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Welfare effects of the use of recombinant bovine somatotropin in the USA

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The welfare effects of increased milk production associated with the use of recombinant bovine somatotropin (rBST) on dairy operations in the USA were examined for 1996. Results that derived from three different estimates of the milk-production response to rBST were evaluated and compared. One estimate, derived from a survey of dairy producers in Connecticut, led to economic-impact estimates that were not statistically significant. A second, derived from a national survey that concentrated on the health and management of dairy cattle, led to estimates that were unbelievably high. A third, derived from a national survey that concentrated on the economics of dairy producers, provided the most reasonable estimates of economic impacts. Results of economic analysis, using the latter results, indicated that if rBST had not caused milk production to increase, then the market price of milk would have been 2·2 ± 1·5 cents/kg higher, and the total value of the milk produced would have risen from $23·0 ± 0·6 billion to $24·1 ± 1·0 billion. A welfare analysis demonstrated that the increased milk production (and the reduced market price) associated with the use of rBST in the USA caused the economic surplus of consumers to rise by $1·5 ± 1·0 billion, while the economic surplus of dairy producers fell by $1·1 ± $0·8 billion. Increased milk production associated with rBST yielded a total gain to the US economy of $440 ± 280 million. An analysis of annual percent changes in the number of dairy cows per operation, milk production per cow, total milk production, total number of dairy cows, and total number of dairy operations in the USA suggested that the dairy industry's long-term economic growth path was stable from 1989–2001 inclusive, and did not receive a shock resulting from the introduction of rBST.

Keywords: Dairy cattle, dairy farm technologies, milk production, recombinant bovine somatotropin.

Bovine somatotropin, also called bovine growth hormone, is produced in the pituitary gland of cows (Butler, 1999). Experiments in the 1930s demonstrated that bovine somatotropin, when extracted from the pituitary gland of one cow and injected into another cow, could increase milk production in the cow that received the injection (Butler, 1999). In the 1970s, the gene responsible for the production of bovine somatotropin was successfully transferred to a bacterium, and the resulting product, called recombinant bovine somatotropin (rBST), was subsequently capable of being produced in commercial quantities (Collier, 2000). The use of rBST to increase milk production in dairy cows in the USA was approved by the US Food and Drug Administration in 1994. Monsanto is presently the only company that markets rBST (under the brand name of Posilac) to increase milk production in dairy cows.

Initial apprehensions concerning the use of rBST in dairy cows centered on potential animal-health and human-health issues, including various side effects in cows (such as mastitis, increased somatic cell counts, various reproductive and digestive disorders, metabolic disease, lameness, stress, internal bleeding, swelling at the injection site, and enlargement of internal organs), possible increase in the use of antibiotics in cows (to treat mastitis), and the effect of rBST on Insulin-like Growth Factor-I (Aboulafia, 1998). The US Food and Drug Administration determined that the health risks to dairy cows were manageable (Abaloufia, 1998). Various studies have demonstrated that the use of rBST in dairy cows has virtually no impact on human health (Collier, 2000). The European Union voted to ban the use of rBST on cows in member countries, not so much out of anxieties over public health,

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but more due to concerns about potentially exacerbating the over-production situation (Brinckman, 2000).

The introduction of rBST to increase milk production was attended by considerable debate over anticipated social and economic consequences. Many people worried that the use of rBST would result in disastrous declines in dairy prices and ruinous competition for dairy producers (Barham et al. 2002). Disagreements have persisted over whether adoption has been fast or slow, whether or not rBST is profitable for dairy operators, whether rBST is more beneficial to large-scale or small-scale producers, and whether the introduction of this technology will accelerate ongoing industry transformations in the USA. Fetrow (1999) opined that rBST had been 'very rapidly adopted' by the US dairy industry; that it was safe, effective and profitable if used in adequately managed dairies; and that its economic value was independent of the scale of the farm. Butler (1999), on the other hand, characterized the adoption of rBST among dairy producers as 'slow to moderate,' and that it appeared to have 'reached a plateau.' Butler (1999) considered dairy producers who were using rBST to be 'a fairly stable minority, some of who are not at all sure whether they are making a profit on rBST.'

Barham et al. (2000) stated that the increase in the number of producers using rBST in Wisconsin had been diminishing, and that adoption had fallen short of some of the more enthusiastic forecasts. Much of the increase in the percent of producers using rBST was attributed to demographic shifts (including the retirement of older producers) (Barham et al. 2000). In 1999, 75% of Wisconsin dairy producers with ⩾200 cows used rBST, compared with 5·3% of producers with <50 cows, indicating that rBST adoption was not scale neutral (Barham et al. 2000). Barham et al. (2000) felt that most Wisconsin dairy operators might not adopt rBST because of their small scale and lack of management practices that would be required to make rBST use advantageous; moreover, operations using rotational grazing (with a strategy of minimizing feed costs) would be less likely to use rBST.

Tauer (2001; 2005) concluded that, while rBST increased milk production on dairy operations in New York, using rBST had virtually no impact on profit. Tauer (2001; 2005) found further that larger operations, and operators with education beyond high school, were more likely to use rBST.

Barham et al. (2000) observed that larger dairy operations, and higher use of complementary (productivity-enhancing) technologies, were associated with an increased likelihood of a dairy producer using rBST. Barham & Foltz (2002) felt that the impact of rBST on milk production levels was roughly the equivalent of 2 years of secular growth trends in milk productivity, and that the role of rBST in shaping dairy production in the USA has been minimal.

In a mail survey of 124 dairy operations in Connecticut, Foltz & Chang (2002) found that dairy operators who were younger, who were more highly educated, who had larger herds, and who used more productivity technologies, were more likely to use rBST. However, while Foltz & Chang (2002) found that rBST significantly increased milk production, they found no evidence that the use of rBST increased profits.

Using data from the 2000 Agriculture Resource Management Survey, which included detailed economic information from 872 dairy operations in 22 states, McBride et al. (2004) found that rBST was associated with increased milk production, and that the estimated financial impact was not statistically significant.

