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Bovine Somatotropin and the Dairy Sector

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Abstract

A control model of the U.S. dairy sector was constructed to determine optimal policy when bovine somatotropin is released. Social welfare defined as consumer plus producer surplus minus adjustment and net government costs was maximized. Control variables were the milk support price and government purchases of cows. Compared to previous simulation research where government policy and adoption were modeled exogenously, the results show that policy not overly disruptive to the dairy sector is possible.

Keywords: Dairy Policy, Optimal Control, Bovine Somatotropin, Bovine Growth Hormone, Technology.

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Optimal Agricultural Policy with Biotechnology: Bovine Somatotropin and the Dairy Sector

Bovine somatotropin (bST) is a protein produced in the pituitary gland of a dairy cow that regulates and stimulates milk production. Through advances in genetic engineering, bST can now be manufactured using recombinant DNA technology and injected into cows to increase milk yields. This product is not yet available on the commercial market, but supplemental bST administered to cows has increased milk yields from 10 to 25% in experimental trials across the country (Animal Health Institute). While feed intake of dairy cows treated with bST also increases, the evidence from these trials indicates an increase in feeding efficiency of 5 to 15 percent. Bovine somatotropin is currently under regulatory review and is expected to be approved soon by the FDA (Fallert).

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 necessary adjustments in dairy policy. In a USDA study mandated by Congress, Fallert, et al. examined market impacts due to bST adoption under four different policy scenarios, using simulation models to predict equilibrium price and quantity values for 1989 through 1996. One of their major findings was that the impact of bST depends largely on adjustments in dairy policy (e.g., the milk support price). Their results suggest that if the support price is not lowered after bST is adopted, then government purchases of surplus milk will rise significantly. This is consistent with Kaiser and Tauer who found that the use of combined flexible support prices and voluntary supply controls, defined as cow removals similar to the 1986-87 Dairy Termination Program, was a more attractive policy in terms of stabilizing government costs and maintaining farm income than either policy alone. Arguing that adoption of bST would be significantly lower than the rates used in the research listed above, Schmidt used adoption rates of 20 to 30 percent to find that cow numbers would drop by less than 6% during a comparable simulation period, a much smaller reduction compared to previous research results.

This article reports a model which determines the dynamic adjustments in dairy policy that maximizes social welfare upon the availability of bST. A discrete dynamic optimization model of the national dairy sector with two control variables is constructed and solved for the period 1990 through 2005. The first policy control variable is the milk support price level, which may be changed annually in response to the effects of bST on the dairy sector. The second policy control variable is a supply control program involving annual cow removals. Unlike previous research, the adoption rate of bST is endogenous in the model, dependent upon the profitability of using bST (Thirtle and Ruttan). This model differs from the control model of McGuckin and Ghosh since the objective of their model was to minimize government milk purchases from a policy target. They employed one control variable, the support price for milk, and an exogenous adoption rate.

Conceptual Framework

The use of control theory for agricultural policy analysis was presented 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 positions. Since then control models in agriculture have been formulated for a number of commodities, including wool (Hincky and Simmons) and beef (Rausser and Freebairn).

Following Burt's suggestions, the model presented here uses social welfare as the objective function. Social welfare (SW) is defined as the sum of consumer and producer surplus minus sector adjustment costs and the net cost of government dairy programs. It is assumed that the government's objective is to select a set of dairy policies over time so as to maximize the discounted sum of social welfare with respect to the dairy sector. Instead of imposing ancillary constraints to protect farmers' income position as Burt suggests, this model uses Pindyck's approach and incorporates adjustment costs explicitly in the objective function as an augmentation to producers' surplus.

The general structure of the discrete control model is

$$(1) \quad \text{Max} \sum_{t=1}^{n} SW(\Delta X, X, U)$$

s.t.

$$(2) \quad \Delta X = f(X, U)$$

where: SW is the welfare function, X is a two variable state vector which includes the number of cows and the adoption rate, ΔX is a vector of state variable changes, and U is a two variable control vector consisting of cow removals and the milk support price level. In the empirical model, components of the welfare function, such as the milk demand and supply functions to determine the milk price, are treated as constraints, increasing the apparent but not the real complexity of the problem. The following discusses the components of the social welfare function and sketches how milk supply and demand are modeled.

Consumer Surplus

Consumer surplus can be measured under temporal conditions for the cases of price certainty or price uncertainty (Just, Heuth, and Schmitz). However, milk and many dairy products are highly perishable which suggests that the potential to use inventories to benefit from price variability are modest at best. Also, milk products comprise a small proportion of the typical consumer's budget and hence the disutility associated with price risk is also modest (Wright and Williams). Therefore, temporal consumer surplus is measured nonstochastically in the model as the summation of the discounted flows of its static measure for each year in the time horizon. Assuming a linear consumer demand function for milk, Marshallian consumer surplus (CS) for year t is measured as:

(3) $CS_t = 0.5 (\alpha_t - P_t) Q^d_t$,

where: α_t is the intercept term for year t, and P_t and Q^d_t are the equilibrium consumer milk price and quantity demanded for year t.

Producer Surplus and Adjustment Cost

If income is uncertain, then producer welfare should be measured by expected utility. Due to the absence of any aggregate estimate of dairy producers' utility function, the expected utility method is not used here to compute producer surplus. Rather, risk neutrality is assumed and producer surplus is measured as the summation of the discounted flow of annual net income for each year of the time horizon.

Producers may also face significant costs of adjusting to new optimal output levels over time, since the introduction of bST and the associated potential changes in dairy policy may cause dramatic farm sector adjustments. Adjustment costs are implicitly included in supply response via the cow number and production per cow equations by the use of lagged dependent variables in the estimation of these equations. To explicitly include adjustment costs into social welfare, a negative quadratic function of the change in milk price is augmented to net income. The quadratic functional form for adjustment costs in a deregulatory optimal control model was suggested by Pindyck and used by Chang and Stefanou in their control model of the dairy sector.[1] Adding the adjustment term to producer welfare yields the following producer surplus (PS) and adjustment cost (ADJ) measure:

(4) $PS_t - ADJ_t = (P_t - W_t)\, Q^s{}_t - \delta\, \Delta P_t^2$,

where: W_t is variable costs per cwt. of milk, $Q^s{}_t$ is equilibrium milk supply in year t, δ is the adjustment cost parameter, and ΔP_t is the change in the milk price from the previous year.

Net Cost of the Dairy Price Support Program

Under the dairy price support program, the government indirectly supports the market price for manufacture grade (Grade B) milk by agreeing to purchase unlimited quantities of storable dairy products at specified support (purchase) prices. By doing so, the government may maintain the milk price above the market price. The dairy products bought by the government are stored and then later released by selling them at either full or reduced prices, or given away for domestic and foreign food assistance programs.

Although net monetary costs of the dairy price support program can be estimated quite accurately with the use of Commodity Credit Corporation data, net monetary costs would overstate the true social cost because it does not include the value to society of domestic and foreign donations.[2] While government donations undoubtedly have some value to society, they also entail distribution costs and costs of displacing commercial products. Hence, valuing donations either at zero or at the market price would be inappropriate. In this application, it was assumed that domestic and foreign donations have a value of 50% of the government purchase prices for butter, cheese, and nonfat dry milk. Using these procedures, the net cost to society of the dairy price support program (CDPSP) for year t was modeled as:

(5) $CDPSP_t = \Phi\ PS_t\ Q^g{}_t$,

where Φ is net monetary costs minus the value of foreign and domestic donations per cwt., divided by the support price; PS_t is the support price per cwt. in year t; and $Q^g{}_t$ is quantity of government purchases in year t measured in cwts. of raw milk equivalent.

Net Cost of Voluntary Supply Control Program

The supply control instrument in the model is a cow removal program. When and if implemented, it is assumed that each farmer would submit a bid on how much he must receive to dispose of his cows and remain out of dairying indefinitely. It is implicitly assumed that the producers (cows) leaving the industry are "bribed" by the government to leave and that the value of each bribe is equal to the disutility associated with leaving the industry. Hence, there is no net benefit to these exiting dairy farmers to be included in social welfare. Since payment of this bribe is borne by the government, the net cost of this program (CDTP) for year t is equal to:

(6) $CDTP_t = B_t\ Y_t\ CP_t$,

where B_t is the national average bid per cwt. in year t determined empirically by expected profitability, Y_t is average production per cow (in cwts.) in year t, and CP_t is the number of cows purchased by the government in year t.[3]

Based on the assumptions and methods underlying the calculation of the five components of social welfare with equal weighting to each component, the total social welfare for year t is:

(7) $$SW_t = [(.5\ (\alpha_t - P_t)\ Q^d{}_t) + ((P_t - W_t)\ Q^s{}_t) - (\delta\ \Delta P_t{}^2) - (\Phi\ SP_t\ Q^g{}_t) - (B_t\ Y_t\ CP_t)]$$

Adjustment cost is the only dynamic component of this welfare specification. The remaining terms are static measures of welfare, discounted and summed. As such, if the adjustment cost parameter was zero, the optimal solution would be equivalent to the comparative static result that the government immediately remove itself from the market to eliminate deadweight loss.

