be equal to .04. Limited experimentation indicated that parameter estimates were very robust to the specification of r. The same result also has been reported in other studies (e.g., Taylor and Monson).

$$(4)\quad \begin{bmatrix} K_t \\ L_t \end{bmatrix} = r\begin{bmatrix} A_{21}^{-1}a_2 \\ a_3 - A_{31}A_{21}^{-1}a_2 \end{bmatrix} + \begin{bmatrix} I + r + A_{21}^{-1} & rA_{21}^{-1}A_{22} & rA_{21}^{-1}A_{23} & rA_{21}^{-1}A_{24} \\ -A_{31}A_{21}^{-1} & r(A_{32} - A_{31}A_{21}^{-1}A_{22}) & r(A_{33} - A_{31}A_{21}^{-1}A_{23}) & r(A_{34} - A_{31}A_{21}^{-1}A_{24}) \end{bmatrix}\begin{bmatrix} K_{t-1} \\ P_t \\ W_t \\ Z_t \end{bmatrix}$$

which is an accelerator model with adjustment matrix $M = r + A_{21}^{-1}$.

To ease the computational burden associated with the estimation of (4), the data were transformed using farm-specific effects and autocorrelation coefficients obtained from unrestricted estimation of (2). These estimates were obtained using a generalized least squares with dummy variables technique which corrects for potential heteroskedasticity and serial correlation in residuals. Dummy variables were used because in panel data there may be effects which are specific to cross sections. The firm-specific effects may be treated either as fixed or as random. Since this sample of dairy farms is not a random sample of the population, and since inferences will be restricted to this sample, a fixed-effects model was applied. In particular, intercept shifters were introduced in every equation in (2).

System estimates of structural parameters of (4) were obtained using an iterative seemingly unrelated nonlinear regressions estimation technique. Estimates of the reduced form parameters of the system [equivalent to the parameters in (2)] are presented in table 2. The implied adjustment process is stable (i.e., the eigenvalues of $M + I$ are less than one in absolute value), and estimated adjustment coefficients may be interpreted in the following way. If the dairy herd is at its steady state level, then (100 − 70.8 =) 29.2% of the adjustment to any desired change in machinery occurs within one year. For the dairy herd, (100 − 49.4 =) 50.6% of the adjustment occurs in one year. The difference in these rates of adjustment is not unreasonable. Changes in machinery may require: (*a*) more extensive reorganizations in a farm plan than do changes in the dairy herd, and (*b*) higher investment expenditures, which in turn may imply higher financing costs for machinery investment. Marginally increasing financing costs can cause the firm to spread out its machinery investment over time so as not to have too high a rate of investment in any one period which would incur heavier capital costs. These factors could be expected to generate a more sluggish response for machinery.

The estimate of the machinery own-adjustment coefficient is very close to that of Vasavada and Chambers (.2628) and Vasavada and Ball (.3019). Taylor and Monson estimated a larger own-adjustment coefficient for machinery (.554). Vasavada and Ball reported a much lower adjustment coefficient for farm produced durables (including livestock capital) than the value obtained here.

The symmetry of matrices A_{22}, A_{33}, the equality of A_{23} to A_{32}^T, and the interrelatedness of equations in (4) were tested following a procedure proposed by Gallant and Jorgenson. The test statistic is equal to

$$n \times [s(\theta_U, \Sigma_U) - s(\theta_R, \Sigma_U)],$$

where n is the number of observations; $s(\theta, \Sigma)$ is a generalized sum of squared residuals which obtains a minimum at parameter estimates θ, and variance-covariance matrix of errors across equations Σ; θ_U and θ_R are the estimates of parameters for the unrestricted and restricted models, respectively; and Σ_U is the estimate of the variance-covariance matrix of errors across equations for the unrestricted model.

This statistic is asymptotically distributed as a chi-square random variable. The null hypothesis that all restrictions hold is rejected if the statistic exceeds the upper $\alpha \times 100$ percentage point of the chi-square distribution with degrees of freedom equal to the difference in the number of free parameters between the restricted and unrestricted models (α is the level of statistical significance). In this case $\chi^2(.05,21) = 32.6$, $\chi^2(.01,21) = 38.9$, and the test statistic is equal to 97.38. Thus the set of restrictions implied by continuous intertemporal optimization, which is implicit in (4), is rejected. However, it should be pointed out that the validity of the hypothesis test depends: (*a*) on whether the chosen functional form is an adequate approximation to the value function, and (*b*) on whether the errors are independent and identically distributed. Furthermore, the statistical results hold only asymptotically and the small sample implications of asymptotic results are unknown.

