Supply Growth and Dairy Industry Deregulation

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Optimal control models of aggregate milk supply and demand behavior are used to describe the optimal phasing of the deregulatory dairy price support in the presence of supply growth. Producers are assumed to face costs of adjustment, and are myopic with respect to price expectations and the adoption of the new quasi-fixed factor augmenting technology.

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Agricultural price policy and regulation by governments have become common institutional fixtures for many nations. Depending on how these policies are implemented the market conditions of agricultural commodities can be greatly affected. The dairy industry in the U.S. is no exception and is a prominent case of government policy intervention in the production and marketing of a commodity. The quantity, quality, and location of milk produced are significantly influenced by the price support and marketing order programs. While many agree that the elimination of the dairy price support policy is desirable, there is less agreement over how to accomplish this goal.

Previous studies on dairy policy are restricted to the comparative static supply-demand framework. For example, Buxton, Ippolito and Masson and Dahlgran, among others, focus on the measures of welfare transfers and net social losses (or gains). Hallberg, Hammond and Brooks and Westcott simulate the impact of various policy alternatives in price and quantity. The failure to consider dynamic adjustment processes and costs may lead to substantial biases of the measures of welfare and policy impacts (LaFrance and de Gorter, Berck and Perloff). The implications of these studies on the direction of policy in the future is inconclusive and sometimes predetermined by the model assumptions and characterization (Gardner). Dairy policy is typically assumed to be exogeneous to the market. However, the model presented below develops an optimal rule where the government adjusts simultaneously as market conditions warrant. The objective of this article is to describe the optimal dairy price support path under deregulation and deregulation's impact on herd size in the presence of supply growth given that producers are myopic with respect to price expectations and to the adoption of a new technology.

Dairy production is characterized by the presence of quasi-fixed factors of production such as buildings, materials, and dairy cows. Consider the case where costs of adjustment are present. These costs are penalties for the rapid expansion or contraction of the stock of quasi-fixed factors. In addition to adjustment costs, the form of the price expectations influences the timing of the price support elimination (Pindyck). Figure 1 identifies a few alternative strategies assuming a competitive market: (a) the support price falls gradually from the initial level, p_{SP}, (but is still above the long-run price) and then the price support is phased out achieving the long-run equilibrium at p_{∞}; (b) the support price falls to a point below the current support level but above the long-run equilibrium level and then is gradually decreased until the long-run equilibrium is attained; (c) the support price is immediately set at the long-run equilibrium price; (d) the support price falls to a point below long-run equilibrium price and above the short-run

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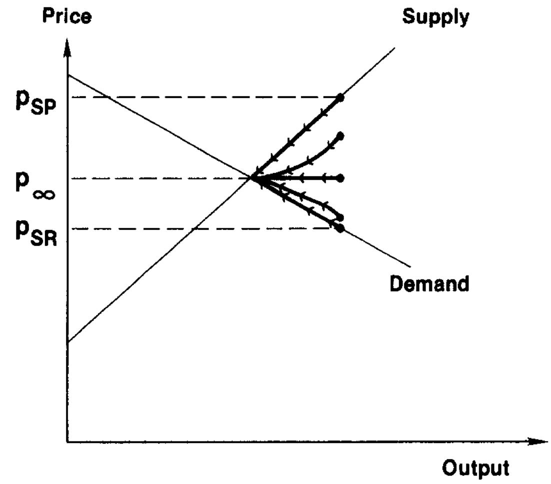

Figure 1. Alternative Dairy Decontrol Pricing Strategies

market clearing price, p_{SR}, and then is gradually increased until the long-run equilibrium is attained; and (e) immediate and complete control where the new support price falls to the short-run market clearing price where the market is expected to force the price up to the long-run equilibrium price.

