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Hedonic Pricing of Components and Cointegration Relationships: A Dynamic Analysis of Dairy Product Prices

by

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Abstract: The paper investigates the implications of hedonic pricing of components, with an application to the dynamics of dairy product prices. A conceptual model of hedonic pricing is developed under a Leontief technology, showing how commodity prices reflect the underlying value of their components. Implications for the existence of cointegration relationships among commodity prices are derived. An application to the pricing and dynamics of selected U.S. dairy commodities is presented. It provides evidence on the role of component valuation in the dynamics of dairy commodity prices in the short run as well as in the long run. Distinguishing between market regime and government regime (when the government price support is active), the analysis finds significant differences in dairy price dynamics between the two regimes.

Keywords: price dynamics, cointegration, hedonic pricing, dairy.

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1. Introduction

The pricing of differentiated products has been the subject of much interest. When differentiated products include non-market characteristics, these characteristics have shadow or hedonic prices reflecting their underlying scarcity (Rosen). Starting with the work of Gorman, Becker and Lancaster, a growing literature has developed on the implicit pricing of product characteristics (e.g., Griliches; Dhrymes; Deaton and Muellbauer; Stigler and Becker). Under competition, Rosen has shown that these shadow prices reflect both marginal rate of substitution (on the demand side) and marginal rate of transformation (on the supply side) of the underlying characteristics. This has stimulated much research on the implicit pricing of characteristics imbedded in differentiated products (e.g., Ball and Kirwan; Brorsen et al.; Buccola and Iizuka; Epple; Gillmeister et al.; Jacobson and Walker; Lenz et al.; Lucas; Palmquist; Perrin; St-Pierre and Scobie; Updaw).

The dairy sector provides a good example of differentiated products. Milk can be processed into a variety of dairy products, including fluid milk, cheese, butter, yogurt, ice cream, nonfat dry milk, etc. Each dairy product is different in terms of price and nutritional composition. This has stimulated interest in the pricing of dairy components (e.g., fat, protein). Previous research has investigated the economics of dairy component pricing at the farm level (e.g., Buccola and Iizuka; Gillmeister et al.; Jacobson and Walker), at the retail level (e.g. Lenz et al), as well as the market level (e.g., Perrin; Schwart; St-Pierre and Scobie). In addition, the classified pricing schemes in U.S. milk marketing orders (MMO) for both California and federal MMO's is currently based on component pricing formulas for dairy products. At this point, the linkages between the value of components and actual commodity prices are not fully understood. First, the hedonic prices of components are shadow prices that are not directly observable. This means that their empirical analysis must rely on indirect measurements. Second, both hedonic prices of components and commodity prices change over time in response to evolving market conditions. Yet, previous work has been based on static analysis. With market conditions constantly changing over time, it remains unclear how dairy commodity prices evolve with the underlying shadow prices of dairy components. This suggests a need to study how hedonic pricing relates to commodity price dynamics.

The objective of this paper is to investigate the evolving linkages between hedonic pricing of components and commodity prices, with an application to the U.S. dairy sector. We focus our attention on wholesale prices for selected dairy commodities. Essentially, the production of differentiated dairy products involves rearranging non-market milk components. Hedonic pricing implies that the prices for milk and dairy commodities reflect the implicit value of their components. We show how hedonic pricing can generate long-term relationships among the prices of milk and dairy commodities. Using techniques developed in the time series literature, we can characterize these as cointegration relationships (e.g., Hamilton; Johansen). This raises several questions. First, are the long-term dynamics of dairy prices consistent with hedonic pricing? Second, is component valuation the only source of cointegration relationships among dairy prices? Third, are there short-term dairy price dynamics unrelated to the hedonic pricing of dairy components? Addressing these questions requires studying the dynamics of commodity prices. These issues also become more complex when considering that the last few decades have seen substantial government intervention in the U.S. dairy markets. This raises the additional question of how does government intervention affect the hedonic pricing and price dynamics of dairy commodities.

This paper is organized as follows. First, a model of arbitrage pricing of components is presented in section 2. Under a Leontief technology, it provides a conceptual basis for analyzing hedonic pricing of differentiated commodities. Section 3 discusses the implications of hedonic pricing for the dynamics of commodity prices. Under fixed proportion technology (Lancaster), we show how hedonic pricing can generate cointegration relationships among dairy prices. An application to selected U.S. dairy prices is presented in section 4, with a focus on monthly wholesale prices of American cheese, butter and non-fat dry milk. This leads to the specification of a time series model representing price dynamics, relying on a vector autoregression (VAR) representation. For each market, the model distinguishes between two regimes: a government regime (G) with significant domestic government purchases implemented as part of the milk price support program; and a market regime (M) with no significant government intervention on the domestic market. Using dummy variables, the model allows for price determination and its dynamics to vary between the two regimes. The model is estimated using data from January 1970 to June 1999. The econometric results are presented in section 5. We find evidence that long-term dairy price relationships are consistent with the hedonic pricing of dairy components under both regimes. Johansen's approach to cointegration analysis suggests that hedonic pricing is the only source of long-term relationships among dairy prices under the government regime. However, under the market regime, Johansen's tests indicate the existence of additional cointegration relationships unrelated to hedonic pricing. Finally, our analysis uncovers evidence of significant short-term dairy price dynamics that are unrelated to hedonic pricing of dairy components. Concluding remarks are presented in section 6.

2. Hedonic Pricing

Consider a sector that transforms a primary product into n final products. Let x denote the quantity of the primary product, and y_i be the quantity of the i-th final product, i = 1, …, n. The primary product x is comprised of m components. As in the Lancasterian model, we assume that the underlying technology is represented by a Leontief production function, where the m components are in fixed proportions in the primary as well as final products. Let δ_{0k} denote the quantity of the k-th component contained in one unit of the primary product x, k = 1, …, m. Let δ_{ik} denote the quantity of the k-th component contained in one unit of the i-th final product y_i, i = 1, …, n, k = 1, …, m. The processing technology transforming the primary product into the i-th final product satisfies

$$\Sigma_{i=1}^{n} \delta_{ik}\, y_i \leq \delta_{0k}\, x, \quad k = 1, \ldots, m, \tag{1a}$$

and

$$y_i \leq f_i(z_i, y_{-i}), \quad i = 1, \ldots, n, \tag{1b}$$

where $y_{-i} = (y_1, \ldots, y_{i-1}, y_{i+1}, \ldots, y_n)$, z_i is a vector of non-components inputs (e.g., capital, labor) used in the production of y_i, and $f_i(z_i, y_{-i})$ is a function non-decreasing in z_i, and concave in (z_i, y_{-i}), i = 1, …, n. Equation (1a) implies that the total quantity of the k-th component contained in all n final products cannot exceed the quantity of the k-th component obtained from the primary product. It corresponds to a Leontief technology with respect to components, where the δ's are the fixed proportions of components in each product. It also implicitly assumes that components can be costlessly reallocated among final products. In equation (1b), $f_i(z_i, y_{-i})$ is a multi-product production function relating inputs z_i and other outputs y_{-i} to output y_i. Note that this imposes no a priori restriction on the elasticities of substitution among the inputs z_i.

