Working Papers in
AGRICULTURAL ECONOMICS

December 1992 92-12

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Fude Wang
Richard N. Boisvert
and Harry Kaiser

Department of Agricultural Economics
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853-7801

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Fude Wang, Richard N. Boisvert, and Harry M. Kaiser are former research assistant, professor, and associate professor, respectively, in the Department of Agricultural Economics at Cornell University. Fude Wang would like to acknowledge Andrew Novakovic's help in the early part of this research. The research is supported in part by the New York State Agricultural Experiment Station under Hatch project NYC-121522.

ABSTRACT

A dynamic optimal control model is constructed to study U.S. dairy policy alternatives under bovine somatotropin (bST). The results indicate that the adoption of bST might be slower than that indicated by the early surveys. Even if adoption is widespread, the government can have the potentially large milk surplus problems under control with a combination of price support, generic milk advertising, and a cow-buy-out. With bST adoption, the government would set lower support prices and would increase assessment for milk advertising, compared with the no-bST case. The higher the adoption rates, the lower the support prices and the higher the advertising assessments. It is found that bST adoption is socially beneficial; consumers gain at the expense of producers. The government can, however, help producers by giving a larger policy weight to producers in setting the optimal levels of policy variables. Finally, it is found that the current levels of generic advertising are too low, and the allocation of advertising between fluid milk and manufactured products is not optimal.

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I. INTRODUCTION

The U.S. dairy industry has been under government regulation since the 1930s, first through Federal Milk Marketing Orders, which were to establish and maintain orderly marketing conditions in interstate commerce, to protect the interest of the consumers and to avoid unreasonable fluctuations in supplies and prices (Manchester, 1983). Second, In 1949 the government introduced price supports for milk by purchasing surplus products such as cheese, butter and non-fat dry milk at established prices.

These government policies, particularly the price supports, have helped to close the gap between average farmers' incomes and money incomes of all families that existed at the end of World War II (Manchester, 1983). Consumers have also benefitted; retail prices of dairy products have increased more slowly than the average for all foods (Manchester, 1983).

Prior to 1980, milk production and commercial disappearance were reasonably in balance and surplus purchases were at manageable levels. The average annual government purchases of manufactured products were about 3.6 billion pounds, milk equivalent, in the 1970s, with an annual budget cost of about $200 million (USDA, 1959-91). In the late 1970's, support prices were increased substantially to fulfill presidential campaign promises, and milk production expanded significantly without any corresponding increase in commercial demand (Kaiser et al., 1988). Government purchases of surplus dairy products increased to a high of 16.8 billion pounds, milk equivalent, in 1983, with annual costs of about $2 billion (Kaiser et al., 1988).

This serious milk surplus problem, coupled with concern over the budget deficit, led the U.S. government to adopt a series of supply and demand management programs in the early 1980s

(Kaiser et al., 1988). Some programs, such as the Milk Diversion Program, reduced milk production, but the effects proved temporary (Bausell et al., 1992). In 1984, a generic milk advertising program (GMAP)[1] was instituted in an attempt to increase demand for dairy products. In addition, a triggered adjustment mechanism has been coupled to the price support program so that when projected government purchases rise above target levels, the price support is automatically lowered. As currently administered, however, these measures have not brought supply and demand sufficiently into balance. In 1989 and 1990, the annual government purchases of about 9 billion pounds, milk equivalent, were substantially less than those in the early 1980s, but still considerably more than the program target of between 2.5 and 5 billion pounds, milk equivalent (USDA, 1959-1991).

This milk surplus situation is likely to worsen if bovine somatotropin (bST)[2], which promises up to a 40% increase in milk production per cow (Kalter et al., 1985), is approved by the Food and Drug Administration (FDA) and is adopted widely by dairy farmers. Under these conditions, the effectiveness of current policy would be in serious doubt, and other policy instruments, or at least some alterations in existing policy, would be needed to deal with the seemingly inevitable large milk surpluses.

This paper contributes to understanding the effects of policy alternatives in the face of commercial availability of bST and the uncertainty about its rate of adoption. The combined

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[1] GMAP is a voluntary program to promote milk consumption through advertising. It is funded through an assessment on milk marketed by participating farmers.

[2] Bovine Somatotropin is a naturally occurring protein in the pituitary gland of dairy cows that regulates and stimulates milk production. Scientists have discovered how to create synthetic bST through recombinant DNA technology. When injected into dairy cows, synthetic bST increases milk yield by as much as 40% (Kalter et al., 1985) with most experimental results in the range of 10-25% (Animal Health Institute). The FDA is reviewing the effects of bST on cow health, but the sale of milk and meat from cows given bST has been approved by the FDA for several years.

effects of price supports, generic milk advertising, and a cow-buy-out program are studied in the context of a dynamic optimal control framework, which is appropriate since the biological nature of milk production is inherently dynamic (LaFrance and de Gorter, 1985). Policy-makers are assumed to maximize a multi-attribute objective function (which includes the welfare of consumers and producers, net government costs, and industry adjustment costs) subject to various constraints, including an econometric model of the dairy industry.

While others have studied the effects of exogenous dairy policies (LaFrance and de Gorter, 1985; Kaiser et al., 1988; Bausell et al., 1992; Liu and Forker, 1988), and the possible impacts of bST (Fallert et al., 1987; Zepeda, 1988; Tauer and Kaiser, 1991; etc.), they have not endogenously linked policy making to bST adoption. For example, Kaiser et al. (1988) compared the welfare effects of alternative policies and Liu and Forker (1988) focused on the effects of generic milk advertising. Studies of the impacts of bST are usually based on surveys of the attitudes of farmers toward bST to determine the possible adoption rates.

This study is unique in several respects. First, while previous studies have specified government policy responses to bST exogenously[3], this study makes government policy making endogenous. Government responds to bST by setting support price levels, producer advertising assessments, and cow buyout levels in a manner that maximizes social welfare. This study is also the first to consider generic advertising as a policy control variable under bST.

Given the uncertainty regarding bST adoption rates, this study examines three approaches to bST adoption. While the results of survey studies are used to model bST adoption exogenously, bST adoption is also assumed to respond to economic incentives similar to those that explain the

[3] There are two exceptions. Tauer and Kaiser (1991), and McGuckin and Ghosh (1989) did endogenously consider the policy effects in the existence of bST. Neither study, however, incorporated a generic advertising program into their model and both studies modelled bST adoption rates based on data from a survey study.

adoption patterns of two other technology advances now widely adopted by dairy farmers, i.e., artificial insemination (AI) and Dairy Herd Improvement Association (DHIA). Historically, the adoption of AI and DHIA have followed very different patterns, but do reflect dairy farmers' attitudes toward adopting new technology. It is found that the historical adoption rates of AI and DHIA are functions of the incremental profitability in the dairy industry due to the respective new technology. While these two relationships are used to model possible bST adoption paths, the simulated rates of adoption of bST in the model will differ from those of AI or DHIA to the extent that future changes in yearly dairy profits due to bST will differ from those experienced historically for AI and DHIA.