Given the objective of maximizing the flow of consumer and producer surplus, it is not clear, *a priori,* which price support elimination strategy is optimal. If operators are blessed with perfect foresight, immediate and complete decontrol is optimal. Since the firm can perfectly anticipate the action, they can perfectly adjust. However, firms may be myopic in their investment decisions and may assume that the current policy and technological situation will prevail. Such a strategy on the part of milk producers can hardly be considered excessively naive. The price support system has been a fixture in U.S. agriculture since the Agricultural Adjustment Act of 1933 and for dairy since the 1940's. While economists and politicians have addressed the possibility of eliminating price supports for dairy (and other commodities) in recent years, this policy tool is still in place. When firms behave myopically, immediate and complete elimination of the price support sends the price signal that encourages firms to divest too much. As a result there is a waste of resources in the adjustment process (Pindyck). A further complication for the dairy industry is the prospect of the bovine Growth Hormone (bGH) becoming available in the near future. The introduction of bGH has been estimated to increase industry supply of milk by as much as 15 percent (Hallberg and Parsons). At this time it is uncertain whether this new input to the production process will be able to reach its projected level or even be approved for distribution.[1]

The next section presents a simple, but robust, model of the aggregate supply and demand behavior which is used to determine optimal dairy price support level in the presence of adjustment costs, supply growth and myopic producer behavior. The final section presents some concluding comments.

The Model

The model developed here assumes that competitive milk producers have a production function that is linear in herd size, which is assumed to be the only relevant input, and exhibits Hicks-neutral supply growth

(1) $$q = A(t)K$$

where q is the quantity of milk produced, K is the herd size, and $A(t) = Ag(t)$ and $g(t)$ is a logistic growth index. Thus, technical progress is assumed to be bounded (Wibe). The growth index is defined as

(2) $$g(t) = G_T[1 + e^{-\alpha t}(G_T - G_0)/G_0]^{-1}.$$

This index serves as an indicator of the impact of bGH on aggregate production and is characterized by parameters α, G_0 and G_T. Assume that once bGH is fully adopted by the industry, it will increase production by 15 percent. Since $g(t)$ is an index describing the change in supply arising from the adoption of bGH, the boundary values are $g(0) = 1$ and $g(t) \rightarrow 1.15$ as $t \rightarrow \infty$; i.e., $G_0 = 1$ and $G_T = 1.15$. The parameter α is known as the intrinsic rate of growth which characterizes the speed of adoption. The greater the value of α, the faster the rate of change in g. Further, it is assumed that cows can be bought or sold at per unit price v,

[1] The scenario discussed in this article can also be viewed as a dynamic game of the Stackelberg type where the follower (the producers as a unit) take the actions of the leader (the government regulatory agency) as given. The follower solves an ordinary control problem whose solution implicitly defines a reaction function. The leader treats the follower's optimization conditions as constraints in the solution of his control problem. Clemout and Wan and Karp (Chapter 1) provide excellent introductions to the theory of dynamic games. Karp and McCalla applies the theory of dynamic games to agricultural trade policy.

but that adjustment costs are incurred according to $(1/2)cI^2$, where I is the rate of acquiring new dairy cows and c is the marginal cost of adjustment per cow. One can consider a dairy cow in this context in terms of some sort of "reference" cow which has been adjusted for technological and productivity changes. The demand for milk is assumed to be static and linear according to

(3) $$p = a_0 - a_1 q.$$

Net Surplus Maximization

Surplus measurement in a dynamic context is complicated by two considerations: aggregation over time and the market conditions. The aggregation of consumer surplus over time simply involves summing the discounted flow. However, producer surplus should be traced out from the long-run supply curve rather than the short-run supply curves since the adjustment of quasi-fixed factors of production move the firm from one marginal cost curve to another. An alternative measurement of producer surplus is to use the total adjustment cost, which includes the change in short-run variable cost and investment cost, as the long-run supply curve (Just, Hueth and Schmitz, pp. 64-68). Since the quasi-fixed factor of herd size is assumed to be the only relevant input, the total adjustment cost is the acquisition cost of new cows plus the adjustment cost, $vI + (1/2)cI^2$. The second consideration in the dynamic measurement of surplus concerns the situation when the market environment is distorted by the presence of a price support that is greater than the long-run equilibrium price.