Denote the total benefit generated by the n final products by $B(y_1, \ldots, y_n)$.[1] Also, denote by $C_0(x)$ the cost of producing the primary product x. We assume that the benefit function $B(y_1, \ldots, y_n)$ is increasing and concave in $(y_1, \ldots, y_n)$, and that the cost function $C_0(x)$ is increasing and convex in x. Finally, let s be the vector of prices for the inputs z used in the transformation process. The corresponding net benefit (NB) is

$$NB = B(y_1, \ldots, y_n) - C_0(x) - \Sigma_{i=1}^{n} (s' z_i).$$

Efficient resource allocation corresponds to the allocation that maximizes the net benefit NB subject to technical feasibility:

$$\max_{x, y_1, \ldots, y_n, z_1, \ldots, z_n} \{B(y_1, \ldots, y_n) - C_0(x) - \Sigma_{i=1}^{n} (s' z_i): \text{subject to equations (1a) and (1b)}\}. \quad (2)$$

Consider the cost minimization problem

$$C_i(s, y_1, \ldots, y_n) = \min_{z_i} \{s' z_i: \text{subject to } y_i \leq f_i(z_i, y_{-i})\}, \quad (3a)$$

where $C_i(s, y_1, \ldots, y_n)$ is a restricted cost function. It is homogeneous of degree zero, increasing and concave in prices s, and convex in $(y_1, \ldots, y_n)$, $i = 1, \ldots, n$. Note that equation (2) implies (3a). It follows that (2) can be alternatively written as

$$\max_{x, y_1, \ldots, y_n} \{B(y_1, \ldots, y_n) - C_0(x) - \Sigma_{i=1}^{n} C_i(s, y_1, \ldots, y_n):$$
$$\text{subject to } \Sigma_{i=1}^{n} \delta_{ik} y_i \leq \delta_{0k} x, k = 1, \ldots, m\}, \quad (3b)$$

where $C_i(s, y_1, \ldots, y_n)$ is defined in (3a). The optimization problem (3b) is a standard concave optimization problem subject to linear constraints. It can be expressed in terms of the corresponding Lagrangean

$$L = B(y_1, \ldots, y_n) - C_0(x) - \Sigma_{i=1}^{n} C_i(s, y_1, \ldots, y_n) + \Sigma_{k=1}^{m} \lambda_k [\delta_{0k}\, x - \Sigma_{i=1}^{n} \delta_{ik}\, y_i],$$

where $\lambda_k \geq 0$ is the Lagrange multiplier measuring the hedonic shadow price of the k-th component associated with the constraint $\Sigma_{i=1}^{n} \delta_{ik}\, y_i \leq \delta_{0k}\, x$. Assuming interior solutions, the first-order conditions characterizing the maximization problem (3b) give

$$\partial L/\partial x \equiv \Sigma_{k=1}^{m} \delta_{0k}\, \lambda_k - \partial C_0/\partial x = 0, \quad (4a)$$

$$\partial L/\partial y_i \equiv \partial B/\partial y_i - \partial C_i/\partial y_i - \Sigma_{k=1}^{m} \delta_{ik}\, \lambda_k = 0, \; i = 1, \ldots, n. \quad (4b)$$

Equations (4a) and (4b) are standard marginal conditions for efficient resource allocation. Equation (4a) states that, at the optimum, the marginal cost of producing the primary product x, $\partial C_0/\partial x$, must equal its marginal benefit represented by the shadow price of its m components $\Sigma_{k=1}^{m} \delta_{0k}\, \lambda_k$. Equation (4b) shows that, at the optimum, the marginal benefit of the i-th final product, $\partial B/\partial y_i$, must equal its marginal cost, as measured by $\partial C_i/\partial y_i$ plus the shadow price of its components $\Sigma_{k=1}^{m} \delta_{ik}\, \lambda_k$, $i = 1, \ldots, n$.

Competitive markets can support this efficient resource allocation. Under competition, market prices equal marginal benefit as well as marginal cost. Denote by q the competitive price of the primary product. And let p_i be the competitive price for the i-th final product. Under competitive markets, marginal cost pricing for the primary product implies $q = \partial C_0/\partial x$. Marginal benefit pricing for the i-th final product gives $p_i = \partial B/\partial y_i$. Substituting these expressions into (4a) and (4b) yields

$$q = \Sigma_{k=1}^{m} \delta_{0k}\, \lambda_k, \quad (5a)$$

$$p_i = \partial C_i/\partial y_i + \Sigma_{k=1}^{m} \delta_{ik}\, \lambda_k, \; i = 1, \ldots, n. \quad (5b)$$

Equation (5a) and (5b) establish the competitive relationships between market prices and the hedonic shadow price of the underlying components. Equation (5a) states that the price of the primary product equals the weighted sum of the hedonic prices (the λ_k's), where the weights are the component composition of the primary product (the δ_{0k}'s). Equation (5b) states that the price of the i-th final product equals the marginal cost $\partial C_i/\partial y_i$, plus the weighted sum of the hedonic prices (the λ_k's) with weights being the component composition of the i-th final product (the δ_{ik}'s). It indicates that the price of each final product p_i depends on the shadow prices of the m components, $(\lambda_1, \ldots, \lambda_m)$. This intuitive result shows that the pricing of final products reflects the underlying scarcity of the components.

Note that equations (5a) and (5b) correspond to competitive markets under marginal cost pricing rules. How would these results change under non-competitive scenarios? Corresponding to (5b), departure from competitive behavior can be represented by the following pricing rule

$$p_i = w_i + \partial C_i/\partial y_i + \Sigma_{k=1}^{m} \delta_{ik} \lambda_k, \quad i = 1, \ldots, n. \tag{5b'}$$

where w_i is a "price wedge" for the i-th market, i = 1, …, n. If $w_i > 0$, equation (5b') implies that price the i-th commodity <u>exceeds</u> its marginal cost $(\partial C_i/\partial y_i + \Sigma_{k=1}^{m} \delta_{ik} \lambda_k)$. This is clearly a departure from marginal cost pricing. The interpretation for w_i can vary depending on the situation considered. In the presence of government pricing policy, w_i could represent either a unit subsidy (e.g., obtained under a government price support program) or a unit quota rent generated by a production quota. In the presence of market power, the price wedge w_i can also reflect a departure from competitive pricing. This can arise if processing firms have market power (in which case their marginal revenue differs from the market price p_t). Also, it can represent a price discrimination scheme across markets (where increasing prices in markets with more inelastic demand would increase revenue) (e.g., Cox and Chavas). In these situations, from (5b'), the price wedge w_i is added to the marginal cost to reflect pricing in distorted markets. The empirical implications of these relationships are explored next.

3. Implications

This section develops the implications of hedonic pricing for the analysis of price dynamics. Evaluated at time t, the hedonic pricing relation (5b') gives

$$p_{it} = w_{it} + \partial C_{it}/\partial y_{it} + \Sigma_{k=1}^{m} \delta_{ik} \lambda_{kt}, \ i = 1, \ldots, n. \tag{6a}$$

where p_{it} is the price of commodity i at time t, w_{it} is a price wedge representing possible departures from competitive pricing, $\partial C_{it}/\partial y_{it}$ is the marginal processing cost of the i-th commodity at time t, and λ_{kt} is the hedonic shadow price of the k-th component at time t. Using a vector notation, this can be written as

$$p_t = c_t + Z \lambda_t, \tag{6b}$$

where $p_t = (p_{1t}, \ldots, p_{nt})'$ is a (n×1) vector of commodity prices at time t, $c_t = (w_{1t} + \partial C_{1t}/\partial y_{1t}, \ldots, w_{nt} + \partial C_{nt}/\partial y_{nt})'$ is a (n×1) vector at time t, $\lambda_t = (\lambda_{1t}, \ldots, \lambda_{mt})'$ is a (m×1) vector of hedonic prices of components at time t, and $Z = \{\delta_{ik}\}$ is a (n×m) matrix of commodity composition, where δ_{ik} is the quantity of the k-th component in the i-th commodity, k = 1, …, m, i = 1, …, n. The matrix Z is assumed constant over time, where product composition identifies the nature of each product. In the absence of price distortions, w = 0 and c_t represents the marginal processing cost. As noted above, policy distortions and/or the exercise of market power imply non-zero price wedges $w_t = (w_{1t}, \ldots, w_{nt})'$ which would be included in c_t.

Equation (6a) or (6b) provides a static relationship at time t between market prices and implicit component values. However, the vector p_t changes over time due to fluctuating market conditions. In order to model such changes, consider that p_t is a random vector, possibly non-stationary. However, we assume that $\Delta p_t = (p_t - p_{t-1})$ is covariance-stationary (i.e. that the mean and covariances of Δp_t are independent of time t). We assume that p_t can be represented by a (possibly non-stationary) vector autoregressive process of order h, VAR(h),

$$p_t = \beta_0 + \beta_1\, p_{t-1} + \ldots + \beta_h\, p_{t-h} + e_t \tag{7}$$

where β_0 is a (n×1) parameter vector, β_i is (n×n) parameter matrix for i = 1, …, h, and e_t is a (n×1) vector of error terms independently distributed and satisfying $e_t \sim N(0, \Omega)$.[2] While equation (6a) or (6b) are structural equations reflecting the role of hedonic pricing in a static framework, equation (7) can be interpreted as reduced form equations capturing price dynamics. The relationships between these two formulations are further explored below.

