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Abstract

A discrete optimal control model is constructed and solved to determine optimal adjustments in dairy policy over time in response to bovine somatotropin (bST). The results indicate that after bST is introduced and widely adopted, the government should remove cows from the dairy sector through the implementation of several cow disposal programs. The timing of the policy adjustment is invariant to the magnitude of the bST response; with a larger bST yield response more cows are removed. The ability to wait until the impacts of bST are manifested is extremely beneficial since the eventual impact of bST may not be known until it occurs.

Introduction

Although the magnitude and timing of the shock from introducing bovine Somatotropin (bST) into the dairy sector is debatable, most believe that its introduction will entail some necessary adjustments in dairy policy. Yet, none of the studies estimating bST impacts have examined the question of how government should make those adjustments over time. Given the federal government's significant role in the nation's dairy market, it is imperative that such questions be answered prior to the release of bST.

This article focuses on the dynamic adjustments in dairy policy that would optimize social welfare. A discrete optimal control model of the dairy sector is constructed and solved using mathematical programming. The results indicate that after bST is introduced and widely adopted, the government should remove cows from the dairy sector through implementation of several cow disposal programs. The timing of the policy adjustment is invariant to the magnitude of the bST response. The ability to wait until the impacts of bST are manifested is extremely beneficial since the eventual impact of bST may not be known until it occurs.

Economic Studies of bST

Bovine somatotropin is a protein regulating milk production produced in the pituitary glands of dairy cows. Through advances in genetical engineering, bST can now be manufactured outside the cow using recombinant DNA technology and injected into cows to increase milk yields. While not yet available on the commercial market, experimental trials have shown that bST supplements increase milk yields from 10 to 25% in trials across the country (Animal Health Institute).

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Feed intake of dairy cows treated with bST also increases. Bovine somatotropin is currently under regulatory review. It is expected to be approved by the FDA as early as 1990 (Fallert).

Economic studies of bST at the farm level have centered on impacts of bST adoption on farm organization relative to non-adoption. Kalter, et. al. looked at farm profitability of bST for New York dairy farmers, concluding that adoption would be profitable for most farmers in the state. They found that farm organization should change for all categories of farms under bST, with the adjustments depending upon a farm's resource characteristics. Magrath and Tauer examined the social costs of bST under various dairy policy scenarios. They concluded that reducing the support price to market clearing levels could eliminate the profitability of using bST except on high producing cows.

Other studies have analyzed the market adjustments that would occur under bST by simulating different scenarios based on alternative bST impact and dairy policy assumptions. Ardhyula and Krog simulated the impact of bST adoption on the nation's dairy sector assuming that some of the provisions of the 1985 Food Security Act would be the policy rule for the 1990's. They found that government surpluses of milk would be sufficiently large to trigger successive support price reductions until the support price fell to $7.10 per hundredweight and the nations' dairy herd fell to just under 10 million cows in 1995. In a similar study, Kaiser and Tauer found that the use of combined flexible support prices and voluntary supply controls was a more attractive policy in terms of government costs than either control alone.

In a comprehensive farm and sector level study, Fallert, et. al. examined market impacts due to bST adoption under several different policy scenarios. They used simulation models to predict price and quantity equilibrium values from 1989 through 1996, assuming bST adoption begins in 1990. One of their major findings was that the impact of bST would depend largely on how dairy policy (e.g., support price) adjusts. Their results suggest that if the support price is not lowered after bST is adopted, then government purchases of surplus milk will rise significantly. On the other hand, if the support price is lowered, the impacts of bST will not be as profound as others have suggested.

All of these studies have treated government policy exogenously. Although some have analyzed different policy scenarios, none have attempted to find the optimal dairy policy with introduction of bST.

Optimal Control for Agricultural Policy Analysis

Dynamic optimization techniques have a long traditional use in studying natural resource usage (Hotelling), as well as economic growth and investment (Domar). The techniques used have included calculus of variation, dynamic programming, and optimal control. The use of control theory for agricultural policy was discussed by Burt in 1969. He stated that the most challenging aspect of using control theory for policy decisions was choosing an appropriate and meaningful criterion function. He suggested using social value measures directly in the criterion function, and possibly imposing ancillary constraints to protect farmers' income position. We define a social welfare function consisting of consumer and producer surplus minus government costs. Producers' income is further protected by limiting support price changes based upon government purchases of milk. Burt used dairy policy as an example, and suggested the use of nonlinear programming for numerical solutions as proposed by Rosen. We use nonlinear programming to obtain numerical results.

