Food Animal Economics

Economic impacts of reduced milk production associated with an increase in bulk-tank somatic cell count on US dairies

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Objective—To measure the economic impacts attributable to an increase in bulk-tank somatic cell count (BTSCC) on US dairies.

Design—Meta-analysis of data from various sources.

Procedure—Economic impacts attributable to reduced milk production associated with an increase in BTSCC (≥ 200,000 cells/mL) in dairy cows during 1996 were estimated from supply-and-demand curves for milk and from an estimate of the effect of increased BTSCC on milk production.

Results—Reduced milk production associated with an increase in BTSCC in dairy cows during 1996 caused an economic loss (mean ± 2SE) of 3.1 ± 2.1 billion dollars to consumers, an economic gain of 2.2 ± 1.7 billion dollars to dairy producers, and a total loss of 810 ± 480 million dollars to the US economy as a whole.

Conclusions and Clinical Relevance—Consumers would stand to benefit from increased milk production associated with reducing the BTSCC to < 200,000 cells/mL on all dairy operations, whereas the US dairy industry would experience an economic loss. Individual dairy producers need to compare the costs of measures intended to reduce BTSCC with the anticipated benefits from a decrease in BTSCC. (*J Am Vet Med Assoc* 2005;226:1652–1658)

Numerous reports[1-9] have documented that cows with mastitis (including subclinical infections) produce milk with an increased **somatic cell count (SCC)** and that increased SCCs are associated with reduced milk production per cow. A number of studies[10-16] have examined costs that dairy producers may incur as a result of increased SCC; however, these studies have generally focused on costs faced by each producer and did not consider the consequences of price effects nor the larger economic effects (including impacts on dairy producers and consumers) of reduced milk production associated with increased SCCs in dairy cows.

Welfare analysis offers an important tool for assessing economic impacts on the basis of changes in producer and consumer surplus.[17] Consumer surplus measures the difference between what consumers are willing to pay for a product and the amount that consumers actually pay. A demand curve illustrates the amount of milk that consumers would demand at each possible market price (**Figure 1**). Consumers who would have been willing to pay more than the market price, but who only have to pay the market price, enjoy an economic surplus that they may choose to spend on items other than milk. Producer

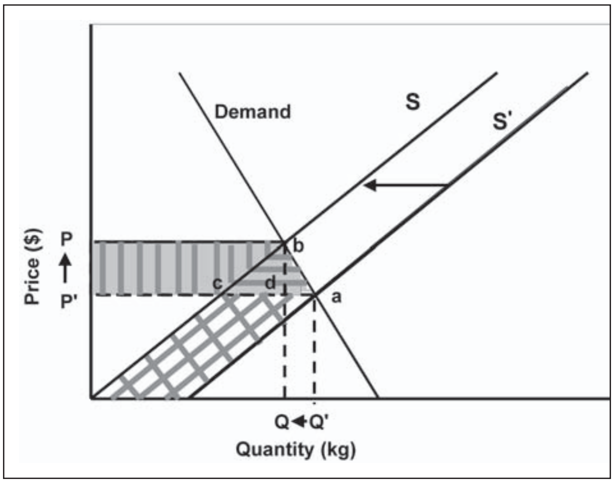

Figure 1—Illustration depicting supply-and-demand curves for milk. When supply (S) is shifted to a higher supply (S'), the original equilibrium quantity (Q) is shifted to a higher equilibrium quantity (Q') and the equilibrium market price (P) is shifted to a lower equilibrium market price (P'). Consumer surplus is the difference between what consumers are willing to pay for a product and the amount that consumers actually pay for that product. Producer surplus measures the difference between the amount of money that producers receive for a commodity and the amount that they would accept to supply a given quantity of that commodity. When supply decreases from S' to S (eg, as a result of an increase in bulk-tank somatic cell count in milk from dairy cows), the equilibrium price increases from P' to P, whereas quantity decreases from Q' to Q. Consumer surplus decreases by the amount represented by the quadrilateral with corners P, P', b, and a (gray-shaded area). A portion of the lost consumer surplus (quadrilateral with corners P', P, b, and c; gray-shaded area with vertical stripes) is transferred to producers as a gain. Producer surplus increases by this gain but decreases by the area between the 2 supply curves (triangle with corners a, b, and c; gray-shaded area with horizontal stripes). Total loss to the US economy is the area below the demand curve and between the 2 supply curves (gray-shaded area with horizontal stripes plus the cross-hatched area).