A Disequilibrium Model of Dynamic Firm Behavior

The value function approach is quite restrictive in that it postulates that the firm is continually in equilibrium—subject to adjustment costs—even as it responds to large unanticipated price changes. A somewhat less restrictive model might postulate that the adjustment process is one of disequilibrium, with the firm only attaining an equilibrium position with respect to capital stocks in the long run. Norsworthy and Harper review several specifica-

Table 2. Estimates of Reduced Form Parameters[a]

	Explanatory Variables												
			Beginning-of-Period Stocks		Rental Prices		Netput Prices						
Dependent Variable	Real Estate (160)[b]	Farm Labor (4,719)	Machinery (36,044)	Dairy Herd (79)	Machinery (.185)	Dairy Herd (.265)	Crops (121)	Milk (114)	Crop Inputs (1.27)	Hired Labor (1.09)	Livestock Inputs (121)	R^2	Autocorrelation Coefficient
Machinery	17.2	.5610000	.7080000	60.3	130,000	−1,080	−240	80.5	4,710	105	171	.931	−.1000
(39,137)[b]	18.0	.3810000	.7170000	62.7	83,000	−934	−62.7	−11.4	2,097	−135	31.2	.935	−.0003
Dairy Herd	−.0419	.0003160	.0004340	.494	−274	9.24	.137	.0882	16.3	46.8	−.0658	.936	.2000
(82)	−.0410	−.0001860	.0004740	.553	−31.1	−35.0	.0808	−.193	2.87	15.0	.0695	.939	.0012
Crops	.283	.0019200	.0007110	−.120	517	2.56	−.408	−.387	20.2	33.4	.298	.692	.4000
(147.86)	.251	.0015000	.0007290	−.0775	1,120	−23.3	−.748	−.338	.391	10.9	.265	.710	.0046
Milk	.0914	.0013400	.0000074	.825	−136	−14.2	.107	2.01	35.4	−2.50	−.856	.790	.2000
(138.86)	.0981	.0011400	.0001820	.790	705	−215	−.320	2.33	16.9	−157	−.406	.831	.0001
Crop Inputs	−30.1	−.3390000	−.0410000	−29.4	−15,100	435	−13.0	100	2,310	2,610	−15.5	.873	.5000
(−15,236)	−27.4	−.2750000	−.0733000	−21.3	−32,700	4,890	−11.5	7.51	5,600	−1,000	6.77	.881	.0072
Hired Labor	4.18	.7260000	−.0251000	−15.4	−13,200	153	8.70	95.2	213	−3,130	−55.2	.889	.2000
(−2,834.7)	3.46	.7670000	−.0287000	−16.5	−36,400	18,600	6.23	−137	−1,950	16,900	6.38	.902	.0039
Livestock Inputs	−.111	−.0010700	−.0003310	−.726	−622	11.7	.128	−.165	−6.43	4.39	−.264	.772	.3000
(−154.15)	−.122	.0000962	−.0004930	−.784	−658	77.4	.203	−.665	5.64	33.4	−.0237	.811	.0020

[a] Top values are estimates of parameters associated with the value function model in (4). Bottom-row values are estimates of parameters associated with the disequilibrium model in (8). R^2 values are computed as squared correlation coefficients between observed and predicted values of the dependent variables.

[b] Figures in parentheses are sample mean values of the variable named above.

tions of such ad hoc models. They each differ in the manner in which the adjustment process is incorporated. Here a variant of the Nadiri-Rosen interrelated factor demand approach is employed, leading to the following disequilibrium adjustment specification:

$$(5)\qquad \begin{bmatrix} K_t - K_{t-1} \\ L_t - L_{t-1} \end{bmatrix} = D \begin{bmatrix} K_t^* - K_{t-1} \\ L_t^* - L_{t-1} \end{bmatrix}.$$

In (5), K and L are vectors of observed levels and K^* and L^* are vectors of fully adjusted levels determined by maximizing fully adjusted returns to fixed factors. This specification does not provide any a priori restrictions on the elements of D. However, it is postulated that netputs are variable (i.e., $d_{ii} = 1$ when i is a netput, and $d_{ij} = 0$ when j is a netput and $i \neq j$). This assumption leaves 14 adjustment parameters to estimate.