Freebairn and Rausser suggested using various weights on the components of the social welfare function. Their justification is that policy decision makers may value different groups unequally and the researcher should be optimizing the objective function of the policy decision makers. Agricultural producers who are affected by policy decisions will generally communicate those concerns to policy decision makers much more strongly than consumers. We measure the impact of assigning unequal weights to producers, consumers and the government.

The optimal phasing of deregulation using optimal control was addressed by Pindyck. Chang and Stefanou implemented Pindyck's approach in exploring dairy industry deregulation with a growth in supply from a technology such as bST. Although Chang and Stefanou included the cost of adjustment at the firm level, they did not include the social cost of dairy farmers exiting the industry or consumer gains from stabilization. If no adjustment costs are modeled, then social welfare is maximized by immediate and complete deregulation of an industry. Since adjustment costs are not included in our objective function, and we optimize the discounted sum of annual consumer and producer surpluses minus government costs, our model would generate a zero support price after the first period. To prevent this, we introduce a support price change decision rule as a constraint, based upon government purchases of milk.

The Optimal Dairy Policy Model

Three types of agents are represented in the model: dairy farmers, consumers, and government. It is assumed that the governments' objective is to maximize the discounted value of social welfare of the dairy sector from 1988 through 2010. Social welfare is defined as the sum of consumer and producer surplus minus the cost of government dairy programs. Consumer surplus is measured as the area under the demand curve above the price line. Producer surplus is defined as the returns to dairy producers above variable costs. These net returns should be capitalized into fixed assets. Government costs are purchase costs not including administrative, storage or disposal costs (benefits). Annual measures are discounted and summed.

Two government programs are captured by the model: The dairy price support program and a voluntary supply control program designed to remove cows, similar to the 1986 Dairy Termination program. The price support program is modeled as an equation in the constraint set, which adjusts the support price based on the quantity of milk purchases bought by the Commodity Credit Corporation. The cow removal program is the control variable in the model. The government maximizes social welfare by determining the optimal timing and level of the cow removal in response to bST. The support price is not modeled as a control since given the objective function of maximizing welfare as traditionally defined in static analysis, but now discounted and summed, the optimal support price would be zero after the first period to eliminate government deadweight loss.

The model and parameter values are listed in Table 1. Equations (1), (2), and (3) are accounting equations which define real and nominal profits of dairy farmers. Real profit per hundredweight (RPROFH) is equal to gross income from the sale of milk minus variable costs (net of culled cow revenue), deflated by the consumer price index (CPI, 1967 = 100). Variable costs include all variable expenses plus general farm overhead, taxes and insurance, interest, and capital replacement. The cost of bST was set at $50 per cow annually about equivalent to the 24 cents per day for 215 days used by Fallert et al.. Nominal profit per hundredweight (NPROFH) is equal to RPROFH times the CPI. Real profits per cow are real profits per cwt. times production per cow.

Equations (4), (5), and (6) are the cow number (COW), production per cow (PRODCOW), and milk production (MLKPROD) equations. Milk production was disaggregated into two equations in order to incorporate the cow removal program directly into the cow number equation. It was assumed that dairy farmers make adjustments in cow numbers and production per cow following a naive profit expectations scheme based upon previous year's profit.

The cow equation was estimated as a function of real profits per cow (RPROFC) lagged one period, number of cows in the previous period, and a dummy variable (DTP) equal to 1 for 1986-87 to account for the Dairy Termination Program.[1] Real profit per cow was used instead of real profit per hundredweight since this was deemed more appropriate in determining the number of cows. The variable RPROFC was obtained by multiplying RPROFH by production per cow. The estimated linear equation for cow numbers using ordinary least squares (OLS)[2] is:

$$\underset{(38.4)}{COW = 0.97\ COW(-1)} + \underset{(1.3)}{0.1272\ RPROFC(-1)} - \underset{(-2.4)}{280\ DTP} \quad R^2 = 0.58;\ DW = 2.2$$

Production per cow was estimated as a function of RPROFH lagged one period, a time trend (T), and a constant term. The time trend was used as a proxy for technological improvements other than bST. The estimated linear equation using OLS is:

$$PRODCOW = \underset{(37.2)}{102.62} + \underset{(0.7)}{69.97\ RPROFH(-1)} + \underset{(19.4)}{2.327\ T} \quad R^2 = 0.98;\ DW = 2.1$$

While the t-value on the profit variable is low, this variable was included in the PRODCOW equation because it was judged a priori to be an important determinant of milk yield. Also, we did not want a trend variable being the sole determinant of milk yields. Since real profits per cwt. averages only about .01, its impact on production per cow is about 70 pounds a year. Using these estimated coefficients equation (5) was modified to account for the impact of the bST response and adoption rate on average milk production per cow.