The case of the price support set above long-run equilibrium price is illustrated in figure 2. The consumer surplus shrinks by the area CBED and the producer surplus expands by the area CDEF. Initially, there is a gain of area BEF. The government has to pay area BFqK to purchase the surplus milk, whose value to society is area BGqK. Thus, government intervention leads to a loss of area BFG in the absence of storage costs. The ultimate welfare effect is the dead weight loss of area EFG.

The total surplus, w(t), is calculated as the consumer surplus, area a_0GH, plus producer surplus, area HGqO − area LFqO. Further simplification yields the total surplus as area a_0EL − area EFG which is equivalent to (4).

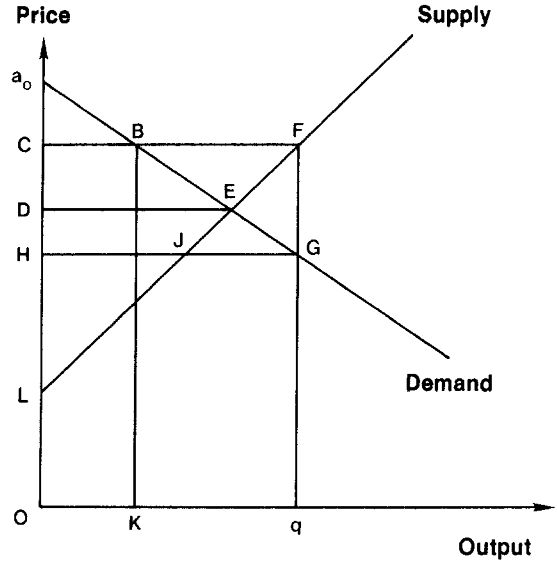

Figure 2. Net Surplus Calculation

The instantaneous surplus is consumer surplus plus producer surplus, which is expressed as

(4)
$$\begin{aligned} w(t) &= [(1/2)(a_0 - p)q] + [pq - vI - (1/2)cI^2] \\ &= (1/2)a_1q^2 + (a_0 - a_1q)q - vI - (1/2)cI^2 \\ &= a_0q - (1/2)a_1q^2 - vI - (1/2)cI^2. \end{aligned}$$

Consider the situation where at the current period, $t = 0$, the milk price support has been set above the long-run equilibrium price implying that output is greater than the long-run equilibrium level. The problem is to choose an investment path to maximize the discounted flow of consumer and producer surplus. The instantaneous flow of net surplus can be rewritten using (1) as

(4′) $$w(t) = a_0A(t)K - (1/2)a_1A(t)^2K^2 - vI - (1/2)cI^2.$$

Thus, the formal statement of this problem is to choose an investment path to

(5) $$\max \int_0^\infty e^{-rt}w(t)dt$$

subject to the herd accumulation equation

$$\dot{K} = I - \delta K$$

where r is a constant discount rate, $(\cdot)$ denotes the time derivative, δ is the depreciation rate and $I(t) \geq 0$, $K(t) \geq 0$. Depreciation here refers to the reduction in productivity of the "reference" dairy cow. The current value Hamiltonian is

(6) $$H = a_0AK - (1/2)a_1A^2K^2 - vI - (1/2)cI^2 + \mu(I - \delta K),$$

where μ is the current value co-state. Choosing I to maximize H and assuming an interior solution yields the first order conditions

(7.1) $\mu = v + cI$

(7.2) $\dot{\mu} = (r + \delta)\mu - a_0A + a_1A^2K.$

Differentiating both sides of (7.1) with respect to time and substituting this into (7.2) yields the optimizing investment dynamics

(8) $$\dot{I}^* = [(r + \delta)(v + cI^*) + a_1A^2K - a_0A]/c$$

Given the optimal solution to the investment functional, $I^*(t)$, the price trajectory can be found using the demand function.