Milk Supply and Demand

The supply of milk is determined by the number of cows multiplied by production per cow. Being a biological stock, the number of cows in a given year is dependent upon the number of cows in the previous year and economic decisions to adjust those numbers based upon expected profit per cow. Also, the government can reduce the cow herd through cow purchases. Production per cow is a function of lagged production per cow. The technology of bST will increase production per cow, but increase production costs per cow due to the additional feed required and the cost of the compound. The adoption of bST will depend upon the profit differential between treated and non-treated cows.

The consumer demand for milk is a function of milk price, population and income. In addition to consumer demand, the government purchases milk via the dairy price support program whenever the market price falls below the government support price.

The Empirical Model

The empirical model is presented in Table 1. The governments' decision problem is to choose the level and time path of the support price (SP_t) and number of cows to purchase (CP_t) that maximizes discounted social welfare subject to a set of equations of motion and constraints. The time horizon for this problem is from 1990 through 2005.

The first expression in brackets following the discounting term in the objective function represents consumer surplus (discussed below). The second expression is producer surplus, which is equal to net economic profit per cwt. (P_t - W_t) times total milk supply (Q_t^s) in cwt. The next expression represents sector adjustment costs, where a marginal adjustment cost coefficient (δ) of \$2.5 billion is assumed.[4] The last two expressions in the objective function are the social costs of the dairy price support program and government cow disposal program, respectively. The net support price cost coefficient, Φ, was estimated to be 0.85 using a simple average of previous years.

Equation (2.1) in the constraint set is the estimated demand equation expressed in price inverse form. To obtain this function, per capita commercial disappearance on a cwt. of milk equivalent basis ($Q^d{}_t/POP_t$) was estimated as a function of the real all milk price per cwt. (P_t/CPI_t), real per capita disposable income (INC_t/CPI_t), a time trend (T_t), and a constant term.[5] The time trend was included to capture the effects of other exogenous demand determinants. To correct for potential simultaneity bias due to P_t being endogenous, a two step estimation procedure similar to that used by La France and de Gorter was used. First, an instrument for the all milk price was constructed by regressing P_t on the exogenous milk support price per cwt. (PS_t), a time trend (T_t), and a constant term. Using ordinary least squares (OLS), this resulted in the following instrumental variable for the all milk price[6]:

$$(8)\quad P_t = \underset{(7.5)}{2.9025} + \underset{(13.9)}{0.7310}\, SP_t + \underset{(4.0)}{0.1050}\, T_t$$

$$R^2 = 0.98;\ DW = 1.3$$

The predicted value ($PHAT_t$) from equation (8) was then used in place of the actual all milk price in estimating the demand function. This resulted in the following equation using OLS:

$$(9)\quad Q^d_t/POP_t = \underset{(8.2)}{5.6770} - \underset{(-3.5)}{0.0553}\ PHAT/CPI_t + \underset{(1.7)}{0.00007}\ INC_t/CPI_t - \underset{(-3.1)}{0.0256}\ T_t$$

$R^2 = 0.65$; $DW = 1.7$

The price and income elasticities of aggregate demand using 1989 values are -0.14 and 0.19, respectively, which are consistent with estimates from previous research. To calibrate the price inverse demand equation (2.1) in Table 1, the intercept was reduced about 3 percent so that demand predicted by this equation was equal to its actual value for 1989.

Constraint (3.1) in Table 1 restricts the market price from being lower than a multiple of the support price. Since regional supply and demand vary over time, there is no exact relationship between the support price and the U.S. average milk price. Thus, constraint (3.1) is based on the following regression of the all milk price on the support price:

$$(10)\quad P_t = \underset{(63.0)}{1.103}\ SP_t$$

$R^2 = 0.90$; $DW = 0.4$

Constraint (4.1) guarantees that if the government is buying milk through the dairy price support program, then the relationship between the market and support price in constraint (3.1) is binding.

Equation (5.1) is an equilibrium condition for the nation's milk market. This condition requires that aggregate milk demand in year t is equal to aggregate milk supply (Q_t^s) minus the quantity of milk removed by the government through the dairy price support program (Q^g_t) plus net imports

(I_t), which are assumed to be exogenous based upon quotas and set equal its recent level of 2.5 billion pounds of milk equivalent.

Equations (6.1) - (6.3) define milk yield per cow for cows not treated with bST (Y_t), cows treated with bST (BY_t), and average milk yields for all cows (AY_t), respectively. Milk yield per cow in cwt. was originally estimated as a function of milk yield in the previous period, and real profits per cwt. $((P_{t-1} - W_{t-1})/CPI_{t-1})$ lagged one period. It was assumed that dairy farmers make adjustments in production per cow (and cow numbers) following a naive profit expectations scheme based upon the previous year's profit. The term W_t is variable costs less culled cow receipts on a cwt. basis. Variable costs include all variable expenses plus general farm overhead, taxes and insurance, interest, and capital replacement (Shapouri, et al.). Real profit was deleted from the final equation since it was statistically insignificant. The estimated equation using OLS is:

$$(11)\quad Y_t = \underset{(254.8)}{1.020}\, Y_{t-1}$$

$$R^2 = 0.98;\ DW = 2.1$$

This estimated equation is used in (6.1) in Table 1 to represent milk yields for cows not treated with bST. To model milk yields for cows treated with bST, the estimated equation was multiplied by the assumed percentage increase in yields due to bST (1 + BST), which is modeled in equation (6.2). A bST response of 13.5 percent is demonstrated in the results section. Finally, equation (6.3) in Table 1 gives average yield per cow which is a weighted average of equations (6.1) and (6.2) with the weights being the adoption (A_t) and non adoption ($1-A_t$) rates.

Equations (7.1) - (7.3) define real profit per cow for cows not treated with bST (Π_t), cows treated with bST ($B\Pi_t$), and average profit for all cows ($A\Pi_t$), respectively. Bovine somatotropin affects profits per cow in two ways. First, profits are increased due to a higher milk yield term (i.e., $BY_t > Y_t$). Second, since cows require more feed and there is a cost for bST, variable costs increase. Fallert, et al. estimated cost for bST of $50 per cow annually and their adjustment in variable costs for a 13.5 percent response from bST were used for variable costs (BW_t).

The cow number equation was estimated as a function of real profits per cow lagged one period, $\Pi_{t-1} = (P_{t-1} - W_{t-1})\ Y_{t-1}/CPI_{t-1})$, and the number of cows in the previous period. The estimated linear equation for cow numbers using ordinary least squares (OLS) is:

$$(12)\quad C_t = \underset{(97.5)}{0.974}\ C_{t-1} + \underset{(1.9)}{.000405}\ \Pi_{t-1}$$

$$R^2 = 0.81;\ DW = 1.8$$

These estimated parameters were used in equation (8.1). To incorporate the cow removal program, the number of cows purchased by the government in year t (CP_t), was subtracted from cow numbers in (8.1). Yet, cow numbers can rebound over time due to profitability in the sector.

Adoption of bST is determined in equations (9.1) and (9.2) by the logistic function $A_t = K_t/(1 + \exp(-a-b*t))$. This specification incorporates the impacts of profitability and interaction that have been debated between economists and sociologists since Griliches' seminal work on hybrid corn. The term K_t is the ceiling adoption rate that varies as a function of the incremental profits from bST. The denominator represents the process of learning and approaches the value of one as t increases.

A function for K_t was estimated from a published survey of dairy farmers who were given hypothetical bST return data and were asked whether they would eventually adopt at various prices of bST (Kinnucan, et al.). Subtracting the various prices of bST from the net return provided observations on the net profitability of bST with the percentage of farmers who would adopt. Fitting a linear, quadratic, and linear no-intercept functions to the data indicated that the linear no-intercept function provided the best fit:

$$(13)\quad K_t = \underset{(11.71)}{.01074}(B\Pi_t - \Pi_t) \qquad R^2 = 0.90;\ DW = 0.94$$

where $(B\Pi_t - \Pi_t)$ is the incremental profit per cow from the use of bST.