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surplus measures the difference between the amount of money that producers receive for a commodity and the amount that they would accept to supply a given quantity of that commodity. Animal diseases or other factors (such as subclinical mastitis) may cause milk production to decrease and thus reduce the amount of milk that producers are willing to supply for a given price. Such a downward shift in supply puts pressure on the market price (ie, the point at which supply intersects with demand) to increase. The increase in market price diminishes the economic surplus that consumers enjoyed. The economic impact on producers is less clear because a portion of the lost consumer surplus is transferred to producers as economic gain. Welfare analysis methods can be used to quantify the economic impacts of animal diseases (or other factors that affect production) as they relate to producers, consumers, and the economy as a whole.

Scientific researchers agree that a measurement result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty is required to decide whether the result is adequate for its intended purpose and to ascertain whether it is consistent with other similar results.[18] The National Institute of Standards and Technology[18] has provided some practical guidelines for computing and expressing uncertainty in measurement, which are similar to those described in a **guide to uncertainty in measurement (GUM)** written by the International Organization for Standardization.[19] The GUM entails the application of Taylor-series approximation for combining uncertainties and the presentation of uncertainty budgets that assess the relative contribution of input quantities to the uncertainty of the measured output.[19]

The purpose of the study reported here was to apply a welfare analysis to estimate changes in producer and consumer surplus and the total loss to the US economy that resulted from increases in **bulk-tank (BT)** SCCs for US dairy cattle in 1996. Uncertainties in these estimates were evaluated in accordance with the GUM written by the International Organization for Standardization.[19]

Materials and Methods

Estimated changes in producer and consumer surplus were based on the assumptions of linear supply-and-demand curves, of a parallel supply shift, and that all dairy operations had reduced BTSCC to < 200,000 cells/mL in 1996 (Figure 1). As mentioned previously, consumer surplus is the difference between what consumers are willing to pay for a product and the amount that consumers actually pay for that commodity, whereas producer surplus is the difference between the amount of money that producers receive for a commodity and the amount that they would be willing to accept to supply a given quantity of that commodity. Thus, 2 static economic situations were compared. Input quantities were summarized (**Appendix 1**). Model equations used in the analysis were selected (**Appendix 2**).

In 1 study,[21] data from the USDA, Animal and Plant Health Inspection Service, **National Animal Health Monitoring System (NAHMS)** Dairy '96 study were used to develop a model that provided estimates of reduced milk production (reported as the number of kg/cow) on dairy operations with a BTSCC between 200,000 and 399,999 cells/mL and on dairy operations with a BTSCC ≥ 400,000 cells/mL, compared with results for dairy operations with a BTSCC < 200,000 cells/mL.

The NAHMS Dairy '96 study revealed that (mean ± SE) 15.6 ± 1.5% of dairy operations had a BTSCC between 200,000 and 399,999 cells/mL and 54.6 ± 2.2% of dairy operations had a BTSCC ≥ 400,000 cells/mL during 1996.[22] Data were not available on the number of dairy cows for each BTSCC category. For the purpose of the analysis reported here, the percentage of operations for each BTSCC category was assumed to be reflective of the percentage of dairy cows for that BTSCC category. Loss in milk production for operations with a BTSCC between 200,000 and 399,999 cells/mL (compared on the basis of milk production for operations with a BTSCC < 200,000 cells/mL) was computed by multiplying the reduced milk production (number of kg of milk/cow) on operations with a BSTCC between 200,000 and 399,999 cells/mL by the proportion of dairy operations with a BTSCC between 200,000 and 399,999 cells/mL, and that value was then multiplied by the number of dairy cows in 1996. Loss in milk production for operations with a BTSCC ≥ 400,000 cells/mL (compared on the basis of milk production for operations with a BTSCC < 200,000 cells/mL) was calculated in a similar manner. Total loss in milk production for dairy operations with a BTSCC ≥ 200,000 cells/mL (compared on the basis of milk production for operations with a BTSCC < 200,000 cells/mL) was the sum of loss in milk production for dairy operations with a BTSCC between 200,000 and 399,999 cells/mL and dairy operations with a BTSCC ≥ 400,000 cells/mL.

The **National Agricultural Statistics Service (NASS)** of the USDA estimated in 1996 that the total US population of dairy cows in 1996 was 9,372,000 and that they produced 70,003,000 kg of milk at a mean price of $0.328/kg.[25] For the 1996 data, the NASS calculated that the root mean square error for all dairy cows was 1.3% and for milk production was 0.9%.[23] The NASS did not provide an uncertainty of the estimate of the average price of milk during 1996. Therefore, we selected a conservative estimate for the uncertainty in the price of milk (ie, 1.3%), which was the larger of the root mean square errors calculated for the number of dairy cows and milk production.