On the other hand, using data from the Dairy '96 Survey of the National Animal Health Monitoring System (**NAHMS**) of the United States Department of Agriculture (**USDA**), Ott & Rendleman (2000) computed an 'optimal rBST use of 73 percent … at the national level … if all of the nation's cows were combined into a single herd.' Ott & Rendleman (2000) concluded that optimal rBST use would be 73% of cows, causing herd-level milk production to increase by 616 kg/cow and net returns to increase by $126/cow. Ott & Rendleman's (2000) analysis of the economic impacts of rBST ignored the effects of price elasticities of supply and demand, which would lead to the conclusion that only producers were affected by the increased productivity. It is common knowledge that the demand for milk in the USA is fairly inelastic, meaning that consumers generally purchase a relatively fixed amount of milk over a given period of time, regardless of normal price fluctuations (Maynard, 2000). This suggests that a lot of the benefits associated with a revolutionary new technology that greatly expands the supply of milk will be passed to consumers in the form of lower prices. If no producers had used rBST, then microeconomic theory suggests that a smaller quantity of milk would have been produced, at an increased price (Fig. 1).

Thus far, no-one has examined the welfare implications of the use of rBST, including changes in consumer and producers surplus. Understanding how the benefits of rBST are divided between producers and consumers, and whether dairy producers will, as a whole, benefit at all from the new technology, has very important implications for policy decisions. The European Union voted to ban the use of rBST in dairy cows in member countries, primarily because of concerns about exacerbating the over-production situation (Brinckman, 2000). Consumer surplus is the difference between what consumers are willing to pay for a product, and the amount that consumers actually pay (Nicholson, 1995). For example, a consumer who would have been willing to pay $1 for a kg of milk, and who only has to pay 33 cents for a kg of milk, enjoys a surplus of 67 cents, which he may either save or spend on other items. Producer surplus is the difference between the amount of money that producers receive for a commodity, and the amount that they would have been willing to accept to supply a given quantity (Nicholson, 1995). A dairy producer who would

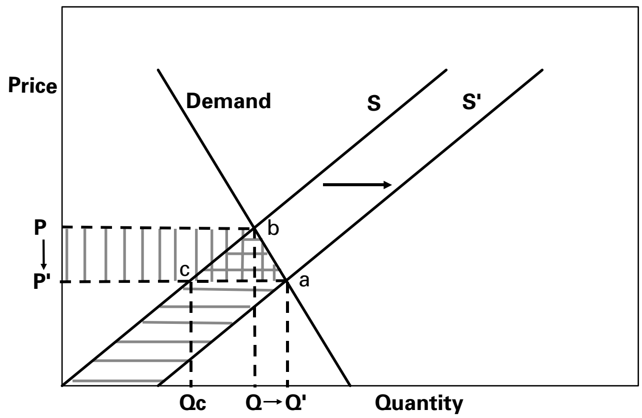

Fig. 1. Demand and Supply for Milk. When Supply is determined by S, the equilibrium market price is P and the equilibrium market supply is Q. Consumer Surplus is the area below the demand curve and above the line-segment P-b. Producer Surplus is the area above the Supply Curve (S) and below the line-segment P-b. When Supply increases from S to S′ (because of dairy cows being treated with rBST), the quantity of milk produced increases from Q to Q′, which causes the equilibrium price falls from P to P′. Consumer Surplus increases by the amount represented by the quadrilateral whose corners are P′, P, b and a (the area with vertical stripes, plus the cross-hatched area). A portion of the gain in Consumer Surplus (P′, P, b, c, the area with vertical stripes only), which was previously a part of the Producer Surplus, is transferred from producers to consumers. Producer Surplus decreases by the transferred amount, but increases by the area (with horizontal lines) between the two supply curves and below the line segment c–a. The total gain to the economy is the area below the demand curve and between the two supply curves (the area with horizontal stripes, plus the cross-hatched area).

have been willing to sell a kg of milk for 30 cents, and who receives 33 cents, enjoys a surplus of 3 cents. The objective of this report was to measure the effects of rBST adoption on equilibrium prices and quantities, and on economic welfare (in terms of changes in consumer and producer surplus), that resulted from the use of rBST on dairy operations in the USA in 1996. Uncertainties in the estimates were evaluated in accordance with the *Guide to the Expression of Uncertainty in Measurement* (**GUM**) (International Organization for Standardization, 1995), similar to methods introduced by Losinger (2005).

Materials and Methods

A welfare analysis was performed to measure changes in producer and consumer surplus based on the assumption of linear demand and supply curves and a parallel supply shift caused by the use of rBST in the USA in 1996 (Fig. 1). The procedures were akin to those developed by Losinger (2005) to evaluate the economic impacts of Johne's disease in dairy cows.

Table 1 lists the input quantities used in the analysis, their sources and uncertainties. 'Standard error' is the term most frequently used to denote the variability of estimates, and is usually calculated based on the statistical evaluation of a series of measurements. In the terminology of the GUM (International Organization for Standardization, 1995), this corresponds to a 'Type A evaluation of standard uncertainty.' The term 'standard uncertainty' includes both Type A evaluations and Type B evaluations. A Type B evaluation derives from sources other than the statistical evaluation of a series of measurements, and may include data from previous measurements, general knowledge, uncertainties taken from handbooks or government publications, and data taken from scientific journal articles.

The NAHMS Dairy '96 Study indicated that 10·1% (SE=1·7) of dairy cows received rBST treatments in 1996 (USDA: APHIS, 1996). This analysis made use of estimates of milk-production response to rBST that were provided by McBride et al. (2004), Foltz & Chang (2002), and Ott et al. (2003). McBride et al. (2004) and Foltz & Chang (2002) provided linear statistical models that included rBST use as a linear term among a series of other variables, with milk production as the dependent variable. Using their models, the increased milk production caused by rBST in 1996 was calculated by multiplying the coefficient associated with rBST by the proportion of cows treated with rBST and the number of dairy cows in the USA in 1996.