Given the dynamic nature of the dairy industry which is subject to asset fixity (Manchester, 1983), the adjustment costs associated with frequent price changes are obviously of concern, but there is little basis on which to determine how these adjustment costs should be reflected in the objective function. Therefore, historical simulations are conducted to help specify the adjustment cost parameter in the objective function. Finally, an experiment is conducted to examine the effects of policies when the weights on the welfare of particular groups in the objective function are changed, reflecting relatively greater concern for the welfare of dairy producers.

II. MODEL STRUCTURE

In the optimal control framework, the dynamic nature of economic policy and dairy industry adjustments are recognized. The current control variables influence the evolution of state (endogenous) variables while the current relationships among policy instruments, endogenous variables and exogenous variables are affected by past policy implementation. Mathematically, the decision problem is to optimize a preference function subject to the constraints which define relationships among control and state variables (Chow, 1980). The general structure of the control model is presented in Table 1 and the variables are defined in Table 2.

Table 1. The Structure of the Control Model

(1) Max: SW	$= \sum_{t=0}^{n} (1/(1+i)^t)$ $(WC * CW_t + WP * PW_t - \delta\, \Delta AMP^2 - \psi\, CB_t - \psi\, CCC_t\, SP_t)$
s.t.:	
(2) $PCQ1_t$	$= PCQ1\ (P1_t,\ ADF_t,\ PCQ1_{t-1},\ D1_t)$
(3) $PCQ2_t$	$= PCQ2\ (P2_t,\ ADM_t,\ PCQ2_{t-1},\ D2_t)$
(4) $Q1_t$	$= PCQ1_t * POP_t$
(5) $Q2_t$	$= PCQ2_t * POP_t$
(6) PPC_t	$= PPC\ (AMP_t,\ DRC_t,\ T,\ PPC_{t-1})$
(7) COW_t	$= COW\ (AMP_t,\ DRC_t,\ SCP_t,\ COW_{t-1},\ COW_{t-2})$
(8) Q_t	$= PPCA_t * (COW_t - COWB_t)$
(9) $PPCB_t$	$= (1 + \mu)\ PPC_t$
(10) $PPCA_t$	$= A_t\ PPCB_t + (1 - A_t)\ PPC_t$
(11) A_t	$= C1*\pi_t/(1+\exp(C2+C3*T))$
(12) π_t	$= \mu*PPC_t*AMP_t*100/CPI_t$
(13) BID_t	$\geq 620*CPI_t/100$
(14) 0	$\geq (620*CPI_t/100 - BID_t) * COWB_t$
(15) $P2_t$	$\geq G1 + G2\ SP_t$
(16) $P1_t$	$= P2_t + DIF$
(17) 0	$\geq CCC_t\ (G1 + G2\ SP_t - P2_t)$
(18) AMP_t	$= (P1_t\ Q1_t + (Q2_t + CCC_t)\ P2_t)/(Q1_t + Q2_t + CCC_t)$
(19) CCC_t	$= Q_t - Q1_t - Q2_t$
(20) $ADF_t + ADM_t$	$= PRO\ UA_t\ Q_t\ 1000$

Note: 1) To be consistent with the estimation of DHIA and AI adoptions, the adoption of bST is also assumed influenced by its incremental revenue.
2) The real bidding price (1967 terms) per cow in 1989 was \$620 (USDA).

Table 2. Variable Definitions

SW	= social welfare function value, in billion $
CW	= consumer welfare, in billion $
PW	= producer welfare, in billion $
ΔDAMP	= change in real milk prices
CB	= cow-buy-out cost in billion $, defined as COWB * BID
WC	= weight on consumer welfare
WP	= weight on producer welfare
δ	= adjustment cost coefficient
ψ	= coefficient on government cost, equal to 1 for the base scenarios
i	= discount rate, set equal to 0.05
AMP	= all milk price received by farmers, $/cwt.
CCC	= government program purchases of dairy products, in billion cwt.
P1	= Class I milk price, $/cwt.
P2	= Class II milk price, $/cwt.
SP	= support price level, $/cwt.
PCQ1	= per capita consumption of fluid milk, cwt.
PCQ1	= per capita consumption of manufactured dairy products, cwt.
Q1	= Aggregate consumption of fluid milk, in billion cwt.
Q2	= Aggregate demand for manufactured milk products, in billion cwt.
Q	= total milk supply, in billion cwt.
ADF	= advertising expenditures on fluid milk, in million $
ADM	= advertising expenditures on manufactured dairy products, in million $
ADFPL	= logarithm of per capita advertising on fluid milk, $
ADMPL	= logarithm of per capita advertising on manufactured products, $
UA_t	= unit assessment on milk marketed, $/cwt.
DUM_{67-89}	= dummy variable, equal to 1 for 1967-89, 0 otherwise.
DUM_{73-76}	= dummy variable, equal to 1 for 1973-76, 0 otherwise.
DUM_{88-89}	= dummy variable, equal to 1 for 1988-89, 0 otherwise.
D1	= demand shifters for fluid milk consumption
D2	= demand shifters for manufactured products consumption
BID_t	= bidding price per cow in $
COW	= aggregate cow number in million
$COWB_t$	= number of cow-buy-out in million
PPC	= production per cow for cows not treated with bST, thousand cwt.
PPCA	= the average production per cow for all cows, in 1,000 cwt.
PPCB	= production per cow for cows treated with bST, in 1,000 cwt.

Table 2. (continued)

μ	= proportional increase in PPC due to bST
DIF	= class price differential, predetermined
PRO	= % of market assessment actually used in advertising (0.437)
T_t	= time trend year t (1990 = 32, 1991 = 33, ...)
A_t	= adoption rate of bST
π_t	= incremental revenue due to new technology
AI	= proportion of dairy cows bred by AI
DHIA	= proportion of dairy cows on DHIA test
$AU19_t$	= proportion of the population aged under 19
CPI_t	= consumer price index for all items (1967 = 100)
DRC_t	= dairy ration cost, which is a major cost for milk production
POP_t	= population in million
SCP_t	= slaughter cow price, forecasted for the policy period
VC_t	= variable cost to determine farmers' income position

The objective function (equation 1) includes welfare measures for consumers and producers and government program costs. In an industry characterized by asset fixity (Manchester, 1983), industry adjustment costs, such as those caused by price changes, are also included in the objective function (Tauer and Kaiser, 1991).

