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DYNAMIC ADJUSTMENT IN THE U. S. DAIRY INDUSTRY

Wayne H. Howard and C. Richard Shumway

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The authors are, respectively, a former Research Associate and a Professor, Department of Agricultural Economics, Texas A&M University.

Texas Agricultural Experiment Station Technical Article No. ____.

DYNAMIC ADJUSTMENT IN THE U.S. DAIRY INDUSTRY

ABSTRACT

A dual model is used to examine the dynamic structure of the U.S. dairy industry. Properties implied by the theory of the competitive firm and independent adjustment of two quasi-fixed inputs, labor and herd size, are tested and not rejected. Instantaneous adjustment, however, is soundly rejected for each quasi-fixed input. Input adjustment to optimal levels is estimated to take about two years for labor and ten for cows. Quality adjustments of the labor and cow series do not fully embody the technological change that has occurred in this industry over the study period.

DYNAMIC ADJUSTMENT IN THE U.S. DAIRY INDUSTRY

The supply side of the dairy industry has been the subject of several recent studies, motivated largely by government needs to anticipate the effects of possible policy changes. Both single-equation and multiple-equation econometric studies have estimated milk supply to be very inelastic in the short run, and a number have even found the price of milk in the supply function to be not significant (Wilson and Thompson; Prato). The long-run supply is estimated to be more elastic in these studies, as one would expect. The greater responsiveness of producers to relative price changes in the long run can be explained by the possibility of changing herd size and other quasi-fixed inputs and by genetic improvement as cows are replaced. Herd size and the factors affecting it are of particular concern now with the dairy herd buy-out program in progress.

Herd size has been considered an endogenous variable in several dairy supply models (Halvorson; Wilson and Thompson; Prato; La France and de Gorter; Chavas and Klemme). Each of these studies used some sort of lag structure to acknowledge that decisions made today about breeding or culling cows, retaining heifer calves, or genetic improvements through a breeding program take one to three years before their impact is felt. An estimate of the actual rate of adjustment from current to desired herd levels can give policy makers a time-frame for the impact of policy decisions. Dynamic models are required, however, for such estimation.

Dynamic models have been applied in various forms, primarily in partial adjustment and flexible accelerator models. Three recent models of the dairy industry that incorporate dynamics do so by using lag structures to model changes in the dairy herd (Dahlgran; LaFrance and de Gorter; Chavas and Klemme). These models appear to represent the dairy industry well, but incorporate dynamics in a largely ad hoc nature. More than a decade ago, Nerlove (p. 293) noted that the applications of distributed lag models in empirical economic studies "...is astounding, but, what is more remarkable, is the virtual lack of theoretical justification for the lag structure superimposed on basically static models."

Dynamic models that are consistent with the theory of the firm have also been derived from applications of optimal control theory but have not previously been used to examine the dairy industry. Primal and dual models can be derived from an intertemporal value function in the form of a Hamilton-Jacobi equation that is the present value of a stream of future profits (or costs)¹. The behavioral equations may be obtained via a primal approach using first order (to the Hamilton-Jacobi equation) Euler equations, or one may apply the envelope theorem to the value function to directly obtain the behavioral equations. The primal approach was developed by Treadway, and has been applied to U.S. manufacturing by Berndt, Fuss, and Watkins, and to the Canadian food processing industry by Lopez. The dual approach is based on results by McLaren and Cooper that have been formalized by Epstein, and have been

used in empirical studies of U.S. manufacturing by Epstein and Denny, and U.S. agriculture by Taylor and Munson, and Vasavada and Chambers. The primal approach is limited to either modeling only one quasi-fixed input or assuming independent adjustment between two or more quasi-fixed inputs. This study will use the dual approach, as we wish to model more than one quasi-fixed input and to test for independent adjustment rather than assuming it.

The purpose of this study is to examine the dynamic structure of the U.S. dairy industry. Rates of adjustment of two quasi-fixed inputs, labor and herd size, are estimated using a dynamic dual approach. Properties consistent with the theory of the competitive firm are tested as are the hypotheses of independent and instantaneous adjustment of the quasi-fixed inputs. The model is estimated using annual data for 1951-1982, a period of rapid technological change. Quality indexes for labor and cows are constructed to adjust the data prior to estimation, and tests are conducted to determine whether the technological change that occurred during this period is fully embodied in these indexes.