Ott et al. (2003) estimated a milk-production increase of 110·7 kg/cow (SE=16·5) per unit increase in the square root of percent rBST use on US dairy operations 'if all of the nation's cows were combined into a single herd.' Using the model of Ott et al. (2003), the increased milk production (attributed to treating 10·1% of dairy cows with rBST) was calculated by multiplying Ott et al.'s (2003) estimate of the milk-production increase per unit increase in the square root of percent rBST use, by the square root of the percent of cows treated with rBST in 1996. The model of Ott et al. (2003) was the last in a series of statistical models that derived from the NAHMS Dairy '96 Survey, and that included rBST use as an explanatory variable for milk production. The series of statistical models is provided in Table 2. Ott & Novak's (2001) model had percent rBST use as a linear term. Ott & Rendleman (2000) used a quadratic expression for percent rBST use. Ott et al. (1999) provided statistical models with the square root of the percent rBST use as an explanatory variable, but did not provide coefficients for a model with milk production as a dependent variable. Ott & Novak (2001) had attempted to use factor analysis to combine 18 management-practice variables into four management indices, but decided instead to use the employment of Dairy Herd Improvement Association records as a measure of management ability. Ott et al. (2003) used correspondence analysis to combine 24 different management-practice variables into two

Table 1. Input quantities used in the computation of economic impacts of rBST, their sources and uncertainties

Input quantity	Distribution	Value	Standard Uncertainty	Degrees of Freedom	Source
Kg/cow milk-production increase with rBST	Normal	1212	641	50†	McBride et al. 2004
Kg/cow milk-production increase with rBST	Normal	1883	915	50	Foltz & Chang, 2002
Kg/cow milk-production increase per square root of % increase in rBST use	Normal	110·7	16·5	50	Ott et al. 2003
Cows treated with rBST (%)	Normal	10·1	0·7	50	USDA, APHIS, 1996
Number of dairy cows	Normal	9 327 000	122 000‡	50	USDA, NASS, 1999
Kg milk produced in 1996	Normal	70·003 billion	630 million‡	50	USDA, NASS, 1999
Mean price of milk in 1996 ($/kg)	Normal	0·328	0·004‡	50	USDA, NASS, 1999
Price elasticity of demand for milk	t	−0·25	0·05	14	Meilke et al.1996
Price elasticity of supply for milk	Rectangular§	0·56995	0·18855	∞	Adelaja, 1991

† For normally distributed Type B data, the GUM Workbench assigns a default value of 50 to the degrees of freedom (Metrodata GmBH, 1999)
‡ Uncertainties are based on USDA, NASS, 1996
§ For the rectangular distribution, the value is the midpoint between the upper and lower limits, and the half-width of this limit is listed in the uncertainty column. Degrees of freedom are infinite by definition (Metrodata GmBH, 1999)

Table 2. Models of milk production derived from the United States Department of Agriculture's National Animal Health Monitoring System Dairy '96 Survey. The dependent variable is kg of milk produced per cow per year. SE in parentheses

Variable	Ott & Novak, 2001	Ott & Rendleman, 2000	Ott et al. 2003
% of cows administered rBST			
Square root	—	—	110·7 (16·5)
Linear	140·00 (16·85)	32·07 (6·3)	—
Squared	—	−0·185 (0·072)	—
Herd size (natural log)	384·07 (68·98)	384·8 (68·9)	220·9 (75·2)
Region			
Midwest	Reference	Reference	Reference
West	−202·65 (133·97)	−200·3 (133·4)	49·3 (156·4)
Southeast	−1128·97(186·29)	−1135·4 (195·1)	−547·8 (220·4)
Northeast	−235·39 (109·51)	−238·6 (109·3)	−54·0 (117·0)
Bulk-tank somatic cell count (thousands of cells/ml)			
Low (<200)	Reference	Reference	Reference
Medium (200–399)	−371·69 (96·57)	−375·3 (96·8)	−229·9 (109·7)
High (400+)	−958·90 (142·77)	−967·1 (142·2)	−759·0 (146·5)
Intensive pasture grazing (pastures supply ⩾90% of summer forage)	−452·91 (122·12)	−454·3 (124·0)	−409·1 (145·7)
% Holstein breed	24·56 (1·91)	24·6 (2·0)	25·5 (1·9)
Days dry, ⩾70 d	−327·12 (124·37)	−327·0 (125·2)	−280·7 (133·0)
DHIA records	834·09 (89·94)	835·9 (90·2)	—
>90% of cows registered	218·94 (154·05)	226·0 (152·5)	193·5 (141·8)
% change in dairy cow Inventory	−1·61 (2·13)	−1·6 (2·1)	−4·9 (2·6)
Cows in third lactation			
% of herd	—	—	11·9 (7·9)
% in excess of 37%	—	—	−36·5 (10·6)
Management practices			
Dimension 1	—	—	−755·2 (123·8)
Dimension 2	—	—	−867·7 (179·2)
Bovine Leukosis Virus (% seropositive)	—	—	−4·7 (1·7)
Intercept	4070·91 (337·23)	4049·8 (338·1)	5014·6 (436·5)
R-squared	0·474	0·475	0·535

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Table 3. Model equations used in the analysis. The analysis starts from the price (P′) and quantity (Q′) of milk produced in the USA in 1996 (Fig. 1), and then computes what the price, quantity, value and changes in economic surplus would have been if recombinant bovine somatropin had not been used in US dairy cows. The economic impacts associated with using of rBST (Table 4) are then simply the numeric opposite of the results of the equations presented below (e.g., the price of milk would have been higher without rBST, therefore rBST caused the change in the price of milk to be negative)

Model Equations:

For the models of McBride et al. (2004) and Foltz & Chang (2002):
$\Delta Q = rBSTeffect * (rBSTpercent/100) * cows$