Although K_t specifies the final adoption of bST, that adoption will increase over time. Unfortunately, Kinnucan et al. did not ask farmers how soon they would adopt. A four year adoption curve of 5.4%, 15.3%, 39.7% and 79.0% from a separate published survey was used to estimate the a and b parameters of the logistic equation:

$$(14)\quad \ln\left(\frac{A_t}{K - A_t}\right) = \underset{(-16.67)}{-4.38} + \underset{(14.44)}{1.39}t \qquad R^2 = 0.99;\ DW = 2.07$$

assuming that the eventual adoption would be complete (K=1) (Lesser et al.).

Aggregate milk supply in equation (10.1) is the product of average milk yield per cow (AY_t) and number of milk cows (C_t), where historically 1.5 percent of production is lost due to leakages such as on-farm use of milk.

Equations (11.1) and (12.1) define the purchase price per cow (B_t) that the government pays to remove cows from production. Since there were inadequate data available to estimate the cow purchase price, equation (11.1) was constructed assuming that the price per cow should be based on farmers' present profitability minus a cow slaughter market value of $500. It was assumed that the cow purchase program would require participants to stay out of dairy farming for five years. Equation (11.1) combines these assumptions so that B_t is equal to profits per cow minus $500, with the result multiplied by five to reflect the five year duration of the program but discounted to the first year. Constraint (12.1) restricts B_t to not be less than $2,304 increased annually by the CPI, which was the average cow purchase price under the 1986 cow removal program.

Initial values for all exogenous and predetermined variables were set equal to their beginning 1990 levels. The CPI was assumed to increase at a rate of 4 percent a year and a nominal discount rate of 7 percent was used. Costs per cow were increased 3 percent a year starting at it's past three year average of $1,590. A population increase of 1 percent a year was assumed given recent growth. The problem was solved using GAMS/MINOS non-linear programming software (Brooke et al).

Results

Three scenarios are reported: (1) a base line scenario which assumes that bST is not available and government cannot implement a cow buyout, (2) bST availability with a yield increase of 13.5% and no cow buyout programs, and (3) 13.5% bST and a cow buyout.

The addition of bST in scenario 2 increases welfare from that of scenario 1 (Table 2). However, the introduction of bST shocks the dairy sector so that welfare reductions to producers occur, especially during a transitional period as profits are lower. This can be observed from Figure 1 where profits from bST with no cow buyout are negative during most of the 1990s. Discounted consumer surplus increases $21.32 billion with bST due to lower milk prices and greater milk consumption so that the net benefits to society increase even with producer surplus net of adjustment costs decreasing $16.56 billion and government costs increasing $.63 billion. Removing cows in scenario 3 increases total welfare relative to scenario 2, with producers gaining over $6.50 billion, consumers losing less than $5.91 billion, but government costs significantly lower ($.64 billion).

If bST is not made available then the nominal price of milk slowly increases to $16.06 (Figure 2). If bST is released in 1991 then the milk price decreases slightly to a low of $10.94 in 1992 but increases each year thereafter, reaching $15.01 by the year 2005. In contrast, if the government buys cows optimally then the milk price does not decrease much with bST and prices in every year are greater than or equal to the price in the comparable scenario without cow purchases.

Milk consumption is inversely related to the milk price, with the demand function shifting each year. With the no bST scenario milk consumption steadily increases as population and income increases and as the real milk price decreases. A 13.5% bST shock with no cow purchases increases milk consumption by 2 billion lbs. in 2000 as compared to no bST. However, if cows are optimally purchased then the increase in milk consumption is only slightly greater than consumption without bST.

The support price is binding for the first years under all scenarios (Table 3). Without bST, annual CCC purchases are 6.55 billion lbs. in 1991 but decrease each year to zero by 1997 (Figure 3). With bST and no cow buyouts the support price first decreases but then increases through the adoption of bST, with CCC purchases increasing only slightly during the mid 1990s. It is interesting that the support price increases while these purchases occur, but the purpose is to keep producers' profits from being even more negative than what they are during the early 1990s (Figure 1). With cow buyouts, CCC purchases are negligible during the bST simulation period because cow removals are used to control the milk supply.

The adoption of bST is illustrated in Figure 4. With no cow buyout program the additional real profits per cow from bST fall during the early 1990s, slowing the adoption rate. With a cow buyout program, dairy farm profitability is restored, allowing greater additional profits from the use of bST. The adoption of bST is enhanced; by the year 1995 the adoption rate is 72 percent rather than only 50 percent without government cow buyouts. In both cases the ceiling adoption rate is about 90 percent with bST incremental real profits of slightly more than $80. These adoption rates are lower than those that have typically been used in previous bST studies, and supports the contention of Schmidt that bST adoption will be slow and incomplete.

Cows numbers decrease over time under all scenarios (Figure 5). The reduction partly reflects the long term downward trend in cow numbers that was captured in the econometric estimation of the cow number equation. When production per cow increases fewer cows are required to produce a given quantity of milk. The slower downward trend in cow numbers under scenario 1 is due to higher profits without bST. Total milk production is shown in Figure 6.

Cow purchases by the government in scenario 3 significantly reduce milk cow numbers in the initial year (1990) and then in 1992, 1993 and 1994. With bST 390,000 cows should be purchased in 1990 at an average price of $2,396, and an additional 90,000 cows are purchased during 1992 and 1993, as bST is adopted starting 1991 (Table 3). The cow buyout price in all years is determined by the minimum price constraint (eq. 12.1). After the last cow purchase in 1993, the CCC purchases a small amount of milk during 1994 through 1996 to control milk supplies.

Average profits per cow are adversely affected by bST, especially during the adoption period. With no cow purchases, profits are negative during the adoption and adjustment period (Figure 1). With cow purchases, profits per cow are slowly restored to the levels without bST. Milk production per cow increases over time but is significantly enhanced with bST.

Technology rents typically accrue to those who adopt a new technology first. This is illustrated in Figure 7 where the profit per cow of adopters is always higher than the profit per cow of non-adopters. Also demonstrated is the fact that early bST adopters earn larger profits in the initial years than what they would have earned if bST was not made available. Those greater profits occurred for 3 years beginning in 1991. Beginning in 1995 a sufficient number of dairy farmers would have adopted bST, increasing milk production and lowering the milk price, that profits per cow would have been greater without the availability of bST than availability and adoption of bST. However, since profits per cow would be even lower with the availability but non-adoption of bST, adopting farmers would continue to use bST.

The bST technology shock to the sector occurs during the early 90s as bST is adopted but adjustment occurs during the entire decade, requiring government involvement in the sector through milk purchases and cow removals. That adjustment is completed by the next century when government involvement in the sector is negligible, implying the government could remove itself from the market. However, this is a deterministic, not a stochastic model, and the probability of another shock similar to bST may suggest continued government involvement in the dairy sector.

The movement towards a long-run equilibrium is suggested by the values of variables in the year 2005. In all scenarios the milk price is from $15.00 to $16.00 by the year 2005, although slightly lower under bST. Total production also appears to have reached a long-run path by 2005, with an increase from the use of bST. Profits per cow with and without the availability (but adoption) of bST are almost identical, suggesting a continued long-run convergence. This implies that bST and policy shocks have essentially worked their way through the dairy sector by 2005, producing only a slight long-run shift in the supply curve as demonstrated by Magrath and Tauer.

One of the most interesting results of this model is the divergence in values of key variables from previous simulation models that have treated government policy as exogenous. It is interesting to note that comparable simulation models have predicted much larger decreases in support and milk prices, as well as farm profitability. Kaiser and Tauer reported that the support price, milk price, and farm profitability would fall as low as $8.10 per cwt., $8.87 per cwt, and negative $9.52 per cow under 8% bST with comparable support price adjustments and cow buyouts. Moreover, buyouts of cows would total over 1.1 million cows between 1992 and 2000, well over the number indicated by this model for comparable years. In a similar scenario Fallert et al. found the support price falling to $8.60 per cwt. from 1992 through 1996 with cow numbers falling 12 percent by 1996.

While some of this divergence in results is undoubtedly due to different model specifications, another explanation for this difference is the fact that our model assumes that government responds optimally to maximize social welfare. An important implication is that if government behaved optimally in an economic sense, then the disruption associated with the restructuring of the dairy sector would be substantially lower than previous simulation models have indicated.