This study goes beyond Nadiri and Rosen by specifying a specific, fully adjusted profit function which the firm is seeking to attain. (Nadiri and Rosen specified a similar model but they did not impose technology related restrictions on the parameter estimates.) The quadratic form is utilized for the fully adjusted profit function

$$(6)\qquad \Pi^* = b_0 + [b_1^T\ b_2^T\ b_3^T] \begin{bmatrix} P \\ W \\ Z \end{bmatrix} + \frac{1}{2}[P^T\ W^T\ Z^T] \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} \begin{bmatrix} P \\ W \\ Z \end{bmatrix},$$

with $B_{ii} = B_{ii}^T$, and $B_{ij} = B_{ji}^T$. Application of Hotelling's lemma to this profit function yields

$$(7)\qquad \begin{bmatrix} K_f^* \\ L^* \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \end{bmatrix} \begin{bmatrix} P \\ W \\ Z \end{bmatrix},$$

where K_f^* is a vector of fully adjusted flows of capital services. Assuming a diagonal matrix V which transforms flows of capital services into capital stocks, and substituting (7) into (5) gives

$$(8)\qquad \begin{bmatrix} K_t \\ L_t \end{bmatrix} = DV \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + DV \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \end{bmatrix} \cdot \begin{bmatrix} P_t \\ W_t \\ Z_t \end{bmatrix} + (I - D) \begin{bmatrix} K_{t-1} \\ L_{t-1} \end{bmatrix},$$

where I is an identity matrix.

The model in (8) differs from Norsworthy and Harper's disequilibrium model in that they specified a translog cost function, and as a result, they estimated a system of cost-share equations. However, if the profit function itself is not fitted to the data, it is unattractive to work with the cost-share formulation. Levels of capital stocks and netputs cannot be deduced from predicted shares without an estimate of fully adjusted profits (which are not observable). The model in (8) has the advantage of generating predicted values for capital stock levels.[3] In this case, the latter are consistent with adjustment towards the fully adjusted profit function.

System estimates of the structural parameters in (8) were obtained using the same procedure discussed above.[4] Estimates of the reduced form coefficients in (8) along with estimates of the autocorrelation coefficients and R^2 values are presented in table 2.

The validity of the less restrictive dynamic specification embodied in (8) was tested following the same procedure as above. The relevant values for the chi-square statistic were: $\chi^2(.05,19) = 30$, $\chi^2(.01,19) = 36$, and the test statistic was equal to 31.38. Thus, for this particular set of dairy farms, the disequilibrium model—coupled with the notion of a fully adjusted profit function—appears more acceptable. The data seem to support a model which does not assume that farms are in equilibrium in the short run, and restrictions are imposed only on the long-run structure.

A comparison of estimates suggests that the capital stock adjustment matrix is relatively stable across alternative sets of behavioral assumptions. For example, the values of the own-adjustment coefficient for the dairy herd across the two models are .506 and .447. Similarly for machinery they are .292 and .283. The same is true for the majority of the estimates of cross-adjustment coefficients in the capital stock and netput equations.

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[3] The Generalized Leontief (Diewert) also generates a quantity dependent system of equations. However, it was not chosen because application of the homogeneity-in-prices condition requires dropping the zero- and first-order terms. Thus, it becomes inappropriate for estimating a fixed-effects model when it is assumed that the intercepts vary over cross sections.

[4] Fixed firm effects and autocorrelation coefficients were simultaneously estimated with structural parameters. This was possible due to the simpler set of nonlinear restrictions. The firm effects were associated with b_1 and b_2 in (6).

A Focus on Adjustment Coefficients of the Disequilibrium Model

This section focuses on the modified Nadiri-Rosen model specified in (8). The estimates of the adjustment coefficients indicate that: (*a*) the system is stable [all eigenvalues of $(I - D)$ are less than one in absolute value], (*b*) the own-adjustment coefficient for dairy herd (.447) is about twice as large as that of machinery (.283), and (*c*) excess demand for any capital stock decreases the short-run demand for the other capital stock. In this case, when machinery is in excess demand ($K_t^* > K_{t-1}$), the dairy herd will underadjust if it is also in excess demand. Conversely, the dairy herd will overadjust if it is in excess supply ($K_t^* < K_{t-1}$).