The Producer's Strategy

At the firm level, the instantaneous flow of profit is $\pi(t) = pq - vI - (1/2)cI^2$. Assuming that producers are myopic with regard to the changes in the future level of prices and the availability of the new technology, the firm level optimization problem is to choose an investment path to

$$\max \int_0^\infty e^{-rt}\pi(t)dt$$

subject to

$$\dot{K} = I - \delta K.$$

Since production is linear homogeneous in K and adjustment costs are convex, the optimal investment level is a function of the growth in supply, and current and future prices (Gould, 1968). When current prices and no growth in supply are assumed to prevail over the planning horizon (i.e., $\dot{p} = \dot{v} = \dot{c} = 0$ and $A(t) = A$), the optimal level of investment is constant over time (i.e., $\dot{I}^* = 0$). This implies that

(9) $$I^* = Ap/[c(r + \delta)] - v/c.$$

Since firm level output is assumed to follow $q = AK$, the supply dynamics is a continuous version of the Koyck lag

(10) $$\dot{q} = A\dot{K} = A(I^* - \delta K) = A^2p/[c(r + \delta)] - Av/c - \delta q.$$

Equation (10) characterizes the supply response behavior of the myopic firm.

Optimal Price Support Policy

The government's goal is to determine the price level, p(t), over time that will maximize the discounted flow of net surplus subject to producer supply response behavior. Formally stated, the problem is to choose the price trajectory to

(11.1) $$\max \int_0^\infty e^{-rt}w(t)dt$$

subject to

(11.2) $$\dot{q} = -\delta q + A(t)^2p/[c(r + \delta)] - A(t)v/c, \quad q(0) = q_0$$

where q_0 is the quantity of milk produced under the current price support regime. Note that the supply dynamics equation exhibits supply growth as represented by the substitution of A(t) for A. That is, the optimal price support policy does acknowledge that supply will grow according to g(t) even though producers do not. Using (9) in (4′), the current value Hamiltonian is

(12) $$H = a_0q - (1/2)a_1q^2 - [(A(t)p)^2]/[2c(r + \delta)^2] + v^2/2c + \lambda(-\delta q + A(t)^2p/[c(r + \delta)] - A(t)v/c),$$

where λ is the co-state variable. Assuming an interior solution, the first order conditions are

(13.1) $\lambda = p/(r + \delta) \Rightarrow \dot{\lambda} = \dot{p}/(r + \delta)$

(13.2) $\dot{\lambda} = (r + \delta)\lambda + a_1q - a_0.$

Using (13.1) in (13.2), the optimal price dynamics can be expressed as

(14) $$\dot{p} = (r + \delta)(p + a_1q - a_0).$$

The supply dynamics is the equation of motion (11.2). Since (11.2) and (14) constitute a nonautonomous system the phase plane analysis cannot be employed effectively in the presence of supply growth.[2] However, this does not prevent the generation of numerical solutions of the optimal price support path.

Estimation

The supply and demand equations are estimated using annual data for the U.S. dairy sector over the period 1955–78 found in Thraen and Hammond. The variables used are:

a) the total domestic production of milk in million pounds, q_S;

[2] Any nonautonomous system of ordinary differential equations can be reduced to an autonomous system by simple substitution. Unfortunately, the treatment of autonomous systems in more than two dimensions is more complex than the two dimensional case.

b) the number of dairy cows with the changes in technology and productivity adjusted so that this variable only reflects the relationship between production and animal units (thousand head), K;
c) the quantity of fluid and manufactured milk consumed less commercial stocks and farmers' use of milk (million pounds), q_D;
d) the composite price of fluid and manufacturing milk (dollars/cwt), p;[3] and
e) the total U.S. population (thousand persons), POP.