The next section gives a brief overview of the theory of the dynamic dual model. The empirical model employed in this study, together with a description of the data and the quality indexes, follow. Results of theoretical and structural tests, along with short- and long-run elasticities, are presented in the final section prior to the conclusions.

The Dynamic Model

To establish the relationship between the production function, restricted profit function, and intertemporal value function, first consider a profit maximizing, competitive firm with a static restricted profit function,

$$(1) \quad \mathbb{N}(P, W, Z) = \max Pf(X, Z) - W'X,$$

where P is price of output $f()$, W is a vector of prices of variable inputs X , $f()$ is a "well behaved" production function (i.e., f is twice continuously differentiable, concave over the relevant range of production, $f_x, f_z > 0$), and Z is a vector of quasi-fixed inputs. The duality between $\mathbb{N}()$ and $f()$ is well known: a "well behaved" production function is sufficient to obtain the relevant input demand and output supply functions, as well as the curvature properties of $f()$, from the restricted profit function.

In many cases the short-run static model is all that is necessary for analysis. In the present study, however, the objective is to examine the nature of dynamic adjustments in the quasi-fixed inputs, Z , and so the static model is inadequate. In this case an intertemporal value function must be specified. At any point in time, $t = 0$, the firm is presumed to act as though it solves the following infinite horizon problem:

$$(2) \quad J(P, W, C, r, Z_0) = \max \int_0^{\infty} e^{-rt} [PF(X, Z, Z) - W'X - C'Z] dt$$

subject to $X, Z \geq 0$, $\dot{Z}_t = I_t - \delta Z_{t-1}$, and $Z(0) = Z_0 > 0$, where C is

the rental price vector of the quasi-fixed inputs, r is the real discount rate, I is gross investment in Z , δ is the (constant) depreciation rate, Z_0 is the initial endowment of Z , and \dot{Z} is the net change in Z (may be positive or negative). All variables are implicit functions of time, so time subscripts t are dropped to minimize notational clutter.

Equation (2) is termed the "value function" and is central in dynamic duality. The regularity assumptions of $f(\cdot)$ sufficient to establish its duality with $\mathbb{I}(\cdot)$ are presumed to apply also to $F(\cdot)$. In addition, it is assumed that $F_z < 0$, that $\lim_{t \rightarrow \infty} Z(t) = 0$, and that $J(\cdot)$ is twice continuously differentiable, convex in prices, and concave in quasi-fixed inputs. The first assumption implicitly maintains positive adjustment costs, and the second assures that a steady state (long run equilibrium) exists for $Z^*(P, W, C)$. The last three assumptions insure that both short run and long run solutions exist for the value function maximum; they enable us to apply the envelope theorem to establish a duality between $J(\cdot)$ and $F(\cdot)$.

Static prices are assumed in the model. This assumption of the Markovian property (Hillier and Lieberman, P. 351) is that current prices contain all relevant information about future prices. As the base period changes, new expectations about prices come into being. Decisions made in period t are based on information available in that period. Reasons why a firm that recognizes the cost of acquiring information may rationally choose to formulate expectations in this manner while

continuously updating decisions subject to new information are outlined by Chambers and Lopez.

The value function in (2) can be thought of as the static approximation of a dynamic optimization problem. Assuming the regularity conditions on $F(X, Z, \dot{Z})$ listed above and a constant discount rate, $J()$ satisfies the Hamilton-Jacobi equation for an optimal control problem which takes the form:

$$(3) \quad rJ(P, W, C, Z) = \text{Max}[PF(X, Z, \dot{Z}) - W'X - C'Z + J_z \dot{Z}],$$

where J_z is the shadow price of the quasi-fixed input.