Using $\Delta p_t = (p_t - p_{t-1})$, equation (7) can be equivalently written as the "error-correction" representation

$$\Delta p_t = \beta_0 + \gamma_1\, \Delta p_{t-1} + \gamma_2\, \Delta p_{t-2} + \ldots + \gamma_{h-1}\, \Delta p_{t-h+1} + \pi\, p_{t-1} + e_t, \tag{8}$$

where $\gamma_j = -[\beta_{j+1} + \beta_{j+2} + \ldots + \beta_h]$ for j = 1, …, h-1, and $\pi = [-I + \Sigma_{i=1}^{h} \beta_i] = -B(1)$ (Hamilton, p. 580). It follows from (8) that Δp_t can be stationary only if $\text{rank}(\pi) \equiv r < n$. In this case, π can be written as $\pi = B\, A$, where B is (n×r) matrix of rank r and A is a (r×n) matrix of rank r, A' being a basis of the column space spanned by π'. This represents a situation of cointegration (e.g., Hamilton, chapters 19 and 20). From the Granger representation theorem, the r rows of the A matrix can be interpreted as cointegration vectors where [A p_t] is stationary. This means that there exist r linear combinations of the p_t's that are stationary, thus establishing r long-term relationships among prices in p_t.

Next, consider the hedonic pricing equation (6b). Since Z is (n×m) matrix, we have rank(Z) ≤ min(n, m). Let K' be a basis of the null space of Z', where K Z = 0. Of particular interest is the situation where rank(Z) < n, in which case the dimension of the null space of Z' is [n - rank(Z)] > 0, i.e. the matrix K is of dimension ([n - rank(Z)]×n). Then, premultiplying the hedonic pricing relation (6b) by K gives

$$K\, p_t = K\, c_t. \tag{9}$$

Equation (9) implies that a linear combination of the prices p_t depends only on c_t.[3] In other words, the linear combination [K p_t] has been purged of all effects of the changing implicit component prices λ_t. In the case where [K c_t] is stationary, this implies that [K p_t] is also stationary, even if p_t is not stationary. Then, the rows of the matrix K are <u>cointegration vectors</u> for the (n×1) price vector p_t. This means that hedonic pricing generates long-term relationships among market prices p_t. It also shows the exact nature of these long-term relationships. In addition, from equation (9), finding evidence that [K p_t] is not white-noise would mean that the dynamics of p_t are due in part to the dynamics of c_t. As noted above, equation (9) holds under competition as well as under market distortions. In the former case, c_t is the marginal processing cost. In the latter case, under price distortions generated by government policy and/or the exercise of market power, c_t also includes the price wedges w_t representing departures from competitive pricing. These key results will be used below in the empirical investigation of hedonic pricing.

4. Application to U.S. Dairy Prices

In this section, we apply our analysis to the U.S. dairy markets. We investigate the dynamics of dairy commodity prices and their relationship with hedonic pricing of its components. The analysis focuses on prices of three dairy commodities: American cheese, butter, and non-fat dry milk, over the period January 1970- June 1999. Monthly data on the corresponding wholesale prices were obtained from USDA.[4]

Our analysis relies on the VAR(h) specification given in equation (7). We extend this specification in several ways. First, we introduce a time trend t and quarterly dummy variables (Q_i equals 1 for the i-th quarter, zero otherwise) in the model. The time trend accounts for the effects of inflation and other long-term trends. The quarterly dummy variables Q_i account for seasonality effects in the dairy markets. Second, over the last few decades, a government price support program for milk has influenced U.S. dairy markets. The program consists in government purchases of American cheese, butter and non-fat dry milk as means of stimulating demand whenever the milk price falls below its price support level. Assuming that government purchases have a significant effect on the dynamics of dairy prices, we consider two regimes: a market regime (M) when prices are determined by supply-demand conditions, and a government regime (G) when government intervenes in the market. We represent these two regimes by dummy variables D_{it}, where D_{it} equals zero if the i-th commodity is in the market regime at time t, and equals 1 if it is in the government regime at time t. For each period, the government regime (when the price support is active) is identified by the extent of government purchase of each commodity compared to its total consumption. Thus, for the i-th commodity at time t, we define $D_{it} = 1$ (corresponding to the government regime) if the ratio of government purchases of the commodity at time t is greater than 10 percent of its total consumption.[5] Otherwise, we let $D_{it} =$

0, corresponding to the market regime. During the sample period, government intervention (represented by $D_{it} = 1$) was present 81 percent of the time in the non-fat dry milk market, 47.2 percent of the time in the butter market, and 22.2 percent of the time in the American cheese market.

For the i-th commodity price at time t, this generates the following specification

$$p_{it} = \beta_{0i} + \beta_i\, t + \beta_{Q1i}\, Q_1 + \beta_{Q2i}\, Q_2 + \beta_{Q3i}\, Q_3 + \Sigma_{k=1}^{h}\Sigma_{j=1}^{n}\ \beta_{ijk}\, p_{j,t-k}$$

$$+ \beta_{D0i}\, D_{it} + \beta_{Di}\,(t \cdot D_{it}) + \Sigma_{k=1}^{h}\Sigma_{j=1}^{n}\ \beta_{Dijk}\,(D_{jt} \cdot p_{j,t-k}) + e_{it}, \qquad (10)$$

where e_{it} is an error term distributed with mean zero and finite variance, i = 1, …, n. Equation (10) is a VAR(h) specification that includes a time trend t, seasonal dummies (Q_1, Q_2, Q_3), and the dummy variables D_{it} that allow for different price dynamics between the two regimes M and G.[6] In equation (10), the differences across regimes are represented by the parameters β_{D0i}, β_{Di} and β_{Dijk}. The parameter β_{D0i} is an intercept shifter, while β_{Di} is a slope shifter associated with the time trend t across regimes. The parameters β_{Dijk} allow the marginal effects of price $p_{j,t-k}$ on p_{it} to be affected by the regime D_{jt} at time t. As a result, price dynamics vary between regimes. The specification (10) means that, at time t, government intervention in any market can influence price determination in all markets. It reflects the role of government intervention in the joint determination of prices across markets. Equation (10) provides the econometric specification used below in the empirical investigation of price dynamics in U.S. dairy markets.

5. Empirical Results

In this section, we investigate the dynamic properties of U.S. dairy prices, using the data described in the previous section. First, the stationarity of prices for American cheese, butter and non-fat dry milk is investigated. This is done using an augmented Dickey-Fuller (ADF) test of the null hypothesis that each price exhibits a unit root. The ADF test was implemented based on an AR(7) representation of prices including a time trend and seasonal dummy variables.[7] The order 7 was chosen as it maximized the adjusted R^2. The ADF test statistic for this hypothesis is 2.818, 3.102 and 5.917, respectively, for American cheese, butter and non-fat dry milk. At the 5 percent significance level, the critical value of the test is 3.43. Thus, we fail to reject the null hypothesis of a unit root for American cheese and butter. This suggests that these prices are nonstationary. The hypothesis of a unit root is rejected at the 5 percent significance level for non-fat dry milk, indicating that the price of non-fat dry milk is stationary.[8]

As indicated in equation (6a) or (6b), hedonic pricing means that market prices p_t depend on product composition Z and the shadow values of the components λ_t. To gain some insights on the role of hedonic pricing in dairy markets, we focus on the two most important components of dairy products: fat and protein. The standard composition of American cheese, butter and nonfat dry milk are $Z = \{\delta_{ik}\} = \begin{bmatrix} 0.3397 & 0.2462 \\ 0.8111 & 0.0085 \\ 0.0075 & 0.3563 \end{bmatrix}$, where k = {fat, protein}(USDA, 1976,1980). This means, for example, that the standard composition of American cheese is 0.3397 lb. of fat and 0.2462 lb. of protein per pound of cheese. First, the fat content of non-fat dry milk is very low. From equation (6a), the evidence of stationarity for non-fat dry milk price can then be interpreted as indirect evidence that the shadow price of protein has been stationary during the sample period. This suggests that the evidence of non-stationarity for American cheese and butter prices may be due to the non-stationarity of the shadow price of fat over the last few decades. Second, we have seen in section 3 that hedonic pricing can generate cointegration relationships among dairy prices. A basis of the null space of Z' is K' = $\begin{bmatrix} -0.7823 \\ 0.3227 \\ 0.5328 \end{bmatrix}$. As indicated in equation (9), under hedonic pricing, the vector K = [-0.7823, 0.3227, 0.5328] would be a cointegration vector for prices p_t if c_t in (9) is stationary. More generally, from (9), hedonic pricing implies that [K p_t] reflects solely the dynamics of c_t, at the exclusion of component prices effects. In order to investigate the stationarity of [K p_t], the ADF test was used. It was implemented for AR representations of [K p_t], including a time trend and seasonal dummy variables. The test results showed statistical evidence against the null hypothesis regardless of the AR order. For example, the ADF test statistic for an AR(3) representation is equal to -6.192. The critical value at the 5 percent significance level equals 3.43. Therefore, we reject the null hypothesis of a unit root for [K p_t]. This means that there is strong statistical evidence that [K p_t] is stationary. Since we reported evidence that the prices p_t are nonstationary, this implies that the vector K is indeed a cointegration vector for the dairy prices p_t. This has two implications. First, this provides indirect evidence that c_t (reflecting marginal processing cost and/or price distortions) may be stationary. From equation (9), if c_t is stationary, then the linear transformation [K p_t] eliminates the (possibly nonstationary) effects of component prices and would necessarily be stationary. Second, finding that the vector K is a cointegration vector for prices p_t provides evidence that U.S. dairy markets behave in a way consistent with hedonic pricing at least in the long-term. This issue is further explored below using Johansen's approach.

