Expectations, Demand Shifts, and Milk Supply Response

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Abstract. *The demand for dairy products shifted during the past decade to items with less fat This, along with a dairy surplus, has led to a generic advertising campaign by the industry Consumers have responded by increasing dairy product purchases, while changes in the provisions of the dairy support program have altered Government demands as well This study compares effects of a shift in demand under two different assumptions regarding producer expectations*

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Over the past decade, shifts in the demand for dairy products have altered the state of the dairy economy For example, since generic advertising began in 1984, fluid milk sales have increased an estimated 4 4 percent and cheese sales an estimated 2 25 percent through 1990 (Blaylock and Blisard, 1988) [1] New, lower fat products that reflect consumers' health concerns have been introduced into the market Understanding how such demand shifts affect the dairy economy is critical to understanding its reaction to a change in policy The effect of a shift in demand on the state of the dairy economy is examined within a dynamic general equilibrium framework (see Liu and Forker (1990) for an example of a general equilibrium analysis)

To illustrate the appropriateness of a general equilibrium analysis, consider the effect on supply of a positive shift in demand for dairy products Since the dairy herd management is inherently dynamic, a milk supply decision taken today affects future profits Hence, if the shift in demand results in dairy farmers expecting to receive permanently higher milk prices, milk supply might increase, farm prices might fall, and government purchases might increase If farmers expect only transitory increases in the price of milk, supply might change very little, higher farm prices might be realized, and government purchases might fall This scenario shows that expectations are a key component of a dynamic general equilibrium analysis A rational-expectations supply response to a demand shift depends critically on the distribution of the demand shift A naive-expectations supply response ignores the distribution of the demand shift Liu and Forker assumed expectations are naive This article differs from the Liu and Forker study because it formally and empirically compares the supply response to a shift in demand under both the rational- and naive-expectations assumptions

I have estimated a pair of supply functions by solving or partially solving an explicit dynamic optimization problem One result is a rational-expectations supply function and another is a naive- or static-expectations supply function The coefficients of the rational-expectations supply function depend on production and technology parameters of representative firms, and on parameters defining the movement of input prices and market-level demand shifts For the purposes of this discussion, the former set of parameters consists of structural parameters, the latter set consists of state parameters Production and technology parameters are structural because they describe a production process of firms that is invariant to changes in the conditions of the market Shifts in consumer preferences do not alter the production process of farm firms On the other hand, state parameters define the movement (or the distribution) of the state variables of the problem shifts in demand and input prices The aggregate supply response of milk-producing firms does not alter the distribution of these state variables Under the rational-expectations hypothesis, the distribution of both demand shifts and input prices and the specification of the objective functions of firms induce a distribution of (endogenous) milk prices and supply of milk This distribution defines the conditional, mathematical expectation of milk price and aggregate supply Changes in the distribution of state variables alter the mathematical or rational expectation of milk price and aggregate supply (which in turn affect supply) Separating state parameters from structural parameters is essential under the rational-expectations paradigm if changes in supply due to systematic changes in state variables are to be correctly evaluated The naive-expectations assumption breaks the link between the distribution of state variables and milk supply Under the naive-expectations paradigm, a separation of state and structural parameters is unnecessary

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[1]Sources are listed in the references section at the end of this article

Under the rational-expectations assumption, state variables are characterized as being generated from permanent or transitory shocks or disturbances Suppose a growth hormone alters the taste of dairy products, but otherwise leaves the production process unchanged If this shock alters the demand shifter for protracted periods, the shock is said to be permanent If it shifts demand for only a short period, the shock is transitory The different distributions of the demand shifter imply different distributions of the farm price of milk, different expected milk prices, and hence a different supply function To assess how the supply function will change when consumer tastes change, it is necessary to separate structural from state parameters The econometric problem of separating these two sets of parameters is termed the identification problem Successfully separating structural and state parameters results in a model of a market in which suppliers make no systematic errors in prediction

The identification problem does not arise under the naive-expectations paradigm The reason is that a change in the distribution of the demand shifter in no way alters the fixed and assumed distribution of milk prices Under naive expectations, only changes in the structural parameters (for example, a change in the production process) can alter a naive supply function, so that identifying state and structural parameters is unnecessary On the other hand, invoking the naive-expectations assumption virtually ensures that agents *make* systematic errors in prediction

Dynamic Optimization in Agricultural Economics

Agricultural economists see dynamic optimization techniques as a means of uncovering the underlying structure of dynamic reduced-form econometric models (for example, Wohlgenant, 1985, Eckstein, 1985, Lopez, 1985, Holt and Johnson, 1989) Studies appealing to dynamic duality and static expectations deliver reduced-form models with well-defined restrictions on their coefficients as do studies appealing to stochastic dynamic programming and rational expectations While both sets of restrictions are defined at least partly in terms of the structural parameters, the restrictions are usually different