Since the bGH had not been commercially introduced during the data series the relevant production function is $q = AK$. A first-order autocorrelated error term is appended to both the supply and demand equations. The results of the estimation correcting for autocorrelation are

i) the production function[4]:

$$q_S = \underset{(225.4)}{3.156}K \qquad R^2 = .94 \qquad D.W. = 1.678$$

ii) the demand function (per capita level):

$$q_D/POP = \underset{(15.6)}{0.629} - \underset{(-2.14)}{0.013}p \qquad R^2 = .78 \qquad D.W. = 1.438$$

where t-values are in parentheses. The elasticity of aggregate milk demand evaluated at the mean is −0.156, which is between the estimates of the elasticities of fluid and manufacturing milk demand generated from other studies (George and King, Boehm, and Hallberg et al.). The depreciation rate is assumed to be 0.2 since each cow spends 5 years in the herd on the average. The discount rate is assumed to be at the average level of 0.06. The purchase price of a dairy cow in production is assumed to be \$1000.[5] The intrinsic rate of adoption of the bGH is evaluated for four values: 0, 0.30, 0.60 and 0.90. The population level of 240 million is assumed.

Using the estimated and assumed parameter values, the optimal price, supply and growth dynamics are

(15.1) $\dot{p} = 0.26p + 0.00008346q - 12.5788$

(15.2) $\dot{q} = -0.2q + 7661.8g^2p - 63120$

(15.3) $\dot{g} = \alpha g[1 - (g/1.15)].$

The boundary conditions are (1) the long-run (terminal) price, p_∞, and quantity, q_∞; (2) the starting quantity, q; and, (3) the starting and terminal values of g. To determine the long-run price and quantity consider the steady-state behavior of the system; i.e., $\dot{p} = \dot{q} = \dot{g} = 0$. Since g is independent of p and q, $\dot{g} = 0$ implies $g_\infty = (0, 1.15)$. Using $g_\infty = G_T$, the long-run price and quantity are

(16.1) $p_\infty = a_0 - a_1 q_\infty$

(16.2) $q_\infty = [a_0(g_\infty A)^2 - g_\infty Av(r + \delta)]/[a_1(g_\infty A)^2 + \delta c(r + \delta)].$

Table 1 presents p_∞ and q_∞ for the various assumed values of c.

No Growth in Supply

Once the initial value q_0 is defined the optimal price support trajectory can be identified. Using the average 1985 government price support level of \$11.975 per cwt in (16.2) yields the initial supply level 143.18 billion pounds.[6] The case of no growth in supply implies that $\alpha = 0$ and the system in (15) is autonomous. Phase-space theory states that the separatrix will approach the long-run equilibrium as $t \to \infty$. Trajectories very close to the separatrix will follow a path that will travel near the stable node (Clark, Chapter 6).

Table 1. Steady State Prices and Quantities

	$\alpha = 0$		$\alpha \neq 0$	
Adjustment Cost per Cow	P_∞	q_∞	P_∞	q_∞
c = \$25	9.81	1,201.7	8.39	1,245.7
c = \$50	11.25	1,156.5	9.56	1,212.6
c = \$75	12.60	1,114.6	10.64	1,175.6
c = \$100	13.85	1,075.6	11.68	1,143.4

Note: The unit of price is \$/cwt and the unity of quantity is 10^6 cwt.

[3] In fact, the support price is only for manufacturing milk, not the blend price. A more accurate characterization entails specifying aggregate demand to be a piece-wise linear kinked schedule. The assumption implied in this article is that the price support on manufacturing milk dictates the milk blend price behavior.

[4] A Cobb-Douglas production function of the form $q_S = AK^b$ was also estimated with the result that the point estimate for b = 0.864 is not significantly different from unity at the .01 significance level. In the interest of simplicity, the linear form appears to be reasonable.

[5] This figure is calculated from averaging milk cow prices over the period 1980–1985 (see USDA, Table 3, page 8).

[6] This average price is calculated as follows: [January–March price (\$12.60)] × .25 + [April–June price (\$12.10)] × .25 + [July–December price (\$11.60)] × .5. The estimated initial supply level used here is very close to USDA's recent estimate of 1985 milk production of 143.2 billion pounds (see USDA, p. 11).