Consumer welfare is measured by consumer surplus; producer welfare is measured by net revenue (total revenue minus variable cost), while government cost includes the purchase costs of manufactured dairy products at support prices and costs due to a cow-buy-out program[4]. Following Tauer and Kaiser (1991), the adjustment cost is specified as the squared change in real prices. This quadratic approach for adjustment costs was suggested by Pindyck (1982) and also used by Chang and Stefanou (1987). However, unlike Chang and Stefanou (1987) and Tauer and Kaiser (1991), instead of "arbitrarily" selecting the parameter on adjustment cost, this study uses

[4] With a cow buyout, the government reduces milk production by paying willing farmers to dispose of their dairy herds through slaughter or export. Farmers submit bids ($/cow) for disposing of their dairy cattle. The government is free to accept or reject each bid.

historical simulations to determine the value for the adjustment parameter. The procedure is outlined in the empirical simulation section.

The constraints are mostly self-explanatory. Equations (2) through (8) reflect supply and demand conditions for the U.S. dairy industry. Equations (2) and (3), for example, are per capita demand for fluid and manufactured products, respectively. Equations (6) and (7) are production per cow (PPC) and cow numbers (COW), respectively. Equation (8) is total milk supplied (Q).

Equations (9) through (12) are related to bST adoption. Equation (9) is production per cow for cows given bST (PPCB). Average production per cow (PPCA) is a weighted average of production per cow for cows given bST and cows not given bST (PPC), with the weights being the adoption rate (A) and the non-adoption rate (1-A), equation (10). Equation (11) portrays bST adoption, which depends on the incremental revenue (π) due to bST, equation (12).

The next block specifies major policy relationships. Equation (13) is in the model only when a cow-buy-out policy is assumed. It specifies that the bid price per cow should not be lower than the 1989 level. If it does fall below the 1989 level, the cow-buy-out number is set to zero (equation (14)). Given the way the price support program is implemented in the dairy industry, the support price, equation (15), is a targeted floor for the price of manufactured milk products (i.e., the Class II milk price). Equation (16) is a provision in the Federal Milk Marketing Order Program, which specifies that the Class I price is equal to Class II price plus a pre-specified differential. Equation (17) specifies the condition of government involvement. The price received by dairy farmers, equation (18), is a weighted average of Class prices. Equation (19) reflects that government will purchase any surplus dairy products to clear the market. Total expenditures on advertising must also not exceed the total assessment, equation (20).

III. ESTIMATION OF THE MODEL COMPONENTS

The econometric model is rather simple because of the difficulties in solving dynamic optimal control problems including more complicated structures. Most of the equations are linear in the parameters.

Dairy Demand and Supply

The milk demand equations are estimated using annual data[5] from 1959 to 1989 and an instrumental variable technique[6] (LaFrance and de Gorter, 1985). The estimated results are presented in Table 3, with variable definitions in Table 2.

In each estimated equation, parameters have the expected signs with appropriate statistical significance. Per capita demands for fluid milk and manufactured dairy products are negatively related to milk prices and positively related to advertising. Price elasticities at the means are -0.09 and -0.16 for fluid milk and manufactured products, respectively; the respective elasticities for advertising are 0.007 and 0.003. These estimates are within the range of previous estimates (e.g., Kaiser et al., 1988; Liu et al., 1990).

Both production per cow and cow numbers are positively related to milk prices, but negatively related to feed prices. The long-run price elasticities are 0.075 and 1.575, respectively, for production per cow and cow numbers. The corresponding elasticities of feed prices are -0.14 and -0.99, respectively. The inclusion of the second-order lagged variable in the cow number

[5] The original sources of data are from *Agricultural Statistics, Dairy Situation and Outlook, Economic Report of the President and Ad $ Summary*. For a complete description of the data, see Wang, 1993.

[6] In the dairy industry, the predetermined support price serves as a good instrument for both Class I and Class II prices given the way the price support policy is implemented (see LaFrance and de Gorter, 1985).

equation is intended to reflect the biological nature of reproduction of dairy herd (Manchester, 1983). While the aggregate cow stock is influenced by many factors, the principal determinant is the level of cow stock in the two previous years. As estimated, a continuous reduction in cow numbers is indicated approximately by the sum of the coefficients on lagged cow numbers, assuming no change in the other exogenous variables.

Table 3. Econometric Model Estimation

Fluid Milk Demand

$$PCQ1 = \underset{(2.63)}{1.071} - \underset{(-2.80)}{0.042}\, DP1 + \underset{(1.91)}{0.017}\, DADFPL + \underset{(1.54)}{1.080}\, AU19 - \underset{(2.67)}{0.080}\, DUM_{67\text{-}89} - \underset{(-1.80)}{0.008}\, T + \underset{(5.08)}{0.605}\, PCQ1_{-1} \qquad R^2 = 0.992$$

Manufactured Milk Product Demand

$$PCQ2 = \underset{(4.49)}{7.368} - \underset{(-2.95)}{0.124}\, DP2 + \underset{(1.34)}{0.009}\, DADMPL - \underset{(-4.25)}{11.490}\, AU19 - \underset{(-4.00)}{0.048}\, T + \underset{(2.43)}{0.338}\, PCQ2_{-1} \qquad R^2 = 0.902$$

Production Per Cow

$$PPC = \underset{(4.13)}{0.426} + \underset{(1.34)}{0.0009}\, DAMP - \underset{(-2.83)}{0.0027}\, DDRC + \underset{(3.65)}{0.0013}\, T + \underset{(3.01)}{0.4442}\, PPC_{-1} \qquad R^2 = 0.997$$

Aggregate Cow Stock

$$COW = -\underset{(-0.13)}{0.0464} + \underset{(1.04)}{0.1404}\, DAMP_{-1} - \underset{(-0.97)}{0.1398}\, DDRC_{-1} - \underset{(-1.71)}{0.0236}\, DSCP + \underset{(2.01)}{0.0275}\, DSCP_{-1} + \underset{(8.80)}{1.4310}\, COW_{-1} - \underset{(-3.00)}{0.4630}\, COW_{-2} \qquad R^2 = 0.996$$

Class II Price

$$P2 = \underset{(2.33)}{0.2489} + \underset{(3.82)}{0.1407}\, DUM_{73\text{-}76} + \underset{(6.59)}{1.2975}\, DUM_{88\text{-}89} + \underset{(74.98)}{0.9614}\, SP \qquad R^2 = 0.996$$

Note: 1) The t-values are in parentheses;
2) D in front of a variable name means that the variable is deflated by CPI.