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[1] The data used to estimate all equations was based on a time series of national observations from 1975-87. All data and data sources are listed in Appendix table A.

[2] The numbers in parentheses are t-values, R^2 is the adjusted coefficient of variation, and DW is the Durbin-Watson statistic.

Table 1. The Dairy Optimal Control Model.

The mathematical model is:

$$\text{Max} \sum_{I=1988}^{2010} \text{DISCOUNT(I)} * [.5(\text{INTERCEPT(I)} - \text{MLKPR(I)}) * \text{MLKCON(I)} + \text{NPROFH(I)} * \text{MLKPROD(I)} - (\text{SUPPR(I)} + 1.20) * \text{GVNPUR(I)} - (\text{PRCOW(I)} * \text{COWPUR(I)})/10]$$

subject to:

(1) (MLKPR(I) - VCOST(I)/PRODCOW(I))/CPI(I) = RPROFH(I)

(2) RPROFH(I) * CPI(I) = NPROFH(I)

(3) RPROFH(I) * PRODCOW(I) = RPROFC(I)

(4) .1272 * RPROFC(I) + .97 * COWS(I) - COWPUR(I) = COWS(I+1)

(5) (2.327 + PRODCOW(I)) * (1 + BST * PRODCHG(I)) + 69.97 * RPROFH(I) = PRODCOW(I+1)

(6) .98 * (COWS(I) * PRODCOW(I))/10 = MLKPROD(I)

(7) 5 * RPROFC(I) - 500 = PRCOW(I)

(8) PRCOW(I) $\geq$ 1000

(9) MLKPROD(I) + IMPORTS(I) - MLKCON(I) = GVNPUR(I)

(10) INTERCEPT(I) - .18095 * CPI(I) * MLKCON(I)/POP(I) = MLKPR(I)

(11) MLKPR(I) $\geq$ 2.65 + .847 * SUPPR(I)

(12) .50 - .1 * GVNPUR(I) + SUPPR(I) = SUPPR(I+1)

(13) ((2.65 + .847 * SUPPR(I)) - MLKPR(I)) * GVNPUR(I) $\geq$ 0.

with variables:

COWPUR(I) $\geq$ 0	government purchases of cows (mil.)
COWS(I) $\geq$ 0	number of cows (millions) COWS(1988) = 10.334
GVNPUR(I) $\geq$ 0	government purchases of milk (bi. lbs.)
MLKCON(I) $\geq$ 0	consumer milk consumption (bi. lbs.)
MLKPR(I) $\geq$ 0	milk price (dollars per cwt.)
MLKPROD(I) $\geq$ 0	total milk production (billion lbs.)
PRCOW(I) $\geq$ 0	cow buyout price (dollars per cow)
PRODCOW(I) $\geq$ 0	annual milk production per cow (cwt.) PRODCOW(1988) = 137.86
RPROFC(I)	real variable profits per cow
RPROFH(I)	real variable profits per cwt.
SUPPR(I) $\geq$ 0	support price (dollars per cwt.) SUPPR(1988) = 10.60
NPROFH(I)	nominal variable profits per cwt.

with parameters:

ADJ	impact of bST on production costs
ADOPT(I)	bST adoption rate
BST	percentage impact of BST
CPI(I)	consumer price index
DISCOUNT(I)	discount factor
IMPORTS(I)	imports of milk
INTERCEPT(I)	intercept of the milk demand function
POP(I)	population
PRODCHG(I)	increase in adoption
TREND(I)	trend
VCOST(I)	variable cost per cow

with values:

CPI(I) = 340.4 * (1.04)^i
DISCOUNT(I) = 1/(1.07)^i
IMPORTS(I) = 2.5
INTERCEPT(I) = CPI(I) * (.1556 - .001416 * TREND(I))
POP(I) - 240.5 * (1.01)^i
TREND(I) - I + 13
VCOST(I) = 959.5 * (1.03)^i * (1 + ADJ * ADOPT(I)) + ADOPT(I) * 50

Parameter	1988	1989	1990	1991	1992	1993	1994	1995	1996	2010
ADOPT(I)	.0	.0	.05	.17	.44	.76	.93	.98	1.	1.
PRODCHG(I)	.0	.0	.05	.12	.27	.32	.17	.05	.02	.0

Parameter	No BST	13% BST	16% BST	32% BST
BST	.0	.135	.1607	.3214
ADJ	.0	.064	.076	.151

The product of COW and PRODCOW is by definition equal to milk production. Milk production was multiplied by 0.98 in equation (6) to account for leakages from the farm to the processor, e.g., on-farm use.