The price elasticity of demand[17] measures the degree to which changes in the price of a commodity interrelate with changes in the quantity purchased and is defined as the ratio of the relative change in quantity purchased to the relative change in price as follows:

$$e_D = (\Delta Q/Q)/(\Delta P/P) = (\Delta Q/\Delta P) \times (P/Q),$$

where e_D is the price elasticity of demand, ΔQ is the change in quantity purchased, Q is the quantity purchased, ΔP is the change in price, and P is the price.

In 1 study,[24] investigators reported a list of estimates of price elasticity of demand for milk in the United States and Canada compiled from 15 researchers. Estimated price elasticities of demand had a mean of –0.25, SD of 0.20, and SE of 0.05. In another study,[20] price elasticity of milk supply was 0.6785, 0.3815, and 0.7585 for small, medium, and large farms, respectively. In that study,[20] it was found that elasticity varied on the basis of farm size (medium-sized farms were considerably more inelastic than small and large farms) because of size-related differences in capital intensity, specialization, yield variability, herd-size variability, and rates of entry into and exit from dairy production. The present analysis used a rectangular distribution with 0.3815 and 0.7585 as the lower and upper limits, respectively, for the price elasticity of supply for milk.

In the study reported here, a specialized computer program for the measurement of uncertainty[26,a] was used to create estimates and propagate uncertainties for the change in consumer surplus, change in producer surplus, and total economic loss attributable to reduced milk production as a result of an increase in BTSCC in dairy cows during 1996. The specialized computer program computes estimates, combined standard uncertainties, and coverage factors in accordance with the GUM.[27] Furthermore, the specialized computer program calculates sensitivity coefficients by use of numeric partial differentiation, applies Taylor-series approximation to compute combined standard uncertainties, and uses the Welch-Satterthwaite formula for combining the individual number of degrees of freedom for various input quantities.[27] The specialized computer program can be used to generate uncertainty budgets, which allows researchers to assess the relative contribution of each input quantity to the overall uncertainty of the measured variable.[19]

Results

The value of milk produced during 1996 was the product of the number of kilograms of milk produced during 1996 and the market price, which amounted to 23.0 billion dollars (standard uncertainty, 0.3 billion dollars). Analysis of results from the model equations and data entered into the specialized computer program for the measurement of uncertainty indicated that dairy operations with a BTSCC ≥ 200,000 cells/mL caused milk production to decrease by 2.3 billion kg (standard uncertainty, 0.6 billion kg) during 1996. If all dairy operations in 1996 had a BTSCC < 200,000 cells/mL, then milk production would have increased to 72.2 billion kg (standard uncertainty, 0.9 billion kg) and the market price would have decreased to \$0.285/kg (standard uncertainty, \$0.015/kg). The value of milk production would have decreased to 20.6 billion dollars (standard uncertainty, 1.0 billion dollars).

Uncertainty budgets, estimates, and expanded uncertainties for the change in consumer surplus, change in producer surplus, and total economic loss attributable to reduced milk production associated with dairy operations having a BTSCC ≥ 200,000 cells/mL were calculated (**Tables 1–3**). The sensitivity coefficient is the partial derivative of the measured variable with respect to the input quantity, and it reveals how the value of the measured variable varies with changes in the value of the input quantity. For example, the average decrease in milk production for dairy operations with a BTSCC between 200,000 and 399,999 cells/mL was 229.9 kg/cow (Appendix 1). Analysis of the sensitivity coefficient indicates that when the average decrease in milk production increases by 1.0 kg/cow (ie, decrease of 230.9 kg/cow instead of 229.9 kg/cow), then consumer surplus would be reduced by an additional 6.9 million dollars.

The uncertainty contribution is the product of the standard uncertainty of the input quantity and the absolute value of the sensitivity coefficient. Via Taylor-series expansion, the sum of the squares of the uncertainty contributions equals the square of the combined standard uncertainty of the measured variable.[19] The calculated indices reveal the percentage contribution of each input quantity to the square of the uncertainty of the measured variable (Tables 1–3). For uncertainties in the change in consumer surplus and total economic loss, the principal contributor was the estimate of the reduced milk production per cow on operations with a BTSCC between 200,000 and 399,999 cells/mL. The price elasticity of demand for milk accounted for most of the uncertainty in the estimated change in producer surplus, followed by the estimate of the reduced milk production per cow on operations with a BTSCC between 200,000 and 399,999 cells/mL.