To assess the model's ability to represent the dairy industry, the model is dynamically simulated for both in-sample and out-of-sample prediction. The root mean squared percentage errors of prediction for the endogenous variables range from 1 to 3% for in-sample prediction (Wang, 1993). In out-of-sample prediction, the percentage differences between the predicted and the actual 1990 levels of the endogenous variables are, with one exception, less than 4%.

Estimating bST Adoption in the Dairy Industry

The effects of bST on the dairy industry depend critically on the adoption rates, which should be closely related to the incremental profitability of bST. To incorporate bST into the model, one must make assumptions about the effects of bST on profitability and the adoption rate. The range of increases in production per cow for cows given bST as shown by experimental trials is 0 to 40%. However, many agree that, on average, a 10 to 25% response under farm conditions is reasonable (Fallert et al., 1987). A 15% increase (μ) is assumed for this study.

Existing studies on bST adoption are mostly based on surveys (Zepeda, 1988, Kalter et al., 1985, Fallert et al., 1987). The exogenous (EXOG) adoption path used by Fallert et al.[7] is used because it is similar to several other studies as summarized in Zepeda (1988).

Here, the adoption of DHIA and AI are also estimated econometrically to help understand the possible adoption paths of bST. Both these technologies have had important influences on dairy productivity, but have been adopted at quite different rates historically. They may reflect extremes in the response of dairy farmers to new technology.

The adoption model which recognizes that the variation in incremental revenues over time influences the adoption ceiling (Tauer and Kaiser, 1991) is specified as a logistic function

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[7] The yearly accumulative rate for the "exogenous" path are 10%, 20%, 36%, 44%, 48%, 52%, 56%, 60%, 64% and 68% for the 10-year policy period in this study. Because Fallert et al. only considered the first seven years, the rates of the last 3 years are assumed to continue the trend of a 4% increase in adoption rate per year.

(equation (11)), following the traditional approach of Griliches (1957) and others (Zepeda, 1988). A_t is the cumulative adoption rate as of year t, π_t is the incremental revenue in year t, T_t is a time trend; c1, c2 and c3 are constants and c3 indicates the rate of acceptance.

Table 4. Estimation of Adoption of DHIA and AI

The Adoption of DHIA

$$DHIA = \underset{(3.25)}{0.0082}\ \pi / (1 + \exp(\underset{(24.77)}{4.9578} - \underset{(-14.35)}{0.0737}\ T)) \qquad R^2 = 0.967$$

The Adoption of AI

$$AI = \underset{(34.70)}{0.0027}\ \pi / (1 + \exp(\underset{(11.40)}{3.4649} - \underset{(-9.82)}{0.2230}\ T)) \qquad R^2 = 0.940$$

Annual data on adoption from 1930 to 1990 are used for estimating DHIA adoption; annual data from 1943 to 1982 are used for AI adoption[8]. The adoption of both AI and DHIA is positively related to the incremental revenue of the respective technologies. The adoption of AI over time was more rapid than DHIA, i.e. a larger c3 (Table 4).

IV. EMPIRICAL SIMULATION

Before running the model simulation, the exogenous variables were forecast for the policy period, and a value of the adjustment cost parameter was established. The exogenous variables include: population, dairy ration cost, slaughter cow price, variable cost, the percentage of population under 19 years of age, and the consumer price index. They are forecast with autoregressive procedures that provide the best fits over the data period. The forecasts generally follow the historical trend of each variable (Wang, 1993).

[8] The data on adoption rates of AI and DHIA are compiled from various USDA publications, including *Dairy Situation and Outlook, Agricultural Statistics, and USDA-DHIA Sire Summary*, etc. The data and the calculation of incremental revenues of the respective technologies are referred to Wang (1993).

To select an appropriate value for the adjustment cost parameter, the dynamic control model is solved over the historical period from 1972 to 1989 with adjustment coefficient, δ, varying from 1 to 60, while other coefficients in the objective function are set equal to 1. The criteria used to measure the "goodness of replication" for each endogenous variable is a modified percentage root mean squared error (PRMSE)[9].

As δ increases from 1 to 60, the PRMSE for each of the endogenous variables generally falls before starting to rise. In general, the PRMSEs are at minimum for these variables when δ is about 40, the value assumed for this study. The interpretation of δ equal to 40 is straightforward, i.e., for a \$0.50 change in real milk price, the associated adjustment costs are 40 times 0.5 squared, or \$10 billion.

With these preparations, the model is simulated for a 10-year period, assuming a 5% discount rate, with the starting values of the variables set at the 1989 levels. The model is solved using the GAMS/MINOS non-linear programming software (Brooke et al., 1988).

Base Scenario

The base scenario seeks to capture the effects of a combination of policy variables in the absence of bST. These policy variables include the support price, generic advertising and a cow-buy-out. The adjustment parameter is set equal to 40, while other weights in the objective function, such as WP, WC and ψ, are set equal to 1. The welfare results of this scenario are presented in Table 5. The numbers are the sum of the discounted values in billion dollars over the 10-year period.

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[9] PRMSE is defined as

$$PRMSE = \sqrt{\sum_t (V_t - CV_t)^2 / T_t} / AV$$

where V_t is the actual value of a variable, CV_t is the simulated value of the variable for a specific δ, T is time period and AV is the average of the actual values of V.

With these policy variables at its disposal, the government can control the surplus problem in a short time in the absence of bST. Program purchases continuously decrease over the subsequent four years from 9 billion pounds at the beginning of the policy period to less than 1 billion pounds four years later. The market price equals the support price only in the first five years and in the last year, and the government spends a total of $1.37 billion in the policy period. This reduction in government purchases is achieved by increased advertising expenditures paid by producer assessment to promote milk consumption, and by a slower increase in support price than those historically to discourage milk production and encourage dairy consumption.

The values of other endogenous variables over time generally follow the historical trend. The aggregate cow numbers continue the historical trend of reduction. The annual reduction in the number of cows over the 10-year period is about 2.5%, while the corresponding number was 1.9% from 1959 to 1989. As a result, total milk production declines. The nominal support price, reversing the trend in the late 1980s, actually increases in the policy period. The increase in nominal price and decrease in cow numbers are also consistent with the findings of Tauer and Kaiser (1991). The results further indicate that total expenditure on generic advertising should be substantially more than the historical level and that it is optimal to allocate most of the increased advertising to fluid milk promotion.