Equations (7) and (8) compute the purchase price per cow (PRCOW) that the government must pay to remove cows from production. Since there were inadequate data available to estimate the cow purchase price equation, equation (7) was constructed using the following assumptions. First, it was assumed that the price per cow should be based on farmers' present profitability. Second, it was assumed that a cow has a salvage value of $500. Finally, it was assumed that the cow purchase program would require participants to stay out of dairy farming for five years. Equation (7) combines these three assumptions so that PRCOW is equal to profits per cow minus $500, with the result multiplied by five to reflect the five year duration of the program (no discounting). Equation (8) constrains PRCOW to not be less than $1,000, which was arbitrarily chosen as the minimum cow purchase price.

Equation (9) is another accounting equation used in the model. By definition, government purchases are equal to milk production plus milk imports minus commercial milk consumption. Milk imports have recently averaged about 2.5 billion pounds of milk equivalent annually so were fixed at 2.5 billion pounds in this identity.

Equations (10) and (11) pertain to the equilibrium price for milk. Equation (10) is the all milk demand equation expressed in price inverse form. Demand was aggregated into demand for all milk, including fluid and manufacturing uses. Commercial per capita milk demand (MLKCON/POP) was estimated as a function of the real all milk price (MLKPR/CPI), a time trend (T), and a constant term. Two-stage least squares was used in the estimation by regressing the real all milk price on the real milk support price

(SUPPR/CPI), a time trend, and a constant and then using the predicted value as a price instrument. The milk price instrument and demand equations, which were estimated in linear form, are:

$$MLKPR/CPI = \underset{(5.5)}{0.031} + \underset{(5.4)}{0.559}\ SUPPR/CPI - \underset{(-6.4)}{0.001}\ T \quad R^2 = 0.98;\ DW = 2.1$$

$$MLKCON/POP = \underset{(12.2)}{86.0} - \underset{(-4.7)}{552.63}\ MLKPR/CPI - \underset{(-3.8)}{0.782}\ T \quad R^2 = 0.76;\ DW = 2.0$$

Solving this equation for MLKPR produces equation (10).[s] Equation (11) gives the relationship between the all milk price and the support price. The all milk price was estimated as a simple function of the milk support price and a constant term, which resulted in:

$$MLKPR = \underset{(4.7)}{2.65} + \underset{(17.4)}{0.847}\ SUPPR \qquad R^2 = 0.97;\ DW = 1.7$$

The annual support price adjustment rule is defined in equation (12). As was the case under the 1985 Farm Act, the support price is adjusted on the basis of how large milk surpluses are expected to be. However, unlike the 1985 Farm Act, the annual change in the support price is a continuous function of government purchases (GVNPUR) of excess milk the previous year. For example, if government purchases are zero, then the support price is increased by $0.50 per hundredweight. On the other hand, if government purchases are positive, then the change in the support price is equal to: 0.50 - 0.1 GVNPUR. The continuous adjustment was necessary to expedite the use of mathematical programming.

The last equation (13) insures that if the government is buying milk through the dairy price support program, then the relationship between the market and support price in equation (11) is binding.

The CPI was increased 4 percent a year and a nominal discount rate of 7 percent was used. Variable cost per cow was increased 3 percent a year starting at $959.50 (1988). A population increase of 1 percent a year was assumed. The logistic adoption rate was estimated from Lesser et al. and the adjustment in variable costs from the adoption of bST were taken from Fallert et al.

Results

Four scenarios were analyzed (1) A base line scenario which assumes that bST is not adopted and government cannot implement a buyout, (2) bST adoption with an average yield increase of 13.5%, but no cow buyout, (3) bST adoption with a yield increase of 13.5% with cow buyout programs, and (4) bST adoption with a yield increase of 32% and cow buyout programs. A 16% bST response was also modeled but is not reported in detail since the results are similar to the 13.5% bST results. Since the first two scenarios do not include the control variable of COWPUR, they are strictly simulations of the dairy sector using the constraint set equations, parameters, and initial conditions. Three other applications separated weighted

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[s] The demand price elasticity using 1987 variable values is -.36.

consumer, producer, and the government segments of the objective function by 1.25 with a 13.5% bST response and a cow buyout.[4]

The total discounted surplus of the five scenarios are $462.09 billion dollars for scenario (1), $465.68 billion for (2), $465.72 billion for (3), and $470.14 billion for (4). The components of these surplus values to consumers, producers and government cost are shown in Table 2. The addition of bST in scenario (2) increases welfare from that of scenario (1). Typically, technology benefits society. However, the introduction of bST shocks the dairy sector so that welfare losses to producers occur, especially during a transitional period. The reason can be observed from Table 7 where the variable profits from bST with no cow buyout are negative for three years. Consumers do benefit from a lower milk price (Table 3) and greater milk consumption (Table 4) with bST so that the net benefit to society is increased. The addition of optimizing behavior by removing cows does increase total welfare with producers gaining over $10 billion and consumers losing less than $10 billion under 13.5% bST. Government costs are also slightly lower with cow removals.