Table 1—Uncertainty budget for the reduction in consumer surplus as a result of reduced milk production attributable to an increase in bulk-tank somatic cell count (BTSCC) in cows on US dairy operations.

Input quantity	Sensitivity coefficient*	Uncertainty contribution†	Index (%)‡
Reduced milk production on operations with a BTSCC between 200,000 and 399,999 cells/mL (kg/cow)	6.9×10^6	7.6×10^8	52.9
Operations with a BTSCC between 200,000 and 399,999 cells/mL (%)	2.9×10^7	6.4×10^7	0.4
Reduced milk production on operations with a BTSCC ≥ 400,000 cells/mL (kg/cow)	2.0×10^6	2.9×10^8	7.7
Operations with a BTSCC ≥ 400,000 cells/mL (%)	9.6×10^7	1.4×10^8	1.9
No. of dairy cows	3.3×10^2	4.0×10^7	0.1
Milk produced in 1996 (kg)	-7.0×10^{-4}	4.4×10^5	0
Mean price of milk in 1996 (\$/kg)	9.3×10^9	2.0×10^7	0
Price elasticity of demand for milk	3.0×10^8	6.4×10^8	36.9

The final estimate for the reduction in consumer surplus is 3.05 billion dollars with a standard uncertainty of 1.05 billion dollars (64 degrees of freedom). The resulting value and expanded uncertainty with a coverage factor of 2 is (mean ± 2 standard uncertainties) 3.1 ± 2.1 billion dollars.

*The sensitivity coefficient (ie, $\partial y/\partial x_i$) describes how the estimated value of the measured variable (ie, y) varies with changes in the estimated value of the input quantity (ie, $x_1, x_2, \ldots x_n$). †Absolute value of the product of the standard uncertainty 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 measured variable (ie, y). ‡Percentage of the contribution to the square of the uncertainty for the measured variable; this value is 100 times the ratio of the uncertainty contribution for the input quantity to the square of the uncertainty in the estimated value of the measured variable. Values in this column should sum to 100% but may not because of rounding errors.

Table 2—Uncertainty budget for the change in producer surplus as a result of reduced milk production attributable to an increase in BTSCC in cows on US dairy operations in 1996.

Input quantity	Sensitivity coefficient*	Uncertainty contribution†	Index (%)‡
Reduced milk production on operations with a BTSCC between 200,000 and 399,999 cells/mL (kg/cow)	5.0×10^6	5.5×10^8	41.8
Operations with a BTSCC between 200,000 and 399,999 cells/mL (%)	2.1×10^7	4.6×10^7	0.3
Reduced milk production on operations with a BTSCC ≥ 400,000 cells/mL (kg/cow)	1.4×10^6	2.1×10^8	6.1
Operations with a BTSCC ≥ 400,000 cells/mL (%)	6.9×10^7	1.0×10^8	1.5
No. of dairy cows	2.4×10^2	2.9×10^7	0.1
Milk produced in 1996 (kg)	2.0×10^{-4}	1.2×10^5	0
Mean price of milk in 1996 ($/kg)	6.8×10^9	1.5×10^7	0
Price elasticity of demand for milk	1.2×10^{10}	6.0×10^8	50.1
Price elasticity of supply for milk	-2.0×10^8	2.1×10^7	0

The final estimate for the change in producer surplus is an increase of 2.24 billion dollars with a standard uncertainty of 0.844 billion dollars (46 degrees of freedom). The resulting value and expanded uncertainty with a coverage factor of 2 is an increase (mean ± 2 standard uncertainties) of 2.2 ± 1.7 billion dollars.

See Table 1 for remainder of key.

Table 3—Uncertainty budget for the total economic loss resulting from reduced milk production attributed to an increase in BTSCC in cows on US dairy operations in 1996.