The cow-buy-out, while available to the policy makers, is not used in the base scenario. With the continuous downward adjustment of cow stock, coupled with the increased milk demand due to advertising, adjusting support prices is sufficient to bring milk supply and demand into balance. The adjustment of cow stock is driven more by the biological factors than the economic factors, as indicated by the lagged coefficients in econometric estimation, which implies that the cow stock will continue to decrease in the simulation period as it happened historically.

bST Adoption and the Dairy Industry

As mentioned earlier, bST adoption is modelled in three ways. The first case assumes adoption follows patterns suggested in survey studies. In the second case, it is assumed that bST adoption depends on the incremental revenue due to this new technology, where the parameters of this functional relationship are estimated from data on the historical adoption of DHIA. Similarly, the third case assumes that bST adoption is a function of incremental revenue associated with bST, where the parameters of this functional relationship are estimated from data on the historical adoption of AI. Therefore, if the incremental revenue due to bST over the simulation were similar to those for the industry historically, bST adoption would mirror that of either AI or DHIA. If the incremental revenues due to market conditions or policy change are not the same as they were historically, then the adoption rates will differ from those based on the historical relationships between profitability and technological adoption. Other assumptions in the model remain and the model is re-solved over a 10-year period for each bST adoption scenario. The welfare results are in Table 5.

Compared with the base scenario, the adoption of bST would increase the discounted sum of the net welfare by 0.13%, 0.30% and 0.95%, as the adoption path is assumed to follow DHIA, AI and EXOG, respectively. With higher and faster adoption of bST (e.g. the EXOG scenario), consumers gain more at the expense of producers. Consumer welfare increases 0.40%, 1.13% and 3.20% over the simulation period under the three bST adoption cases, respectively, while the corresponding producer net income would decrease by 16%, 47% and 136%, respectively. Government costs increase by as much as 81% if the adoption follows "EXOG" and industry adjustment costs would also increase with higher adoption rates (Table 5).

Of interest are the adoption rates with each pattern (Figure 1). If bST adoption is assumed to respond to incremental revenue changes in a manner similar to that of DHIA, 4% of the dairy

Table 5. Discounted Surplus Values With SP & ADV & COWB (Billion $)

Surplus	Base	DHIA	AI	EXOG
Consumer Surplus	919.40	923.05 (0.40)	929.77 (1.13)	948.82 (3.20)
Producer Net Inc.	12.40	10.36 (-16.45)	6.68 (-47.13)	-4.49 (-136.21)
Government Cost	1.37	1.61 (17.52)	2.45 (78.83)	2.48 (81.02)
Adjustment Cost	0.51	0.72 (41.18)	1.29 (152.94)	3.13 (513.73)
Net Surplus	929.92	931.08 (0.13)	932.71 (0.30)	938.72 (0.95)

- The percentage change from the base scenario is in parentheses.

cows would be given bST in the first year with adoption reaching only 8% in 10 years. If bST adoption responds to incremental revenue changes in a manner similar to that of AI, bST would be given to 19% of dairy cows in the first year and would slowly increase to 21% in the tenth year of the policy period. These final rates at the end of the simulation period are substantially lower than those indicated by survey studies. The low initial adoption in the case of model DHIA and slow increase over time of model AI are not that surprising when the actual adoptions of DHIA and AI are examined. It took more than 15 years for AI to reach 20% and more than 25 years for DHIA adoption to reach 5% (Wang 1993).

These predicted adoption rates are indeed much slower than those obtained from surveys of dairy producers. However, those surveys were conducted at a time when the level of consumers' concern about possible adverse effects of bST was not well understood (Kaiser et al., 1992, McGuirk et al., 1991, Smith, 1991). There is also great concern now about the long-term effects

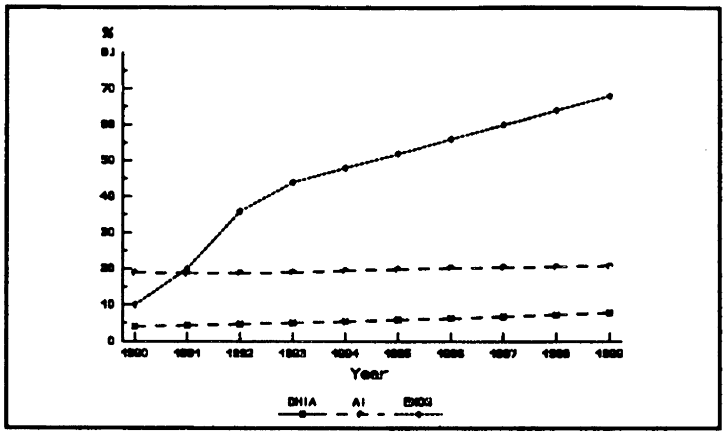


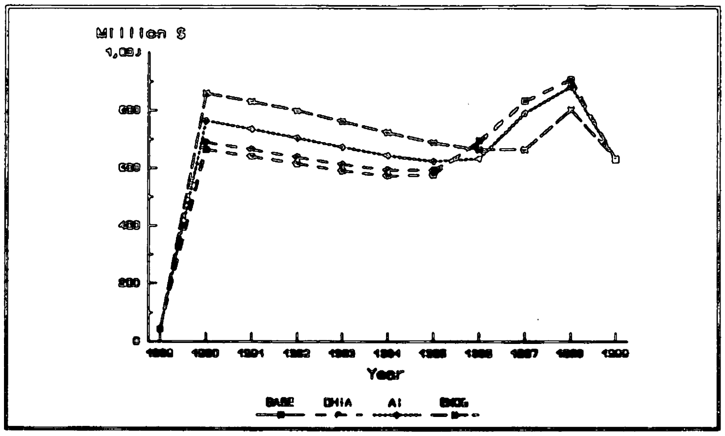
Figure 1. BST Adoption Rates

of bST on dairy cows. These factors would suggest that the actual adoption of bST is likely to be slower than those indicated by the surveys.

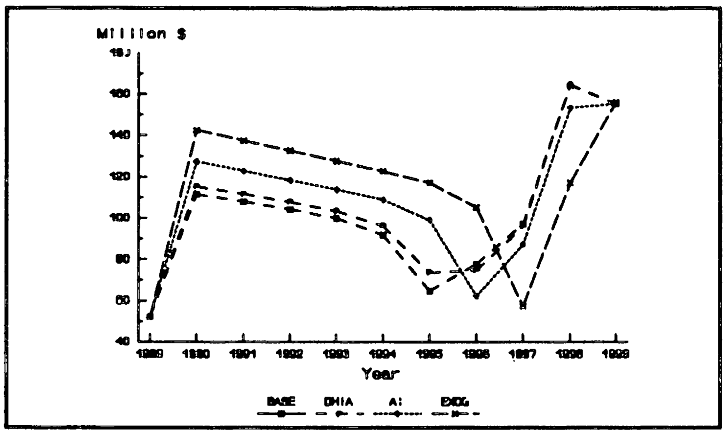
The optimal paths of the policy control variables in response to various bST adoption rates[10] are presented in Figure 2. Generic advertising expenditures are larger with faster adoption rates of bST in most years of the simulation. There is a tendency for the levels of generic advertising to be higher under bST than in the base scenario when the price support policy is binding, and vice versa. One reason for this is that government is encouraging greater milk consumption in response to larger production through more advertising in order to reduce bST-induced increases in government purchases. In the second half of the simulation period, where the support price is generally not binding, there is no need to spend more on advertising.