The control model results of McGuckin and Ghosh more closely follow the results reported here than do the simulation studies results, but significant differences exist. Because their objective was to minimize government milk purchases from a target, while the objective here was to maximize social welfare, their milk support price tracked lower when bST was released. Their government purchases of milk were also greater, but they used exogenous adoption rates more rapid than the endogenous adoption rates generated here.

Summary and Conclusions

A discrete control model of the U.S. dairy sector was constructed to demonstrate how optimal policy can be determined to maximize social welfare as bST is adopted. Social welfare was measured as consumer and producer surplus minus adjustment and net government costs. The control variables were the milk support price and government purchases (removals) of dairy cows. The annual adoption of bST was determined endogenously, based upon the net profitability of adopting bST and learning, represented by time.

Empirical results indicate that an optimal support price path can be determined that maximizes social welfare which is not overly disruptive to the dairy industry. Since dairy producers appear to respond slowly to profit decreases, a government cow removal program enhances social welfare with some shift of welfare from consumers to producers. The results clearly show that dairy policy similar to that authorized under the 1985 Farm Bill can be constructed to handle the shock of bST technology. Compared to previous simulation results where government policy and adoption were exogenous, the results here show that decreases in milk prices and farm profits are not as severe.

All of these results were obtained from a deterministic control model. As such, the support price mechanism was only used during an adjustment period and then was non-effective, in order to eliminate dead weight loss. However, one stated purpose of the support price mechanism is to provide a safety net for producers in case of stochastic shocks to the dairy sector. This rationale of the support price program needs to be explored by the use of a stochastic control model.

Footnotes

1. Using price rather than cow numbers as the determinant of adjustment costs acknowledges that inputs in addition to cow numbers would be adjusted by farmers when milk price changes. The use of a symmetric cost adjustment implies that the same inefficiency can be caused by either a price increase or decrease as farmers search for new output levels. The adjustment cost parameter may also be interpreted as the inclusion of social and regional adjustment costs precipitated by a change in milk price.

2. Net monetary cost is equal to gross program outlays less gross program receipts. The gross outlays include total purchases, storage and handling, transportation, processing and packaging, and domestic and foreign donations. The monetary receipts consist of proceeds from the sale of products either at market prices or reduced prices.

3. The cost of the cow disposal program was modeled as being borne solely by the government, although remaining producers could be required to pay some or all of the program costs. In fact, this could be incorporated as a control variable. Shifting the cost to producers would simply shift government cost to producers' cost in the welfare function, but would indirectly affect producer surplus via supply since supply is a function of profits.

4. Unfortunately, previous empirical estimates of adjustment costs have employed either a primal or dual approach with technology modeled as a trend variable, providing estimates not consistent or compatible with our model formulation (Howard and Schumway). Moreover, empirical values of adjustment costs are not available, only the empirical impacts. Consequently, a marginal adjustment cost coefficient (δ) of \$2.5 billion for the quadratic adjustment equation was chosen after experimenting with values of 1.0, 2.5, 5.0 and 7.5. The \$1.0 billion value seemed to provide little penalty to changes in price and the \$5.0 billion and \$7.5 billion values produced only slightly different results from 2.5 billion.

5. All data used in the econometric estimation of equations are national time series data for the period 1972 through 1989. All prices and costs are deflated by the consumer price index (1989 = 1.0). The all milk price is the average price received by dairy farmers from fluid and manufactured product processors. Since fluid processors pay more than manufactured processors for farm milk, the all milk price is a weighted average with the weights based on fluid and manufactured utilization rates in the market.

6. For all the estimated equations that follow, the numbers in parentheses are t-values, R^2 is the adjusted coefficient of determination, DW is the Durbin-Watson statistic.

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Table 1. The Empirical Dynamic Optimization Model of the Dairy Sector.

(1.0) Max: $W = \sum_{t=1}^{n} [1/(1 + i)^t] [(.5(\alpha_t - P_t) Q^d{}_t) + ((P_t - W_t) Q_t{}^s - \delta \Delta P_t{}^2) - (\Phi PS_t Q^g{}_t) - (B_t AY_t CP_t)]$

s.t.:

(2.1) $P_t = \alpha_t - 18.180 CPI_t Q^d{}_t / POP_t$

(3.1) $P_t \geq 1.103 SP_t$

(4.1) $0 \leq (1.103 SP_t - P_t) Q^g{}_t$

(5.1) $Q^d{}_t = Q^s{}_t - Q^g{}_t + I_t$

(6.1) $Y_t = 1.02 Y_{t-1}$

(6.2) $BY_t = Y_t(1 + BST)$

(6.3) $AY_t = (1 - A_t)Y_t + A_t BY_t$

(7.1) $\Pi_t = (P_t - W_t)Y_t / CPI_t$

(7.2) $B\Pi_t = (P_t - BW_t)BY_t / CPI_t$

(7.3) $A\Pi_t = (1 - A_t)\Pi_t + A_t B\Pi_t$

(8.1) $C_t = 0.974 C_{t-1} + 0.000405 A\Pi_{t-1} - CP_t$

(9.1) $A_t = 0.01074(B\Pi_t - \Pi_t)/(1 + \exp(4.38 - 1.39 T_t))$

(10.1) $Q^s{}_t = 0.985 AY_t C_t$

(11.1) $B_t = (A\Pi_t(1 - (1 + i)^{-5})/i - 500) * CPI_t$

(12.1) $B_t \geq 2304 * CPI_t$

where:

α_t = intercept of the aggregate demand function year t ($\alpha_t = CPI_t(100.3 - 0.473 T_t + 0.00127 INC_t/CPI_t)$);

CPI_t = consumer price index for all items year t (1989 = 1.0) with a 4% annual increase;

T_t = time trend year t (1990 = 19, 1991 = 20, ...);

INC_t = disposable per capita income year t (\$) with a 5% annual increase, INC_{1990} = \$15,951;

P_t = equilibrium all milk price (\$/cwt.) year t;

$Q^d{}_t$ = equilibrium milk demand (cwt. of milk equivalent) year t;

W_t = variable costs per cwt. for cows <u>not</u> treated with bST less culled cow income per cwt. year t, W_{1990} = \$11.29;

$Q^s{}_t$ = aggregate milk supply (cwt.) year t;

δ = marginal cost of adjustment (set at 2.5);

ΔP_t = change in the equilibrium all milk price from previous year;

Φ = average net social cost of price support program per cwt. divided by average milk support price per cwt. (Φ was estimated to be 0.85 with data from 1977 - 1987);

SP_t = milk support price per cwt. year t (PS_{1990} = \$10.10);

$Q^g{}_t$ = government purchases of milk equivalent in cwt. in year t under the price support program;

B_t = bid price per cwt. for cow removal program year t;

AY_t = average milk production per cow in cwts. year t;

CP_t = number of cows purchased by government cow removal program in year t;

POP_t = civilian population in millions year t with an annual increase of 1%, POP_{1990} = 250;

I_t = net imports of dairy products (cwt. of milk equivalent);

Y_t = milk production per cow (in cwts.) for cows not treated with bST in year t, Y_{1989} = 142.44;

BY_t = milk production per cow (in cwts.) for cows treated with bST in year t;

BST = percentage increase in production per cow due to bST;

AY_t = average milk production per cow (in cwts.) for all cows in year t;

A_t = percent of cows treated with bST in year t;

Π_t = real profit per cow not treated with bST in year t;

$B\Pi_t$ = real profit per cow treated with bST in year t;

BW_t = variable costs per cwt. for cows treated with bST less culled cow income per cwt. in year t;

$A\Pi_t$ = average real profit per cow for all cows in year t;

C_t = number of cows in millions in year t, C_{1989} = 10.127;

i = interest rate (set at .07);

All milk quantities are listed in units of cwt. for exposition purposes. The model was solved in milk quantity units of 10 million pounds to avoid scaling problems.

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

	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout
Consumer Surplus	935.80	957.12	951.21
Producer Surplus	24.10	5.95	12.17
Adjustment Cost	3.65	2.06	1.78
Net Government Cost	2.01	2.63	1.99
Net Surplus	954.24	958.38	959.61

Table 3: Control Variables - Support Price ($/cwt.) and Government Cow Purchases in Parentheses (Millions of Cows).