Table 2: Discounted Surplus Values (Billions of Dollars).

	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
Consumer Surplus	407.18	429.07	419.19	421.32	431.74
Producer Surplus	60.80	43.75	53.62	52.46	47.92
Government Cost	5.89	7.14	7.09	7.47	9.52
Net Surplus	462.09	465.68	465.72	466.31	470.14

The all milk price changes over time by scenario. If bST is not made available then the nominal price of milk remains stable from about $11.00 to $13.00 (Table 3). If bST is released in 1990 and has a 13.5% average increase then the all milk price decreases to a low of $7.00 by 1998. The all milk price increases each year thereafter, reaching $12.80 by the year 2010. In contrast, if the government buys cows optimally then the lowest all milk price is only $9.18 in 1996 and prices in every year are greater than or equal to the price in scenario 2. The impact of 16% bST on the all milk price and other variables is very similar to that of 13.5% bST. With 16% bST the lowest all milk price was $9.11 rather than $9.18 with 13.5% bST. The impact of 32% bST on the all milk price is

[4]Scenario 2 was also solved with the adoption rate as a control. The optimal adoption rate by year beginning in 1989 is .18, .34, .47, .58, .66, .72, .76, .79, .80, .81, .85, .91, .96, 1.0 (2002). Government milk purchases peak at 13 billion pounds in 1992.

slightly more significant, with a low milk price of $8.13 in 1998. However, with the government optimally buying cows even 32% bST does not produce the dramatic milk price decrease as 13.5% bST does with no cow purchases. In all scenarios, however, the all milk price is around $13.00 by the year 2010, implying that bST and policy shocks have essentially worked their way through the dairy sector by that time.

Milk consumption is inversely related to the all milk price with the demand function shifting each year. With the no bST scenario milk consumption steadily increases as population increases and as the real milk price decreases (Table 4). There is some reduction in milk consumption in the later years as the shift in the demand function slows and the price of milk increases. A 13.5% bST shock with no cow purchases increases milk consumption by 12 billion lbs. in 1998 as compared to no bST. However, if cows are optimally purchased then the increase in milk consumption is less than one half of this increase.

The support price is effective for the first 12 years in all scenarios (Tables 5 and 6). Annual CCC purchases without bST are approximately 5 billion lbs. of milk equivalent or less. When bST enters the picture CCC purchases increase as bST is adopted. Without a cow buyout program CCC purchases remain high and the support price is reduced more than a dollar in 1995 and again in 1996. The reduction in support price does eventually trim milk production as CCC purchases decrease. With a cow buyout program CCC purchases do initially climb in the early 1990s as bST is adopted, but it is optimal to purchase cows rather than milk during this period (Table 10). As a result CCC purchases fall dramatically after the government begins to purchase cows. Annual CCC purchases increase in order to allow the support price and then the all milk price to drop. This benefits consumers. Since farmers are adversely affected, cows are purchased to restore profits. In all bST scenarios the support price mechanism is not very effective after 1999.

Variable profits per cow are adversely affected by bST at least during the adoption period. With no cow purchase, profits become negative from 1997 through 1999. With cow purchases variable profits per cow are reduced compared to no bST but still positive. Partly offsetting the reduction in profit per cwt. is greater milk production per cow under bST (Table 9).

Cows numbers are reduced over time under all scenarios (Table 8). The reduction partly reflects the long term downward trend in cow numbers that were captured in the econometric estimation of the cow number equation. When production per cow increases then fewer cows are required to produce a given quantity of milk. Slowing the downward trend in cow numbers is the higher profits without bST.

Cow purchases by the government significantly reduces milk cow numbers in 1993 and 1994. With 13.5% bST 610,000 cows should be purchased in 1994 at an average price of $1,897 (Table 10). It is interesting that the following year cows could be purchased at only $1,120 a cow, but only 4,000 cows are purchased. With 16% bST more cows are purchased and some are purchased earlier; 360,000 cows are purchased in 1993 at a price of $2,278 per cow and 510,000 cows are purchased in 1994 at a price of $1,829. Under 32% bST 1.61 million cows are purchased in 1993 at a cost of $2,212 per cow and 230,000 cows are purchased in 1994 at $1,285 per cow. The results also indicate that another 10,000 or 15,000 cows would be purchased over 3 years beginning in 2005 or 2006 but this is a trivial amount and can be ignored.