The market price equals the support price in the first five years under all three scenarios. The support prices are lower with higher adoption rates because CCC purchases (Figure 3a) increase with higher adoption rates. The government lowers the support price to compensate for upward pressure on expenditures due to increased CCC purchases. The support price is also lowered to

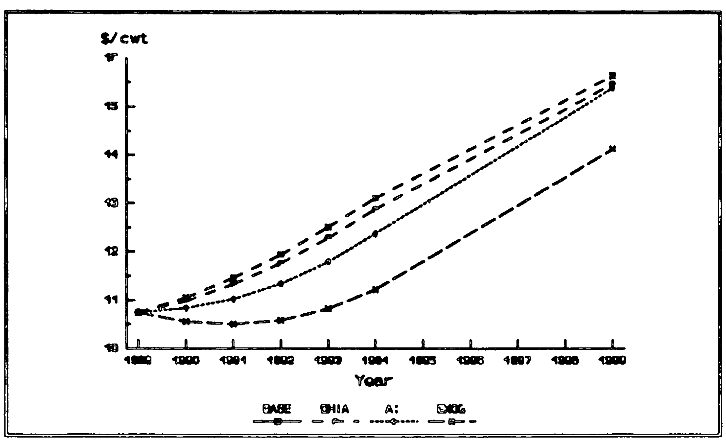
[10] The policies not only respond to the adoption rates, but also influence the adoption rates through their effects on profitability.



(a): Advertising on Fluid Milk

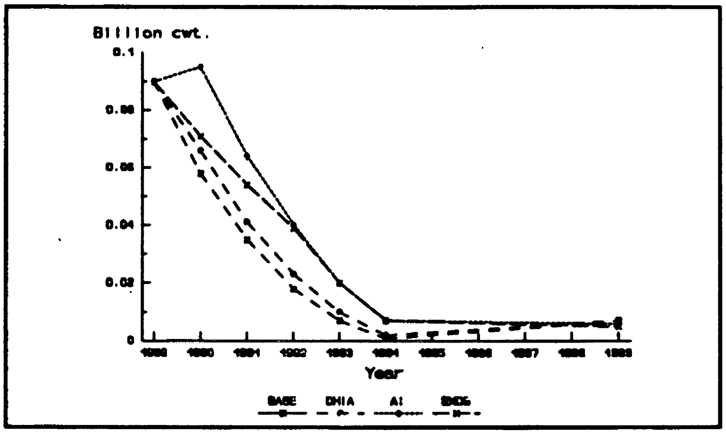


(b): Advertising for Manufactured Products

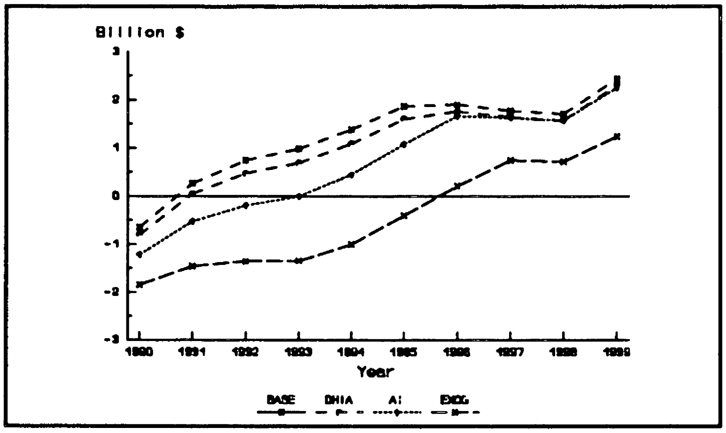


(c): Nominal Support Prices

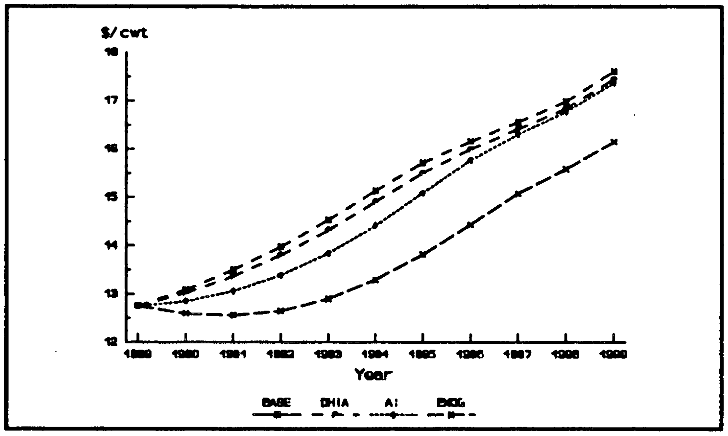
Figure 2. Policy Instruments



(a). Government Purchases



(b). Producers' Net Incomes

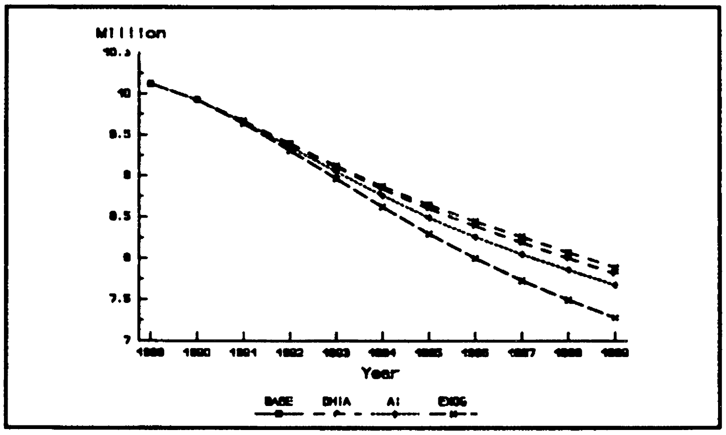


(c). Nominal All Milk Prices
Figure 3: Government Purchases, Incomes and Prices

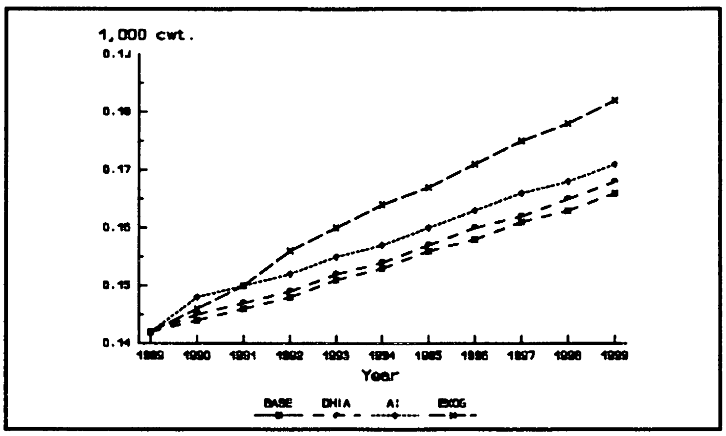
discourage production. As a result, producers' net income position (Figure 3b) deteriorates substantially with bST adoption. The higher the adoption rates, the lower the incomes. In all scenarios, however, net income increases over time due to the interaction between the adjustments of government policies and the adjustments of the industry, such as smaller cow stocks (Figure 4a). Although production per cow (Figure 4b) increases over time, it can not compensate for the reduction in cow stocks. Therefore milk supply decreases (Figure 4c).