The Hamilton-Jacobi equation allows us to transform the dynamic problem in (2) into a more manageable form. Specifically, (3) states that the value function is defined as the discounted present value of the current profit plus the marginal value of optimal change in net investment.² Epstein (p.84-86) has shown that the properties of $F()$ are fully manifested in the value function $J()$, given the regularity conditions maintained on $F()$. The Hamilton-Jacobi equation allows us to obtain (3) from (2) and vice-versa. Thus, a full dynamic duality exists between $F()$, $J()$, and $rJ()$. Application of the envelope theorem to (3) permits variable and quasi-fixed input demand functions to be derived in a simple and direct manner. By differentiating equation (3) with respect to prices and rearranging, equations for output supply and variable and quasi-fixed input demands are obtained:

$$(4) \quad F(P, W, C, Z) = rJ_p - J_{zp} \dot{Z},$$

$$(5) \quad X(P, W, C, Z) = -rJ_V + J_{ZV} \dot{Z},$$

$$(6) \quad \dot{Z}(P, W, C, Z) = J_{ZC}^{-1} (rJ_C + Z).$$

If the value function has a form such that $J_{ZC}(P, W, C, Z) = (M - r)^{-1}$ where M is the rate of adjustment matrix, (6) can be expressed as a multivariate flexible accelerator model,

$$(7) \quad \dot{Z}(P, W, C, Z) = M[Z - Z^*(W, C)]$$

where $Z^*(\cdot)$ is the desired level of the Z matrix (Epstein p. 93). In such a case the multivariate flexible accelerator model would be consistent with the underlying theory of the firm. Further, as $M \rightarrow H$, where H is a negative identity matrix, producers adjust instantaneously to the desired level of Z , and Z shows no degree of fixity. The off-diagonal elements in H are not necessarily symmetric and measure the interdependence of the quasi-fixed inputs.

The Empirical Model

The behavior of the industry is modeled as a single representative firm using aggregate data. One should consider whether it is reasonable to model the dairy industry as a single representative firm and whether the functional form used is consistent with aggregation. The lack of firm-level data and the simplicity of an aggregate model as opposed to a model that adjusts for each individual firm causes aggregate data and models to be frequently used. The dairy industry does consist of many

price-taking firms, and the theory of such firms suggests that in long-run competitive equilibrium all firms operate at the minimum average cost. Blackorby and Schworn (p. 600) have extended this line of reasoning on aggregation to the case where there are firms with different levels of fixed factors. Given certain regularity conditions, it is necessary and sufficient for consistent aggregation across firms that the value function be affine in capital; i.e., that the value function have a form such that $J_{ZZ} = 0$.

To express the net demand for quasi-fixed inputs in the flexible accelerator form of equation (7), the value function must also have a form such that J_{ZC} is not a function of (P, W, C) .

Functional Form

Following Vasavada and Chambers (1982), a functional form for the Hamilton-Jacobi form of the value function (3) that meets the above requirements and also maintains linear homogeneity and concavity of quasi-fixed inputs is a modified generalized Leontief:

$$\begin{aligned}
 (8) \quad J(P, W, C, Z, T) = & [P \ W]'AZ + C'M^{-1}Z + [P^{.5} \ W^{.5}]'EC^{.5} \\
 & + C^{.5}'FC^{.5} + [P^{.5} \ W^{.5}]'G[P^{.5} \ W^{.5}] \\
 & + TH[P \ W \ C]
 \end{aligned}$$

where P is the average blend price of fluid milk, W is the price of concentrates, Z is two dimensional and includes the number of dairy cows in the U.S. that have calved and labor in the dairy sector,³ C is two dimensional and includes the annual average rental price of a dairy cow

in the U.S. and the agricultural labor wage rate, T is year and is included to capture the effects of disembodied technological change. Parameters A , M^{-1} , E , G , and F are each (2×2) , and H is (1×4) .

Equations (4), (5), and (6) are the estimation equations and are appended with error terms to account for measurement errors and errors in optimization. They are estimated using the form specified in (8). Z is approximated discretely as $Z_t - Z_{t-1}$. Lagged milk price is used as a proxy for expected milk price. Equation (6) is nonlinear in parameters and the quasi-fixed inputs are jointly dependent variables, so the system is estimated using nonlinear three-stage least squares (SYSNLIN, the nonlinear estimation program in SAS). Instruments for the quasi-fixed inputs are estimated using current input prices, lagged output price, and lagged quasi-fixed input quantities. The resulting estimates are asymptotically efficient. Several very different starting values produced estimates identical to the fourth decimal, which suggests that a global optimum was likely achieved.

Data

The model was estimated using annual data for years 1951-1982. The quantity of milk produced in the U.S. (as approximated by the combined marketings of milk and cream) and the average blend price for milk were from Milk: Production, Disposition, and Income (USDA, 1951-1983b). Pounds of concentrate fed per cow and concentrate price were from Milk Production (USDA, 1955-1983a). Concentrate prices before 1955 were computed from the milk/feed price ratio in the same publication (USDA,

1951-1955). Prices of dairy cows were from Agricultural Prices (USDA, 1965, 1984a).