What is interesting about these results is that the control (the purchase of cows) does not occur until after bST is well adopted. Until these cows are purchased it is optimal to let CCC purchases increase. This result has an enormous benefit. The eventual impact of bST is not known at this time, but our results indicate that decisions concerning cow purchases can wait until the impact of bST is determined. In contrast, many would expect that policy adjustments would be necessary before bST is introduced.

Weighing consumers, producers and the government segments of the objective function separately by 1.25 increases the value of each segment. Valuing consumers more by a factor of 1.25 essentially replicates the results of scenario (2) with no cow buyout. Cows bought out would reduce milk production and thus consumer surplus. Valuing producers more by a factor of 1.25 causes cows to be bought out in 1988 (480,000 head), 1996 (819,000 head), 1997 (1,431,00 head), and 2006 (420,000 head). The cow purchases in 1997 causes the all-milk price to increase to $19.17 and then decrease until the next cow buyout. Valuing government cost more by a factor of 1.25 causes the government to wait until 1995 rather than 1994 to remove cows since the cow purchase price is lower because of reduced dairy profits. This occurs even though the government buys more milk because of the year delay.

Table 3: All Milk Price ($ per cwt.).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	$11.63	$11.63	$11.63	$11.63	$11.63
1989	11.72	11.72	11.72	11.72	11.72
1990	11.71	11.71	11.71	11.71	11.71
1991	11.63	11.63	11.63	11.63	11.63
1992	11.52	11.44	11.44	11.42	11.33
1993	11.39	11.05	11.05	10.99	10.58
1994	11.28	10.29	10.29	10.10	8.89
1995	11.20	9.18	9.28	9.31	8.86
1996	11.16	8.11	9.18	9.19	8.63
1997	11.17	7.36	9.21	9.11	8.33
1998	11.22	7.00	9.34	9.14	8.13
1999	11.32	7.03	9.58	9.31	8.13
2000	11.45	8.19	9.91	9.59	8.32
2001	11.61	9.34	10.29	9.95	8.78
2002	11.80	10.16	10.74	10.45	9.50
2003	12.01	10.76	11.14	10.88	9.96
2004	12.23	11.22	11.55	11.21	10.29
2005	12.46	11.58	11.85	11.63	10.55
2006	12.70	11.88	12.03	12.03	10.78
2007	12.93	12.14	12.73	12.45	11.20
2008	13.17	12.38	13.15	12.88	11.62
2009	13.39	12.59	13.58	13.30	12.04
2010	13.62	12.80	13.90	13.64	12.47

Table 4: Milk Consumption (Billions of Lbs.).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	138.17	138.17	138.17	138.17	138.17
1989	139.02	139.02	139.02	139.02	139.02
1990	140.18	140.18	140.18	140.18	140.18
1991	141.52	141.52	141.52	141.52	141.52
1992	142.91	143.18	143.18	143.23	143.56
1993	144.26	145.37	145.37	145.58	146.92
1994	145.49	148.62	148.62	149.23	153.08
1995	146.55	152.78	152.47	152.39	153.78
1996	147.41	156.58	153.35	153.32	155.01
1997	148.09	159.19	153.78	154.08	156.36
1998	148.58	160.54	153.91	154.47	157.33
1999	148.92	160.71	153.69	154.44	157.68
2000	149.13	157.81	153.24	154.09	157.48
2001	149.22	155.11	152.63	153.53	156.55
2002	149.26	153.36	151.90	152.61	155.02
2003	149.16	152.20	151.28	151.92	154.15
2004	149.03	151.43	150.63	151.45	153.63
2005	148.86	150.89	150.04	150.77	153.26
2006	148.67	150.49	149.54	150.16	152.97
2007	148.45	150.17	148.89	149.49	152.22
2008	148.21	149.88	148.24	148.82	151.47
2009	147.96	149.60	147.59	148.15	150.73
2010	147.70	149.32	147.13	147.66	149.99