An AR(3) representation of [K p_t], including a time trend and seasonal dummies, was estimated.[9] The results are presented in table 1. Most estimated coefficients are significant. The AR(3) model has an R^2 of 0.6641. It suggests that lagged values have significant predictive power for [K p_t]. The nature of dynamics of [K p_t] was evaluated by calculating dynamic multipliers (also referred to as impulse response function), measuring the delayed impact of a shock in the error term after j periods. They are reported in figure 1. Figure 1 shows that there are significant short-term dynamics in [K p_t]. It means that there are significant short-term changes in dairy prices p_t that cannot be explained by the effects of component values. In other words, even if long-term relationships exist among dairy prices (e.g. due to hedonic pricing), short-term dynamics still allows for adjustments that depart from these long-term relationships. It means that, at least in the short term, dairy price dynamics are <u>not</u> determined solely by their underlying component prices. This can raise questions about the empirical validity of <u>static</u> component pricing formulas in a changing world.

Next, the VAR(h) specification in (10) is estimated for the three dairy prices. The order of the VAR process was chosen using the Schwarz criterion.[10] The Schwarz criterion suggested h = 3. Thus, the analysis presented below is based on a vector autoregressive process of order three. The model parameters are consistently estimated by least squares.[11] The explanatory variables being identical for the three commodity prices, the least squares estimates are also the maximum likelihood estimates under homoscedasticity.[12] The VAR(3) estimates are presented in table 2. The econometric results indicate that the model provides a good fit to the data. The R^2 varies between 0.9803 for American cheese to 0.9879 for butter. Most coefficients are significantly different from zero, indicating the presence of significant dynamics.

The model provides a basis to investigate whether price dynamics vary between the market regime ($D_{it} = 0$) and the government regime ($D_{it} = 1$). The null hypothesis of that $\beta_{Dijk} = 0$ is tested using a standard F-test to examine the overall effects of government intervention on dairy price dynamics.[13] The F-test statistic equals 3.730, with 27 and 957 degrees of freedom. The corresponding p-value for this test is 0.001. Therefore, we find strong evidence of structural change in dairy price dynamics between the two regimes. Next, the same hypothesis is tested for each commodity (using a F test) to examine the source of structural change. The p-value for the F test is 0.034, 0.1325 and 0.001, for American cheese, butter and non-fat dry milk, respectively. Thus, using a 5 percent significance level, we reject the null hypothesis that the two regimes are identical for American cheese and non-fat dry milk. For these two commodities, this provides statistical evidence that government intervention affects the dynamics of prices. For butter, the evidence is weaker: the null hypothesis is rejected only at the 13 percent significance level. Overall, these results indicate that price dynamics tend to differ between the market regime and the government regime.

The implications of the price dynamics associated with the estimated VAR(3) were evaluated. The dynamic multipliers reflecting the effects of a shock in the error terms are presented in figure 2. The analysis is done separately for the market regime ($D_{it} = 0$, $i = 1, 2, 3$) and the government regime ($D_{it} = 1$, $i = 1, 2, 3$). This provides useful information on the dynamic interaction effects of prices across markets. Figure 2a shows the dynamic effects of a shock in the American cheese price. It suggests that those dynamic effects are quite different across the two regimes. It shows that the American cheese market has a significant impact on both butter and non-fat dry milk markets. This impact is persistent under the government regime. However, under the market regime, this impact is temporary as it converges to zero in the long run. Figure 2b illustrates the effects of a shock in the butter price. Again, it identifies different price adjustment behavior across regimes: the dynamic effects are persistent under the government regime, but temporary under the market regime. Finally, figure 2c shows that the effects of a shock in the non-fat dry milk price. It suggests that in the short run, significant dynamics take place in all three markets. Also, the long-term effects of a shock in the non-fat dry milk price on American cheese and butter prices are stronger under the government regime. In general, the results illustrate the linkages among dairy prices and their joint dynamics under each regime.

They show that a price shock is more quickly absorbed under the market regime, suggesting less flexibility under the government regime.

Next, an analysis of cointegration among the three dairy prices is conducted. Johansen's tests concerning the existence of cointegration relationships in p_t are performed for each regime, based on our VAR(3) representation. They involve the maximum likelihood estimation of cointegrated systems (Hamilton, chapter 20; Johansen). The Johansen tests are implemented as follows. In a first step, the least squares residuals u_t are obtained from regressing Δy_t on (Δy_{t-1}, Δy_{t-2}, t, Q_1, Q_2, Q_3) along with the terms involving the dummy variables D in equation (10) (i.e., D_{it}, the interactions of D_{it} with t, and the interactions of D_{jt} with $p_{j,t-k}$). And the least squares residuals v_t are obtained from regressing y_{t-1} on the same variables. In a second step, the sample variance-covariance matrices for u and v are obtained: Σ_{uu} for the variance of u, Σ_{vv} for the variance of v, and Σ_{uv} for the covariance (u, v). Then, the eigenvalues of $[\Sigma_{vv}^{-1}\, \Sigma_{uv}'\, \Sigma_{uu}^{-1}\, \Sigma_{uv}]$ are calculated. They provide the basis for implementing Johansen tests (see Hamilton; Johansen). In a third step, obtain the eigenvectors of $[\Sigma_{vv}^{-1}\, \Sigma_{uv}'\, \Sigma_{uu}^{-1}\, \Sigma_{uv}]$, which provide a basis for the cointegration vectors A (as defined in section 3). When applied as described above, this allows testing for cointegration under the market regime (where $D = 0$). To test for cointegration under the government regime (where $D = 1$), we apply the above procedure after replacing D by (1-D). The Johansen likelihood ratio tests involve a maximal eigenvalue test, and a trace test. The tests rely on the Osterwald-Lenum critical values reported in Hamilton (p. 767-768). First, we consider the government regime (with $D_{it} = 1$ under an active price support). The hypothesis of no cointegration (tested against the alternative of a one cointegration relationship) is rejected at the 5 percent significance level: the eigenvalue test statistic is 53.37 with a critical value of 20.97;[14] and the trace test statistic is 53.87 with a critical value of 29.68. Thus, under the government regime, there is strong evidence that at least one cointegration relationship exists in the p_t. However, the eigenvalue and trace tests fail to find statistical evidence that there are more than one cointegration relationships in the government regime.[15] This suggests that that there is a single cointegration relationship among the three dairy prices in the presence of the government price support program. The Johansen's approach estimates the corresponding cointegration vector to be A_G = [-0.7087, 0.2430, 0.6624].