Year	No BST No Cow Buyout	BST (13.5%) No Cow Buyout	BST (13.5%) Cow Buyout
1990	10.10	10.10	10.10(.39)
1991	10.43	9.97	10.17
1992	10.82	9.92	10.28(.06)
1993	11.24	9.94	10.40(.03)
1994	11.70	10.04	10.56
1995	12.18	10.22	10.79
1996	12.66	10.49	11.09
1997	10.82	10.83	9.89
1998	10.43	11.23	11.92
1999	13.83	11.68	12.30
2000	10.64	12.15	12.62
2001	14.10	12.55	12.90
2002	14.24	12.88	13.13
2003	14.38	12.96	10.18
2004	14.19	9.96	8.75
2005	14.56	6.58	9.99

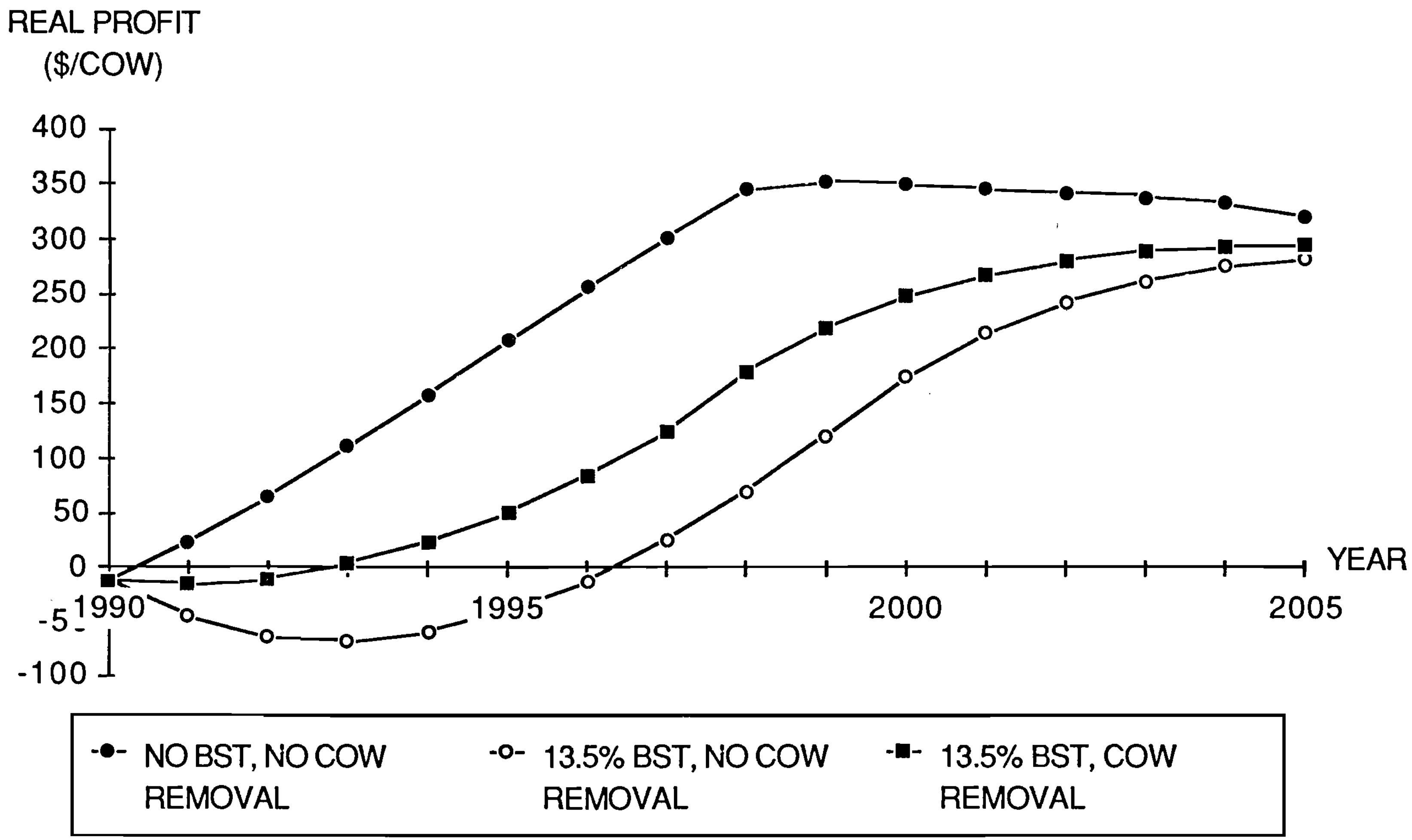

Figure 1: Real Profits per Cow.

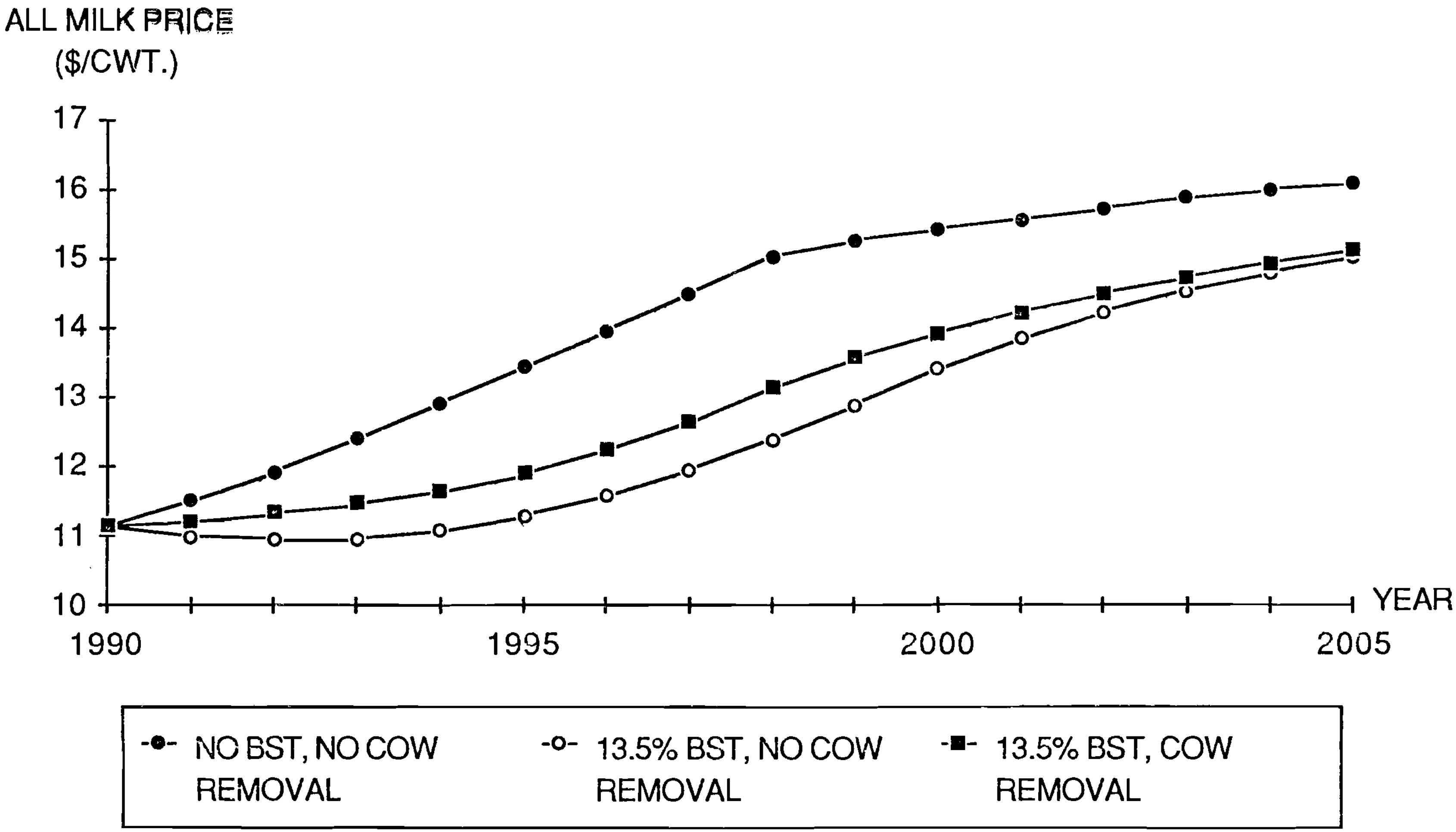

Figure 2: Nominal All Milk Price.

