Economics of Measuring Costs Due to Mastitis-Related Milk Loss

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Abstract

Reduced milk yield due to mastitis has been estimated throughout the literature to be the largest source of loss due to an occurrence of mastitis in dairy cattle, though there is a high amount of variability amongst these estimates. The objective of this paper is to estimate yield loss due to mastitis using a large sample size of cows throughout the United States to reduce the variability of the loss estimates. 38,150 test day observations from December 2013 were used from herds in Wisconsin, New York, Illinois, and Michigan to estimate milk yield loss due to mastitis. A base model and a model with an interaction term between SCC and lactation number based on Bartlett et al. (1990) was used to calculate milk yield loss. Milk yield loss was estimated to be 0.0428 kg/day in the base model and 0.0388 kg/day in the interaction model per 1% increase in the natural log of the SCC. This paper is part of ongoing research to create a mastitis cost calculation tool for United States dairy farmers.

Introduction

The economics of livestock disease prevention and control incorporates biological and economic factors. For livestock diseases that cannot be completely eradicated, such as mastitis, there is a diminishing return in the relationship between losses due to disease and costs to prevent/control the disease (McInerney, Howe, and Schepers, 1992). While mastitis is treatable, occurrences are accompanied by direct and indirect costs, including treatment costs, decrease in milk yield, increase in somatic cell count (SCC), and increased risk of removal from the herd or death. From an asset management standpoint, mastitis degrades the earning potential of affected cows as well as the profitability of the entire dairy operation. Therefore, dairy farmers seek to strike an optimal balance between investments into disease management and economic losses due to mastitis.

Reduced milk production is the largest indirect cost associated with mastitis, although the exact amount of the loss is variable within the literature (Bar et al., 2008; Hagnestam, Emanuelson, and Berglund, 2007; Hagnestam-Nielsen and Ostergaard, 2009; Hagnestam-Nielsen et al., 2009; Halasa et al., 2007; Huijps, Lam, and Hogeveen, 2008; Hultgren and Svensson, 2009; Kossaibati and Esslemont, 1997; Ostergaard and Grohn, 1999; Seegers, Fourichon, and Beaudeau, 2003). The National Mastitis Council estimates yield loss to be 70 percent of total mastitis costs (Ott, 1999). Milk loss due to mastitis results in an average milk yield loss per cow of 0-9% in the first lactation and approximately 0-11% in the second lactations and beyond (Heikkila, Nousiainen, and Pyorala, 2012). Regardless of the precision of this estimate, the magnitude of the loss to the industry is staggering. As current milk prices trend lower, the production losses due to mastitis will further stress dairy operators' labor and financial resource constraints.

The objective of this analysis is to calculate milk production loss due to a mastitis event by estimating lactation curve decreases. Reduced milk production is the source of the largest loss due to mastitis. Thus, determining the amount of milk production lost, and its resultant cost value, will allow for a more accurate economic evaluation of mastitis for U.S. dairy producers.

Literature Review

Past research has demonstrated cost and yield loss estimates vary among breeds, herd sizes, and regions. The lactation curve estimation and comparison methodologies and cost assumptions used for these analyses create a wide range of estimates that make cost efficiency recommendations difficult for mastitis management. Mastitis costs are dependent upon the origin of the data, disease classification, and the definition of loss (Hultgren and Svensson, 2009).

Table 1 shows previous studies in milk yield loss and costs due to mastitis. The majority of this research has been conducted in the United States and Western Europe. The studies in the United States were similar in milk loss calculations (Bar et al., 2008; Bartlett et al., 1990), although the European estimates had a higher range of variation. Cost and loss estimates spanned many different breeds of dairy cattle, although a significant relationship between breed and mastitis yield loss was not established.

Many variations of linear regression and simulations were used to calculate yield losses and costs. Estimates from simulations were higher than estimates calculated from other methods (Swinkels, Hogeveen, and Zadoks, 2005; Bar, et al., 2008; Hagnestam-Nielsen and Ostergaard, 2009). Linear regression modeling was the most common approach to calculating milk yield loss (Bartlett et al., 1990; Ostergaard and Grohn, 1999; Hultgren and Svensson, 2009; Hagnestam-Nielsen and Ostergaard, 2009; Hagnestam-Nielsen et al., 2009) as it predicts a larger amount of variation in milk production (Bartlett et al., 1990). Two of the sources of milk yield loss and cost estimates were literary reviews of previous studies of the same topic (Hortet and Seegers, 1998; Seegers, Fourichon, and Beaudeau, 2003).