The optimal starting price is chosen such that the price trajectory that numerically solves (15.1) and (15.2), with g = 1, satisfies the boundary condition that this path hits the long-run equilibrium price. Solutions to this system of differential equations are generated using the sixth-order Runge-Kutta-Verner method by the fortran routine DVERK. For the case of c = 50,[7] the separatrix implies a starting price support level between \$9.09 and \$9.10. Both of these trajectories are presented in columns (a) and (b) in Table 2. As a practical matter, the optimal price support trajectory can follow the path with the initial price \$9.10 hitting \$11.21 in three and a half years and then increasing the support price to \$11.25. Immediate and full deregulation implies that the initial price is the short-run market clearing price \$2.42, which is the price consumers are willing to pay for the production level encouraged by the current support price of \$11.975 per cwt. This strategy leads to disinvestment taking place too quickly [column (c) in Table 2]. Instantly lowering the price support to the long-run equilibrium level of \$11.25 leads to a high capital stock level being maintained [column (d) in Table 2].

Following the trajectory starting at \$9.10 implies that over the three and a half years it takes to reach long-run equilibrium 18 percent fewer cows will be in production as compared to the starting herd size. The optimal herd reduction is 1.26 million cows in the first year (an 11 percent reduction), 0.56 million, 0.24 million and 0.07 million in the succeeding years.

[7] A preliminary estimate of this parameter for the Pennsylvania dairy industry is c = 50.

With no growth in supply and taking price exogeneously, the supply dynamics equation implies the following approximate solution for output[8]

$$(17)\quad q(t) = q_0e^{-\delta t} + [(A^2p(t)/\delta c(r + \delta)) - (Av/c\delta)](1 - e^{-\delta t}).$$

An approximation of the elasticity of supply along the adjustment path is

$$(18)\quad \eta(t) = (p(t)/q(t))A^2(1 - e^{-\delta t})/(\delta c(r + \delta)),$$

and is presented in table 3 for the price trajectory starting at \$9.10. The results indicate that the magnitude of the supply elasticity exceeds unity within two years. However, one observes that as time goes on, supply becomes more elastic. Thus, as the adjustment process proceeds, the quasi-fixed factor of herd size becomes more flexible.

Growth in Supply

Numerical solution of (15.1) through (15.3)

[8] The supply dynamics equation implies the solution

$$(*)\quad q(t) = \left[q_0 + (A^2/c(r + \delta)) \int_0^t p(s)g(s)^2e^{\delta s}ds - (Av/c) \int_0^t g(s)e^{\delta s}ds\right]e^{-\delta t}.$$

The first integral in the brackets can be integrated by parts to yield

$$p(t) \int_0^t g(s)^2e^{\delta s}ds - \int_0^t \dot{p}(s)g(s)^2e^{\delta s}ds.$$

With $\dot{p}(s) = 0$ and $g(s) = 1$, (*) reduces to (17). With $\dot{p}(s) = 0$, (*) reduces to (19).

Table 2. Price Support and Quantity Trajectories with No Growth in Supply and c = \$50

	(a) p(0) = 9.09		(b) p(0) = 9.10		(c) p(0) = 2.42		(d) p(0) = 11.25	
Months	P	q	p	q	p	q	p	q
0	9.09	1,431.8	9.10	1,431.8	2.42	1,431.8	11.25	1,431.8
6	9.80	1,340.7	9.82	1,341.1	1.64	1,073.8	12.45	1,427.1
12	10.28	1,279.6	10.30	1,280.5	*	*	13.70	1,470.5
18	10.60	1,238.6	10.62	1,240.1	*	*	15.86	1,571.1
24	10.81	1,211.0	10.85	1,213.4	*	*	18.70	1,748.6
30	10.95	1,192.2	11.00	1,196.1	*	*	22.95	2,037.0
36	11.03	1,179.1	11.12	1,185.2	*	*	29.41	2,490.8
42	11.08	1,169.8	11.21	1,179.2	*	*	39.30	3,196.0
48	11.10	1,162.5	11.30	1,176.9	*	*	54.48	4,285.8
54	11.09	1,156.0	11.40	1,178.3	*	*	77.82	5,965.8
60	11.05	1,149.3	11.52	1,184.6	*	*	113.72	8,553.3

Notes:
* = irrelevant values associate with negative prices. The unit of price is \$/cwt and the unit of quantity is 10^6 cwt.