It is also interesting to examine how machinery and the dairy herd adjust to economic conditions. For this purpose a within-sample analysis of adjustment speeds is conducted. The latter is defined as the portion of the desired adjustment that is accomplished within the first period.[5] So, the adjustment speed for machinery is

$$v_{1t} = (K_{1t} - K_{1,t-1})/(K_{1t}^* - K_{1,t-1}), \quad \text{or}$$
$$v_{1t} = d_{11} + d_{12} \times (K_{2t}^* - K_{2,t-1})/(K_{1t}^* - K_{1,t-1}),$$

where K_t and K_t^* are fitted values for actual and fully adjusted levels of capital stocks, and K_{t-1} is the observed beginning-of-period value of capital stock. The parameters d_{11} and d_{12} are estimates of elements of matrix D in (5). The magnitude of the adjustment speed is determined not only by the machinery's own-adjustment coefficient (d_{11}) but also by the cross effect. In this case, the adjustment speed will be larger than the own-adjustment coefficient if one of the stocks is expanding and the other stock is contracting. This happens because excess demand for any capital stock decreases the short-run demand for the other stock (i.e., the estimates of d_{12} and d_{21} are both negative). But if both stocks were simultaneously expanding or simultaneously contracting, the adjustment speed would be smaller than the own-adjustment coefficient. In such a case the adjustment speed could even be negative. The adjustment speed of a variable netput would also differ from its postulated own-adjustment coefficient value of one. Adjustment speeds vary across time and across farms, and the sample means of these measures and their components are presented in table 3. Two-period speeds of adjustment are also presented in table 3.

The adjustment speed of machinery is similar to its own adjustment coefficient. But the adjustment speed of the dairy herd (−.0245) is significantly different from its own-adjustment coefficient (.447) because: (*a*) both capital stocks tended to be simultaneously in excess demand or excess supply, and (*b*) the cross-adjustment coefficient of the dairy herd is negative (−.000474). However, the two-period dairy adjustment speed is positive. Milk also has a negative one-period adjustment speed because of the effect of disequilibrium in the dairy herd. Both the dairy herd and milk tended to be simultaneously in excess demand or excess supply during the sample period. This combined with the negative adjustment coefficient of milk with respect to the dairy herd (−.790) produces the negative component of milk's adjustment speed (−.945).

The sample means of fully adjusted stock and netput levels (table 3) are all larger, in absolute value, than the corresponding means of observed levels. For machinery, hired labor, and the dairy herd, the mean of the fully adjusted level exceeds the mean of observed values by 25% or more. For other variables, this spread varies from 6% to 17%.

Summary and Conclusion

U.S. agriculture has long been thought to be characterized by disequilibrium and the tendency towards resource fixity. Yet most applications of neoclassical models of firm behavior either treat all inputs as variable or treat some as exogenously fixed. This type of analysis is not adequate when short-run behavior may not only be quantitatively but perhaps also qualitatively different from long-run behavior. In such cases, a dynamic model should be specified.

Econometric analysis of dynamic behavior can be very demanding of data. Parameter estimates from cross-sectional data are more likely to reflect interfirm differences than intrafirm dynamics. On the other hand, estimates with time-series data have their own

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[5] This concept of adjustment speed is discussed in Mohnen, Nadiri, and Prucha.

Table 3. Speeds of Adjustment Versus Own-Adjustment Coefficients and Variable Means[a]

	One-Period Adjustment Speed[b] and Components					Sample Means of Stock and Netput Values	
		Effect of Disequilibrium in:		Own-Adjust. Coeff.	Two-Period Adjust. Speed[c]		
Variable	Adjust. Speed	Machinery	Dairy Herd			Observed	Fully Adjusted
Machinery	.234* (.0167)	d	−.048* (.0167)	.283	.395 (.0212)	39,137	52,023
Dairy Herd	−.0245 (.170)	−.472* (.170)	d	.447	.0658 (.216)	82.2	102.5
Crops	.900* (.232)	.0659 (.360)	−.166 (.172)	1	1.050 (.245)	147.9	157.7
Milk	−.0349 (.556)	−.0894 (.0762)	−.945 (.489)	1	.216 (.471)	138.9	159.9
Crop Inputs	.565 (.467)	−.364 (.319)	−.0707 (.156)	1	.634 (.386)	−15,236	−16,817
Hired Labor	.785* (.128)	−.0902 (.0769)	−.124* (.0605)	1	.828 (.109)	−2,834	−3,663
Livestock Inputs	.665* (.174)	−.104 (.0751)	−.230 (.144)	1	.710 (.151)	−154.1	−180.0

[a] Standard errors are in parentheses. Asterisks indicate statistics which are significantly different from zero at .10 level.
[b] Defined as that portion of desired adjustment accomplished in one period.
[c] Defined as that portion of desired adjustment accomplished in two periods.
[d] This component is equal to the own-adjustment coefficient.

drawbacks. First, suitably long time series usually represent aggregate data which do not correspond closely to the hypotheses formulated in terms of individual behavior. Furthermore, aggregation bias is likely to produce a dynamic structure which is not representative of any of the subaggregates. This is not satisfactory for structural analysis.