Farm size has not yet been shown to have an impact on mastitis occurrence and subsequent losses in the literature. The study by Bartlett et al. (1990) contained the largest sample of cows. European herds tend to be smaller, thus fewer cows in fewer herds were analyzed in these studies. Four of the studies used data from research farms (Ostergaard and Grohn, 1999; Hagnestam, Emanuelson, and Berglund, 2007; Hagnestam-Nielsen and Ostergaard, 2009; Hagnestam-Nielsen et al., 2009). While the studies all had sizeable samples, only Bartlett et al. (1990) used a population measure.

Milk loss and cost estimates due to mastitis found in the literature were combined in Table 2. Measurements for milk yield loss due to mastitis were variable throughout the literature, as well as the values of these measurements. Total milk yield loss per lactation ranged from 183.37 kg to 797 kg (Kossaibati & Esslemont, 1997; Seegers, Fourichon, and Beaudeau, 2003; Hagnestam-Nielsen and Ostergaard, 2009). Milk loss due to mastitis is dependent upon lactation cycle, with higher yield losses occurring after the second parity (Hagnestam-Nielsen et al., 2009). First lactation losses ranged from 31 kg to 749 kg (Hultgren and Svensson, 2009) and subsequent lactation losses ranged between 117 kg and 860 kg (Ostergaard and Grohn, 1999; Hultgren and Svensson, 2009). As a percentage of each lactation, losses were 0-9% in the first lactation and 0-12% in the second lactation (Hagnestam, Emanuelson, and Berglund, 2007; Hultgren and Svensson, 2009; Hagnestam-Nielsen et al., 2009; Heikkila, Nousiainen, and Pyorala, 2012). Short-term losses established a variable loss range of 0 kg to 511 kg over a span that varied across studies between 1 day in milk (DIM) and 23 weeks in milk (WIM) (Hortet and Seegers, 1998).

Resultant mastitis costs due to mastitis also varied in measurement as well as value. Per lactation, costs ranged from $138 to $1,169 (Heikkila, Nousiainen, and Pyorala, 2012). There was a wide range in the cost per case of mastitis metric, from $16.43/case to $572.19/case (Hagnestam-Nielsen and Ostergaard, 2009; Swinkels, Hogeveen, and Zadoks, 2005). Costs per cow per year were $71/cow/year (Bar et al., 2008) and $95/cow/year (Hultgren and Svensson, 2009). Cost classifications and calculations were not always consistent across studies, accounting for this wide variation.

In a single lactation, Hagnestam-Nielsen, Emanuelson, and Berglund (2007) determined losses to be greatest earlier in the lactation. In fact, production losses were higher if mastitis occurred in the third week after parity and in later lactations. Over a cow's productive lifespan, Hagnestam-Nielsen et al. (2009) concluded multiparous cows in late lactation could be expected to be responsible for the majority of the herd-level production loss caused by subclinical mastitis. Mastitis risks and subsequent costs were attributed to cow traits and management factors (Bar et al., 2008) as well as factors or events at the lactation level (Hultgren and Svensson, 2009). Additionally, culling costs were estimated to account for 23% of total mastitis costs (Heikkila, Nousiainen, and Pyorala, 2012).

The variability with which mastitis losses have been estimated over the years causes difficulties in comparing loss estimates across studies and communicating research findings to producers. Loss figures for large samples of dairy cows spanning across a population-level number of commercial herds have not been previously observed in the literature (Hortet and Seegers, 1998), although would contribute to reducing the amount of variability found in the mastitis-related yield loss literature.

Methods and Model

Many studies in previous analyses seek to classify and estimate mastitis costs (Blosser, 1979; Kaneene and Hurd, 1990; Schepers and Dijkhuizen, 1991; Kossaibati and Esslemont, 1997; Bar et al., 2008). The methodology in this paper follows that of Kaneene and Hurd (1990), who define the total cost of mastitis as the sum of the money spent on treatment (direct) and lost potential (indirect). For the purposes of this research, direct costs will include veterinary and drug treatments, discarded milk, labor, fatality, and repeated mastitis cases. Indirect costs include decreased milk yield, premium loss and penalty based on fluctuating milk quality, and early culling and replacement costs. The indirect cost of decreased milk yield is the focus of this analysis.