Two main strategies exist for estimating the structural parameters of a dynamic optimization problem using time-series data One strategy involves solving for the unobserved expectation of a relevant variable in terms of observed variables and substituting the solution for the unobserved variable In this substitution approach, the parameters of the reduced-form solution are explicit nonlinear functions of the state and structural parameters Wohlgenant and Eckstein (1984) employed this substitution method when invoking the rational-expectations hypothesis Lopez employed the substitution method when invoking the static- or naive-expectations hypothesis Because the nonlinear restrictions on the parameters of a rational-expectations reduced form are complex, the substitution method seems limited to small-scale dynamic optimization problems

The other strategy involves direct estimation of structural parameters by replacing unobserved expectations of a variable with the observed variable The resulting errors-in-variable estimate is attractive because it can be computed even for large-scale models Weersink and Tauer (1990) follow this estimation strategy, invoke static expectations, and compute reduced-form elasticities of regional milk supply from the structural parameter estimates Antle (1987) gives a classic argument for an errors-in-variable estimate under rational expectations in cases in which a rational-expectations equilibrium cannot be found, structural parameters of the model are obtained from the first-order conditions of firms

Regardless of which strategy the analyst chooses, the parameter estimates of a dynamic optimization problem must imply a reduced-form solution In the analysis below, a reduced-form solution obtains only if the parameter estimates satisfy the inequality restrictions sufficient for a solution In this paper, these restrictions are placed on the parameter estimates

The estimation approach in this report combines the substitution and the errors-in-variables approaches (see Tauchen, 1986, Boos and Monahan, 1986, and Kling and Sexton, 1990) Estimated from this combined approach are closed-form, ex-post rational- and naive-expectations milk supply functions Because modeling the U S Dairy Support Price program prohibits a closed-form rational solution (Holt and Johnson, 1989), the program is ignored Nevertheless, the closed forms illustrate the fundamental difference between the paradigms static (naive) supply functions are invariant to systematic changes in the demand shifter, whereas rational-supply functions are not Econometric estimates are used to assess how the rational-expectations supply response changes when demand shifts change from permanent to transitory

Economic Model

The properties of milk supply under rational or naive expectations are established from a full or partial solution to a dynamic social welfare problem of the dairy industry In the following problem, the producer begins each period with a given stock of milk-producing animals and must decide on the number of replacement heifers to add to the herd next period The structural economy consists of the parameters of the representative farm firm's dynamic objective function and the parameters of the derived demand for farmer's milk The model is closed with an expectation assumption For the rational-expectation assumption, closure entails the specification of an information set and a description of the difference equations describing the movements of cow prices, cull cow prices, and the demand shifter Again, the analysis ignores the endogenous features of the dairy support program so as to attain closed-form rational-supply solutions (See notations and definitions in table 1)

Consider the optimization problem facing each farm firm in a competitive dairy economy In particular, each firm chooses $\{k_t\}$, the sequence of the firm's stock of milk-producing cows to maximize the expected, discounted future value of the firm, defined as

$$\max E_0 \Sigma_{t=0}^{\infty} \beta^t \Pi_t, \tag{1}$$

where

$$\Pi_t = fk_t p_t - (J_t - \beta J_{t+1})\, k_t + c_t \sigma k_t - (1/2)\, hk_t^2 - (1/2)\, dr_t^2, \tag{2}$$

subject to

$$k_t = (1 - \sigma)\, k_{t-1} + r_t \qquad \textit{(equation of motion)} \tag{3}$$

$$p_t = a_0 - a_1 fK_t + z_{t-1} \qquad \textit{(derived demand for farm milk)} \tag{4}$$

$$J_{t+1} = b_0 + b_1 + J_t + \epsilon_{1t+1} \qquad \textit{(cow price)} \tag{5}$$

$$c_{t+1} = b_2 + b_3 c_t + \epsilon_{2,t+1} \qquad \textit{(cow cull price)} \tag{6}$$

$$z_{t+1} = b_4 + b_5 z_t + \epsilon_{3,t+1} \qquad \textit{(demand shifter)} \tag{7}$$

As each quarter t begins, the representative farmer knows the blend price of milk (p_t), the price of cows (J_t), the price of culled cows (c_t), and the firm's and economy's beginning period stock of milk-producing animals (k_{t-1} and K_{t-1}) The firm's problem is to choose the current period's herd size Last period's demand shifter (z_{t-1}) partly determines the current milk price, a feature consistent with the Federal Milk Marketing Orders valuing milk according to formulas incorporating market conditions for manufacturing milk in Minnesota and Wisconsin The information available to the milk producer at the beginning of the period is summarized in an information set