In this paper, a panel data set of Indiana farms was constructed from business records of the Purdue Farm Accounting Project. Analysis focused on the behavior of 16 dairy farms over the years 1971–82. Two models of dynamic firm behavior were estimated and two sets of conclusions were drawn. The first pertain to the dynamic behavior of the particular dairy farms under investigation. The results suggest that an interrelated, dynamic specification is empirically relevant for these farms. They tend to adjust their capital stocks slowly, and the effect of disequilibrium in capital stocks spills over to the adjustment of variable inputs and outputs. The own-adjustment coefficient for the dairy herd is considerably larger than that for machinery. Yet the reverse is true for adjustment speeds. This arises because excess demand for any capital stock decreases the short-run demand for the other capital stock. Finally, adjustment in capital stocks also gives rise to sluggish adjustment of variable netputs.

A second set of conclusions bears on the more general issue of dynamic model specification for agriculture. The data employed in this study are not consistent with the hypothesis that these farms maximize net present value, subject to adjustment costs and static expectations. However, there does appear to be some support for an alternative, less restrictive disequilibrium formulation.

Until recently, the introduction of quasi-fixed factors in models of firm behavior had taken one of two approaches: (*a*) models that permit quite general substitution possibilities but impose the static expectations assumption about prices (e.g., this study), and (*b*) models that emphasize the expectations formation with elementary treatment of the technology (e.g., Sargent). However, Epstein and Yatchew have recently offered a procedure which allows inferences to be made about both the technology and the expectation formation process. Future efforts should investigate the performance of this approach with panel data.

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References

Berndt, E. R., C. J. Morrison, and G. C. Watkins. "Dynamic Models of Energy Demand: An Assessment and Comparison." *Modelling and Measuring Natural Resource Substitution,* eds., E. R. Berndt and B. C. Field, pp. 259–89. Cambridge MA: M.I.T. Press, 1981.

Brechling, F. *Investment and Employment Decisions.* Manchester: Manchester University Press, 1975.

Brown, R. S., and L. R. Christensen. "Estimating Elasticities in a Model of Partial Static Equilibrium: An Application to U.S. Agriculture, 1947 to 1974." *Modelling and Measuring Natural Resource Substitution,* eds., E. R. Berndt and B. C. Field, pp. 209–29. Cambridge MA: M.I.T. Press, 1981.

Chavas, J-P., and R. M. Klemme. "Aggregate Milk Supply Response and Investment Behavior on U.S. Dairy Farms." *Amer. J. Agr. Econ.* 68(1986):55–66.

Coen, R. M. "The Effect of Cash Flow on the Speed of Adjustment." *Tax Incentives and Capital Spending,* ed., G. Fromm, pp. 131–96. Washington DC: The Brookings Institution, 1971.

Diewert, W. E. "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function." *J. Polit. Econ.* 79(1971):481–507.

Durst, R. L., and R. A. Jeremias. "An Analysis of Tax Incentives for Dairy Investments." Washington DC: U.S. Department of Agriculture, Economic Research Service, February 1984.

Eisner, R., and R. H. Strotz. "Determinants of Business Investment." *Impacts of Monetary Policy,* ed., D. B. Suits et al., pp. 59–337. Englewood Cliffs NJ: Prentice-Hall, 1963.

Epstein, L. G. "Duality Theory and Functional Forms for Dynamic Factor Demands." *Rev. Econ. Stud.* 48(1981):81–95.

Epstein, L. G., and A. J. Yatchew. "The Empirical Determination of Technology and Expectations: A Simplified Procedure." *J. Econometrics* 27(1985):235–58.

Gallant, A. R., and D. W. Jorgenson. "Statistical Inference for a System of Simultaneous Non-Linear, Implicit Equations in the Context of Instrumental Variable Estimation." *J. Econometrics* 11(1979):275–302.