Table 3. Supply Elasticity Along the Optimal Adjustment Path: No-Growth in Supply Case

Months	$\eta(t)$
6	.267
12	.559
18	.850
24	1.129
30	1.386
36	1.620
42	1.833

identifies price trajectories for given values of α and c. Using the same initializing quantity as the no growth case and assuming c = 50, the optimal price support trajectories can be found in table 4 for selected values of α. The α values selected are 0.30, 0.60 and 0.90 which, respectively, imply that 75, 95 and 99 percent of the adoption of bGH has been assimilated by the fifth year. The results indicate that the higher the intrinsic rate of growth the longer the phase out period. This occurs for two reasons. First, the initial optimal price is lower for higher values of α requiring the optimal trajectory to travel a longer distance. Second, the sluggish adjustment in herd size implied by the cost of adjustment can explain this seemingly counterintuitive result. Higher values of α suggest that the effective herd size, g(t)K(t), is growing faster over time than the actual herd size, K(t). Consequently, a greater adjustment in the quasi-fixed factor stock is needed. Since adjustment is costly, the herd size will take relatively longer to adjust to the long-run equilibrium for higher intrinsic rates of growth in supply.

The adjustment of herd size over this period is indicated in table 5. The future herd size is calculated by normalizing the quantity of milk produced to the 1985 average cow productivity level of 12,000 pounds. The normalization factor is 12,000g(t). The higher the growth rate the greater the herd size reduction since fewer cows can produce a given quantity of milk. For α = 0.30 the optimal herd reduction is nearly 19 percent. While this is not significantly different from the no growth case, this reduction takes place in 15 months as opposed to 42 months in the no growth case. For α = 0.60, the optimal herd reduction is 26 percent over the 18 month phase-out period with over 17 percent of the reduction taking place during the first year. For α = 0.90, the optimal herd reduction is 29 percent with over 18 percent of the reduction taking place in the first year. Thus, the magnitude of the intrinsic rate of growth in supply influences the speed in achieving the deregulated equilibrium with the phase out period being 75 percent faster than the optimal phasing of deregulation in the no growth in supply case. These results bound the Magrath and Tauer prediction that a 20 percent herd reduction will be attributed to the introduction of bGH.

Allowing for growth in supply and taking price exogenously, the supply dynamics equation implies that output is approximately

$$(19)\quad q(t) = \left[q_0 + (A^2p(t)/c(r+\delta))\int_0^t g(s)^2e^{\delta s}ds - (Av/c)\int_0^t g(s)e^{\delta s}ds\right]e^{-\delta t}.$$

The approximate supply elasticity along the adjustment in this case is

$$(20)\quad \eta_\alpha(t) = (p(t)/q(t))(A^2e^{-\delta t}/c(r+\delta))\int_0^t g(s)e^{\delta s}ds,$$

Table 4. Optimal Price Support and Quantity Trajectories with Growth in Supply and c = $50

	$\alpha = 0.30$		$\alpha = 0.60$		$\alpha = 0.90$	
Months	p	q	p	q	p	q
0	8.60	1,431.8	8.545	1,431.8	8.485	1,431.8
3	8.95	1,373.0	8.89	1,372.8	8.83	1,372.4
6	9.21	1,324.6	9.15	1,325.7	9.08	1,326.2
9	9.39	1,284.5	9.33	1,288.2	9.26	1,290.9
12	9.50	1,250.9	9.45	1,258.7	9.38	1,264.1
15	9.56	1,222.2	9.52	1,235.2	9.47	1,244.1
18			9.56	1,216.5	9.52	1,229.2
21					9.55	1,218.2
24					9.56	1,210.0

Note: The unit of price is $/cwt and the unit of quantity is 10^6 cwt.