For the model of Ott et al. (2003):
$rBSTeffect = milkincrease * sqrt(rBSTpercent)$
$\Delta Q = rBSTeffect * cows$

For all models:
$Q = Q' - \Delta Q$
$\Delta P = (\Delta Q * P')/(e_D * Q')$
$P = P' + \Delta P$
$Q_c = Q + e_s * \Delta P * Q'/P$
$Surplus_{trans} = \Delta P * Q_c + 0{\cdot}5 * \Delta P * (Q - Q_c)$
$CS_{lost} = 0{\cdot}5 * \Delta P * (Q' - Q_c)$
$\Delta CS = -CS_{trans} - CS_{lost}$
$PS_{lost} = \Delta Q * P'$
$\Delta PS = Surplus_{trans} - PS_{lost}$
TOTAL CHANGE TO ECONOMY $= CS_{lost} + PS_{lost}$
$Value' = P' * Q'$
$Value = P * Q$
$\Delta Value = Value' - Value$

rBSTeffect = increased milk production per cow due to rBST use (kg/cow)
milkincrease = Milk-production increase per cow per square root of percent increase in rBST use (kg/cow per sqrt (%))
rBSTpercent = Percent of cows treated with rBST (%)
ΔQ = Change in total milk production due to rBST (kg)
cows = Number of dairy cows (*n*)
Q' = Quantity of milk produced with rBST (kg)
Q = Quantity of milk that would have been produced without rBST (kg)
ΔP = Change in price of milk ($/kg)
P' = Price of milk with rBST ($/kg)
P = Price that milk would have been without rBST ($/kg)
e_D = Price elasticity of demand for milk
e_S = Price elasticity of supply for milk
Q_c = Quantity of milk produced at Point C (kg). This is useful in simplifying the computation of the economic surplus transferred between producers and consumers, by dividing the area P′, P, b, c into a square and a triangle.
$Surplus_{trans}$ = Economic surplus transferred between producers and consumers ($)
CS_{lost} = Consumer surplus lost ($)
ΔCS = Change in consumer surplus ($)
PS_{lost} = Lost producer surplus ($)
ΔPS = Change in producer surplus ($)
$Value'$ = Total value of milk produced with rBST ($)
$Value$ = Total value of milk that would have been produced without rBST ($)
$\Delta Value$ = Change (due to rBST) in total value of milk produced ($)

management-index variables which, in their statistical model, replaced the employment of Dairy Herd Association records. The present analysis made use of the statistical model of Ott et al. (2003), which was the most recent NAHMS statistical model to provide national-level impacts of rBST on milk production.

Table 3 lists the model equations used in the present analysis. The GUM Workbench (Metrodata GmbH) was used to create the estimates and propagate the uncertainties for the change in consumer surplus, change in producer surplus, and total economic gain due to increased milk production caused by using rBST in US dairy cows in 1996. The GUM Workbench assigns a default value of 50 df for normally distributed data that were not directly measured by the researcher (i.e., that derived from other sources) (Metrodata GmbH, 1999). The input quantities were often based on many more than 50 observations, and thus much greater df could have been