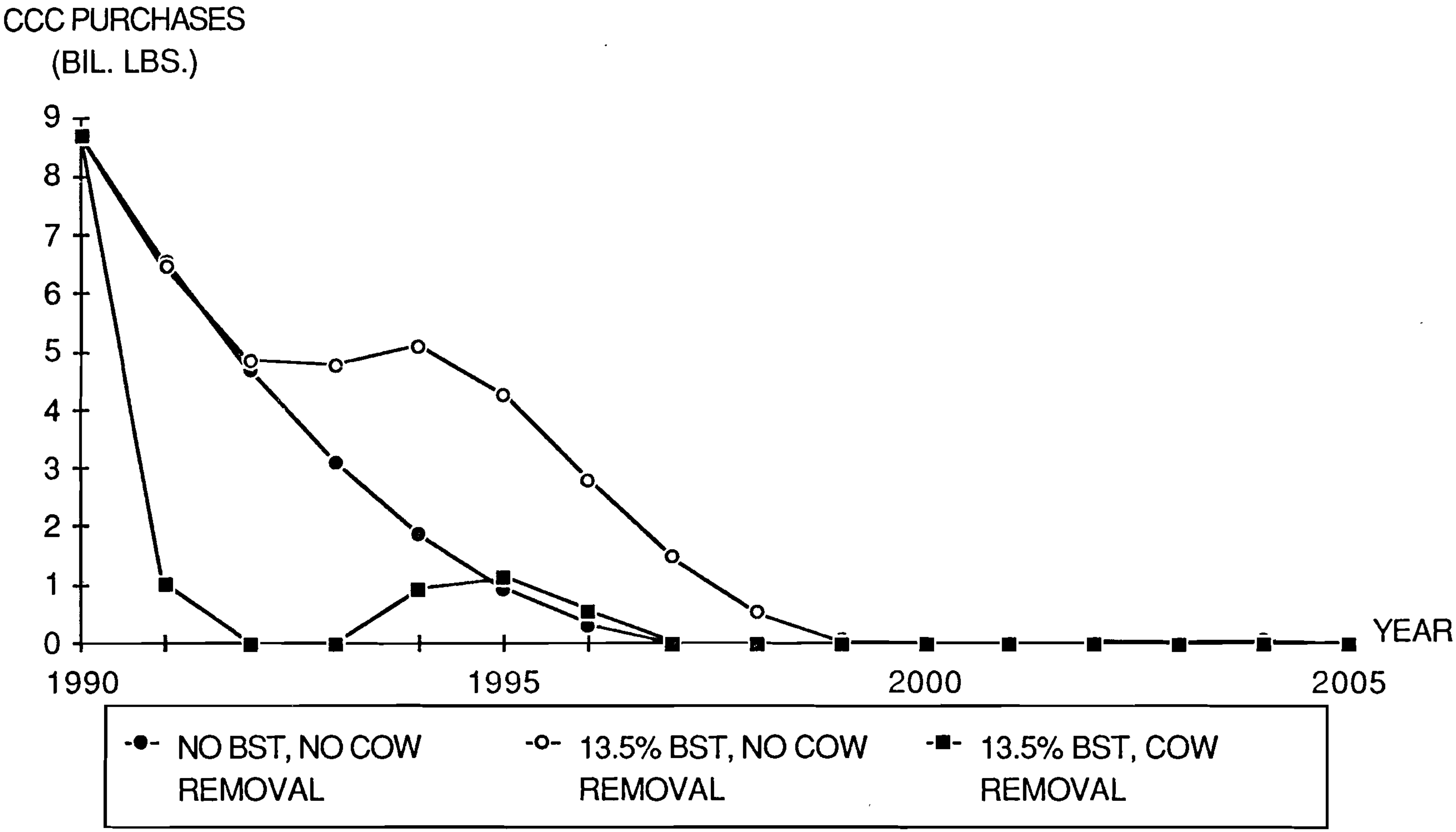

Figure 3: CCC Annual Milk Purchases.

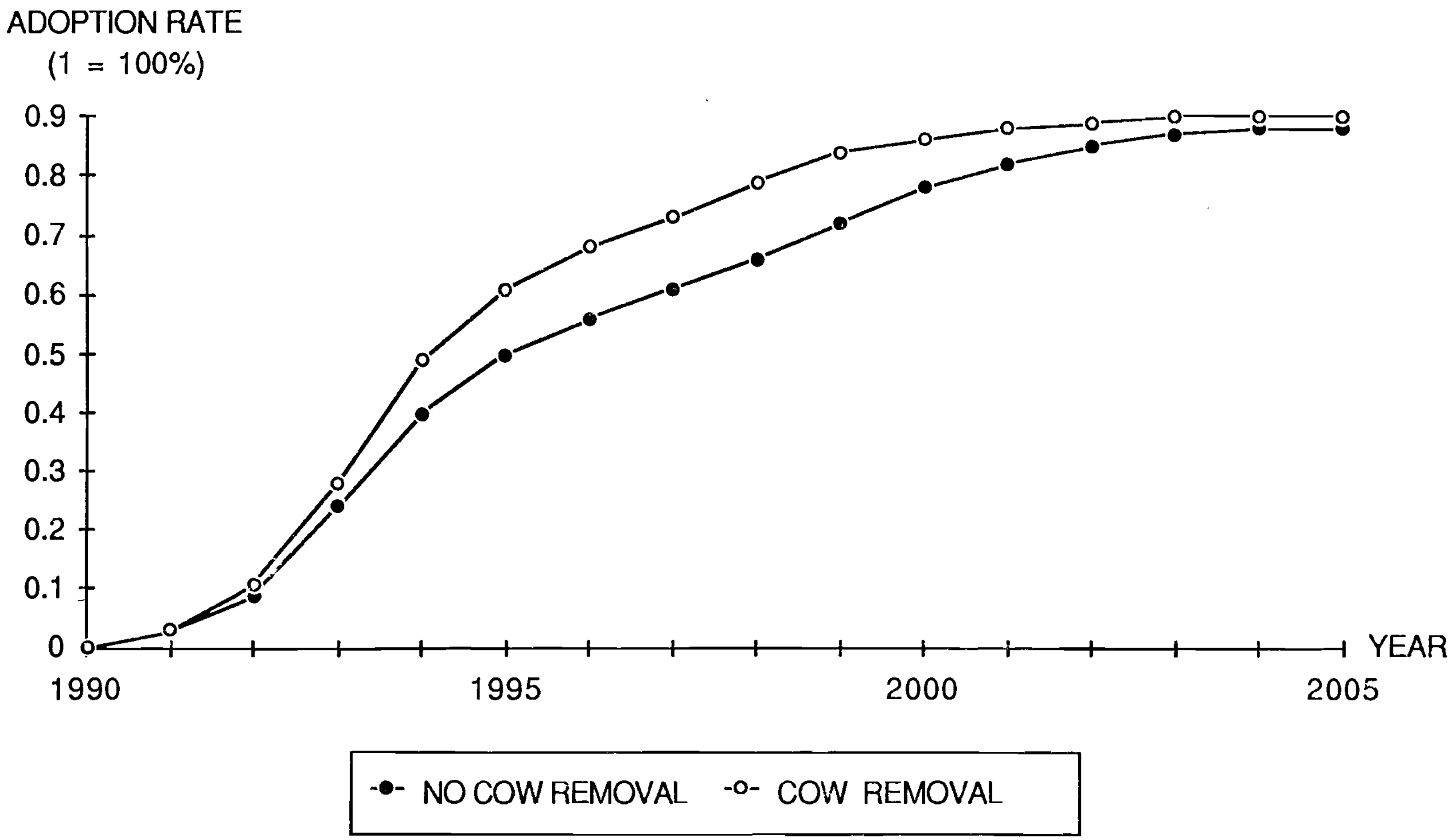

Figure 4: Adoption of bST.