Input quantity	Sensitivity coefficient*	Uncertainty contribution†	Index (%)‡
Reduced milk production on operations with a BTSCC between 200,000 and 399,999 cells/mL (kg/cow)	2.0×10^6	2.1×10^8	81.0
Operations with a BTSCC between 200,000 and 399,999 cells/mL (%)	8.2×10^6	1.8×10^7	0.6
Reduced milk production on operations with a BTSCC ≥ 400,000 cells/mL (kg/cow)	5.6×10^5	8.2×10^7	118
Operations with a BTSCC ≥ 400,000 cells/mL (%)	2.7×10^7	4.1×10^7	2.9
No. of dairy cows	9.3×10^1	1.1×10^7	0.2
Milk produced in 1996 (kg)	-9.0×10^{-4}	5.6×10^5	0.0
Mean price of milk in 1996 ($/kg)	2.5×10^9	5.3×10^6	0
Price elasticity of demand for milk	7.6×10^8	3.8×10^7	2.6
Price elasticity of supply for milk	2.0×10^8	2.1×10^7	0

The final estimate for the total economic loss resulting from reduced milk production associated with an increase in BTSCC in dairy cows is 813 million dollars with a standard uncertainty of 239 million dollars (74 degrees of freedom). The resulting value and expanded uncertainty with a coverage factor of 2 is (mean ± 2 standard uncertainties) 810 ± 480 million dollars.

See Table 1 for remainder of key.

Most (2.89 billion dollars; standard uncertainty, 0.942 billion dollars) of the reduction in consumer surplus was transferred to producers as a gain. For producers, this transfer more than offset the 652 million dollars (standard uncertainty, 150 million dollars) of lost producer surplus (which accounted for most of the loss of 813 million dollars to the total US economy), such that the total impact on producers was an increased surplus of 2.24 billion dollars (Table 2). Lost consumer surplus that was not transferred to producers amounted to 161 million dollars (standard uncertainty, 106 million dollars). Total loss to the US economy was the sum of lost producer surplus and lost consumer surplus that was not transferred to producers (Table 3).

Discussion

Elasticity of supply and demand is generally approximated from observed market situations. The more researchers extrapolate from real-market conditions, the less realistic the assumptions are about the future shape of the supply-and-demand curves. In the study reported here, the basis of the estimated change in consumer surplus was a shift in supply along a small segment of a fixed demand curve. Estimating the change in producer surplus encompassed measuring the area between 2 parallel supply curves projected to the horizontal axis. Thus, the estimated change in consumer surplus may have exuded more confidence about its overall accuracy than the estimated change in producer surplus. Shape of the supply-and-demand curves outside of real-market conditions cannot be known. Therefore, some sort of simplifying assumptions are required when researchers attempt to offer an estimate of changes in producer surplus that result from shifts in supply. The rectangular distribution is suggested in error propagation when researchers believe that all values between 2 limits have the same likelihood and cannot prefer specific values without having more knowledge.[b] Therefore, a rectangular distribution, with wider limits than those used for the elasticity of demand, was selected for the elasticity of supply in our study. Even so, the elasticity of demand contributed more to the uncertainty of measured variables than did the elasticity of supply (Tables 1–3).

In 2 studies,[28,29] researchers have described the impacts that various assumptions (regarding the way in which supply curves shift) can have on the computation of change in producer surplus. When the original and shifted supply curves approach each other as they get closer to the horizontal axis (referred to in 1 study[28] as a divergent shift), then the absolute value of the change in producer surplus will be reduced. When the original and shifted supply curves separate from each other as they approach the horizontal axis (referred to in that same study[28] as a convergent shift), then the absolute value of the change in producer surplus will be higher. A fairly standard working assumption commonly used by economists working in multidisciplinary settings is that a relatively small change (eg, caused by disease) in the unit cost of production can be modeled as a parallel shift of the supply curve. In analyzing changes in economic surplus as a result of bovine-leukosis virus on US dairy operations, investigators in 1 study[21] assumed a parallel shift in the supply curve (on the basis of the same milk production model used here). To measure the change in producer surplus resulting from the National Pseudorabies Eradication Program, investigators[30] presumed a parallel shift in the supply curve. In another study,[31] investigators presumed a parallel supply shift to estimate changes in producer and consumer surplus that resulted from implementation of hazard analysis and critical control points. The principal innovation of the analysis reported here is the use of uncertainty analysis and principles for the measurement of uncertainty to examine changes in economic surplus. The goal of the analysis was not to find exact values for the changes in economic surplus (which is impossible) but, rather, to determine confidence intervals for the changes in surplus such that the confidence intervals encompassed a large fraction of the distribution of values that could reasonably be attributed to the changes in surplus. The final step of the technique for the measurement of uncertainty was to report measurement results together with their uncertainties and to describe how the measurement results and uncertainties were obtained.[19]