Implementation of generic advertising and support price policies also help bring supply and demand into balance by encouraging milk consumption. On the one hand, both the large scale increase in advertising and lower real prices promote milk consumption. With higher adoption rates, the advertising expenditures are larger while the support prices are lower, therefore milk consumption increases with higher adoption rates. On the other hand, lower milk prices (real prices) or slower increases in nominal milk prices (Figure 3c) are responsible for the downward adjustments in cow stocks and milk supply. These adjustments relieve the pressure to reduce support prices, thus producers' net income position improves over time.

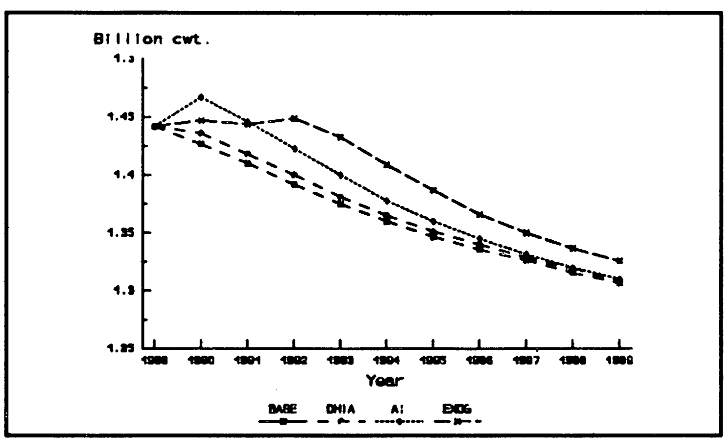
While the cow-buy-out is available as a policy option, it is not used in the base scenario where bST is not available. However, when the adoption pattern of bST is assumed to follow that of DHIA, the cow-buy-out program is implemented in the last year of the simulation period. In this case, the government spends about $123 million to remove 35,000 dairy cows from milk production. When the adoption pattern of bST is assumed to follow that of either AI or "EXOG", the cow-buy-out program is not implemented. While the support price has a double effect on consumption and production, the cow-buy-out is effective only in reducing milk supply. With higher adoption rates and therefore larger milk supply, a reduction in support price that can reduce production while encouraging consumption is preferred. Therefore, it is reasonable to expect that the cow-buy-out policy is used only with low adoption rates.



(a). The Aggregate Cow Stock



(b). Average Production Per Cow



(c). The Aggregate Milk Supply

Figure 4: Supply Related Variables

Weights in the Welfare Function and Policies

Increasingly, it is recognized that government policy often benefits particular groups at the expense of others, i.e., the government weighs the welfare of one group over others (Rausser and Freebairn, 1974). Recently, there exists a body of political economy literature that tries to estimate the actual weights used by policy makers in policy making (e.g., Marchant and McCalla, 1990, Sarris and Freebairn, 1983). While this is not possible in the current framework, one can, by changing the parameters in the objective function, simulate a change in policy, such as the relative weights given to different groups in solving for the optimal path of policy instruments. In particular, by increasing the weight on the welfare of producers (WP) relative to the weight on the welfare of consumers (WC), the government can "transfer" benefits to producers at the expense of consumers and taxpayers, as reflected in the program budget costs.

It is also true that the efficiency of transfer is different under alternative sets of parameters[11]. The historical control model is, therefore, solved over the period 1972 to 1989 with changing WP and WC to find the parameters that produce the highest efficiency of transfer. As WP is increased from 0 to 2, while WC is simultaneously reduced from 2 to 0, producers gain at the expense of consumers. As WP changes from 1.1 to 1.2 while WC changes from 0.9 to 0.8 correspondingly, the costs to consumers and taxpayers for every dollar transferred to producers are lowest, i.e. the efficiency of transfer to producers is the highest. For every dollar transferred to the producers, the consumers lose only about $1.05 while the government spends an extra $0.20 (Wang 1993). To understand the effects of altering the policy makers' preference for

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[11] When policy decisions are made using the new (with new weights) objective function, the new levels of the policy instruments may imply that one group gains at the expense of another, i.e. the "income" is transferred from one group to another due to the change in policy. Associated with each set of parameters (weights) in the objective function, there is a number that measures the amount of "income" other groups have to lose for one dollar transferred to one group. The most efficient transfer is achieved when this number is the smallest.

different groups, WP is set equal to 1.15 while WC is set equal to 0.85. With other assumptions unchanged, the combination of price support, advertising and a cow-buy-out is examined.

The welfare results are in Table 6, where "New" is for the model with new objective function (WP = 1.15 and WC = 0.85), "Old" is for the model with equal weights and "Dif" measures the difference between the values of the "New" and the "Old". The welfare conclusions follow the same pattern as those in last section, i.e. the higher the adoption rates, the more consumers gain and producers lose, while both adjustment costs and government costs increase. The net social welfare increases by 0.13%, 0.31% and 0.97% from the base scenario, respectively, as the bST adoption is assumed to follow the pattern of DHIA, AI and EXOG, respectively.

However, the producers are better off under this new objective function than they were before. When bST is not available, choosing a policy path with WP equal to 1.15 would increase producers' net incomes by $1.33 billion, reduce the welfare of consumers by $1.51 billion and increase government costs by $0.22 billion relative to the solution with WP equal to 1 (Table 6).

Compared with the scenarios with equal weights for the welfare of producers and consumers, no matter what adoption pattern for bST is assumed, producers are always better-off when they are given more policy weight. Total government costs, including costs of surplus purchases and costs of the cow-buy-out program, increase, while adjustment costs decrease. The increase in producers' net income is $1.02, $0.68, and $0.63 billion, respectively, while the loss to consumers is $1.16, $0.79 and $0.81 billion, respectively, with the three adoption patterns of bST. The government would spend $0.21, $0.20 and $0.15 billion more, respectively.