Table 5. Optimal Quarterly Herd Adjustment with Growth in Supply and c = $50

	(1000 cows)		
Months	α = .30	α = .60	α = .90
0	11,931.7	11,931.7	11,931.7
3	11,334.2	11,232.1	11,136.1
6	10,837.9	10,673.7	10,529.5
9	10,422.7	10,228.0	10,068.4
12	10,071.6	9,871.5	9,718.7
15	9,696.0	9,585.1	9,454.1
18		9,325.9	9,253.8
21			9,101.9
24			9,007.8

Note: The herd size is calculated by normalizing the quantity produced to 1985 average cow productivity levels. The normalization factor is g(t) × 12,000.

and is presented in table 6 for the optimal price trajectories for the values of α considered. A comparison of supply elasticities of the various values that α can take on ($\alpha = 0$ from table 3) does not indicate a tremendous difference in supply elasticities for all values of α at a given t. Like the no growth in supply case, supply elasticity becomes more elastic over time.

Concluding Comments

The results presented here are principally intended to indicate the direction price support policy should take if the assumptions maintained above are accepted; i.e., operators face costs of adjustment, and they are myopic with respect to the support price program and the adoption of a new technology. In this context, the analysis presented above can serve as a benchmark for policy makers.

In general, the results indicate that the support price should immediately drop to a point between the short-run market clearing price and the deregulated, long-run equilibrium price. The support level is then gradually increased until the long-run equilibrium is attained via the solution to equations (15.1) through (15.3). The intrinsic rate of growth in supply will influence the speed in which deregulation is achieved. The longest time to attaining a deregulated market is in the absence of supply growth. In the presence of supply growth the speed in which the deregulated market is achieved is *inversely* related to the intrinsic rate of supply growth. For the scenario presented in this article the highest intrinsic growth rate case achieved deregulation 75 percent faster than the no growth in supply case. The introduction of constant short-run average cost of production will result in a parallel downward shift in the $\dot{q} = 0$ equation. This implies that the long-run equilibrium price is lower and the corresponding quantity is higher. While the numerical price and herd adjustment trajectories presented here will be altered, the relative characterization of these trajectories remains the same. Another issue that deserves more attention is the extent of adjustment costs in the dairy sector. The estimation of dynamic adjustment cost models (e.g., Epstein and Denny, Pindyck and Rotemberg) would assist in determining the extent to which these costs are present.

These results indicate the importance of the adjustment process in conducting policy analysis. Frequently, the analyst is preoccupied with behavior at the long-run equilibrium. This article focuses on the role of the adjustment process in dairy deregulation. The impact of price support elimination beyond the milk production sector has not been explicitly addressed here. As the milk producers have been influenced by the price support policy over the decades, so have the processors of milk products. Magrath and Tauer conclude that, despite a 20 percent drop in cow numbers, a free market dairy policy and the adoption of bGH will not affect total output, therefore leaving milk processors largely unaffected. However, the aggregate analysis presented here suggests that a substantial decrease in total milk production and herd size can be expected. The phased elimination of dairy price supports is desirable in order to avoid excess disinvestment in the production sector. However, a reaction from the processing sector is inevitable, especially from firms that mainly process surplus milk for government stockpiles. Future work should attempt to include the pro-

Table 6. Supply Elasticity Along the Optimal Adjustment Path: Growth in Supply Case

		η_α (t)	
Months	α = 0.30	α = 0.60	α = 0.90
3	.123	.123	.124
6	.258	.261	.263
9	.401	.408	.413
12	.547	.558	.567
15	.694	.710	.722
18		.859	.875
21			1.023
24			1.166

cessing sector's reaction to dairy price support elimination.

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