Table 1—Notations and definitions

t	integer denoting a discrete time interval (quarter)
k_t	the firm's stock of milk-producing animals at the end of period t
K_t	the economywide stock of milk-producing animals at the end of period t
r_t	replacement heifers that have entered the herd during period t
p_t	the blend price of milk received by the farmer in period t
J_t	the price of milk-producing animals received in period t
c_t	the cull cow price received in period t
z_t	a demand shifter in period t
β	a discount factor
σ	a parametric slaughter rate
f	a milk-yield parameter
h	capital cost associated with milk-producing cows
d	capital cost associated with replacements
E_t	a mathematical-expectations operator conditioned on the information set available at the beginning of period t
$\epsilon_{1,t+1}, \epsilon_{2,t+1}$, and $\epsilon_{3,t}$	three white noise error terms, each of which is uncorrelated with all elements of the information set available at the beginning of period t

$$\Omega_t = \{\ \ , p_{t-1}, p_t,\ \ , z_{t-2}, z_{t-1},\ \ , J_{t-1}, J_t,\ \ , c_{t-1}, c_t,\ \ , k_{t-2}, k_{t-1},\ \ , K_{t-2}, K_{t-1},\ \ \} \tag{8}$$

When period t begins, the representative producer decides on the herd size by adding replacement heifers and culling cows The farmer receives milk revenues of the amount $p_t f k_t$ for milk produced in period t and receives a return of the amount $c_t \sigma k_t$ for culled animals during period t The cull rate, σ, is assumed fixed so a fixed proportion of the herd size is culled each time period The unit opportunity cost of employing a mature animal in milk production in period t is the rental rate, w_t, of beef animals, where $w_t = J_t - \beta E_t J_{t+1}$, and J_t is the price of beef animals Denote q as a rental rate of capital fixed over all periods of the optimization problem Then, $\frac{1}{2} q h^2 k_t$ denotes the capital costs of holding and maintaining the stock of mature animals, and $\frac{1}{2} q d^2 r_t^2$ represents the capital costs of holding and raising replacement heifers Dividing the value function by q delivers the above optimization problem with prices normalized by the price of capital (Townsend, 1983)

Each firm in the economy satisfies the Euler equation

$$E_t\{fp_t - J_t + \beta J_{t+1} + \sigma c_t - [h+d+\beta d(1-\sigma)^2]\, kt + d(1-\sigma)\, k_{t-1} + d(1-\sigma)\, \beta k_{t+1}\} = 0, \tag{9}$$

for $t = 0, 1,$ The left-hand side of equation 9 is the derivative of equation 1 with respect to k_t. The first term is the marginal revenue product, the second and third terms represent the marginal (opportunity) cost of using animals for milk production, and the fourth is the marginal return from slaughter. The remaining three terms are actually the sum of two terms $-\{h\ k_t + d[k_t - (1-\sigma)\ k_{t-1}]\}$ and $\beta d(1-\sigma)\ \{k_{t+1} - (1-\sigma)\ k_t\}$. The first term is the total marginal capital cost of holding current-period cows and current-period replacements. The second term states that as the herd size increases during the current period, the next period's replacements fall. The second term reflects the next period's savings (in present dollars) due to the current period's decision.

Consider a demand expansion resulting from a shift in demand, so the marginal revenue product rises. What happens to herd size and milk supply? The answer rests on two comparative dynamic results stated in the following two propositions (see proofs in appendix A).

Proposition 1: As the parameter d in equation 2 increases, the response of farm firms to a change in the price of milk decreases. **Proposition 2:** The more permanent the shift in demand, the larger the response of farm firms to the shift in demand.

Proposition 1 states that the speed at which firms respond to an effective change in the price of milk slows as the marginal cost of holding and raising replacement heifers increases, regardless of the particular expectation assumption. Proposition 2 applies only to a rational-expectations solution. Before elaborating on proposition 2, it is necessary to define a permanent shift in demand as well as the concept of a systematic change in the demand shifter.

Equation 7 is a first-order Markov process describing realizations of the demand shifter, z_t. Specifically, equation 7 indicates that a realization of z is composed partly of a fundamental disturbance term (one that is uncorrelated with past z and serially uncorrelated with itself) and a one-period lagged realization of z. Equation 7 could be "inverted" to express each current realization of z as a function of an infinite weighted sum of the present and past disturbance terms. This inversion defines how long a single shock or disturbance translates into changes in realizations of the demand shifter. The state parameter b_5 completely describes the movement of the demand shifter (it defines its mean, variance, and serial covariance). The closer the absolute value of b_5 is to unity, the longer a single shock affects future realizations of the demand shifter, that is, the more permanent is the effect of a shock on demand. The closer the absolute value of b_5 is to zero, however, the more short-lived the effect, making the demand shift transitory.

Proposition 2 states that the more permanent the shift in demand, the greater the current period response to the demand shifter. The implications of proposition 2 are clear. If the shift in demand is permanent, a continued rise in milk price can be predicted. Rational firms will expand beyond the amount justified by the increase in the marginal revenue product alone. On the other hand, if the demand shift is transitory, prices will fall in the next period, and firms may plan to contract, dampening the expansion implied by the increase in the marginal revenue product alone.