The rental price of cows was computed as a discounted stream of payments on a replacement heifer kept for three lactations that would make a producer indifferent between paying three annual payments or a cash purchase price. The salvage value was assumed equal to the maintenance cost of the cow.

The number of cows that have calved was from Milk: Production, Disposition, and Income (USDA, 1951-1983b). The productivity of cows in the U.S. has increased dramatically over the period in question through breeding, improved management, and feeding practices. The usual practice of accounting for productivity changes due to disembodied technological change is to add a trend term to the behavioral equations. In this study at least part of the technological change that has taken place was embodied by using a quality index on the cow numbers. The index was computed by adjusting average U.S. milk yield (1982 base) by the average predicted difference for milk (PDM) for Holstein (the dominant dairy breed) bulls in the U.S. Only the PDM for bulls was used rather than a weighted average of bulls and cows because the cows used to compute dam PDM account for less than ten percent of the U.S. registered Holstein herd. The bull PDM is based on data from all Holstein bulls used for artificial insemination (AI) in the U.S. Since about half the dairy cows in the U.S. are bred by AI, this constituted a much broader sample.

The bull PDM was lagged four years. Heifers are typically bred at

approximately two years and begin milk production at about three years of age. Another year is added to allow for commercial distribution of semen. In addition, an exploratory analysis of quality indexes based on lags of three - five years produced models with unstable rates of adjustment for the alternative lag lengths.

The Holstein Association has maintained PDM records for AI bulls since 1950. PDM's for 1947-1949 were predicted by a linear regression of PDM on year. This OLS equation fit the data with $R^2 = .98$ and $F = 784$.

Labor quantity, in annual average number of workers per year in the U.S. dairy industry, was computed by taking the amount of labor in U.S. agriculture and multiplying it by the percentage of total U.S. agricultural labor hours used in dairy from Economic Indicators of the Farm Sector (USDA, 1965, 1983b). Total agricultural labor was combined family and hired labor from Agricultural Statistics (USDA, 1956-1981) for the 1956-1980 period and from tables provided by the National Economics Division, USDA, for 1950-1955. Quarterly farm labor surveys that generated the annual labor data were discontinued after April, 1981. Annual labor data for 1981-1982 were extrapolated from farm labor surveys of April, 1981, and July, 1982. Wage rate indexes for 1951-1980 were obtained by dividing the total expenditure on hired labor by the number of hired workers. Expenditures for 1950-1979 were from Farm Income Statistics (USDA, 1979), and for 1980 from Economic Indicators of the Farm Sector, (1980). Wage rates for 1981-1982 were computed by adjusting the 1980 wage rate by the rate of change of the average hourly

wage rate from Agricultural Statistics (1980-1983).

The technological change in labor quality that occurred largely from improved education over the period modeled was embodied by using a quality index on labor. Quality indexes for both family and hired labor estimated by Gollop and Jorgenson and extended by Ball were used to adjust labor. Ball's indexes are for the period 1948-1979, and were extended to 1982 by predictions from a linear regression on time. This linear model fit the data with R^2 's of .98 for both the hired and family labor indexes. The rental prices for cows and the wage rate for labor were computed by dividing expenditures by the quality-adjusted quantities.

The extent of collinearity in the independent variable matrix (including instruments for jointly dependent variables appearing on the right hand side of the equations) was assessed by computing the condition index as a diagnostic. Scaling and centering the $X'X$ matrix of independent variables resulted in a condition index of 539. This suggests moderate but not strong collinearity (Hocking and Pendleton, p. 503).