Second, we consider the market regime (with $D_{it} = 0$). Again, the hypothesis of no cointegration (tested against the alternative of one cointegration relationship) is rejected at the 5 percent significance level: the eigenvalue test statistic is 81.22 with a critical value of 20.97;[16] and the trace test statistic is 149.53 with a critical value of 29.68. Thus, under the market regime, there is strong evidence that at least one cointegration relationship exists in the p_t. There is also evidence that there are more than one cointegration relationship. Testing that there are two cointegration relationships (against the alternative of a single cointegration relationship) yields a statistic of 45.85 and 68.30 for the eigenvalue test and the trace test, respectively. At the 5 percent significance level, the corresponding critical values are 13.07 and 15.41. This provides statistical evidence that that there are at least two cointegration relationships among the prices p_t. Finally, testing that there are three cointegrating vectors (against the alternative of two relationships) gives a statistic of 22.46 for both the eigenvalue test and the trace test, with a critical value of 3.76 at the 5 percent significance level. We conclude that, under the market regime, there is strong evidence of three cointegration relationships among the three dairy prices. The Johansen's approach estimates the corresponding cointegration vectors to be A_M =

$$\begin{bmatrix} -0.5412 & 0.1605 & 0.8255 \\ -0.9155 & 0.3635 & -0.1722 \\ 0.3126 & 0.7655 & 0.5613 \end{bmatrix}.$$

These results suggest that there are significant differences in dairy price dynamics between the market regime and the government regime. Finding that the number of cointegration relationships is larger in the market regime than the government regime is new and interesting. It indicates that the long-term relationships among dairy prices vary across regimes. This raises the question about the exact nature of these relationships.

It is instructive to compare the cointegration vector K = [-0.7823, 0.3227, 0.5328] (derived earlier in the context of hedonic pricing) with the cointegration vectors A_G and A_M estimated above from time series modeling. First, consider the government regime (G). Note that A_G is very close to K. We interpret this as evidence that the cointegration relationship A_G estimated under the government regime is consistent with hedonic pricing. The fact that we found evidence of a single cointegration relationship suggests that hedonic pricing is the only long-term relationship that links dairy commodities under the government regime.

Second, consider the market regime (M). Note that the first row of A_M is close to K. We interpret this as evidence that the first cointegration relationship A_M estimated under the market regime is consistent with hedonic pricing. Thus, <u>in either regime</u>, hedonic pricing appears to play an important role in long-term price determination in the U.S. dairy markets. However, under the market regime, we found evidence of <u>three</u> long-term relationships among dairy prices. While we associate the first cointegration vector to hedonic pricing, our empirical evidence suggests that a departure from government intervention creates new long-term relationships. At this point, the exact economic source and nature of these new relationships are unclear. Possible explanations may relate to private inventory management and/or the exercise of market power. To the extent that dairy markets have seen a trend toward less government involvement, this indicates a need for further research to investigate this new type of market behavior.

6. Concluding Remarks

We have presented a dynamic analysis of market prices and of the linkages with the shadow pricing of underlying components. When components are found in fixed proportions in the composition of market commodities, we have shown that hedonic pricing can generate cointegration relationships among these prices. This was used to investigate the determination of U.S. prices for American cheese, butter and non-fat dry milk. The econometric analysis provides useful information on the role of hedonic pricing in the determination of dairy market prices. For each market, our dynamic analysis distinguishes between a government regime (with significant government purchases on the domestic market) and a market regime. We find evidence that long-term price relationships are consistent with hedonic pricing of dairy commodities. This evidence is present whether the government intervenes in domestic markets or not. However, we found significant differences in these long-term relationships across regimes. Under the government regime, a single cointegration relationship was uncovered. This is interpreted to mean that hedonic pricing is solely responsible for determining the long-term relationships among dairy commodity prices when the milk price support program is active. Alternatively, under the market regime (when the milk price support is inactive), we found evidence of three long-term relationships among dairy prices. While the first cointegration relationship was attributed to hedonic pricing, two other long-term relationships emerged. This indicates that there are significant qualitative changes in the determination of dairy market prices in the absence of the government price support program. At this point, the exact motivation for such changes remains unclear. In a period of decreased reliance of government programs, this suggests a need for further research on this issue.

Our analysis also uncovered evidence of significant short-term dynamics that are unrelated to the dynamics of hedonic prices. This shows that, at least in the short run, dairy market prices would not behave in a way consistent with static component pricing formulas. This is somewhat troublesome since Milk Marketing Orders (MMO) currently rely on such formulas in implementing classified pricing. Our analysis suggests that these classified pricing schemes would fail to reflect the dynamic price determination process in U.S. dairy markets.

While providing evidence supporting the importance of hedonic pricing for dairy components, our analysis has also shown that other factors (besides component values) are influencing U.S. dairy price dynamics, both in the short term and in the long term. These factors may include the allocation of labor and capital, private inventory management, as well as the possibility of non-competitive behavior. Future research is needed to investigate the role of such factors in the functioning of dairy markets.

References

Andrews, Donald W.K. "Tests for Parameter Instability and Structural Change with Unknown Change Point." Econometrica 61(July 1993): 821-856.

Andrews, Donald W.K. and W. Ploberger. "Optimal Tests When a Nuisance Parameter is Present Only under the Alternative" Econometrica 62(November 1994): 1383-1414.

Ball, M.J. and R.M. Kirwan. "Urban Housing Demand: Some Evidence from Cross-Sectional Data." Applied Economics 9(1977):343-366.

Banerjee, A., J.J. Dolado, J.W. Galbraith, and D.F. Hendry. Cointegration, Error Correction, and the Econometric Analysis of Nonstationary Data. Oxford, Oxford University Press, 1993.

Becker, G. S. "A Theory of the Allocation of Time." Economic Journal 75(1965):493-517.

Brorsen, B.W., J.T. Akridge, M.A. Boland, S. Mauney and J.C. Forrest. "Performance of Alternative Component Pricing Systems for Pork." Journal of Agricultural and Applied Economics 30(Dec. 1998): 313-24.

Buccola, S. and Y. Iizuka. "Hedonic Cost Models and the Pricing of Milk Components." American Journal of Agricultural Economics 79(May 1997): 452-62.

Cox, T.L. and J.P. Chavas. "An Interregional Analysis of Price Discrimination and Domestic Policy Reform in the U.S. Dairy Sector." American Journal of Agricultural Economics (forthcoming).

Deaton, A. and J. Muellbauer. Economics and Consumer Behavior. New York, Cambridge University Press, 1980.

Dhrymes, Phoebus J. "Price and Quality Changes in Consumer Capital Goods: An Empirical Study." in Price Indexes and Quality Change Zvi Griliches, ed., New York, Cambridge University Press, 1971.

Epple, Dennis. "Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products." Journal of Political Economy 95(1987):59-80.

Gillmeister, W.J., R.D. Yonkers and J.W. Dunn. "Hedonic Pricing of Milk Components at the Farm Level." Review of Agricultural Economics 18(May 1996): 181-92.

Gorman, W.M. "A Possible Procedure for Analyzing Quality Differentials in the Egg Market." Mimeo, Iowa State College, Ames, 1956.

Griliches, Z. "Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change." in Price Indexes and Quality Change: Studies in New Methods of Measurement Z. Griliches, ed., Harvard University Press, Cambridge, Mass., 1971.

Hamilton, J.D. Time Series Analysis. Princeton, NJ, Princeton University Press, 1994.

Jacobson, R.E. and F.E. Walker. "Efficiency Considerations in Butterfat Differential and Component Pricing of Milk." American Journal of Agricultural Economics 55(May 1973): 214-16.

Johansen, S. Likelihood-Based Inference in Cointegrated Vector Autoregressive Models. New York, Oxford University Press, 1995.

Lancaster, K. J., "A New Approach to Consumer Theory." Journal of Political Economy 74(1966): 132-57.

Lancaster, K. J. Consumer Demand: A New Approach. New York, Columbia University Press, 1971.

Lenz, J.E., R. Mittelhammer and S. Hongqi. "Retail-Level Hedonics and the Valuation of Milk Components." American Journal of Agricultural Economics 76(Aug. 1994): 492-503.

Lucas, Robert E.B. "Hedonic Price Functions." Economic Inquiry 13(1975): 157-178.

Luenberger, David G. Microeconomic Theory McGraw-Hill, Inc., New York, 1995.

Maddala, G.S. and I.M. Kim. Unit Roots, Cointegration, and Structural Change. Cambridge, Cambridge University Press, 1998.

Palmquist, Raymond B. "Estimating the Demand for the Characteristics of Housing." Review of Economics and Statistics 66(1984):394-404.

Perrin, R.K. "The Impact of Component Pricing of Soybeans and Milk." American Journal of Agricultural Economics 62(Aug. 1980): 445-55.

Perron, Pierre. "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis." Econometrica 57(November 1989): 1361-1401.

Rosen, S., "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." Journal of Political Economy 82(1974):34-55.

Schwart, R.B. Jr. "The Impact of Component Pricing of Soybeans and Milk: Comment." American Journal of Agricultural Economics 67(November 1985): 881-882.