According to proposition 2, the rational supply response to a demand shifter cannot be understood unless the movement of the demand shifter is understood. A systematic change in the demand shifter, due to a change in advertisement, for example, might transform a transitory demand shifter into a permanent demand shifter. Proposition 2 states that such a change would induce a larger supply response.

Both propositions imply that a rational-expectations milk supply function depends not only on the technology of firms in the economy but also on the distribution of the demand shifter.

The technology parameters of representative firms are contained in equation 9. Since equation 9 is linear in variables, it can be aggregated exactly to the market level. Hence, the technology parameters of the problem might be estimated using aggregate time series data and an aggregated version of equation 9. The obstacle to estimation, however, is that equation 9 is unobservable because of the presence of the expectations operator. However, writing equation 9 compactly as

$$E_t F_t(\Theta) = 0, \tag{10}$$

where $\Theta = [\beta,f,\sigma,h,d]'$, and noting that for any mathematical expectation, $F_t(\Theta) = E_t F_t(\Theta) + u_t$, according to equation 10

$$F_t(\Theta) = u_t \tag{11}$$

Since equation 10 contains unobservable data, its parameters cannot be estimated from time series data. On the other hand, parameter estimates of equation 11 can be obtained by appealing to the rational-expectations hypothesis.

Given the information set Ω_t, the correlation between u_t and more than one variable of $F_t(\Theta)$ cannot be ruled out, so equation 11 violates a regression structure The rational-expectations hypothesis provides a set of orthogonality conditions that are exploited in estimation $Eu_t | \Omega_t = 0$ These conditions imply that if one forms an instrument vector, I_t, with elements of Ω_t, $Eu_t \otimes I_t = 0$ (where $\otimes$ denotes Kronecker product, and E is the unconditional expectation) However, the specification of the information set implies the serial correlation of these moment error terms cannot be ruled out The Generalized Method of Moments (GMM) estimate of Θ is denoted as $\Theta^\#$ The GMM estimator exploits the orthogonality conditions of the model and accounts for serial correlation of the moment error terms Since $\Theta^\#$ minimizes a well-defined objective function of the data sample, the important point for what follows is that $\Theta^\#$ is a statistic of the sample (See Gallant, 1987, chapter 7, for a more detailed description of the GMM estimator)

The final component of the structural model involves the slope parameter of the derived demand for producer milk Wohlgenant and Haidacher have rigorously estimated pairs of static derived demand functions by accommodating general equilibrium effects of a price change from retail to farm Wohlgenant and Haidacher's pairs of functions take the form $\log P = A_0 - A_1 \log Q + \log Z$, where P is retail or farm-level price, Q is farm output, and Z represents marketing costs, demand shifters, and trend The coefficients of this pair of double-log specifications are flexibility estimates Wohlgenant and Haidacher obtain a point estimate of 1 493 on the A_1 coefficient of the dairy farm price equation

Multiplying this number by the mean of the ratio of prices to milk supply gives 1 130, the value assigned to the demand slope parameter, a_1, in equation 4

The remaining task is to estimate the structural and state parameters of the above model and solve for reduced-form supply functions under two different expectations schemes

Methodology

Equations 1-7 pose a dynamic, stochastic programming problem, the solution of which is a rational-expectations competitive equilibrium If sufficient conditions (stated below) for an optimization are satisfied, the herd size that solves this dynamic programming problem is

$$k_t = \psi_1 k_{t-1} + \psi_2 + \psi_3 J_t + \psi_4 c_t + \psi_5 z_{t-1} \qquad (12)$$

Equation 12 is the stochastic equation of motion of cow numbers It is the rational-expectations solution, and solves equations 1-7 The coefficients of equation 12 optimally combine the distributions of cow price, cull price, and the demand shifter with the technology parameters of representative firms The ψ_i of equation 12 are nonlinear functions of the structural and state parameters of the problem Equation 12 is used to compute the rational-expectations ex-post supply function

$$M_t = \lambda M_{t-1} + \kappa_1 + \kappa_2 J_t + \kappa_3 c_t + \kappa_4 z_{t-1} + \alpha_1 p_t \qquad (13)$$

The computation of equation 13 from the equation of motion of cow numbers (see Sargent, 1987(b), chapter 14) ensures that the expected future discounted stream of output price is consistent with the expectation of output price implied by the demand function for producer milk The expected future discounted streams of cow prices, cull prices, and the demand shifter are consistent with the vector autoregression given by equations 4-6