Results and Discussion

The parameter estimates of (8) are reported in the first column of Table 1 (the unrestricted model). Half of the parameters were significant at the 5 percent level, which was quite robust compared to other estimated dynamic dual models (e.g., Epstein and Denny; Vasavada and Chambers, 1987). The model explained nearly all of the variation in

the input demand equations, but very little in the output supply equation. The R^2 for the milk supply, feed demand, cow demand, and labor demand equations were .11, .97, .99, and .98 respectively. The adjustment rates for cows (M_{11}) and labor (M_{22}) were -.127 and -.426, respectively, and each significantly different from -1.0, indicating that both cows and labor exhibited quasi-fixity. Vasavada and Chambers (1987) estimated a much slower labor adjustment of -.069, but they modeled total agricultural labor rather than labor in a specialized subsector, as in this model. The slow adjustment of cows is consistent with the very inelastic short-run milk supply found in previous studies. The rate of adjustment of cows cannot be compared to other dynamic models of the U.S. dairy industry as the others have not explicitly estimated a rate of adjustment. Other studies have estimated the rate of adjustment of capital in aggregate agricultural production; their estimates have ranged from -.12 for the U. S. (Vasavada and Chambers, 1987) to -.55 in the Southeastern U. S. (Taylor and Munson).

Tests of Competitive Behavior and Differentiability

The model was estimated with linear homogeneity and concavity in quasi-fixed inputs maintained by the functional form. Tests of monotonicity, symmetry, and convexity in prices were conducted. The necessary monotonicity conditions on the value function, i.e., $J()$ increasing in output price and decreasing in input prices, held at all observations. Symmetry and convexity of $J()$ in prices were tested sequentially. The results are reported in Table 2. The test statistic

used was the Gallant and Jorgenson T^0 , which compares the minimized distance of the residual vectors of the restricted and unrestricted models, adjusted for the sample size. The resulting statistic is approximately a Chi-square, with degrees of freedom equal to the number of restrictions.

Symmetry and convexity were not rejected at the .05 level. Symmetry required that $F_{ij} = F_{ji}$ and $G_{ij} = G_{ji}$. Symmetry was maintained while convexity was tested. Global convexity is satisfied when $E_{ij} < 0$, $i, j = 1, 2$, and $F_{ij}, G_{ij} < 0$, $i \neq j$.

Because of problems in attaining convergence subject to convexity, a grid search procedure was used to select the value of F_{12} (over the interval $-.00000001$ to $-.1$) that minimized SSE. Other parameters were estimated by nonlinear three-stage least squares for a given value of F_{12} . The parameters of this theoretically restricted model are reported in the second column of Table 1. The restricted model yielded smaller estimates of M_{11} and M_{22} , but the adjustment parameters were within one standard deviation of their unrestricted values.

Structural Tests

Independent adjustment, instantaneous adjustment, and several technological change hypotheses are nested hypotheses that were tested while maintaining homogeneity, symmetry, and convexity of the value function. The tests are reported in Table 2. Independent and instantaneous adjustment were tested sequentially.

Independence of adjustment occurs when $M_{12} = M_{21} = 0$, and means that

each quasi-fixed input adjusts towards its desired level independently of the other. The null hypothesis of independence was not rejected. Instantaneous adjustment (with independence maintained) is actually a test of the dynamic nature of the model. If $M_{ii} = -1$ and $M_{ij} = 0$, the i^{th} quasi-fixed input adjusts instantaneously to its desired level, and should actually be modeled as a variable input. Instantaneous adjustment was tested separately for labor and for cows. With independent adjustment maintained, the null hypothesis of instantaneous adjustment of labor, $M_{22} = -1$, was firmly rejected. Restricting $M_{11} = -1$, i.e., instantaneous adjustment of cows, caused the system to not converge. Consequently, no test statistic can be provided.

The last hypotheses to be tested dealt with technological change. The theoretical properties and independence of adjustment were maintained. The null hypothesis that there has been no change in technology for the period modeled, $h_i = 0$, for $i = 1, \dots, 4$, was soundly rejected. Null hypotheses that the quality index on cows or labor fully captured technological change for these inputs (i.e., $h_3 = 0$ or $h_4 = 0$) were also rejected.⁴

Implications of Final Model

Parameter estimates for the model maintaining all nonrejected hypotheses (i.e., symmetry and convexity of prices, independent adjustment of quasi-fixed inputs, and disembodied technological change) are reported in the last column of Table 1. The adjustment rates were quite stable between the unrestricted and final model. Only five price

parameters and two time parameters changed more than one standard deviation from the unrestricted model.

