OPTIMAL GOVERNMENT POLICY IN RESPONSE TO BOVINE SOMATOTROPIN

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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. Results indicate that government should remove cows after bST is widely adopted. The ability to wait is beneficial since the impact of bST is yet unknown.

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Bovine somatotropin (bST) 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). Bovine somatotropin is currently under regulatory review and is expected to be approved by the FDA as early as 1990 (Fallert).

Previous economic research on bST have centered on impacts of bST adoption on farm organization relative to non-adoption. For example, 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. 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 (see, for example, Ardhyula and Krog; Kaiser and Tauer; Magrath and Tauer; and Fallert, et al.).

All studies have treated government policy exogenously. 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 the type and timing of dairy policy which optimizes social welfare.

The Optimal Dairy Policy Model

The use of control theory for agricultural policy was discussed by Burt in 1969. He suggested using social value measures directly in the criterion function, and possibly imposing ancillary constraints to protect farmers' income position. We use a social welfare function consisting of consumer and producer surplus minus government costs. Producers' income is protected by limiting support price changes based upon government purchases of milk. 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. 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, 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.

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. The dairy price support program and a voluntary supply control program are the two policies incorporated into the model. 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 (CCC). The supply control program (a cow removal program) is the control variable in the model. Social welfare is maximized by determining the timing and level of cow removals in response to bST.

The model is presented in Table 1. Equations (1), (2), and (3) are accounting equations which define real and nominal profits of dairy farmers. Real profit/cwt. (RPROFH) is equal to gross income from the sale of milk (MLKPR) minus variable costs net of culled cow revenue (VCOST), 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. Nominal profit per cwt. (NPROFH) is equal to RPROFH times the CPI. Real profit per cow (RPROFC) is equal to RPROFH times production per cow (PRODCOW).

Equations (4), (5), and (6) are the cow number (COW), production per cow, and milk production (MLKPROD) equations. 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 lagged real profits per cow, 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. The estimated linear equation[1] for cow numbers using ordinary least squares (OLS) is:

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

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

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1 The data used to estimate all equations was based on national observations from 1975-87. The numbers in parentheses are t-values, R^2 is the adjusted coefficient of variation, and DW is the Durbin-Watson statistic. For more details on the model and the data, see Tauer and Kaiser.

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

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. Milk production (COW times PRODCOW) is multiplied by 0.98 in (6) to reflect leakages from farm to 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, the price per cow is based on farmers' present profitability. Second, a cow has a salvage value of $500. Finally, the purchase program requires 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. Government purchases (GVNPUR) are equal to milk production plus milk imports (IMPORTS) minus commercial milk consumption (MLKCON). Milk imports are fixed at their recent average of 2.5 billion pounds of milk equivalent.

Equations (10) and (11) pertain to the equilibrium price for milk (MLKPR). Equation (10) is the all milk demand equation expressed in price inverse form. Commercial per capita demand for milk products (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:

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

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

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:

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

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 milk surplus expectations by the Secretary of Agriculture. However, unlike the 1985 Farm Act, the annual change in the support price is a continuous function of government purchases of excess milk the previous year. Equation (13) insures that if there are CCC purchases, then the relationship between the market and support price in equation (11) is binding.

The CPI was increased 4% a year and a nominal discount rate of 7% was used. Variable cost per cow was increased 3% a year starting at \$959.50 (1988). Population was assumed to increase at 1% per year. 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. 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. All results are summarized in Table 2.[2]

The total discounted surplus of the four 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 at the bottom of Table 2. The addition of bST in scenario (2) increases welfare over 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 is due to negative variable profits for three years from bST with no cow buyout (not all years shown in Table 2). Consumers do benefit from a lower milk price and greater milk consumption 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.

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. Under a 13.5% bST response, the all milk price decreases to a low of $7.00 by 1998 and 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

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2 The results for all years in the period 1988 through 2010 are given in Tauer and Kaiser.

equal to the price in scenario 2. Under 32% bST, all milk price is slightly lower, reaching a low 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 milk price is about $13.00 by 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. 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. 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. 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.

Cows numbers fall over time under all scenarios. 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. It is interesting that the following year cows could be purchased at only $1,120 a cow, but only 4,000 cows are purchased. 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.

One of the most interesting result is 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 the 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.

Summary and Conclusions

A discrete control model of the U.S. dairy sector was formulated and optimal policies in response to bST were discussed. The control variable was a cow disposal program and the support price entered the model as a state variable dependent upon government purchases of milk.