Stigler, G. J., and G. S. Becker. "De Gustibus non est Disputandum." American Economic Review 67(March 1977):76-90.

St-Pierre, N.R and G.M. Scobie. "The Component Pricing of Milk Revisited." American Journal of Agricultural Economics 69(Aug. 1987): 693-96.

Updaw, N.J. "Social Costs and Benefits from Component Pricing of Soybeans in the United States." American Journal of Agricultural Economics 62(Nov. 1980): 647-55.

USDA. "Dairy Market News." Agricultural Marketing Service, various issues.

USDA. "Composition of Milk Products." Agricultural Handbook, No. 51, Agricultural Research Service, Revised November 1976 and September 1980.

Vogelsang, Timothy J. "Wald-Type Tests for Detecting Breaks in the Trend Function of a Dynamic Time Series." Econometric Theory 13(1997): 818-849.

Table 1. Estimate of AR(3) for [K p_t], January 1970-June 1999.

parameters	estimates	standard errors
Intercept	-2.249***	(0.621)
[K p_{t-1}]	0.989***	(0.051)
[K p_{t-2}]	-0.567***	(0.068)
[K p_{t-3}]	0.309***	(0.052)
Q_1	0.333	(0.563)
Q_2	1.103**	(0.560)
Q_3	-0.278	(0.567)
T	-0.008***	(0.002)
	R^2 = 0.671	
	Adjusted R^2 = 0.664	

Note: The (3×1) vector p_t includes prices for American cheese, butter and nonfat dry milk at time t. The matrix K' is a basis of the null space of the commodity composition matrix Z' = $\{\delta_{ik}\}$', satisfying K Z = 0. Standard errors are presented in parentheses, and asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (*) level, respectively.

Table 2. Parameter Estimate for VAR(3) on the prices of American Cheese (P_{AC}), Butter (P_{BU}), and Nonfat Dry Milk (P_{ND}), January 1970-June 1999.

parameters	Price of American Cheese (P_{AC}) estimate	Price of American Cheese (P_{AC}) standard error	Price of Butter (P_{BU}) estimate	Price of Butter (P_{BU}) standard error	Price of Nonfat Dry Milk (P_{ND}) estimate	Price of Nonfat Dry Milk (P_{ND}) standard error
Intercept	10.032***	(2.335)		(4.487)	7.902***	(1.832)
$P_{AC,t-1}$	1.103***	(0.060)	0.023	(0.114)	0.245***	(0.047)
$P_{AC,t-2}$	-0.591***	(0.080)	0.170	(0.154)	-0.165***	(0.063)
$P_{AC,t-3}$	0.174***	(0.055)	-0.244**	(0.106)	0.040	(0.043)
$P_{BU,t-1}$	0.157***	(0.029)	1.297***	(0.055)	-0.016	(0.022)
$P_{BU,t-2}$	-0.035	(0.044)	-0.668***	(0.084)	0.019	(0.034)
$P_{BU,t-3}$	-0.020	(0.031)	0.293***	(0.060)	-0.035	(0.025)
$P_{ND,t-1}$	0.355***	(0.080)	0.052	(0.154)	1.394***	(0.063)
$P_{ND,t-2}$	-0.284**	(0.120)	-0.206	(0.230)	-0.986***	(0.094)
$P_{ND,t-3}$	0.036	(0.083)	0.131	(0.159)	0.241***	(0.065)
$D_{AC,t}{\cdot}P_{AC,t-1}$	0.055	(0.371)	0.581	(0.714)	-0.042	(0.291)
$D_{AC,t}{\cdot}P_{AC,t-2}$	0.098	(0.607)	-0.044	(1.167)	0.023	(0.476)
$D_{AC,t}{\cdot}P_{AC,t-3}$	-0.131	(0.388)	-0.565	(0.745)	0.038	(0.304)
$D_{BU,t}{\cdot}P_{BU,t-1}$	0.041	(0.131)	-0.233	(0.252)	-0.015	(0.103)
$D_{BU,t}{\cdot}P_{BU,t-2}$	-0.327	(0.206)	0.403	(0.396)	-0.091	(0.161)
$D_{BU,t}{\cdot}P_{BU,t-3}$	0.289**	(0.135)	-0.074	(0.259)	0.096	(0.106)
$D_{ND,t}{\cdot}P_{ND,t-1}$	-0.006	(0.142)	-0.086	(0.273)	-0.458***	(0.111)
$D_{ND,t}{\cdot}P_{ND,t-2}$	0.251	(0.219)	0.028	(0.420)	0.874***	(0.172)
$D_{ND.t}{\cdot}P_{ND,t-3}$	-0.082	(0.137)	0.123	(0.263)	-0.195*	(0.107)
$D_{AC,t}$	-0.914	(4.395)	0.131	(8.446)	0.863	(3.448)
$D_{BU,t}$	-1.612	(1.743)	-10.433***	(3.350)	1.129	(1.367)
$D_{ND,t}$	-6.644***	(2.416)	0.700	(4.642)	-7.866***	(1.895)
Q_1	-0.005	(0.742)	2.397*	(1.426)	-0.778	(0.582)
Q_2	0.395	(0.696)	4.867***	(1.338)	0.334	(0.546)
Q_3	1.722***	(0.662)	4.848***	(1.272)	-0.679	(0.519)
$t \cdot D_{AC,t}$	-0.015	(0.027)	0.031	(0.052)	0.022	(0.021)
$t \cdot D_{BU,t}$	0.007	(0.005)	-0.010	(0.097)	0.002	(0.004)
$t \cdot D_{ND,t}$	-0.042***	(0.015)	-0.016	(0.028)	-0.060***	(0.012)
T	0.040***	(0.013)	0.027	(0.024)	0.062***	(0.010)
N	348		348		348	
Adjusted R^2	0.9803		0.9879		0.9846	

Note: Standard errors are provided in parentheses, N denotes the number of observations, and asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (*) level, respectively.

Figure 1. Dynamic Multiplier for [K p_t].