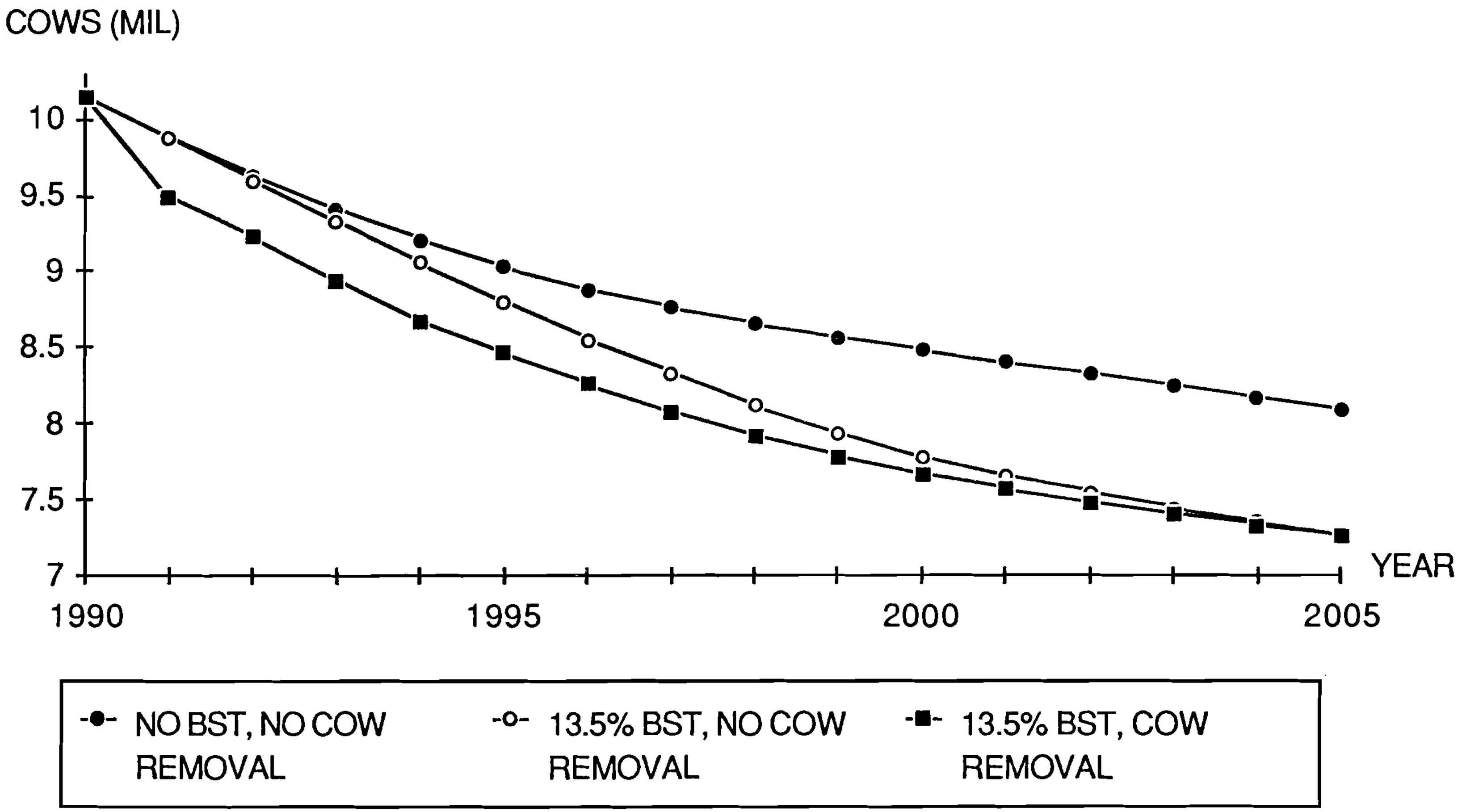

Figure 5: Number of Milk Cows.

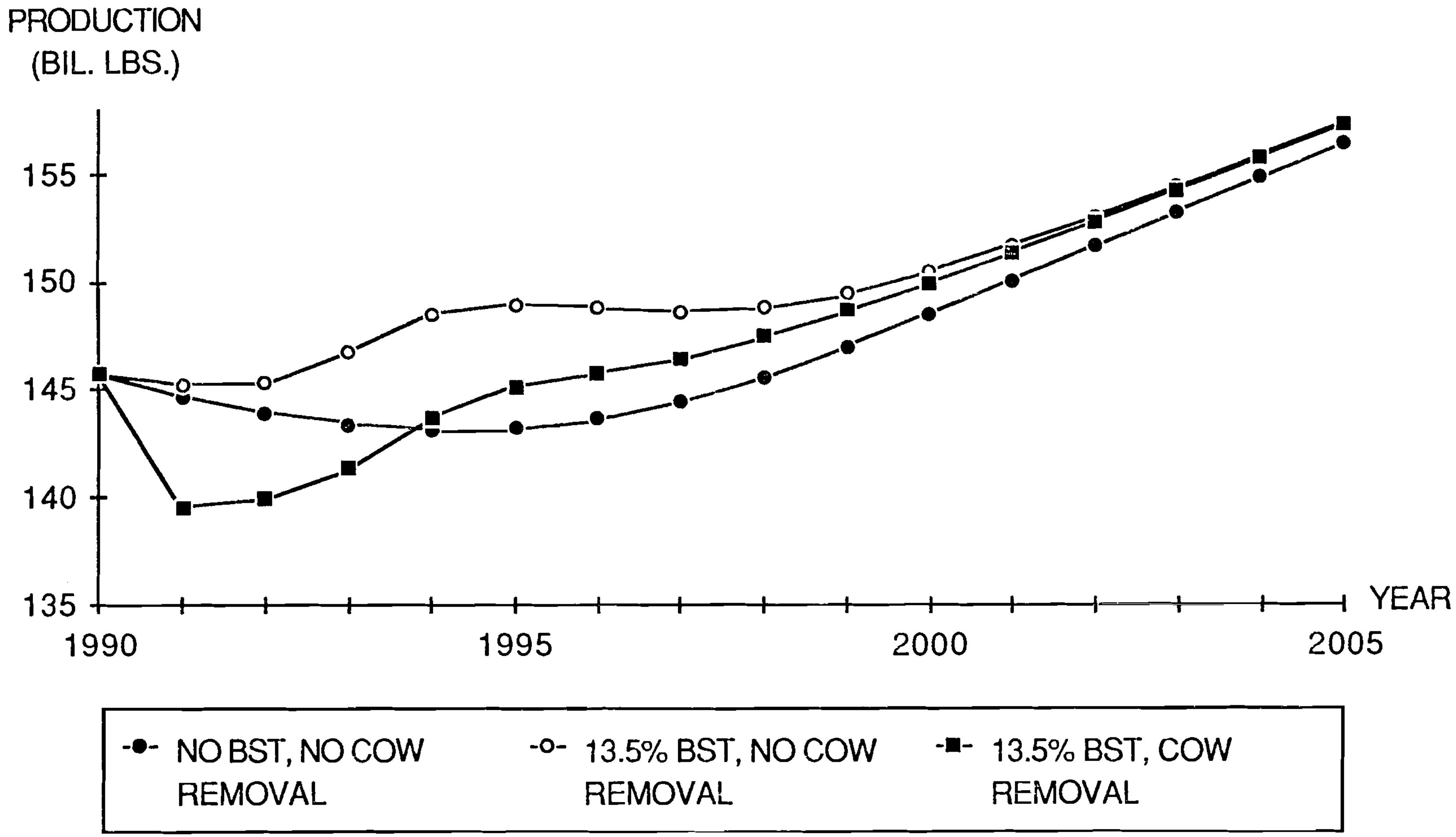

Figure 6: Total Milk Production.