Table 5: Support Price ($/cwt.).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	10.60	10.60	10.60	10.60	10.60
1989	10.71	10.71	10.71	10.71	10.71
1990	10.69	10.69	10.69	10.69	10.69
1991	10.60	10.60	10.60	10.60	10.60
1992	10.47	10.37	10.37	10.36	10.24
1993	10.32	9.92	9.92	9.84	9.36
1994	10.19	9.03	9.03	8.80	7.37
1995	10.09	7.71	7.83	7.86	7.33
1996	10.05	6.44	7.71	7.72	7.06
1997	10.06	5.56	7.75	7.63	6.71
1998	10.12	5.13	7.90	7.67	6.47
1999	10.23	5.17	8.18	7.86	6.47
2000	10.39	5.59	8.57	8.19	6.69
2001	10.58	6.09	9.03	8.62	7.09
2002	10.80	6.59	9.52	9.11	7.59
2003	11.05	7.09	10.02	9.61	8.09
2004	11.31	7.59	10.51	10.11	8.59
2005	11.58	8.09	10.98	10.61	9.09
2006	11.86	8.59	11.40	11.07	9.59
2007	12.14	9.09	11.90	11.57	10.09
2008	12.41	9.59	12.40	12.07	10.59
2009	12.69	10.09	12.90	12.57	11.09
2010	12.95	10.59	13.29	12.97	11.59

Table 6: CCC Annual Purchases (Billion Lbs.).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	3.94	3.94	3.94	3.94	3.94
1989	5.12	5.12	5.12	5.12	5.12
1990	5.90	5.90	5.90	5.90	5.90
1991	6.35	7.30	7.30	7.49	8.62
1992	6.48	9.53	9.53	10.12	13.79
1993	6.33	13.95	13.95	15.44	24.92
1994	5.95	18.14	16.94	14.38	5.42
1995	5.45	17.70	6.17	6.39	7.69
1996	4.91	13.82	4.65	5.93	8.54
1997	4.38	9.25	3.50	4.66	7.36
1998	3.89	4.66	2.16	3.04	4.99
1999	3.45	0.81	1.14	1.72	2.81
2000	3.08	NP	0.44	0.74	1.00
2001	2.78	NP	0.06	0.10	NP
2002	2.54	NP	NP	NP	NP
2003	2.37	NP	0.07	NP	NP
2004	2.27	NP	0.36	0.00	NP
2005	2.22	NP	0.78	0.34	NP
2006	2.21	NP	NP	NP	NP
2007	2.24	NP	NP	NP	NP
2008	2.30	NP	NP	NP	NP
2009	2.37	NP	1.12	1.04	NP
2010	2.45	NP	2.18	2.06	1.13

NP = No Purchases.

Table 7: Variable Profits ($ per cow).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	615	615	615	615	615
1989	635	635	635	635	635
1990	638	635	635	633	630
1991	626	626	626	625	626
1992	599	594	594	593	589
1993	565	558	558	555	543
1994	538	480	480	466	356
1995	519	307	325	352	418
1996	507	103	300	326	374
1997	501	-54	284	299	299
1998	503	-145	300	288	232
1999	509	-168	327	299	207
2000	521	31	373	335	221
2001	539	228	428	386	229
2002	560	366	496	468	437
2003	585	464	556	533	520
2004	612	537	623	582	570
2005	640	589	683	648	605
2006	670	630	738	712	629
2007	698	663	806	781	702
2008	725	689	877	850	776
2009	751	712	949	923	852
2010	777	732	998	974	927

Table 8: Number of Milk Cows (Millions).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	10.33	10.33	10.33	10.33	10.33
1989	10.25	10.25	10.25	10.25	10.25
1990	10.16	10.16	10.16	10.16	10.16
1991	10.06	10.06	10.06	10.06	10.06
1992	9.96	9.96	9.96	9.96	9.96
1993	9.85	9.85	9.85	9.84	9.84
1994	9.72	9.71	9.64	9.35	8.09
1995	9.58	9.56	8.88	8.70	7.72
1996	9.43	9.36	8.66	8.53	7.60
1997	9.28	9.10	8.48	8.36	7.47
1998	9.13	8.82	8.30	8.19	7.32
1999	8.98	8.52	8.13	8.01	7.16
2000	8.83	8.22	7.96	7.84	6.99
2001	8.68	7.98	7.80	7.68	6.83
2002	8.54	7.79	7.66	7.53	6.69
2003	8.40	7.63	7.53	7.40	6.58
2004	8.26	7.50	7.42	7.29	6.49
2005	8.13	7.38	7.32	7.18	6.40
2006	8.01	7.26	7.16	7.05	6.32
2007	7.88	7.16	7.04	6.93	6.23
2008	7.77	7.06	6.92	6.81	6.13
2009	7.65	6.96	6.86	6.75	6.04
2010	7.54	6.86	6.80	6.69	5.99