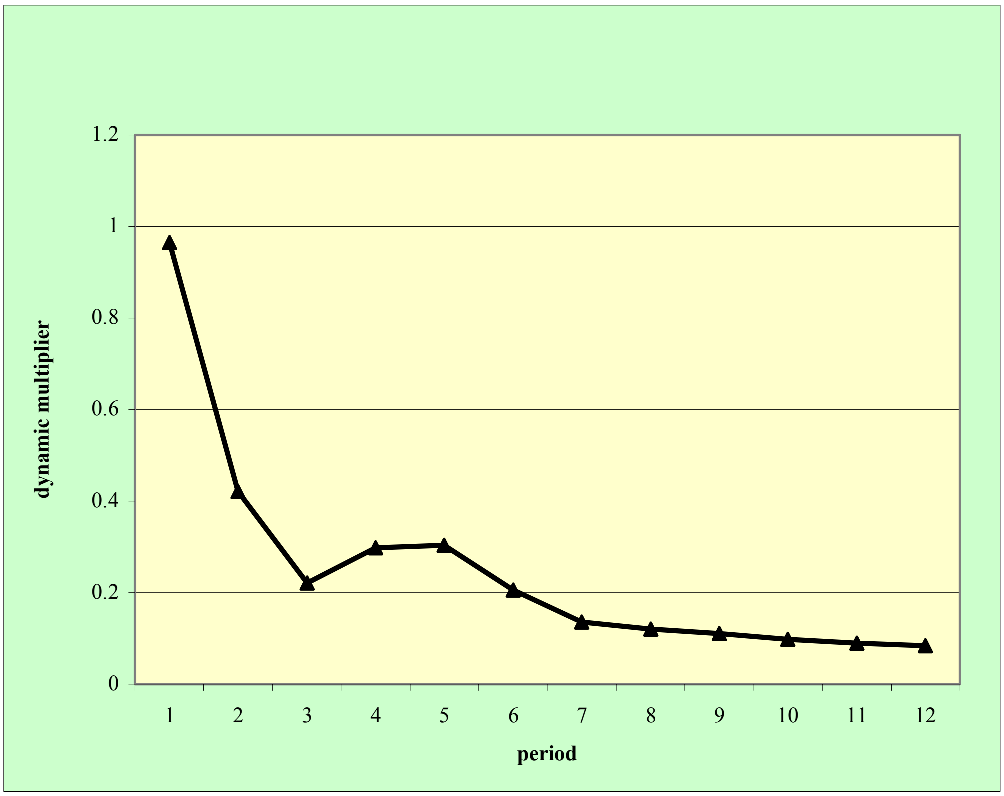
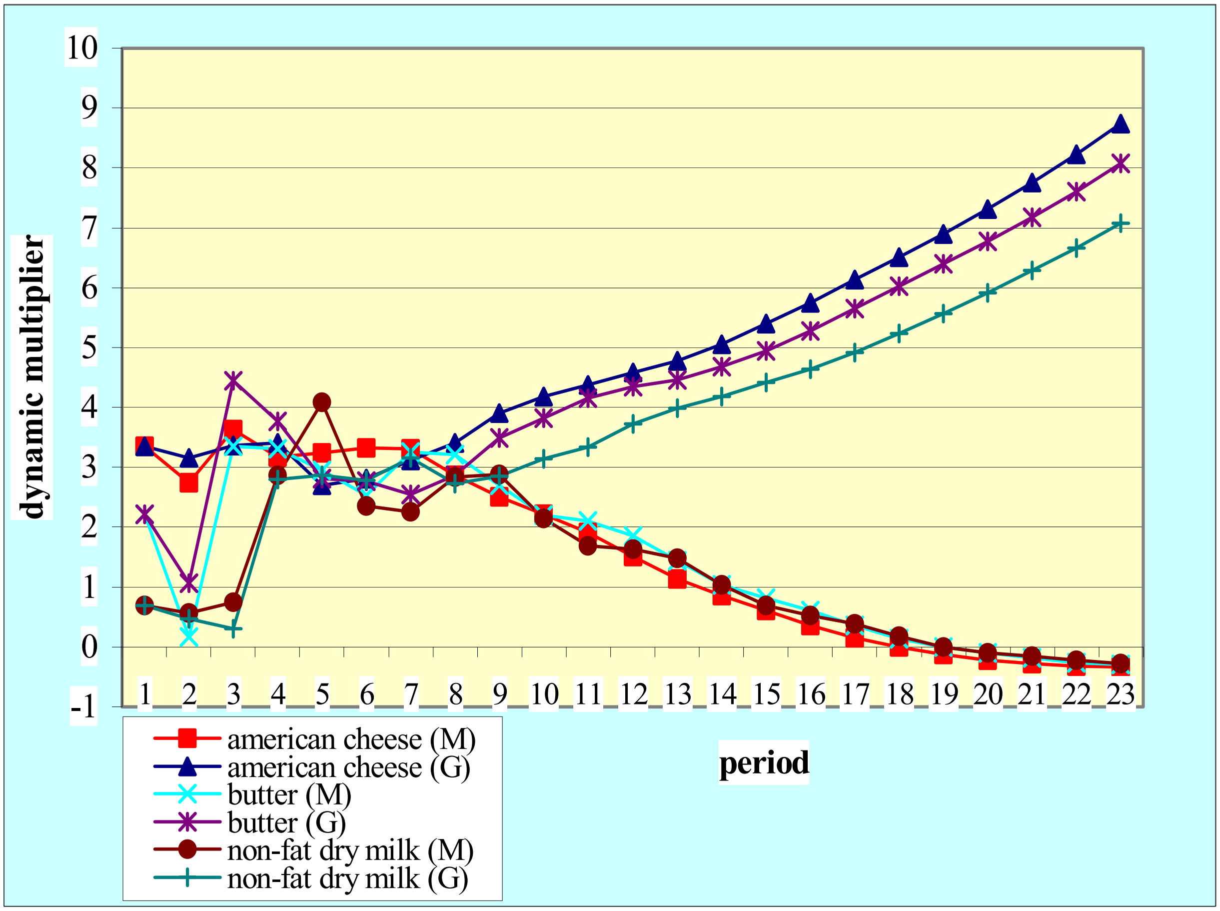
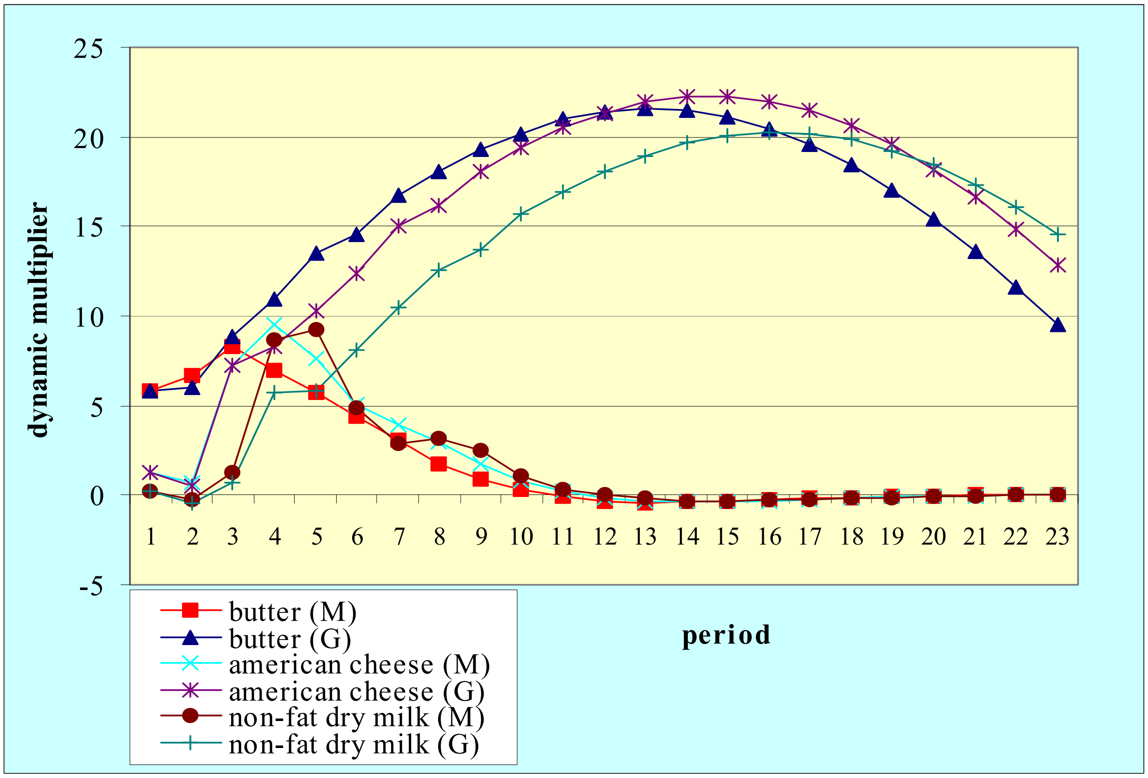


Figure 2a: Dynamic multipliers due to a shock in the price in American cheese.