A principal advantage of computing uncertainties and providing uncertainty budgets, as recommended by the International Organization for Standardization,[19] is the transparent reporting of the methods and results. The uncertainty budget, which lists the source, distribution, value, uncertainty, and degrees of freedom for each input quantity and analyzes its contribution to the uncertainty for each measured variable, effectively conveys the confidence that can be placed in a researcher's results. Indices of the uncertainty contributions clearly reveal the relative importance of each input quantity with respect to its impact on the uncertainty of the measured variable (Tables 1–3). An important source of uncertainty was the estimate of the reduced milk production per cow on operations with a BTSCC between 200,000 and 399,999 cells/mL. Analysis of this finding suggests that the greatest improvement in the estimate of the economic cost of higher BTSCCs could be derived by concentrating on finding a better estimate of reduced milk production per cow on operations with a BTSCC between 200,000 and 399,999 cells/mL. For example, a more precise estimate of the price of milk in 1996 (whose contribution to the overall uncertainties of the economic impacts was < 0.1%) would have had a trivial impact on the uncertainties of the measured variables. Other researchers who want to propose another value for an input quantity or modify the model equations may easily use the information reported here and proceed accordingly.

In 2 reports,[6,21] investigators provided extremely similar statistical models that furnished estimates of reduced milk production on dairy operations with a high BTSCC. For the statistical model in one of those studies,[6] investigators attempted to use factor analysis to combine 18 management-practice variables into 4 management indices, but they decided instead to use Dairy Herd Improvement Association records as a measure of management ability. In the other study,[21] investigators used correspondence analysis to combine 24 management-practice variables into 2 management-index variables, which replaced the use of Dairy Herd Improvement Association records in their statistical model. The analysis reported here made use of the model in the latter study,[21] which was believed to be the most recent statistical model for use in providing national-level impacts of increased BTSCCs on milk production.

In 1 study,[6] investigators concluded that the cost to the US dairy industry attributable to increases in BTSCC was 959 million dollars in lost productivity in 1996. The authors of that study admitted that their analysis did not consider price effects but did observe that aggregate losses are usually less than the sum of changes in producer and consumer surplus. Furthermore, their estimate of lost productivity did not include an uncertainty analysis and is therefore difficult to evaluate. Analysis of the study reported here suggests that dairy producers would have lost considerable economic surplus if the BTSCC had been < 200,000 cells/mL on all dairy operations because the increased milk production would have transferred considerable economic surplus to consumers. In an aforementioned study,[6] investigators reported that dairy operations with a BTSCC ≥ 400,000 cells/mL had significantly fewer calves born alive per dairy cow than dairy operations with a BTSCC < 200,000 cells/mL. Whether this difference was attributable to a longer calving interval or to an increase in the number of abortions is unclear. Operations with a high BTSCC culled fewer dairy cows and had higher mortality of dairy cows than did operations with a BTSCC < 200,000 cells/mL.[6] Whether producers with a high BTSCC would receive higher profits through increased culling depends on the replacement costs for each producer, the income that would be received from culling, and whether the new cows would, in fact, produce more milk or convert feed into milk more efficiently than the culled cows. Other than profit maximization, dairy producers may be motivated by factors such as maximizing utility.

Each dairy producer needs to compare the costs for measures intended to reduce BTSCC with the anticipated benefits of a decrease in BTSCC. Some producers with a high BTSCC may receive lower prices for their milk.[6] Because of the transfer in economic surplus, consumers would stand to benefit a great deal more than would producers from an increase in milk production associated with a reduction in BTSCC.

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a. GUM Workbench, Metrodata GmbH, Grenzach-Wyhlen, Germany.

b. Kessel R. *A novel approach to uncertainty evaluation of complex measurements in isotope chemistry*. Doctor in Science thesis, Department of Chemistry, University of Antwerp, Antwerp, Belgium, 2003.