Adjustment costs were implicitly estimated along with the rates of adjustment. Applying the envelope theorem to the value function yields the marginal effect of investment on output in a derivable form: $PF_z = -J_z$. From equation (8) $J_z = -\{[P W]A + [C'M^{-1}]\}$. As $M \rightarrow 0$, i.e., quasi-fixed inputs adjust more slowly, the cost of adjustment or shadow price of the quasi-fixed input increases. For example, the rental cost of cows per head in 1982 was \$381 per year. Positive adjustment costs increase the cost of immediately reaching the desired level of cows to \$2202 per head. The wage rate index in 1982 was .95 but adjustment costs increased the cost of immediately reaching the desired level to 2.16. Rejecting $M_{ii} = -1$ rejected the absence of positive adjustment costs for the i^{th} input.

Short and long-run elasticities for selected years computed from the final model are reported in Table 3. All the short-run own-price input demand elasticities were negative, but the output own-price elasticity was positive for only 12 of the 32 observations. Unlike static models, dynamic models do not restrict short-run output supply to be positive in order to have a profit maximizing solution, so these results are not theoretically inconsistent (Treadway, p.344-345).

The globally sufficient conditions for a maximum value function impose negative off-diagonal elements on the Hessian of the value function, but they do not imply complementarity of inputs in either the

short or long run. All the inputs were substitutes in the short run.

The short-run own-price input demand elasticities for cows and labor became more elastic over time. The increasing own-price elasticity for labor was consistent with the increasing proportion of hired to family labor over the period.⁵ The increasing own-price elasticity for cows was possibly due to the increased marketings of replacement heifers. Expansion in the dairy industry has been in large commercial dairies, particularly in the West and Southwest. These large dairies purchase more replacement heifers and are able to be more responsive to price changes than small family operated dairies. The cross-price elasticities for feed with respect to prices of cows and labor became less elastic over time. This may indicate that the amount and nutrient composition of feed per animal has become more fixed for a given milk price as information about feeding and milk production relationships has increased.

The short-run cross-price input demand elasticities between cows and labor were effectively zero, indicating that not only did disequilibrium in the level of one quasi-fixed input not affect the other, but price changes in one did not impact very much on the demand for the other quasi-fixed input.

Long-run elasticities are also reported in Table 3. Except for the cross-price elasticities between milk and feed, the long-run values were larger than short-run elasticities, so the Le Chatelier principle held. The short-run cross-price input demand elasticities of milk with respect

to price of feed were negative, while the long-run cross-price elasticities were positive. The changing of signs from the short run to the long run is not theoretically inconsistent nor empirically uncommon (Berndt, Morrison, and Watkins). With regard to long-run trends, milk supply became less elastic with respect to own price over time, and cows and labor became more elastic. The previous discussion about short-run elasticity trends applies also to the long run.

The policy implications of this model suggest that short-term programs, such as the dairy diversion program, that affect economic incentives have had a very small marginal impact on the U.S. dairy industry. Short-run effects can be opposite of what is desired, as evidenced by the negative short-run supply elasticity in most years. In both the short and long run, milk supply was very inelastic, and has become more inelastic over the last several years. Changing price supports to reduce the excess supply of dairy products is likely to have little impact in the short run. It may take only two years or so for labor to adjust in the dairy industry, but the herd level may take a decade to fully adjust. Long-term programs appear necessary if federal intervention in the dairy industry by way of price programs is to fully achieve desired results. But, long term programs are difficult to maintain when both the economic environment and policy makers change in the short term.

Summary and Conclusions

A dynamic dual model has been applied to the U.S. dairy industry in

order to estimate the rate of adjustment of cows and labor to their desired levels while maintaining the underlying properties of the theory of the firm. Linear homogeneity of the value function in prices and concavity in quasi-fixed inputs were maintained. Symmetry and convexity of the value function in prices were not rejected. Independence of adjustment between cows and labor was not rejected, but instantaneous adjustment of either cows or labor was rejected. The rate of adjustment for cows and labor, while maintaining the nonrejected hypotheses, was estimated as $-.095$ and $-.449$, respectively. At these rates it took an estimated 10.5 years for cows to adjust to their optimal levels and 2.2 years for labor during the data period, 1951-1982.

An important finding of this study was the documented validity of using a dynamic dual model on aggregated data for the dairy industry. Dual models are very structured due to their rigorous adherence to theoretical properties; yet these properties frequently have not been satisfied (or not examined) in reports of estimated dual models. The theoretical properties were consistent with the data used in this study, thus allowing investigation of the industry's structure while maintaining theoretical consistency.