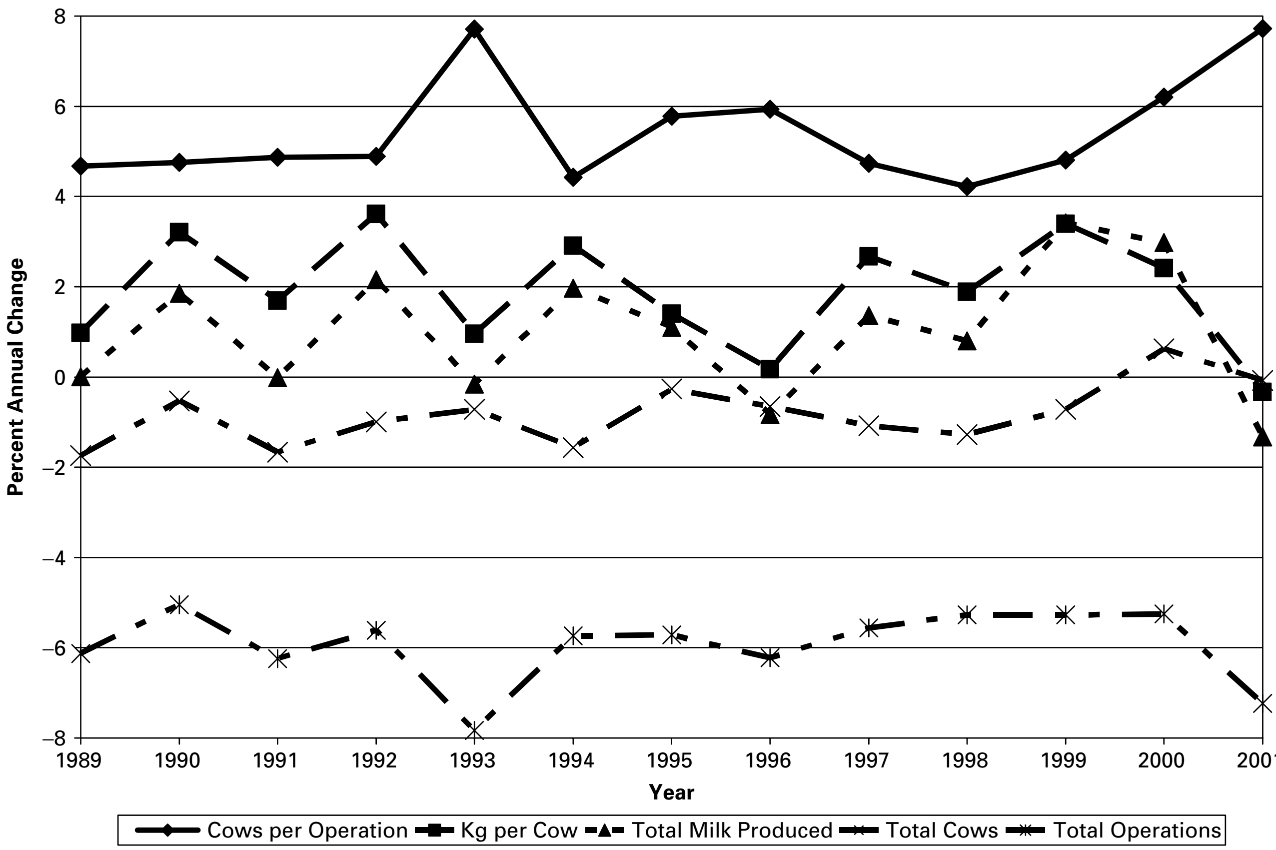

Fig. 2. Percent annual changes in the number of dairy cows per operation, kg of milk produced per cow, total milk produced, total number of dairy cows, and total number of dairy operations, from 1989 to 2001 inclusive, in the USA.

Source: Data from the US Department of Agriculture, National Agricultural Statistics Service. Available on the World Wide Web: http://www.usda.gov/nass. The mean annual percent changes were 5·4% (SD = 1·2%) in the number of cows per operation; 1·9% (SD = 1·3%) in the kg of milk produced per cow; 1·0% (SD = 1·4%) in the total kg of milk produced; −0·8% (SD = 0·7%) in the total number of dairy cows; and −5·9% (SD = 0·8%) in the total number of dairy operations in the USA.

assigned. However, the coverage factor is essentially 2 (for a 95% confidence interval, assuming a Gaussian distribution) once the number of df exceeds approximately 10. Thus, the default value of 50 df was more than adequate. The GUM Workbench is a specialized computer program that calculates standard uncertainties, and coverage factors, following the procedures established by the International Organization for Standardization (1995). The GUM Workbench applies numerical partial differential to compute sensitivity coefficients, uses Taylor-series approximation to compute standard uncertainties, and Satterthwaite's approximation to combine df (Metrodata GmbH, 1999). Losinger (2004) provided a review of the GUM Workbench. The major output of the GUM Workbench is the uncertainty budget that evaluates each input quantity's contribution to the measurand's uncertainty, and that conveys the level of confidence that can be placed in the analytic results.

To obtain a general picture as to how the overall structure of the US dairy industry has been changing in conjunction with the introduction of rBST, data were analysed on the number of dairy cows per operation, kg of milk produced per dairy cow, total milk production, total number of dairy cows, and total number of dairy operations in the USA were acquired for the years 1989–2001 from a website operated by the National Agricultural Statistics Service (**NASS**) of the USDA (http://www.usda.gov/nass). Figure 2 summarizes the percent annual changes in these parameters. To assess whether the impact that rBST has had on the US dairy industry has been very pronounced or minimal, one ought to examine whether the US dairy industry has been following a balanced growth path (where each variable continues to change at a constant rate), or whether evidence exists that the introduction of rBST has been associated with a noticeable upward shift in the average annual increase in milk production per cow. An upward shift in the average annual increase in milk production per cow would presumably be attended by an acceleration in the rate at which dairy producers exit the industry (because fewer producers would be needed to produce a given supply of milk), in addition to an increase in the rate at which

Table 4. Economic impacts of increased milk production associated with the use of recombinant bovine somatotropin in US dairy cows in 1996, based upon different estimates of the milk-production impact of recombinant bovine somatotropin. The coverage factor is 2 (i.e., plus or minus twice the standard uncertainty)

	Source of milk-production impact estimate		
Variable	McBride et al. 2004	Foltz & Chang, 2002	Ott et al. 2003
Change in quantity of milk produced (kg $\times 10^9$)	1·2 ± 0·6	1·8 ± 1·8	3·3 ± 1·0
Change in price of milk (cents/kg)	−2·2 ± 1·5	−3·3 ± 3·6	−6·2 ± 3·2
Change in total value of milk produced (\$ $\times 10^9$)	−1·1 ± 0·9	−1·7 ± 1·9	−3·0 ± 1·9
Change in consumer surplus (\$ $\times 10^9$)	1·5 ± 1·0	2·4 ± 2·6	4·4 ± 2·4
Change in producer surplus (\$ $\times 10^9$)	−1·1 ± 0·8	−1·6 ± 1·7	−2·8 ± 1·8
Total gain to US economy (\$ $\times 10^9$)	0·44 ± 0·28	0·74 ± 0·89	1·6 ± 0·8

the average operation size is increasing. Ordinary least squares regression equations were used to determine whether the slopes of the lines on Fig. 2 were significantly different from zero, and Durbin-Watson tests were used to determine whether first order autocorrelation of error terms existed in the regression models for any of the variables (which would indicate that ordinary least squares regression analysis was not valid) (Neter & Wasserman, 1974).

Results

The value of milk produced during 1996 was the product of the kg of milk produced during 1996 and the market price, which was \$23·0 billion (standard uncertainty = \$0·3 billion). Table 4 provides the change in quantity of milk produced, change in price of milk, change in total value of milk produced, change in consumer surplus, change in producer surplus, and total gain to the US economy that resulted from the use rBST in US dairy cows, based on the estimates of the effect of rBST on milk production as estimated by McBride et al. (2004), Foltz & Chang (2002), and Ott et al. (2003). The model of Ott et al. (2003) indicated the highest economic impacts resulting from the use of rBST. The model of Foltz & Chang (2002) showed no statistically significant economic impacts as a consequence of the use of rBST.

The linear milk-response parameter (based on % rBST use) provided by Ott & Novak (2001) (Table 2) was lower by roughly a factor of 10 than the milk response estimates provided by McBride et al. (2004) and by Foltz & Change (2002) (Table 1), and was somewhat close to the value of the coefficient (based on the square root of rBST use) provided by Ott et al. (2003). If the value reported by Ott & Novak (2001) is projected through the equations of Table 3, then the resulting economic impacts, although statistically significant, are so small as to be inconsequential. It seems probable that the model of Ott & Novak (2001) used the square root of the percent of rBST use as an explanatory variable, although this was not what Ott & Novak (2001) said. The results of the quadratic expression of Ott & Rendleman (2002), when projected through the equations of Table 3, are similar to the results derived from the model of Ott et al. (2003).