Hall, R. E., and D. W. Jorgenson. "Tax Policy and Investment Behavior." *Amer. Econ. Rev.* 57(June 1967): 391–414.

Hrubovcak, J., and M. LeBlanc. *Tax Policy and Agricultural Investment.* Washington DC: U.S. Department of Agriculture, Economic Research Service, Tech. Bull. No. 1699, June 1985.

Hulten, C. R., and F. C. Wykoff. "The Measurement of Economic Depreciation." *Depreciation, Inflation and the Taxation of Income from Capital,* ed., C. R. Hulten, pp. 81–125. Washington DC: The Urban Institute Press, 1981.

Indiana Cooperative Extension Service, Purdue University. *Purdue Farm Accounting Project, 1971–1982.* Unpublished data on farm business.

Jarvis, L. S. "Cattle as Capital Goods and Ranchers as Portfolio Managers: An Application to the Argentine Cattle Sector." *J. Polit. Econ.* 82(1974):489–520.

Karp, L., A. Sadeh, and W. L. Griffin. "Cycles in Agricultural Production: The Case of Aquaculture." *Amer. J. Agr. Econ.* 68(1986):553–61.

LeBlanc, M., and T. Lutton. "Testing for Disequilibrium in the Demand for Agricultural Inputs." *West. J. Agr. Econ.* 9(1984):106–16.

Lucas, R. E., Jr. "Adjustment Costs and the Theory of Supply." *J. Polit. Econ.* 75(1967):321–34.

Mohnen, P. A., M. I. Nadiri, and I. R. Prucha. "R&D, Production Structure and Rates of Return in the U.S., Japanese and German Manufacturing Sectors: A Nonseparable Dynamic Factor Demand Model." *Eur. Econ. Rev.* 30(1986):749–71.

Mortensen, D. T. "Generalized Costs of Adjustment and Dynamic Factor Demand Theory." *Econometrica* 41(1973):657–65.

Mueller, A. G. "Comparison of Farm Management Service Farms and a Random Sample of Farms in Western Illinois." *J. Farm Econ.* 36(1954):285–92.

Nadiri, M. I., and S. Rosen. *A Disequilibrium Model of Demand for Factors of Production.* New York: Columbia University Press, for the National Bureau of Economic Research, 1973.

Nerlove, M. "The Dynamics of Supply: Retrospect and Prospect." *Amer. J. Agr. Econ.* 61(1979):874–88.

Norsworthy, J. R., and M. J. Harper. "Dynamic Models of Energy Substitution in U.S. Manufacturing." *Modelling and Measuring Natural Resource Substitution,* eds., E. R. Berndt and B. C. Field, pp. 177–208. Cambridge MA: M.I.T. Press, 1981.

Penson, J. B., Jr., R. F. J. Romain, and D. W. Hughes. "Net Investment in Farm Tractors: An Econometric Analysis." *Amer. J. Agr. Econ.* 63(1981):629–35.

Sargent, T. J. "Estimation of Dynamic Labor Demand Schedules under Rational Expectations." *J. Polit. Econ.* 86(1978):1009–44.

Taylor, T. G., and M. J. Monson. "Dynamic Factor Demands for Aggregate Southeastern U.S. Agriculture." Paper presented at American Agricultural Economics Association annual meeting, Ames IA, August 1985.

Treadway, A. B. "Adjustment Costs and Variable Inputs in the Theory of the Competitive Firm." *J. Econ. Theory* 2(1970):329–47.

Tsigas, M. E. "Estimation and Hypothesis Testing Using Dynamic Models of Firm Behavior." Unpublished Ph.D. thesis, Department of Agricultural Economics, Purdue University, May 1988.

Usher, D. "Introduction." *The Measurement of Capital,* Studies in Income and Wealth, Vol. 45, ed., D. Usher, pp. 1–21. Chicago: The University of Chicago Press, for the National Bureau of Economic Research, 1980.

Vasavada, U. "An Integrated Investment-Supply Response Model for U.S. Agriculture." Paper presented at American Agricultural Economics Association annual meeting, Ames IA, August 1985.

Vasavada, U., and V. E. Ball. "A Dynamic Adjustment Model for U.S. Agriculture." Paper presented at American Agricultural Economics Association annual meeting, Reno NV, August 1986.

Vasavada, U., and R. G. Chambers. "Investment in U.S. Agriculture." *Amer. J. Agr. Econ.* 68(1986):950–60.