Yield losses in previous analyses were calculated using a variety of methods (Hortet and Seegers, 1998). With/without comparison methods used comparisons of yields of mastitic cows against yields of non-mastitic herdmates. Methods for this approach included direct comparisons, regression models, and comparisons to expected yield curves modeled from samples. After versus before methods directly compare yields of mastitic cows to the yield of the same cow in the previous lactation. Methods for the after versus before approach are using a comparison to an expected yield curve built by the Wood equation (Wood, 1967) and comparing mastitic cows' yield curves to expected yield curves modeled from the sample. The N/N-1 comparison used direct comparison and comparison to an expected yield curve modeled from the sample to evaluate the difference between lactations within each cow.

The model for this analysis uses a direct comparison approach. A general linear regression model is used to predict daily milk production from the monthly test-day milk records at the cow level, which is closely based on Bartlett et al. (1990). Test day milk yield was the dependent variable. Independent variables included SCC as a quadratic function and variables accounting for environmental and seasonal effects to milk production. The model was first run with the actual values of the SCC score to predict the actual milk output:

$$(1) \quad Y_{in} = \propto \, + S_i + \, L_n + \, b_1DIM + \, b_2LNSCC + \, b_3LNSCC^2 + b_4LNSCC^3 + \, \varepsilon_{in}$$

where:

Y_{in} = test day milk yield,

α = intercept,

S_i = effect of location *i* on lactation yield (*i*= WI, NY, IL),

L_n = effect of lactation number on lactation yield (4 classes – L1, L2, L3, L4+),

DIM = continuous variable lactation days in milk (DIM) as of the December 2013 test date,

b_1 = regression coefficient for DIM as of the December 2013 test date,

LNSCC = [natural logarithm of (SCC + 1)]-1.5,

b_2 = regression coefficient for milk yield on LNSCC,

b_3 = regression coefficient for milk yield on LNSCC squared,

b_4 = regression coefficient for milk yield on LNSCC cubed,

e_{in} = residual.

Cows from Wisconsin and in the first lactation were used as the base classes for the states and lactation number. Four lactation categories were included: the first, second, and third, as well as a category for cows in their fourth or greater lactations. DIM represents the stage of lactation at the time of the December test date. The SCC from the AgSource data set was transformed into a level-log function so the LNSCC variable would be approximately balanced around a zero mean to reduce the amount of polynomial correlation between the linear, quadratic, and cubic forms of the transformed LNSCC variable (Bartlett et al., 1990).

The second model was run with an interaction term between SCC and lactation number, as it has been shown that SCC can be impacted by higher levels of production in later lactations (Bartlett et al., 1990; Hagnestam-Nielsen et al., 2009).

$$(2) \quad Y_{in} = \propto + S_i + L_n + b_1 DIM + b_2 LNSCC + b_3 LNSCC^2 + b_4 LNSCC^3 + b_5 LNSCC * S + \varepsilon_{in}$$

where LNSCC*S represents the interaction between SCC and the continuous lactation number value.

Data

The data used in this model contains monthly cow-level test day records from AgSource, one of the four Dairy Records Processing Centers (DRPC) responsible for collecting and computing monthly production records from dairies across the United States.

Generally, the use of monthly test-day observations is not favorable for making predictions about short-term losses and loss estimates when mastitis occurs early in the lactation cycle (Hortet and Seegers, 1998). However, in order to use the maximum amount of cow-level observations to reduce the variability of the estimates, monthly data from the DRPCs was the most feasible way to approach this problem.

Monthly cow-level test day records were obtained using all animals in AgSource's database that completed a lactation in 2013. Of the 11,206,825 test day records from 183 commercial herds in Wisconsin, New York, Illinois, and Michigan, only the December 2013 test period observations were used in this analysis. Furthermore, observations without SCC data were dropped from the analysis, resulting in a total of 38,150 December test day observations used in in the linear regressions.

Individual cow samples from Illinois (1,331) and Michigan (80) were much smaller than Wisconsin (24,660) and New York (20,512). Average herd size was 255 cows per herd. The average cow in this data set had completed 2.28 lactations as of December 2013. Milk production totaled 1,707,042 kg for the data set with an average of 36.83 kg/cow (standard deviation of 11.41 kg/cow) on the December 2013 test date. SCC was measured in units of 1,000 cells/ml in the data with the average lactating cow having a SCC of 191,190 cells/ml (standard deviation of 626,095 cells/ml).

Results

Statistical analysis was performed in STATA (StataCorp, 2011) using a general linear regression method. Table 3 shows the results from both of the models tested as defined in equations (1) and (2), respectively.