Table 9: Production Per Cow (Pounds).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	137.86	137.86	137.86	137.86	137.86
1989	141.07	141.07	141.05	141.07	141.07
1990	144.25	144.25	144.25	144.25	144.25
1991	147.38	148.37	148.37	148.56	149.73
1992	150.46	153.88	153.88	154.53	158.65
1993	153.46	162.55	162.55	164.31	175.58
1994	156.38	172.56	172.56	175.76	196.70
1995	159.24	179.33	179.33	183.36	210.19
1996	162.06	183.14	183.15	187.47	216.23
1997	164.84	186.05	186.22	190.66	220.21
1998	167.59	188.34	188.76	193.21	222.73
1999	170.31	190.56	191.30	195.73	225.19
2000	173.02	192.77	193.85	198.25	227.64
2001	175.72	195.12	196.41	200.79	230.08
2002	178.41	197.59	199.00	203.34	232.56
2003	181.10	200.12	201.61	205.93	235.11
2004	183.78	202.71	204.24	208.54	237.68
2005	186.46	205.31	206.89	211.16	240.26
2006	189.13	207.93	209.55	213.80	242.84
2007	191.80	210.55	212.22	216.45	245.42
2008	194.47	213.17	214.90	219.12	248.01
2009	197.13	215.79	217.60	221.80	250.62
2010	199.79	218.41	220.30	224.48	253.24

Table 10: Cow Purchases by Government (Million of Cows) and Price per Cow (Dollars).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout	BST (16%) Cow Buyout	BST (32%) Cow Buyout
1988	NA	NA	NP	NP	NP
1989	NA	NA	NP	NP	NP
1990	NA	NA	NP	NP	NP
1991	NA	NA	NP	NP	NP
1992	NA	NA	NP	NP	NP
1993	NA	NA	0.07($2,286)	0.36($2,278)	1.61($2,212)
1994	NA	NA	0.61($1,897)	0.51($1,829)	0.23($1,285)
1995	NA	NA	0.04($1,120)	NP	NP
1996	NA	NA	NP	NP	NP
1997	NA	NA	NP	NP	NP
1998	NA	NA	NP	NP	NP
1999	NA	NA	NP	NP	NP
2000	NA	NA	NP	NP	NP
2001	NA	NA	NP	NP	NP
2002	NA	NA	NP	NP	NP
2003	NA	NA	NP	NP	NP
2004	NA	NA	NP	NP	NP
2005	NA	NA	0.06($2,918)	0.04($2,745)	NP
2006	NA	NA	0.04($3,191)	0.03($3,057)	0.02($2,650)
2007	NA	NA	0.05($3,536)	0.04($3,405)	0.03($3,015)
2008	NA	NA	NP	NP	0.04($3,386)
2009	NA	NA	NP	NP	NP
2010	NA	NA	NP	NP	NP

NA = Not Applicable.
NP = No Cow Purchase

Summary and Conclusions

We formulated a discrete control model of the U.S. dairy sector and determined optimal changes to maximize social welfare as bST is adopted. Social welfare is measured as consumer and producer surplus minus government costs. The control variable is government removal of cows. The support price is entered as a state variable dependent upon government purchases of milk.

With no control, a simulation shows that the all milk price could fall as low as $7.00 under a 13.5% bST impact. With optimal cow purchases the price only falls to $9.18. In the process social welfare is increased. Higher bST impacts of 16 and 32 percent with optimal cow purchases have little differential impact on variables except that more cows are purchased.

Purchase of cows does not occur until bST is well adopted. Until these cows are removed it is optimal to let CCC milk purchases increase so that the support price and milk price can be reduced for consumers. Since the eventual impact of bST may not be known until it occurs, the ability to wait until the impacts of bST are manifested before cows are removed is extremely beneficial in policy decisions. Like any model however, the results depend upon the stylized structure of the model and the coefficients used. For instance, in estimating the impact of profits on dairy cow numbers we used recent data where profits varied but were positive. The impact of bST may produce profits lower than those observed historically, questioning the validity of our behavior equation.

Our objective function was the summation of annual consumer and producer surplus minus government costs as typically defined in comparative static analysis. A useful extension of the model would be to include in the objective function costs of adjustment as suggested by Pindyck. This would allow defining the milk support price as a control. The measurement of consumer gains from market stabilization was recently discussed by Wright and Williams. Although the literature on the cost of adjustment in determining firm investment has become extensive, methodology and applications have centered on increases in investment rather than disinvestment as could occur under bST (Howard and Shumway). Finally, the net social impact of farmers leaving farming has not been quantified. This could be a significant cost component since entire farming regions could be affected.

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