Quality indexes on cows and labor are important for capturing exogenous changes in productivity, but additional disembodied technological change was not rejected. It may be possible to fully embody technological change in a quality index, but basing indexes of dairy cow productivity on PDM and labor productivity on the Gollop-

Jorgenson quality index left considerable amounts of technological change disembodied.

Short-term dairy programs that do not consider the rates of adjustment of quasi-fixed inputs can be expected to have a very small impact on the U.S. dairy industry. Programs with at least a ten-year duration are required if the potential effect of federal intervention in the dairy industry by way of price programs is to be fully achieved. Short-term programs probably should be limited to direct supply or quasi-fixed input controls. The herd buyout program thus appears to be more appropriately conceived for impacting milk supplies than did the dairy diversion program.

FOOTNOTES

1. Both the primal and the dual dynamic models are functions of prices. The primal model is obtained from the first order conditions of an optimization problem. The dual model obtains the behavioral equations by applying the envelope theorem directly to the optimization problem.
2. It is also assumed that producers adjust their investment decisions as prices change, so that the value function is not maximized once and the investment path followed to some terminal point, as in an optimal control problem. Producers re-evaluate their investment paths as prices change, with Z_{t-1} considered as an endowment or a starting value for decisions made in period t .
3. In an early specification land was included as a quasi-fixed input. Severe collinearity between the time variable, price of milk, and land led to land being excluded from the model.
4. It should be noted that the upper bound on the probability of rejecting a true joint null hypothesis by sequential testing is the sum of the individual alpha levels. Thus, the probability of rejecting the joint hypothesis of symmetry, convexity, independent and instantaneous adjustment of labor and cows is at most 20 percent. Had an upper limit of 5 percent been desired, that joint hypothesis still would have been rejected (under the assumption that the joint alpha level was equally divided among the sequential tests). The same conclusion applies to the joint hypothesis of symmetry, convexity, and any of the three technological conditions.

5. Hired agricultural labor as a percentage of total agricultural labor was 21.4 percent in 1951 and 38.0 percent in 1982.

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Table 1. Nonlinear Three Stage Least Squares Parameter Estimates of the value functions.

Parameter	Model		
	Unrestricted ^a	Theoretically Restricted ^b	Theoretically and Structurally Restricted ^c
A ₁₁	17.07 (4.412)	14.68 (3.634)	16.08 (3.393)
A ₁₂	1.528 (0.4572)	1.417 (0.4652)	1.581 (0.4464)
A ₂₁	0.1805 (1.059)	0.3629 (1.042)	0.1453 (1.029)
A ₂₂	-0.1029 (0.1154)	-0.09917 (0.1150)	-0.1237 (0.1144)
M ₁₁	-0.1267 (0.05452)	-0.07285 (0.03749)	-0.09484 (0.03393)
M ₁₂	-0.01356 (0.01559)	-0.02971 (0.01373)	---
M ₂₁	-0.01487 (0.3684)	-0.2485 (0.2373)	---
M ₂₂	-0.4256 (0.1366)	-0.3174 (0.1225)	-0.4486 (0.1194)
E ₁₁	-9.021 (3.330)	-9.209 (2.748)	-9.636 (1.842)
E ₁₂	-2.990 (4.092)	-3.688 (2.111)	-0.3316 (1.469)
E ₂₁	-0.9705 (0.7241)	-0.9599 (0.3917)	-0.7054 (0.3644)
E ₂₂	-0.2316 (1.583)	-0.01483 (0.7777)	-0.3851 (0.7677)
F ₁₁	-9.369 (1.981)	0.6243 (9.553)	-2.374 (2.557)
F ₁₂	4.757 (2.098)	-0.0001 ---	-0.0001 ---
F ₂₁	2.518 (2.073)	---	---
F ₂₂	-36.15 (4.021)	-40.68 (13.46)	-33.74 (2.279)
G ₁₁	28.13 (9.196)	20.05 (4.76)	16.44 (4.941)
G ₁₂	-6.187 (5.565)	-0.1100 (0.1916)	-0.1729 (0.1869)
G ₂₁	-0.265 (0.3955)	---	---
G ₂₂	0.8557 (0.7601)	0.8372 (0.7533)	1.057 (0.7506)
H ₁	0.1062 (0.0831)	0.1788 (0.0444)	0.2110 (0.04535)
H ₂	-0.1602 (0.01372)	-0.1662 (0.01273)	-0.1671 (0.01272)
H ₃	0.1187 (0.01971)	0.03594 (0.1000)	0.07686 (0.02200)
H ₄	0.3841 (0.0508)	0.4939 (0.1635)	0.3769 (0.04778)