References

1. Bartlett PC, Miller GY, Anderson CR, et al. Milk production and somatic cell counts in Michigan dairy herds. *J Dairy Sci* 1990;73:2794–2800.
2. Dohoo IR, Meek AH, Martin SW. Somatic cell counts in bovine milk: relationships to production and clinical episodes of mastitis. *Can J Comp Med* 1984;48:130–135.
3. Fetrow J, Anderson K, Sexton S, et al. Herd composite somatic cell counts: average linear score and weighted average somatic cell count score and milk production. *J Dairy Sci* 1988;71:257–260.
4. Jones GM, Pearson RE, Clabaugh GA, et al. Relationships between somatic cell counts and milk production. *J Dairy Sci* 1984;67:1823–1831.
5. Miller RH, Paape MJ, Fulton LA, et al. The relationship of milk somatic cell count to milk yields for Holstein heifers after first calving. *J Dairy Sci* 1993;76:728–733.
6. Ott SL, Novak PR. Association of herd productivity and bulk-tank somatic cell counts in US dairy herds in 1996. *J Am Vet Med Assoc* 2001;218:1325–1330.
7. Raubertas RF, Shook GE. Relationship between lactation measures of somatic cell concentration and milk yield. *J Dairy Sci* 1982;65:419–425.
8. Reneau JK. Effective use of dairy herd improvement somatic cell counts in mastitis control. *J Dairy Sci* 1986;69:1708–1720.
9. Youl BS, Nicholls TJ. The relationship between somatic cell counts and lactation yield of dairy cows. *Aust J Dairy Technol* 1987;2:68–70.
10. Blosser TH. Economic losses from the National Research Program on Mastitis in the United States. *J Dairy Sci* 1979;62:119–127.
11. Dobbins CN. Mastitis losses. *J Am Vet Med Assoc* 1977;170:1129–1132.
12. Hoblet KH, Schnitkey GD, Atbaugh D, et al. Costs associated with selected preventive practices and with episodes of clinical mastitis in nine herds with low somatic cell counts. *J Am Vet Med Assoc* 1991;199:190–196.
13. Kaneene JB, Hurd HS. The National Animal Health Monitoring System in Michigan. III. Cost estimates of selected dairy cattle diseases. *Prev Vet Med* 1990;8:127–140.
14. Kirk JH, Barlett PC. Economic impact of mastitis in Michigan Holstein dairy herds using a computerized records system. *Agri-Pract* 1988;9:3–6.
15. Miles H, Lesser W, Sears P. The economic implications of bioengineered mastitis control. *J Dairy Sci* 1992;73:596–605.
16. Miller GY, Bartlett PC, Lance SE, et al. Costs of clinical mastitis and mastitis prevention in dairy herds. *J Am Vet Med Assoc* 1993;202:1230–1236.
17. Nicholson W. Market demand and elasticity. In: *Microeconomic theory basic principles and extensions*. 6th ed. Fort Worth, Tex: Dryden Press, 1995;196–225.
18. National Institute of Standards and Technology. *Guidelines for evaluating and expressing the uncertainty of NIST measurement results*. NIST Technology Note 1297. Gaithersburg, Md: National Institute of Standards and Technology, 1994.
19. International Organization for Standardization. *Guide to the expression of uncertainty in measurement corrected and reprinted*. Geneva: International Organization for Standardization, 1995.
20. Adelaja AO. Price changes, supply elasticities, industry organization, and dairy output distribution. *Am J Agric Econ* 1991;73:89–102.
21. Ott SL, Johnson R, Wells SJ. Association between bovine-leukosis virus seroprevalence and herd-level productivity on US dairy farms. *Prev Vet Med* 2003;61:249–262.
22. USDA, Animal and Plant Health Inspection Service. *Part III: reference of dairy health and health management*. Fort Collins, Colo: USDA, Animal and Plant Health Inspection Service, Veterinary Services, Centers for Epidemiology and Animal Health, 1996.
23. USDA, National Agricultural Statistics Service. Milk production 12-13-96. NASS Report DA 1-1 (12-96). Washington, DC: USDA, National Agricultural Statistics Service, 1996.
24. Meilke K, Sarker R, Le Roy D. Analyzing the potential for increase trade in dairy products: a Canadian perspective, in *Proceedings*. 2nd Canada/US Agricultural Food Policy Syst Information Workshop, 1996;241–272.
25. USDA, National Agricultural Statistics Service. *Milk production, disposition and income 1998 summary*. NASS Report DA 1-2 (99). Washington, DC: USDA, National Agricultural Statistics Service, 1999.
26. Metrodata GmbH. *GUM Workbench: the tool for expression of uncertainty in measurement. Manual for version 1.2 English edition*. Taastrup, Denmark: Teknologisk Institut, 1999.
27. Losinger WC. A review of the GUM Workbench. *Am Stat* 2004;58:165–167.
28. Lindner RK, Jarrett FG. Supply shifts and the size of research benefits. *Am J Agric Econ* 1978;60:48–58.
29. Miller GY, Rosenblatt JM, Hushak LJ. The effect of supply shifts on producers' surplus. *Am J Agric Econ* 1988;70:886–891.
30. Forsythe KW, Corso B. Welfare effects of the National Pseudorabies Eradication Program: comment. *Am J Agric Econ* 1994;76:968–971.
31. Kennedy TK, Losinger WC, Hoag DL. Who pays for hazard analysis and critical control points? *J Appl Anim Res* 2000;17:197–200.