Tables 5–7 present the uncertainty budgets for the total economic impact of rBST, as derived from the models of McBride et al. (2004), Foltz & Chang (2002), and Ott et al. (2003). Using the parameter estimates of either McBride et al. (2004) (Table 5) or Foltz & Chang (2002), the estimate of the milk production effect of rBST use accounted for >90% of the uncertainty in the estimate of the total economic impact of rBST. The estimates of economic impacts associated with the model of Ott et al. (2003) were smaller than the estimates of economic impacts derived from the models of McBride et al. (2004) and Foltz & Chang (2002) (Table 4). The greater precision afforded by the estimate of Ott et al. (2003) meant that the relative contribution of the estimate of the impact of rBST on milk production was lower (74·4%, Table 7) than when the estimates of McBride et al. (2004) or Foltz & Chang (2002) were used.

Durbin-Watson tests showed no significant first order autocorrelation of error terms in regression models for any of the above variables of Fig. 1 (thus indicating the validity of ordinary least squares regression analysis) (Neter & Wasserman, 1974). Regression equations revealed that only the total number of cows (slope = 0·103, SE = 0·042, P = 0·031) had a slope that differed significantly from zero. Thus, no evidence exists that the annual rates of change in the number of cows per operation, the quantity of milk produced per cow, the total amount of milk produced, nor in the number of dairy operations changed significantly in concomitance with the introduction of rBST in the USA.

Table 5. Uncertainty budget for the total gain to the US economy that resulted from increased milk production caused by the use of recombinant bovine somatotropin in dairy cows, according to the model of McBride et al. (2004)

Input quantity	Sensitivity coefficient†	Uncertainty contribution‡	Index§
Kg/cow milk-production increase with rBST	$4{\cdot}2\times10^{5}$	$1{\cdot}3\times10^{8}$	91·3%
rBST use in dairy cows, %	$5{\cdot}0\times10^{7}$	$3{\cdot}5\times10^{7}$	6·3%
Number of dairy cows	$5{\cdot}4\times10^{1}$	$6{\cdot}6\times10^{6}$	0·2%
Kg milk produced in 1996	$-9{\cdot}3\times10^{-4}$	$-5{\cdot}9\times10^{5}$	0·0%
Mean price of milk in 1996, $/kg	$1{\cdot}3\times10^{9}$	$2{\cdot}9\times10^{6}$	0·0%
Price elasticity of demand for milk	$4{\cdot}0\times10^{8}$	$2{\cdot}0\times10^{7}$	2·0%
Price elasticity of supply for milk	$4{\cdot}9\times10^{7}$	$5{\cdot}4\times10^{6}$	0·1%

† $\partial y/\partial x_i$: describes how the estimated value of the measurand, y, varies with changes in the estimated value of the input quantity x_1, x_2, … (International Organization for Standardization, 1995)

‡ Product of the standard uncertainty (Table 1) and the sensitivity coefficient. The sum of the squares of the values in this column equals the square of the uncertainty in the estimated value of the measurand y

§ Percent contribution to the square of the measurand's uncertainty. This is 100 times the ratio of the square of the input quantity's uncertainty contribution to the square of the uncertainty in the estimated value of the measurand,. This column sums to 100%, and provides information on the relative importance of the contribution of each input quantity to the uncertainty of the measurand. In the table above, most of the uncertainty in the change in consumer surplus derived from the price elasticity of demand for milk, followed by the kg/cow milk-production increase per % increase in rBST use

Table 6. Uncertainty budget for the total gain to the US economy that resulted from increased milk production caused by the use of recombinant bovine somatotropin in dairy cows, according to the model of Foltz & Chang (2002)

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
kg/cow milk-production increase with rBST	$4{\cdot}8\times10^{5}$	$4{\cdot}4\times10^{8}$	96·7%
rBST use in dairy cows, %	$8{\cdot}9\times10^{7}$	$6{\cdot}2\times10^{7}$	2·0%
Number of dairy cows	$9{\cdot}6\times10^{1}$	$1{\cdot}2\times10^{7}$	0·0%
kg milk produced in 1996	$-2{\cdot}2\times10^{-3}$	$-1{\cdot}4\times10^{6}$	0·0%
Mean price of milk in 1996, $/kg	$2{\cdot}3\times10^{9}$	$4{\cdot}9\times10^{6}$	0·0%
Price elasticity of demand for milk	$9{\cdot}6\times10^{8}$	$4{\cdot}8\times10^{7}$	1·2%
Price elasticity of supply for milk	$1{\cdot}2\times10^{8}$	$1{\cdot}3\times10^{7}$	0·0%

Table 7. Uncertainty budget for the total gain to the US economy that resulted from increased milk production caused by the use of recombinant bovine somatotropin in dairy cows, according to the model of Ott et al. (2003)

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
kg/cow milk-production increase per % increase in rBST use	$1{\cdot}9\times10^{7}$	$3{\cdot}2\times10^{8}$	74·4%
BLV† prevalence in cows, %	$1{\cdot}1\times10^{8}$	$7{\cdot}5\times10^{7}$	4·0%
Number of dairy cows	$2{\cdot}3\times10^{2}$	$2{\cdot}8\times10^{7}$	0·6%
kg milk produced in 1996	$-7{\cdot}7\times10^{-3}$	$-4{\cdot}8\times10^{6}$	0·0%
Mean price of milk in 1996, $/kg	$4{\cdot}9\times10^{9}$	$1{\cdot}1\times10^{7}$	0·0%
Price elasticity of demand for milk	$3{\cdot}2\times10^{9}$	$1{\cdot}6\times10^{8}$	19·5%
Price elasticity of supply for milk	$4{\cdot}1\times10^{8}$	$4{\cdot}4\times10^{7}$	1·4%