I used the same estimates of the structural parameters, Θ, and the assumption of static expectations to compute a different equation of motion of herd size This equation of motion solves the dynamic problem specified only by equations 1-3, and so ignores the milk demand equation and the specification of the cow price, cull price, and the demand shifter The solution ensures the expected future discounted stream of any price is consistent with the static-expectations scheme of Chambers and Lopez if $\{x_t\}$ is any sequence, then $E_t X_{t+j} = x_t$ (for $j \geq 0$) is its static expectation By multiplying the static-expectations solution by the parameter f, the milk supply function is

$$M_t = \lambda M_{t-1} + \delta_2 J_t + \delta_3 c_t + \alpha_2 p_t, \qquad (14)$$

which resembles the supply function specified by Liu and Forker

The pair of supply functions presented above are similar in that the λ coefficient is shared by both equations A shared λ coefficient stems from the assumption that the technology of firms is invariant to the expectation assumption The remaining coefficients of the supply functions differ These differences are due solely to the expectation assumption most notably, the static-expectations supply response to a demand shift is zero, the rational-expectations supply response to a demand shift is nonzero

Conditions sufficient to ensure a rational-expectations solution given by equation 12 (and, hence, ensure the computation of equation 13) are (Sargent, 1987b, chapter 1)

$$\{a_1 f^2 + d + h\} > 0 \qquad (15)$$

$$d(1-\sigma)^2\{1 - \frac{d}{a_1 f^2 + d + h}\} \geq 0 \qquad (16)$$

$|b_1|, |b_2|, |b_5| < \beta^{-1/2}$ (see equations 5, 6, 7) (17)

Equations 15 and 16 with $a_1 f^2 = 0$ are sufficient conditions to compute the static-expectations supply function given by equation 14

A bootstrap procedure provides estimates of the structural, vector autoregression, and reduced-form supply parameters of the study that satisfy conditions 15-17 A similar procedure was applied by Kling and Sexton (1990) in a static demand model Tauchen (1986) illustrated how to bootstrap a nonlinear, continuous-time, dynamic, and stochastic programming problem Parameter estimates are robust because the procedure imposes no distribution on the likelihood of the model

A seemingly unrelated and unrestricted linear system of regressions generates bootstrap samples of the herd size, cow prices, cull prices, and the demand shifter (appendix B) This regression model consists of an equation of motion for cow numbers similar to equation 12 with no cross-equation restrictions, and an appended disturbance term Equations 5, 6, and 7 also constitute the regression system The farm price of milk is generated using the demand function defined by equation 4 and the definition of the demand shifter (appendix C) For each set of bootstrap samples, GMM estimates of the parameters h and d of the firms' objective functions are computed If parameters h and d and the parameters of equations 5-7 satisfy the sufficient conditions for a rational-expectations equilibrium given by equations 15-17, the longrun expected supply elasticity and the coefficients of the rational- and static-expectations supply functions are computed If the parameters do not satisfy the sufficient conditions, another bootstrap sample is drawn The probability that the conditions for a rational-expectations solution are satisfied is computed from the number of bootstrap samples for which the conditions given by equations 15-17 hold, divided by the number of bootstrap samples drawn Appendix B furnishes more details of this procedure

Results

Table 2 reports the means and standard deviations (in parentheses) of the bootstrap distribution of parameter estimates that satisfy equations 15-17 The first equation represents the unrestricted (that is, no cross-equation restrictions) cow number equation, and the next three equations represent the stochastic-difference equations governing the cow price, the cow cull price, and the demand shifter variables Next, table 2 reports the bootstrap estimate of the h and d parameters of the Euler equations and a longrun expected supply elasticity of 1.2 for the U S dairy industry The final two equations represent the estimated milk supply functions with all of the cross-equation restrictions implied by the rational- and naive-expectations schemes [2]

The results highlight the notion that supply response critically depends on the assumption of expectations For example, the shortrun rational-expectations supply elasticity with respect to the blend price of milk is approximately 0.06, while the shortrun naive-expectations supply elasticity with respect to the blend price of milk is approximately 0.10

The variable sequence of interest in this study is the demand shift sequence Table 2 shows an estimate of 0.993 for the coefficient on the lagged demand shifter in the demand shift equation, that is, b_5 in equation 7 The magnitude of this estimate implies that historical shifts in the total demand for milk within the U S dairy industry have been permanent, which is not surprising given the nature of regulations over this period The static-expectations response to a demand shift is zero because the static expectation of the price of milk ignores the demand function The rational-expectations response to a one-period-lagged demand shift is 0.1712, and implies milk supply increases of 0.16 percent for each 1-percent increase in the demand shifter The estimated standard error associated with this estimated coefficient indicates that the supply response to lagged demand shifts is computed no less precisely than most of the other responses

I now show how empirical estimates of the supply functions differ under the two expectations schemes, and the manner in which a systematic change in the demand shifter affects supply response Because the point estimates reported in table 2 satisfy conditions 15-17, I was able to compute both a rational- and a naive-expectations supply function from the point estimates The rational-expectations supply function evaluated at the point estimate is [3] $M_t = 8416\ M_{t-1} - 0031 - 3762\ J_t + 1188\ c_t + 1987\ z_{t-1} + 0789\ p_t$, and the naive-expectations supply function evaluated at the point