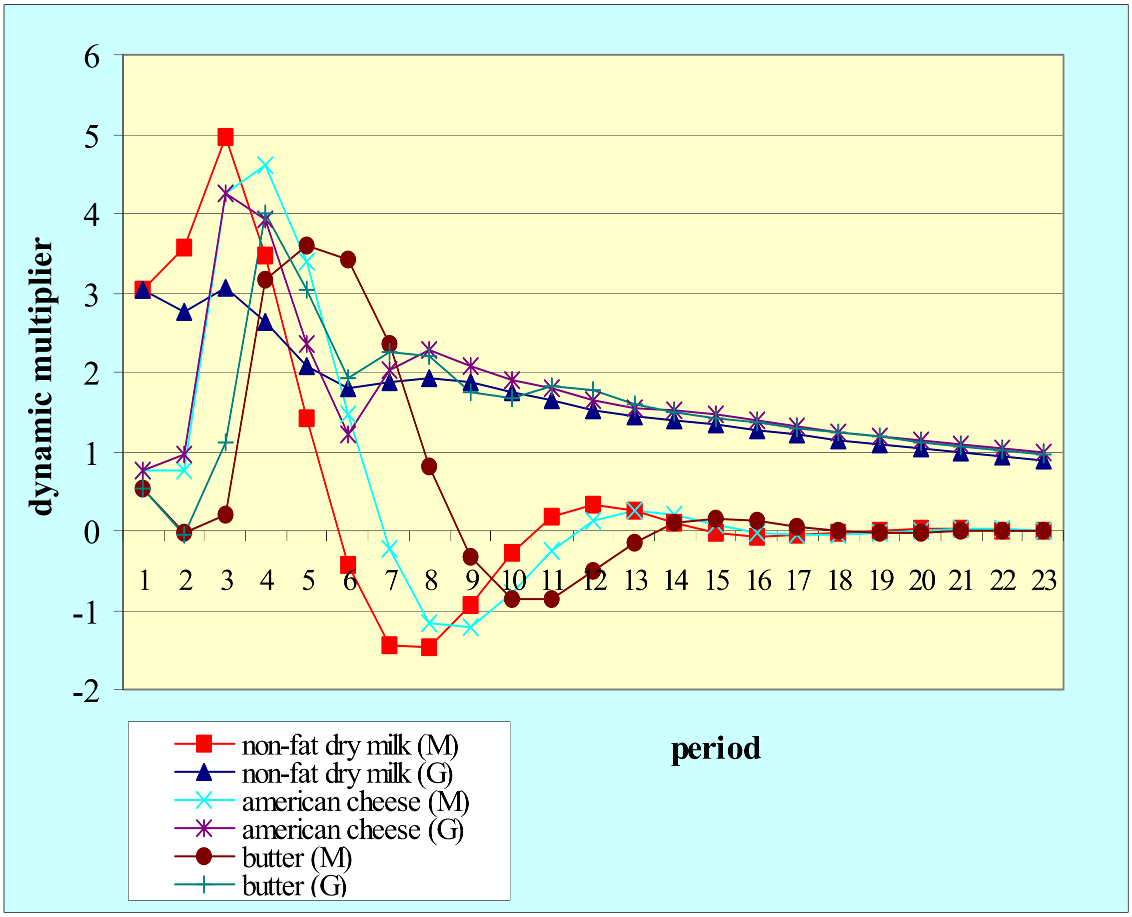
Note: For each commodity, (M) stands for market regime, while (G) represents government (price support) regime.

Figure 2b- Dynamic multipliers due to a shock in the price of butter.



<u>Note</u>: For each commodity, (M) stands for market regime, while (G) represents government (price support) regime.

Figure 2c- Dynamic multipliers due to a shock in the price of non-fat dry milk.



Note: For each commodity, (M) stands for market regime, while (G) represents government price support) regime.

Footnotes

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[1] See Luenberger (chapters 4 and 6) for a discussion of the benefit function $B(\cdot)$ and its use in efficiency analysis.

[2] Note that equation (7) can be alternatively written as $B(L)\, p_t = \beta_0 + e_t$, where $B(L) = [I - \beta_1 L - \beta_2 L^2 - \ldots - \beta_h L^h]$, and L is the lag operator satisfying $L^i\, p_t = p_{t-i}$. The VAR process (7) is covariance-stationary if the roots of $|B(L)| = 0$ are all outside the unit circle (Hamilton, p. 259). It has at least one unit root if $|B(1)| = 0$, in which case the VAR is non-stationary.

[3] Equation (6a) considers that hedonic component prices λ_t are the same across all commodities. This implicitly assumes that the reallocation of components across commodities is costless. Note that the analysis could be extended to allow for costly component reallocation. To see that, assume that equation (6a) takes the form

$$p_{it} = w_{it} + \partial C_{it}/\partial y_{it} + \Sigma_{k=1}^{m} \delta_{ik}\, \lambda_{ikt},\ \ i = 1, \ldots, n. \quad (6a')$$

where $\lambda_{ikt} = \lambda_{kt} + b_{ik}$. This allows the shadow component prices λ_{ikt} to vary across commodities. However, the evolution of component prices is "parallel over time" in the sense that there exists values λ_{kt} such that $[\lambda_{ikt} - \lambda_{kt}]$ is constant over time for each commodity i and for each component k. If $b_{jk} = 0$ for a given j and k, then λ_{jk} is the shadow price of the k-th component in the j-th commodity. Then, if positive, b_{ik} can be interpreted (for $i \neq j$) as the marginal cost of transferring the k-th component from the j-th commodity to the i-th commodity. This implies that equation (6b) becomes $p_t = c_t + Z\, \lambda_t + \Sigma_{k=1}^{m} \delta_{ik}\, b_{ik}$. Given that $K\, Z = 0$, this yields

$$K\, p_t = \alpha + K\, c_t, \quad (9')$$

where $\alpha = K\, [\Sigma_{k=1}^{m} \delta_{ik}\, b_{ik}]$. This is equation (9), with an intercept α added. Thus, a slightly modified equation (9) is still obtained when component prices vary across commodities, as long as the marginal cost of reallocating components is constant over time.

[4] The price data for selected dairy products are obtained from Dairy Market News (1970-1999), Agricultural Marketing Service, USDA. We use Wisconsin assembly point prices for American cheese measured in 40-pound blocks. For butter, we use grade A butter price in Chicago. This price series being discontinued in November 1998, (adjusted) grade AA butter price in Chicago

was used for the latest months. For non-fat dry milk, we use wholesale price of nonfat dry milk for human food. All prices are measured in cents/lb.

5 Note that government purchases of dairy products take place regularly for reasons unrelated to the dairy price support program (e.g., military purchases, government food programs). An examination of the price data and government purchases data lead us to choose "10 percent of consumption" as a minimum threshold used to identify when government purchases can be considered as actively supporting dairy prices. For example, for American cheese, the year 1977 and most of the 1980-86 period are identified to be in the "government regime" since they exhibit large government cheese purchases and relative price stability. And the 1990s fall into the "market regime" because of minimal government cheese purchase during that period.

6 For simplicity, we treat government purchases as exogenous in our analysis. This means that the dummy variables (D's) representing regime switching are also exogenous. This greatly simplifies the analysis of price behavior in each regime (see below). Note that there is a large literature dealing with unknown or endogenous regime switching models (e.g., Perron; Andrews; Andrews and Ploberger; Vogelsang; Hamilton). Analyzing dairy price dynamics with endogenous government purchases appears to be a good topic for future research.

7 Note that this neglects possible differences between the market regime and the government regime. This is a difficult issue. The reason is that the dates of regime change differ for each price. With three prices, this would imply the existence of eight regimes. In the context of an AR(7) applied to single equations, handling eight regimes becomes cumbersome (Maddala and Kim, p. 410). While we neglect such complexities here, this suggests a need to interpret our ADF results with caution.

8 These results appear consistent with the VAR results presented below (see Figure 2a-2c). Since the VAR analysis incorporates the effects of regime-switching, this suggests that our ADF test results may not be adversely affected by their neglect of regime-switching.

9 Note that the order in the AR(3) is consistent with the VAR(3) reported below. By not including the dummy variables D, the AR(3) for [K p_t] reported in table 1 implicitly assumes that hedonic pricing holds under both regimes (D = 0 and D = 1). Empirical support for this assumption is presented below.

[10] The Schwarz criterion consists in choosing the model for which [ln(maximum likelihood) - K/ln(T)/2] is largest, where K is the number of parameters and T is the number of observations..

[11] Note the consistency of the parameter estimates in the VAR model holds whether or not the prices are I(0) or I(1), and whether or not they are cointegrated. However, having I(1) variables and/or cointegration relationships affects the asymptotic distribution of the parameter estimates (see Hamilton). The implications of a VAR model with unbalanced equations (where some of the variables are I(1) and others I(0)) are discussed in Banerjee et al. and Maddala and Kim (chapter 7).

[12] Note that the error variance could differ between regimes, thus creating possible heteroscedasticity across observations. In this case, the least squares estimates would remain consistent, but would no longer be the maximum likelihood estimates. Addressing the issue of how government policy affects price volatility across markets would require a more refined analysis. This appears to be a good topic for further research.

[13] Note that the parameters β_{ijk} and β_{Dijk} in (10) are asymptotically normally distributed, thus justifying the use of a F-test. However, the other parameters in (10) typically have a non-standard asymptotic distribution under cointegration (see Hamilton, chapter 17).

[14] Under the government regime, the estimated eigenvalues are: 0.1410, 0.0011, and 0.0004.

[15] More specifically, under the government regime, testing the null hypothesis that there are two cointegration relationships (under the alternative hypothesis that one cointegration relationship exists) gave a test statistic of 0.38 for the eigen value test, and 0.50 for the trace test. Using a 5 percent significance level, the associated critical values are 14.07 and 15.41, respectively. As a result, we fail to reject the null hypothesis under the government regime.

[16] Under the market regime, the estimated eigenvalues are 0.2066, 0.1224 and 0.0620.