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Appendix 1

Input quantities and their uncertainty values used to calculate economic impacts attributable to an increase in bulk-tank somatic cell count (BTSCC) on US dairies in 1996.

Input quantity	Value	Standard uncertainty	Degrees of freedom	Reference
Decrease in milk production for dairy operations with a BTSCC between 200,000 and 399,999 cells/mL (kg/cow)	229.9	109.7	50*	18
Decrease in milk production for dairy operations with a BTSCC ≥ 400,000 cells/mL (kg/cow)	759.0	146.5	50	18
Dairy operations with a BTSCC between 200,000 and 399,999 cells/mL (%)	15.6	1.5	50	22
Dairy operations with a BTSCC ≥ 400,000 cells/mL (%)	54.6	2.2	50	22
No. of dairy cows	9,327,000	122,000†	50	21
Milk produced in 1996 (kg)	70.003×10^9	630×10^6†	50	21
Mean price of milk in 1996 ($/kg)	0.328	0.004†	50	21
Price elasticity of demand for milk	–0.25	–0.05	14	23
Price elasticity of supply for milk‡	0.56995	0.18855	∞§	24

*For type B data with a normal distribution, the specialized computer program for measurement uncertainty[a] assigns a default value of 50 degrees of freedom.[20] †Uncertainties are based on data contained in reference No. 21. ‡Data had a rectangular distribution; the value is the midpoint between the upper and lower limits, and the half-width of this limit is listed as the standard uncertainty. §By definition, this input has an infinite number of degrees of freedom.[20]

Appendix 2

Model equations used in the analysis of the economic impacts attributable to an increase in BTSCC on US dairies in 1996.

$\Delta Q_M = \text{BTSCCeffect}_M \times M \times \text{No. of cows}$

$\Delta Q_H = \text{BTSCCeffect}_H \times H \times \text{No. of cows}$

$\Delta Q = \Delta Q_M + \Delta Q_H$

$Q' = Q + \Delta Q$

$\Delta P = (\Delta Q \times P)/(e_D \times Q)$

$P' = P + \Delta P$

$Q_c = (\Delta Q - e_s) \times \Delta P \times (Q/P)$

$CS_{trans} = (\Delta P \times Q_c) + (0.5 \times \Delta P \times [Q - Q_c])$

$CS_{lost} = 0.5 \times (\Delta Q)^2 \times P \times ([e_D - e_S]/e_D^2) \times Q$

$\Delta CS = CS_{trans} + CS_{lost}$

$PS_{lost} = \Delta Q \times P'$

$\Delta PS = CS_{trans} - PS_{lost}$

$\text{Total economic loss} = CS_{lost} + PS_{lost}$

ΔQ_M = Reduced quantity of milk produced (in number of kilograms) on operations with a BTSCC between 200,000 and 399,999 cells/mL. BTSCCeffect_M = Reduced milk production (in number of kg/cow) on operations with a BTSCC between 200,000 and 399,999 cells/mL. M = Percentage of dairy operations with a BTSCC between 200,000 and 399,999 cells/mL. ΔQ_H = Reduced quantity of milk (in number of kilograms) produced on operations with a BTSCC ≥ 400,000 cells/mL. BTSCCeffect_H = Reduced milk production (in number of kg/cow) on operations with a BTSCC ≥ 400,000 cells/mL. H = Percentage of operations with a BTSCC ≥ 400,000 cells/mL. ΔQ = Total reduction in milk production (in number of kilograms) on operations with a BTSCC ≥ 200,000 cells/mL. Q = Quantity of milk produced (in kilograms) in 1996. Q' = Quantity of milk (in kilograms) that would have been produced if all operations had a BTSCC < 200,000 cells/mL. ΔP = Change in price of milk (in dollars/kg). P = Price of milk in 1996 (in dollars/kg). e_D = Price elasticity of demand for milk. P' = Price of milk at ΔQ (in dollars/kg). Q_c = Quantity of milk produced (in number of kilograms) at the point where the horizontal line from P' intersects the supply line. e_S = Price elasticity of supply for milk. CS_{trans} = Consumer surplus transferred to producers (in number of dollars). CS_{lost} = Consumer surplus lost (in number of dollars). ΔCS = Change in consumer surplus (in number of dollars). PS_{lost} = Lost producer surplus (in number of dollars). ΔPS = Change in producer surplus (in number of dollars).