[2] The data sources, the transformations, and the sample means are reported in appendix C

[3] The supply functions computed at the point estimates reported in table 2 differ from the supply functions reported at the bottom of table 2 because the parameters of supply are nonlinear functions of the parameters in a firm's objective function (for example, h and d) and the parameters of the vector autoregression describing cow prices, cull prices, and the demand shifter

Table 2—Estimation results

Bootstrapped seemingly unrelated regressions

k_t = 0 9880 k_{t-1} − 0 0082 − 0 0524 J_t + 0 0349 c_t + 0 0320 z_{t-1}
(008) (014) (009) (007) (004)

J_{t+1} = 0 0379 + 0 9530 J_t
(018) (025)

c_{t+1} = 0 0477 + 0 9419 c_t
(009) (007)

z_t = 0 0155 + 0 9929 z_{t-1}
(0116) (0124)

Euler equation

h	d
0 0923	3 4279
(038)	(3 779)

Longrun expected supply elasticity
1 210
(549)

Probability restrictions hold
0 421

Milk supply, rational expectations

M_t = 0 7596 M_{t-1} − 0 0025 − 0 3784 J_t + 0 1098 c_t + 0 1712 z_{t-1}
(145) (006) (017) (017) + (095)
+ 0 0692 p_t
(039)

Milk supply, naive expectations

M_t = 0 7596 M_{t-1} − 0 0323 J_t + 0 0453 c_t + 0 1164 p_t
(145) (018) (025) (065)

estimate is M_t = 8416 M_{t-1} − 0378 − 0529 J_t + 1360 p_t

The response coefficient on the lagged demand shifter in the rational-expectations supply function (0 1987) implies that for a 1-percent increase in the previous period's shift in demand, milk supply increases about 0 19 percent As stated above, the coefficient of 0 9929 on the lagged demand shifter equation describes a permanent demand shift sequence The important point for economic analysis, however, is that under rational expectations, the supply response to a shift in demand depends on the distribution of the shift in demand If the shifts become less permanent (more transitory), the rational-expectations supply function will change, and, in accordance with proposition 2, the supply response to shifts in demand will diminish Under static expectations, the supply response to changes in demand shifts remain zero regardless of how the shifts change

Table 3 displays the relationship of supply response to a permanent and a transitory demand shifter under rational and naive expectations Under rational expectations, a diminished supply response occurs as the demand shift sequence becomes less permanent A supply coefficient (top line) is associated with an almost purely permanent demand shifter, while the bottom line reports a supply coefficient associated with an almost purely transitory demand shifter If firms see the current increase in demand as permanent, milk prices will be expected to continue to increase and firms will expand milk herds If a current increase in demand is viewed as transitory, however, milk prices will be expected to fall in the next period, and firms will dampen any current-period expansion The difference in supply response between an almost purely permanent de-

Table 3—Milk supply response to the lagged demand shifter under different distributions of the demand shifter, with rational and naive expectations

Coefficient on the demand shifter in the demand shifter equation (b_5)[1]	Supply response coefficient to lagged demand shift	
	Rational[2] (κ_4)	Naive
0 992920	0 198687	0
496460	123367	0
248230	112739	0
124115	109128	0
062057	107597	0

[1]The value reported is the b_5 coefficient from equation 7
[2]The value reported is κ_4 from equation 13

mand shifter and an almost purely transitory demand shifter is almost 50 percent Under the static-expectations assumption, firms do not respond to changes in the movement of the shift in demand

The naive-expectations paradigm exploits the artificial separation of supply and demand, a separation legitimately appealed to in static models The rational-expectations paradigm, on the other hand, states that demand and supply cannot be treated independently because the demand function contains information regarding the price of milk

Conclusions

Reduced-form supply functions fully derived in a dynamic optimization context change when consumer demand for milk systematically changes Supply is altered despite a fixed structural economy Changes in supply are not evident when agents are assumed to ignore systematic changes in the demand shifter, as is the case under the static-expectations assumption This point is a general one, but is often ignored in large-scale econometric modeling Perhaps the reason is convenience the cumbersome identification problems associated with the estimation of a rational-expectations model might seem forbidding However, as the methodology in this article and elsewhere (Tauchen, for example) illustrates, techniques are currently available to estimate and solve dynamic and stochastic optimization models of greater complexity than the one I have presented

The comparison of expectation paradigms has little to do with the comparison of the forecasting record of either reduced form It is difficult to judge the forecasting ability of each of the two estimated supply functions Some analysts argue that permitting individual agents to alter supply decisions in the face of systematic changes in their environment is fundamental to the usefulness of a model as a policy tool (Lucas, 1976, 1982) The consequence of allowing individual agents to alter supply decisions in the face of a systematic change in their environment is also illustrated by the results