With no control, 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 32% 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 is not known, the ability to wait until the impacts occur is beneficial in policy decisions.

Table 1. The Optimal Control Dairy Model.

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

subject to:

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(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) > 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) ≥ 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) ≥ 0.
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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:

$\text{CPI(I)} = 340.4 * (1.04)^i$

$\text{DISCOUNT(I)} = 1/(1.07)^i$

$\text{IMPORTS(I)} = 2.5$

$\text{INTERCEPT(I)} = \text{CPI(I)} * (.1556 - .001416 * \text{TREND(I)})$

$\text{POP(I)} - 240.5 * (1.01)^i$

$\text{TREND(I)} - I + 13$

$\text{VCOST(I)} = 959.5 * (1.03)^i * (1 + \text{ADJ} * \text{ADOPT(I)}) + \text{ADOPT(I)} * 50$

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	32% BST
BST	.0	.135	.3214
ADJ	.0	.064	.151

Table 2: Model Results for Selected Years of the Four Scenarios.

Year	No bST, No Cow Buyout	bST (13.5%) No Cow Buyout	bST (13.5%) Cow Buyout	bST (32%) Cow Buyout
All Milk Price ($ per cwt.)				
1988	$11.63	$11.63	$11.63	$11.63
1990	11.71	11.71	11.71	11.71
1995	11.20	9.18	9.28	8.86
2000	11.45	8.19	9.91	8.32
2005	12.46	11.58	11.95	10.55
2010	13.62	12.80	13.90	12.47
Milk Consumption (Billions of Lbs.)				
1988	138.17	138.17	138.17	138.17
1990	140.18	140.18	140.18	140.18
1995	146.55	152.78	152.47	153.78
2000	149.13	157.81	153.24	157.48
2005	148.86	150.89	150.04	153.26
2010	147.70	149.32	147.13	149.99
Support Price ($/cwt.)				
1988	10.60	10.60	10.60	10.60
1990	10.69	10.69	10.69	10.69
1995	10.09	7.71	7.83	7.33
2000	10.39	5.59	8.57	6.69
2005	11.58	8.09	10.98	9.09
2010	12.95	10.59	13.29	11.59
CCC Annual Purchases (Billion Lbs.)				
1988	3.94	3.94	3.94	3.94
1990	5.90	5.90	5.90	5.90
1995	5.45	17.70	6.17	7.69
2000	3.08	NP	0.44	1.00
2005	2.22	NP	0.78	NP
2010	2.45	NP	2.18	1.13
Variable Profits ($ per cow)				
1988	615	615	615	615
1990	638	635	635	630
1995	519	307	325	418
2000	521	31	373	221
2005	640	589	683	605
2010	777	732	998	927

Table 2 (Continued)

Year	No bST, No Cow Buyout	bST (13.5%) No Cow Buyout	bST (13.5%) Cow Buyout	bST (32%) Cow Buyout
<u>Number of Milk Cows (Millions)</u>				
1988	10.33	10.33	10.33	10.33
1990	10.16	10.16	10.16	10.16
1995	9.58	9.56	8.88	7.72
2000	8.83	8.22	7.96	6.99
2005	8.13	7.38	7.32	6.40
2010	7.54	6.86	6.80	5.99
<u>Cow Purchases (Purchase Price)</u>				
1988	NA	NA	NP	NP
1993	NA	NA	.07 ($2,286)	1.61 ($2,212)
1994	NA	NA	.61 ($1,897)	.23 ($1,285)
1995	NA	NA	.04 ($1,120)	NP
2005	NA	NA	.06 ($2,918)	NP
2006	NA	NA	.04 ($3,191)	.02 ($2,650)
2007	NA	NA	.05 ($3,536)	.03 ($3,015)
2008	NA	NA	NP	.04 ($3,386)
<u>Production Per Cow (Pounds)</u>				
1988	137.86	137.86	137.86	137.86
1990	144.25	144.25	144.25	144.25
1995	159.24	179.33	179.33	210.19
2000	173.02	192.77	193.85	227.64
2005	186.46	205.31	206.89	240.26
2010	199.79	218.41	220.30	253.24
<u>Welfare Measures (Billion $)</u>				
Consumer Surplus				
	407.18	429.07	419.19	431.74
Producer Surplus				
	60.80	43.75	53.62	47.92
Government Cost				
	5.89	7.14	7.09	9.52
Net Surplus				
	462.09	465.68	465.72	470.14

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