† Bovine leukosis virus

Discussion

A limitation of the present analysis is that costs associated with using rBST were not included. In analysing the economic feasibility of adopting rBST, Butler (1999) assumed expenditures of 42 cents/d for the rBST, and 40 cents/d in extra feed consumption (for cows receiving rBST treatment). Additional potential costs (associated with rBST use), which are difficult to quantify, include extra labour, added record keeping, increased days open, mastitis, lameness and heat stress (Butler, 1999). Barham et al. (2000) and Foltz & Chang (2002) found that dairy

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producers who had tried rBST often already had higher levels of technology use in place. Other producers, who employed lower levels of technology on their farms, would probably incur higher start-up costs to get their operations to the point where rBST would be beneficial to their production systems. There has been growth in alternative production methods that have lower production per cow. Rotational grazing and organic production are two alternative production methods that do not push cows towards maximum production. Further research would be useful to disaggregate the change in producer surplus into the effect on adopters and non-adopters of rBST, which is beyond the scope of the present analysis (with the data presently available). Many consumers became concerned about the use of rBST by the dairy industry and switched either to higher priced organic milk (in which rBST was not allowed), or to rBST-free milk for which most creameries/bottling operations paid a premium directly to the producer (Collier, 2000). In addition, price elasticities of supply and demand in the USA differ by region, and also between commodities (fluid milk, butter, cheese, etc.). The purpose of the present study was to examine the welfare implications of rBST from the point of view of a broad, national perspective. Further research would be required to delve into the implications for any specific subfacet.

Besides primary producers and consumers, other stakeholders (e.g., feed suppliers, processors, wholesalers, retailers) are involved in the production and distribution of milk. An important question, posed by Butler (1999), was whether Monsanto was extracting all of the innovation rents associated with rBST and, if so, whether it was optimal (even for Monsanto). For a fuller perspective on US society, the impacts of rBST on these stakeholders should be addressed as well. The present analysis was limited to studying the welfare effects of rBST on primary producers and consumers of milk.

It is fairly common for economists working in multidisciplinary settings to use the assumption that a relatively small change in the unit cost of production can be modelled by a parallel shift of the supply curve. Elasticities of supply and demand are generally derived from observed market conditions, and can become less accurate the further one draws inferences beyond those settings. The basis of the change in consumer surplus was a shift in supply along a portion of a fixed demand curve. Measuring the change in producer surplus involved finding the area between two parallel supply curves projected to the horizontal axis. Therefore, the change in consumer surplus is probably less disputable than the estimate of the change in producer surplus. The form of the supply and demand curves outside of observed market conditions are unknown, and simplifying assumptions are necessary to estimate changes in producer surplus that result from shifts in supply. It should be pointed out that the assumptions of both linear demand and supply curves, and constant demand and supply elasticities, are contradictory (i.e., constant demand and supply elasticities suggest non-linear demand and supply curves). These contradictory assumptions may be a source of error, which it is hoped is small, especially relative to to the other sources of error listed in Tables 5–7. Ebel et al. (1992) and Forsythe & Corso (1994) assumed linear supply and demand curves, constant demand and supply elasticities, and parallel shifts in the supply curve, in computing the welfare effects of the National Pseudorabies Eradication Program. Ott et al. (2003) made similar assumptions when they computed the changes in producer surplus that resulted from bovine-leukosis virus on US dairy operations. Lindner & Jarrett (1978) and Miller et al. (1988) discussed the effect on the computation of the change in producer surplus caused by various assumptions about the way in which supply curve shifts. Kessel (2003) recommends the rectangular distribution when the researcher considers that all values between two limits have the same likelihood, or where it is not possible to choose a specific value without having more information. Therefore, a rectangular distribution, with wider limits than those chosen for the elasticity of demand, was used for the elasticity of supply. The goal of the present analysis was not to find the exact value of the change in producer surplus, but rather to determine a confidence interval that encompassed a large fraction of the distribution of values that could reasonably be attributed to the change in producer surplus. The estimates of the milk-production effects of rBST treatment contributed towards most of the uncertainty in the estimates of the total economic impacts (Tables 5–7). The price elasticity of supply contributed relatively little to the uncertainties.

In economics text books (for example, Byrns & Stone, 1987), supply curves are often depicted as having a positive *Y* intercept, because the marginal cost of producing even the first kg of milk is positive. However, an elasticity of supply that is less than 1 yields a negative *Y* intercept, and economic analysts need to be mindful of the implications of computing economic gains from negative prices. Ott et al. (2003) seemed not to have noticed that their supply curves had a negative *Y* intercept, and appear to have over-estimated the impact of bovine-leukosis virus on producer surplus. In general, an outward shift in the supply curve would suggest an increase in producer surplus when the *Y* intercepts are positive (which would be represented by a larger triangular region – similar to the producer surpluses of Fig. 1, but without being truncated at the horizontal axis). Ebel et al. (1992) found that eradicating pseudorabies would have caused some groups of hog producers to gain economic surplus, and others to lose economic surplus, depending on the size of the operation. In the present study, the supply curves, as indicated in Fig. 1, were projected only to the horizontal axis (so as not to attribute economic gains based on negative prices). As Fig. 1 illustrates, the use of rBST in dairy cows caused producers to lose some economic surplus (the area with vertical stripes, which was transferred to consumers), and to gain some economic surplus (based on the area with horizontal stripes below the segment c–a). The present calculations indicated that, for producers, the economic losses outweighed the gains. Since, in reality, dairy producers would stop selling milk if the price fell below a certain threshold, one might argue that the calculation on the gain side for the producer-surplus equation should be reduced to the area that is above this price threshold. This implies that the total loss in producer surplus may be greater than that calculated here. The goal of the present study was not to find exact values for the changes in economic surplus (which, at any rate, is impossible), but rather to apply the analytic principles delineated by the International Organization for Standardization (1995) to find confidence intervals for the changes in economic surplus, such that the confidence intervals included a large fraction of the distribution of values that could reasonably be attributed to the changes in economic surplus. Readers should be very cautious not to use the specific values obtained here outside of the context of their associated uncertainties. The same is true of any measurement result, but especially results that derive from economic analysis.