For analysts intent on measuring the response of the dairy economy to a shift in demand, it seems prudent to carefully consider the expectations of agents whose behavior is assumed to be embedded in the model In particular, the results suggest that a persistent demand shift may have a different effect on milk supply than will a transistory demand shift of the same magnitude The results of this relatively simply model suggest the difference is significant under the rational-expectations assumption and nonexistent under the naive-expectations assumption Work that considers the effect of the support price program on agents' expectations, for example, will undoubtedly alter the magnitude of this effect

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Appendix A—Proving Propositions 1 and 2

This appendix provides the proof of propositions 1 and 2 **Proposition 1:** As the parameter d in equation 2 increases, the response of farm firms to a change in the price of milk decreases

Proof Note the firm's Euler equations are represented as

$$E_t\{\beta k_{t+1} + \varphi k_t + k_{t-1}\} = \frac{1}{d(1-\sigma)} E_t \{-fp_t + (J_{t+1}\beta J_{t+1}) - \sigma c_t\}, \qquad \text{(A1)}$$

where,

$$\varphi = -\{\frac{\beta d(1-\sigma)^2 + d+h}{d(1-\sigma)}\},$$

or as in Sargent (1987, chapter 14)

$$(1-\lambda L)\, k_t = \frac{\lambda}{d(1-\sigma)} E_t \Sigma_{i=0}^{\infty} (\beta\lambda)^i \{fp_{t+1} - (J_{t+1} - \beta J_{t+1+i}) + \sigma c_{t+i}\}, \qquad \text{(A2)}$$

where,

$$\lambda = \frac{-\varphi-(\varphi^2-4\beta)^{1/2}}{2\beta},$$

and the term in brackets on the right-hand side of equation A2 is the effective milk price According to the arguments given by Sargent (1987(b), chapter 8)

$$0 < \lambda < \beta^{-1/2}$$

Setting $i = 0$, and taking the partial derivative of k_t with respect to the term in brackets gives

$$\frac{\partial}{\partial\{\}} k_t = \frac{1}{(1-\sigma)} \cdot \frac{\lambda}{d} > 0$$

The inequality holds because equations 15 and 16 in the text imply $d > 0$ Given the sign of this partial, it suffices to prove

$$d\,(\frac{\partial\lambda}{\partial d}) - \lambda < 0 \qquad \text{(A3)}$$

Using the above definitions, equation A3 can be rewritten as

$$\{1/(2\beta)\ (1/(\varphi^2-4\beta)^{1/2})\} \quad \{\varphi + (\varphi^2-4\beta)^{-(1/2)}\}$$

$$\{1/(2\beta)\}\{(\varphi^2-4\beta)^{(1/2)} - \frac{h}{d(1-\sigma)}\} < 0 \qquad \text{(A4)}$$

By virtue of the fact that λ is real, the first term in { } of equation A4 is positive Since $\varphi < 0$, the second { } term is negative, and since $0 < \beta < 1$, the third { } term is positive Hence, the proof of equation A3 or A4 amounts to the proof of

$$(\varphi^2 - 4\beta)^{(1/2)} - \frac{h}{d(1-\sigma)} > 0, \qquad \text{(A5)}$$

Or, given definitions of φ and λ, the proof of

$$\frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta\lambda > 0 \qquad \text{(A6)}$$

To prove equation A6, note that $\max(\lambda) = \beta^{-1/2}$ This follows from the fact that λ is the inverse root of the characteristic equation formed by the left-hand side of equation A1 Satisfaction of the sufficient conditions given by equations 15 and 16 in the text ensure that the roots of this characteristic equation are not less than $\beta^{1/2}$ in modulus Thus $\max(\lambda) = \beta^{-1/2}$, and

$$\frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta\lambda > \frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta^{1/2}$$

$$= \frac{\beta(1-\sigma)^2 + 1 - 2\beta^{1/2}(1-\sigma)}{1-\sigma}$$

$$> \beta(1-\sigma)^2 + 1 - 2\beta^{1/2}(1-\sigma) > 0 \qquad \text{(A7)}$$

The last inequality holds because $0 < \beta(1-\sigma)^2 < 1$ Q E D

Proposition 2: The more permanent the shift in demand, the larger the response of farm firms to the shift in demand

Proof Proposition 2 states that as the demand shift becomes more permanent, (as $|b_5|$ becomes larger), the economywide response to the demand shifter becomes larger Analogous to equation A2, the economywide solution satisfies

$$(1-\omega L)k_t = \frac{\omega}{d(1-\sigma)} E_t \textstyle\sum_{i=0}^{\infty} (\beta\omega)^i \{f z_{t+i-1}$$

$$- (J_{t+i} - \beta J_{t+1+i}) + \sigma c_{t+i}\}, \qquad \text{(A8)}$$

where,

$$\omega = \frac{-\delta-(\delta^2-4\beta)^{1/2}}{2\beta},$$

and,

$$\delta = \frac{-\beta f^2 a_1}{d(1-\sigma)} + \varphi$$

Proposition 2 requires the computation of

$$E_t \textstyle\sum_{i=0}^{\infty} (\beta\omega)^i z_{t+i-1} \qquad \text{(A9)}$$