Standard errors of the estimates are in parentheses. MSE = 1.5825 with 104 degrees of freedom for the unrestricted model, 1.7904 with 107 degree of freedom for the theoretically restricted model, and 1.9204 with 109 degrees of freedom for the structurally restricted model.

a Homogeneous in prices.

b Homogeneous, symmetric, and convex in prices.

c Homogeneous, symmetric, convex with independent adjustment of cows and labor.

Table 2. Tests of Hypotheses.

Hypothesis	Test Statistic	Critical Value
Symmetry $F_{12}=F_{21}$ $G_{12}=G_{21}$	1.782	$\chi^2_{2,.05} = 5.991$
Convexity ^a $E_{ij} < 0, i, j = 1, \dots, 4$ $F_{ij} < 0, G_{ij} < 0, i \neq j$	4.870	$\chi^2_{6,.05} = 12.592$
Independent Adjustment ^b $M_{12}=M_{21}=0$	4.160	$\chi^2_{2,.05} = 5.991$
Instantaneous Adjustment of Labor ^c $M_{22}=-1.0$	140.318	$\chi^2_{1,.05} = 3.841$
Instantaneous Adjustment of Cows ^c $M_{11}=-1.0$	Did not Converge	$\chi^2_{1,.05} = 3.841$
No Technological Change ^c $H_1=0, i=1, \dots, 4$	245.858	$\chi^2_{4,.05} = 9.488$
No Disembodied Technological Change in Cows ^c $H_3=0$	8.149	$\chi^2_{1,.05} = 3.841$
No Disembodied Technological Change in Labor ^c $H_4=0$	15.710	$\chi^2_{1,.05} = 3.841$

a Symmetry maintained.

b Symmetry and convexity maintained.

c Symmetry, convexity, and independent adjustment maintained.

Table 3. Short and Long Run Output Supply and Input Demand Elasticities for the U.S. Dairy Industry, Selected Years.^a

Quantity	Year	Elasticity with Respect to the Price of			
		Milk	Feed	Cows	Labor
<u>Short Run</u>					
Milk	1951	0.044	-0.012	-0.033	0.002
	1962	0.016	-0.010	-0.008	0.001
	1972	-0.001	-0.008	0.007	0.001
	1982	-0.065	-0.006	0.068	0.004
Feed	1951	0.083	-0.116	0.017	0.016
	1962	0.074	-0.101	0.013	0.014
	1972	0.081	-0.109	0.015	0.014
	1982	0.105	-0.129	0.011	0.013
Cows	1951	0.032	0.002	-0.034	0.0000
	1962	0.044	0.002	-0.046	0.0000
	1972	0.068	0.003	-0.071	0.0000
	1982	0.096	0.003	-0.098	0.0000
Labor	1951	0.003	0.003	0.0000	-0.005
	1962	0.003	0.003	0.0000	-0.006
	1972	0.006	0.004	0.0000	-0.009
	1982	0.017	0.008	0.0000	-0.025
<u>Long Run</u>					
Milk	1951	0.200	0.0002	-0.196	-0.004
	1962	0.156	0.0003	-0.153	-0.003
	1972	0.153	0.0004	-0.151	-0.003
	1982	0.124	0.0008	-0.123	-0.002
Feed	1951	0.010	-0.057	0.035	0.012
	1962	0.009	-0.048	0.029	0.010
	1972	0.010	-0.051	0.029	0.011
	1982	0.014	-0.051	0.028	0.008
Cows	1951	0.834	0.025	-0.860	0.0000
	1962	1.243	0.034	-1.277	0.0000
	1972	2.042	0.042	-2.084	0.0000
	1982	1.559	0.021	-1.579	0.0000
Labor	1951	0.006	0.006	0.0000	-0.012
	1962	0.008	0.008	0.0000	-0.016
	1972	0.014	0.010	0.0000	-0.024
	1982	0.049	0.022	0.0000	-0.071

^a Calculated from the model maintaining symmetry, convexity, and independent adjustment of cows and labor.