The present study made use of the assumption that the price flexibility of demand (i.e., the percent change in price given a 1% increase in quantity) equals the reciprocal of the price elasticity of demand, which is theoretically true only when a good has no substitutes. In the USA, soy-based beverages are the closest substitutes for fluid milk. Even when there is no reason to expect strong substitute relationships, statistical estimates of flexibilities may be different from reciprocals of elasticities estimated from the same data. Huang (1994, 1996) and Eales (1996) debated this issue. Huang (1994) argued that flexibilities should always be estimated directly, whereas Eales (1996) felt that simultaneity tests should be used first to determine whether an ordinary or inverse demand model was appropriate, and that if an ordinary demand system was appropriate, then flexibilities could be obtained from the inverse of the elasticities. Huang (1996) agreed that the flexibility matrix was theoretically equivalent to the inverted elasticity matrix, but demonstrated that the inverse of a directly estimated elasticity matrix did not equal the flexibility matrix estimated from the same data, and suggested that flexibilities should be estimated directly from data (rather than using the inverse of the elasticity).

Data used by McBride et al. (2004) came from the USDA's 2000 Agricultural Resource Management Survey, which included detailed economic information (including rBST use) from 872 dairy operations in 22 states. The data used by Foltz & Chang (2002) came from a mail survey of 124 dairy operations in Connecticut. A total of 2542 US dairy operations participated in the NAHMS Dairy '96 Study, from which Ott et al. (2003) developed their statistical model.

The milk-production model developed by Ott et al. (2003) to study bovine-leukosis virus was quite similar to a series of models that had appeared in three previous reports of economic analyses from the NAHMS Dairy '96 Study. The first model, which was used to examine the economic impacts of Johne's disease, included a square-root representation for percent rBST use because 'initial analysis demonstrated a non-linear relationship between milk production and percent rBST use,' and 'in part because of the large number of herds that did no use any BST' (Ott et al. 1999). In proceeding from the model of Ott et al. (1999) to the model Ott & Rendleman (2000), the 'Johne's Disease' variable was dropped, and the functional form for percent rBST use was transformed from the square root to a quadratic expression 'to measure a potential declining marginal physical product of milk production as rBST increases.' The quadratic model of Ott & Rendleman (2000) proved problematic because it indicated that milk production would fall if >87% of dairy cows were treated with rBST. Ott & Novak (2001) used a simple linear term for percent BST use. Ott et al. (2003) reverted to a square-root representation for percent rBST use. In addition, the model of Ott et al. (2003) incorporated a number of other enhancements. A new variable introduced by Ott et al. (2003) was the percent of cows in third or greater lactation (via 'piece-wise regression'). Moreover, Ott, Johnson & Wells (2003) added two new 'management index' variables that resulted from a 'correspondence analysis' that combined 24 variables into 2. In previous analyses, the use of Dairy Herd Improvement Association records 'served as a proxy measure for management capability' (Ott et al. 1999). Ott & Novak (2001) had attempted to combine 18 variables of management practice into four management indices, using factor analyses, to account for the influence of management ability, but decided instead to use Dairy Herd Improvement Association records as a measure of management ability. The ethics of presenting very similar methods and results in multiple papers may be questioned (Vardeman & Morris, 2003). Indeed, disentangling the various models from Ott et al. (1999) through to Ott et al. (2003) inclusive, was a challenge: the methods and results were very similar, and probably could have been combined into one paper.

The comparatively small scope of the survey that formed the basis of the model of Foltz & Chang (2002) may account for the lack of statistically significant findings when using their model to estimate the economic impacts of rBST use. McBride et al. (2004) and Ott et al. (2003) based their results on large-scale national surveys sponsored by the USDA. The survey that formed the basis of the results of McBride et al. (2004) was designed specifically to gather economic information from US dairy producers. Ott et al. (1999) reported that most of the economic data collected during the NAHMS Dairy '96 Study turned out not to be useful for analysis. The $6{\cdot}2+3{\cdot}2$ cents/kg decline in the price of milk when the milk-production impact of Ott et al. (2003) is used (Table 4), combined with the finding by Ott & Rendleman (2000) that optimal rBST use would be 73 % of cows, would tend to render questionable the economic impact estimates that derived from using Ott et al.'s (2003) model. If rBST had been used in 73 % of cows, then the welfare-analysis model used here suggests that the price of milk would have fallen by 17 cents/kg, and that lost producer surplus would have amounted to $5·6 billion. Clearly, few dairy producers would have considered this result to be optimal. Therefore, the estimates of the economic impacts of rBST that seem most consistent with reality are probably those that derived from using the model of McBride et al. (2004) (first column of Table 4).

Although, as a whole, the use of rBST may cause the US dairy industry to lose economic surplus (owing to the transfer to consumers), individual producers may stand to gain from using rBST, if the cost of administering the rBST is sufficiently low to result in increased profit from the increased production. If the costs of administering rBST had been incorporated into the present analysis, then the estimated economic loss to the dairy industry would have been greater. Further research, including better cost data, would be required before recommendations on the use of rBST could be given to individual dairy producers. An analysis of aggregate welfare impacts, no matter how thoroughly done, will not be a useful decision aid for individual producers. Barham & Foltz's (2002) assessment that rBST represents a relatively minor addition to the technology options available to dairy producers, and that rBST has not played much of a role in shaping the structure of dairy farming in the USA, is probably correct. The analysis of the data presented in Fig. 2 indicated that the introduction of rBST in the USA has not been accompanied by any dramatic changes to the balanced growth path of the US dairy industry.

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