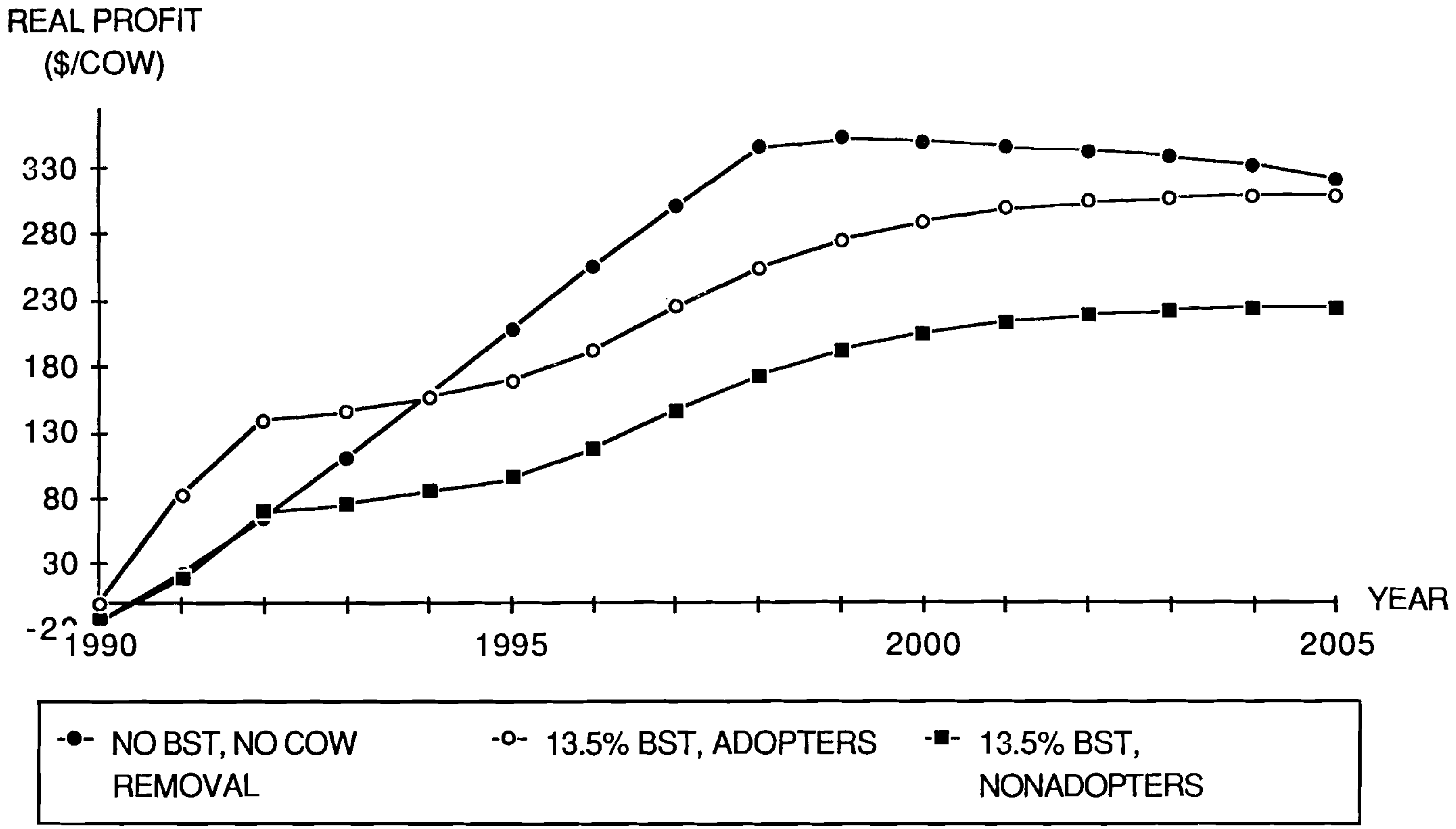

Figure 7: Profits per Cow of Adopters and Non-Adopters of bST.

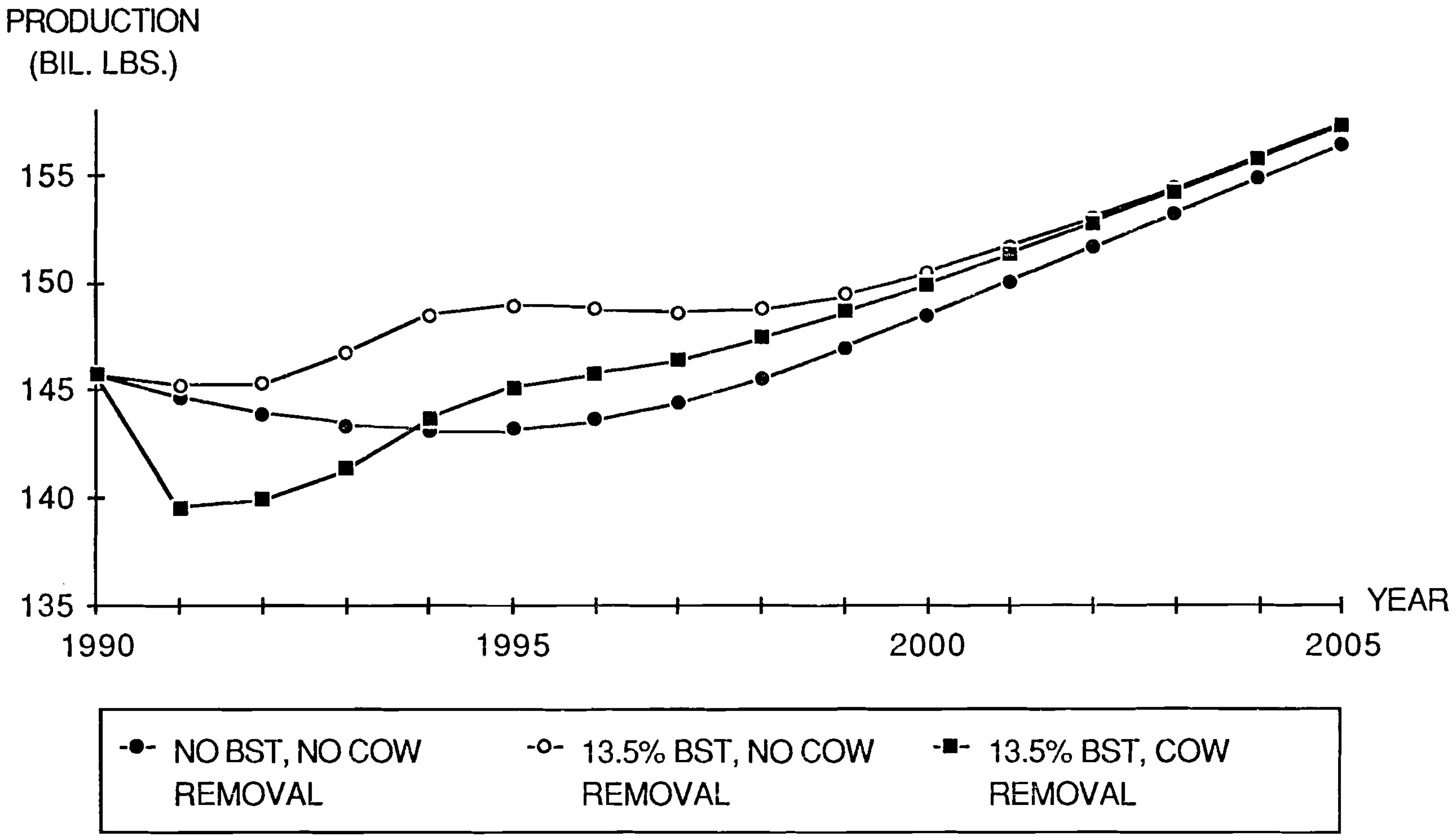

Figure 6: Total Milk Production.

Table A.1. Data used in the Model.

Year	All Milk Price ($/cwt)	Net CCC Removals (bil lbs)	Commercial Demand (bil lbs)	Cow Numbers (1,000)	Consumer Price Index (1989=1)	Per Capita Disposable Income ($)	Profit Per Cow ($/cow)	Civilian Population (mil)	Milk Per Cow (cwt)	Support Price ($/cwt)	Variable Costs ($/cwt)
1972	6.07	5.35	112.90	11,700	0.34	4,000	192.87	208.10	102.59	4.93	4.19
1973	7.14	2.19	112.60	11,413	0.36	4,481	192.26	211.50	101.19	5.34	5.24
1974	8.33	1.35	113.10	11,230	0.40	4,855	158.51	213.30	102.93	6.57	6.79
1975	8.75	2.04	113.80	11,139	0.43	5,291	178.19	210.70	103.60	7.36	7.03
1976	9.66	1.24	116.30	11,032	0.46	5,744	262.55	216.70	108.94	8.16	7.25
1977	9.72	6.08	116.10	10,945	0.49	6,262	291.36	220.50	112.06	9.00	7.12
1978	10.60	2.74	118.80	10,803	0.53	6,968	386.76	223.50	112.43	9.43	7.16
1979	12.00	2.12	120.10	10,734	0.59	7,682	432.10	224.60	114.92	10.61	8.24
1980	13.00	8.80	119.00	10,799	0.66	8,422	401.92	229.20	118.91	12.33	9.62
1981	13.80	12.86	120.30	10,898	0.73	9,247	430.06	228.20	121.83	13.39	10.27
1982	13.61	14.28	122.10	11,011	0.78	9,732	403.64	229.70	123.06	13.10	10.33
1983	13.58	16.81	122.50	11,098	0.80	10,339	339.58	234.70	125.77	12.98	10.88
1984	13.46	8.64	126.90	10,833	0.84	11,257	291.13	234.40	124.95	12.60	11.13
1985	12.75	13.17	130.60	10,981	0.87	11,872	199.27	236.15	130.24	11.97	11.22
1986	12.50	10.60	133.50	10,773	0.88	12,508	211.23	238.30	132.85	11.60	10.91
1987	12.54	6.70	135.60	10,327	0.92	13,048	315.07	240.50	138.19	11.29	10.26
1988	12.24	8.86	137.30	10,262	0.95	13,699	122.72	243.20	141.06	10.60	11.37
1989	13.50	9.00	136.70	10,127	1.00	15,191	172.35	249.00	142.44	10.74	12.29

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