When WP is set equal to 1.15, the cow-buy-out program is implemented for the cases where bST adoption are assumed to follow DHIA and AI. With DHIA, the government would remove 92,000 (35,000 in the "old" case) dairy cows from milk production in the last year of the policy period. With AI, the government would first remove 3,000 in the sixth year and another 74,000 in the final year of the policy period. If bST adoption is to follow the pattern of EXOG, the cow-buy-out program would not be used.

Table 6. Discounted Surplus Values, WP=1.15 (Bil. $)

Surplus	Base	DHIA	AI	EXOG
Consumer Surplus				
New	917.89	921.99	928.98	948.01
Old	(919.40)	(923.14)	(929.77)	(948.82)
Dif	(-1.51)	(-1.16)	(-0.79)	(-0.81)
Producer Net Inc.				
New	13.73	11.28	7.36	-3.86
Old	(12.40)	(10.26)	(6.68)	(-4.49)
Dif	(1.33)	(1.02)	(0.68)	(0.63)
Government Cost:				
Cost (SP)				
New	1.59	1.62	2.48	2.63
Old	(1.37)	(1.54)	(2.45)	(2.48)
Dif	(0.22)	(0.08)	(0.03)	(0.15)
Cost (COWB)				
New		0.21	0.17	
Old		(0.08)		
Dif		(0.13)	(0.17)	
Total				
New	1.59	1.83	2.65	2.63
Old	(1.37)	(1.62)	(2.45)	(2.48)
Dif	(0.22)	(0.21)	(0.20)	(0.15)
Adjustment Cost				
New	0.39	0.56	1.15	2.86
Old	(0.51)	(0.72)	(1.29)	(3.13)
Dif	(-0.12)	(-0.16)	(-0.14)	(-0.27)
Net Surplus				
New	929.67	930.88	932.54	938.66
Old	(929.92)	(931.02)	(932.71)	(938.72)
Dif	(-0.25)	(-0.14)	(-0.17)	(-0.08)

With emphasis on producers' welfare, the government tends to set higher support prices and larger advertising expenditures at the beginning. The price support policy is binding more often with the new objective function, i.e. the government would purchase surplus milk products in more years in the policy period.

IV. POLICY IMPLICATIONS AND CONCLUSIONS

An optimal control model is used to study the policy alternatives to deal with the potentially large milk surplus problems with commercial availability of bST. The study differs from the existing studies in the way bST adoption is modelled and the objective function is specified. It also considers advertising and a cow-buy-out as alternative policies with the existence of bST.

This study not only confirmed the conclusions of other studies that the surplus situation depends on how government adjusts policy, it also explicitly modelled the interaction of policy, technological adoption and industry adjustment endogenously. If farmers respond to bST as they have to other important historical technological advances, adoption may not be as fast as indicated by the previous surveys. Both the adoption of DHIA and AI were slow in spite of their significant contribution to productivity gains and the low costs associated with adopting them. There is no obvious reason to believe the adoption of bST in response to economic forces would be significantly different than those of other technologies, such as DHIA and AI. Furthermore, the consumer response to milk produced by cows given bST and producers' concern with the long-term effects of bST on cow health are likely to influence the adoption of bST.

The study also suggests that the surplus problem may be less serious than previous studies indicate if government responds by optimally setting policies. With an optimal combination of price support, advertising and a cow-buy-out as control variables, the government can successfully deal with the potential surplus problems, even in the face of high adoption rates.

The impact of making policy decision endogenously is in contrast with the surplus situation in the 1980s when the policy variables were normally fixed for a certain number of years. With endogenous policy making, the levels of policy variables change quite significantly in response to bST adoption. Compared with the no-bST case, the support price is lower and the levels of generic advertising are higher with bST adoption. The higher the adoption rates, the larger the changes in policy variables.

The results also show that the adoption of bST would be welfare improving. No matter what adoption pattern that bST is to follow, its adoption would improve consumers' welfare at the expense of producers, but with an overall increase in social welfare. The higher the adoption rates, the larger are the consumers gains and the producers losses. However, this increase in social welfare is accompanied by considerable adjustment costs due to bST. With higher adoption rates, the industry would face lower milk prices, lower aggregate cow stocks and lower incomes to producers. The associated adjustment costs should not be ignored. In particular, the downward adjustment in cow stocks and the continuation of the trend toward fewer but larger farm operations with many smaller farms going out of business also continues to be of concern. The smooth adjustment in this model should be interpreted with some care because the actual adjustment in cow numbers is likely to be such that only the more productive dairy cows are retained. In this sense, the government's ability to gain control over the surplus problems might be somewhat overstated, or the adjustment may proceed somewhat slower than indicated by the model results.

The model also suggests that policy makers might ease this adjustment process by giving a higher weight to producers in the objective function. In particular, if the weight on the welfare of producers is set equal to 1.15 and the weight on consumers' is set equal to 0.85, producers would gain an extra \$0.63-1.33 billion, depending on the bST adoption rates, as compared with the case with both WP and WC equal to 1, in the objective function. With the weight favoring producers, the support prices would increase by 5 to 10 cents per cwt., depending on the bST adoption scenarios. The associated adjustment costs are, therefore, lower.

When the parameters in the objective function are set in favor of producers, the optimal policy would include a cow-buy-out program when bST adoption is assumed to follow the pattern of DHIA or AI. With equal welfare weights, however, the cow-buy-out program is used only in the scenario with DHIA. In this sense, the cow-buy-out program would benefit producers.

The optimal levels of generic milk advertising are about 10 times higher than the historical levels for advertising on fluid milk, and are similar to the historical levels for advertising on manufactured products. With higher adoption rates of bST, the producers are assessed more on milk marketed to cover additional advertising expenditures. Depending on bST adoption scenarios, the unit assessment ranges from 3 to 12%, as compared with the historical levels of 1 to 1.5%. This result regarding the levels of advertising should also be interpreted with care. The nearly ten-fold increase in advertising expenditures is well beyond the range of data from which the demand function is estimated. However, there is other evidence supporting the conclusion that the current levels of advertising are too low, and that the current allocation of advertising between fluid and manufactured products is not optimal (Liu and Forker, 1988, Liu et al., 1990).

This large assessment on milk marketed by dairy farmers suggested by the model is likely to be politically prohibitive. It is the farmers who currently pay for advertising, but the beneficiaries are more likely to be milk processors and retailers because of the growing demand for milk products and higher prices. From an equity perspective, it seems the government should examine the possibility of assessing processors and retailers for part of the additional funds to support more advertising. This is consistent with the Food, Agriculture, Conservation and Trade Act of 1990 that authorizes the establishment of an order to assess fluid milk processors and handlers up to $0.20/cwt for additional advertising.

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