By the multivariate Weiner-Kolmogorov formulas (Sargent, 1987(b), chapter 11), equation A9 is evaluated as

$$\left[\frac{1}{1-\beta\lambda b_5}\right] z_{t-1}$$

Proposition 2 states

$$\frac{d}{db_5}\left[\frac{1}{1-\beta\lambda b_5}\right] > 0,$$

which is easily verified

Appendix B—Computing the Estimates

This appendix details how the restricted bootstrap estimates are computed The inequality-restricted bootstrap estimates and standard errors are computed through the following eight steps

(i) Compute seemingly unrelated, unrestricted estimates of equation 12 That is, compute estimates of the ρ_i in the model

$$k_t = \rho_1 k_{t-1} + \rho_2 + \rho_3 J_t + \rho_4 c_t + \rho_5 z_{t-1} + u_{1t}$$
$$J_{t+1} = \rho_6 + \rho_7 J_t + u_{2t+1}$$
$$c_{t+1} = \rho_8 + \rho_9 c_t + u_{3t+1}$$
$$z_t = \rho_{10} + \rho_{11} z_{t-1} + u_{4t}$$

The ρ_i are free parameters, as they contain no restrictions implied by economic theory

(ii) Compute the 1-by-4 row vector of regression residuals, $u_s = [u_{1s}, u_{2s+1}, u_{3s+1}, u_{4s}]$, s+1 = 2, ,T (where T is the terminal period of the data sequence) from the data and the original seemingly unrelated estimates of the ρ_i Stack each row vector and use the residuals to create the empirical distribution function, with each 1-by-4 row vector having probability mass 1/(T-1) Label the (T-1)-by-4 matrix of residuals $\epsilon^{\#}$

(iii) Resample from rows of $\epsilon^{\#}$ with replacement and construct the kth sample sequence of length T-1 of output prices $\{p_t^*\}^{(k)}$, cow numbers $\{k_t^*\}^{(k)}$, beef prices $\{J_{t+1}^*\}^{(k)}$, cull prices $\{c_{t+1}^*\}^{(k)}$, and the demand shifter $\{z_t^*\}^{(k)}$, using estimates computed in step i and the demand function specified in equation 4 Use the kth sample sequences to compute seemingly unrelated estimates of the (free) ρ_i parameters in step i Label the vector of estimates $\rho^{\#}_k$

(iv) Check the stability conditions (for example, equation 17) of the beef price, cull price, and demand shifter equations using appropriate elements of $\rho^{\#}_k$ If the three conditions hold, proceed to step v If not, return to step iii

(v) Compute a Generalized Method of Moments estimator of Θ in the model specified by equations 9 and 11 from the kth sample sequences generated in step iii In the estimation, β, f, and σ are set to 0 95, 0 18, and 0 07, so Θ = [0 95,0 18,0 07,h,d]', and $[1,J_{t-1},p_{t-1},k_{t-1}]'$ represents the instrumental variable vector Label the parameter estimates of the Euler equation $\Theta_k{}^{\#*}$

(vi) If $\Theta_k{}^{\#*}$ satisfies conditions 15 and 16 (and since the coefficients, $\rho^{\#}_{i,k}$, associated with the state variables satisfy stability), the kth draw is successful Compute the rational- and static-expectations supply functions using $\Theta_k{}^{\#*}$, a_1, the parameters of the cow price, cull price, and demand shifter equations If $\Theta_k{}^{\#*}$ fails to satisfy equations 14 and 15, return to step iii

(vii) If the number of draws is less than the prescribed number, go to step i Otherwise proceed

(viii) Compute the means and variances of the successful parameter estimates in the usual way The mean minimizes a quadratic loss function and represents a restricted estimate Construct the standard derivation from the variance estimate

Appendix C—Data and Description, Transformations, and Fixed Parameters Estimates

Variables used in the study are constructed from data found in various Dairy Situation and Outlook reports and an ERS database The fundamental data sequences are of length 120, being defined over 1960-89 Each series is normalized by the 1982 average, so each variable is an index (1982 = 1 0) The mean is reported in parentheses following the definition

(M) = milk production, United States, 50 States (0 94)
(J) = beef cattle prices received by farmers (0 70)
(c) = cull cow prices received by farmers (0 73)
(K) = milk cows on farms (1 12)
(p) = producer price, all milk wholesale, at average test (0 65)
(z) = demand shifter, $z_{t-1} \equiv p_t + (1\ 13)(0\ 18)K_t$ (0 88)

Setting β = 0 95 corresponds to an interest rate of approximately 5 percent σ = 0 07 is based on a USDA-estimated annual slaughter rate of 28 percent f = 0 18 is the coefficient obtained from a regression of fourth differences of milk supply on fourth differences of cow numbers over the historical period