In Model 1, the level log interpretation of daily milk loss as of the December 2013 test date is as follows: an increase in LNSCC by 1% will decrease daily milk production by 0.0428 kg/day at a 1% significance level. The quadratic and cubic LNSCC coefficients were positive and significant at the 10% significance level. All remaining regression coefficients in model 1 were significant at the 1% significance level. The literature suggests that the reduced significance from the quadratic and cubic LNSCC coefficients do not significantly contribute to the predictive ability of the model (Bartlett et al., 1990).

Cows in New York produced 2.11 kg/day milk less than cows in Wisconsin while cows in Illinois gave 1.91 kg/day less milk than Wisconsin cows. This suggests regional differences impact milk production. Michigan cows produced 9.5 kg/day less milk than Wisconsin cows. However, with only 80 cows in the sample from Michigan, we need to use caution while extrapolating from this estimate, even though it is statistically significant. Further analysis into geographic factors is needed to more fully explain this phenomenon.

In comparison to first parity heifers, second parity cows produced 5.64 kg/day more milk. Third parity cows and cows in their fourth lactation or beyond gave 7.89 kg/day and 8.16 kg/day more milk than heifers. These results are consistent with Hagnestam-Nielsen et al. (2009), who found that milk production increases with each subsequent parity.

The lactation to date DIM represents a 0.03 kg/loss with each additional day a cow progresses in her lactation cycle. This finding is not concerning. Rather, it is consistent with the diminishing nature of the milk yield curve (Wood, 1967), which begins to flatten after peak yield is reached within the first month after freshening (Grossman, Hartz, and Koops, 1999).

Model 2 included an interaction term for SCC and lactation number to capture the interaction between these two variables. The results from this model were very similar to those of the original model. Predicted losses were slightly lower when the interaction variable was included. All regression coefficients, with the exception of the squared and cubed values of LNSCC, were again significant at the 1% significance level.

An increase in LNSCC by 1% decreased daily milk production by 0.0388 kg/day at the 1% significance level. Significance levels changed for the squared variable (0.0022 kg/day increase in milk given a 1% increase in $LNSCC^2$ at 5% significance level), although following Bartlett et al. (1990), the squared and cubic terms do not add to the predictive ability of the model, so this change is not relevant.

The effects of the states and lactation to date DIM in this model were nearly identical to those of the first model. However, a noticeable change in daily milk yields as impacted by lactation number occurred. In comparison to heifers, second lactation cows produced 6.19 kg/day milk, representing a 0.55 kg/day increase. Third lactation cows produced 1.21 kg/day more milk (9.1 kg/day) in the second model in comparison to heifers, while cows in their fourth and greater lactations produced 2.49 kg/day more milk (10.95 kg/day) than heifers.

The regression coefficient for the interaction term was significant at the 1% significance level. Thus, daily milk yield is impacted by an interaction between SCC and lactation number and these variables do not individually impact yield. Rather, there is a mutual relationship between these two variables that result in a 0.0025 kg/day loss in daily milk yield.

Conclusion

The milk yield loss estimates were lower than those of Bartlett et al. (1990) for both models. The first model predicted a milk yield loss of 0.0428 kg/day for every 1% increase in LNSCC. The second model included an interaction term, which suggested a negative impact to yield based on SCC and lactation number, as well as a 0.0388 kg/day loss for every 1% increase in LNSCC.

A relatively low R^2 value for both models (0.2412 for model 1; 0.2389 for model 2) suggests the explanatory variables in this regression do not adequately explain daily milk production, thus other factors should be taken into consideration when determining effects on milk yield. Additionally, Bartlett et al. (1990) suggests the somewhat discrete nature of the LNSCC variable due to its unit conversion may decrease the overall predictive ability of the model.

The next step in this analysis is to include data from two additional DPRCs to increase the sample size and determine if regional differences exist across the U.S. and how that affects milk yield at a national level. The ultimate goal of this research is to use the value for decreased milk production due to mastitis to create a cost calculation tool that allows U.S. dairy producers to estimate their farm’s economics losses due to mastitis. This tool will provide farmers with information to better evaluate decisions made about the economic feasibility of their disease prevention/control management protocols. The resultant analysis will focus on determining an optimal cost level that justifies the initial treatment, continued treatment, and/or culling of cows with mastitis. It will provide a justification for investment in mastitis prevention measures.

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Table 1. Milk Yield Loss and Costs Due to Mastitis Studies

Study	Year	Location	Methodologies	Breeds	Cows	Herds
Bartlett, et al.	1990	Michigan/US	Difference-in-difference linear regression model	Holstein	480,043*	504
Kossaibati & Esslemont	1997	United Kingdom	DAISY Herd Health Economic Index (HEALEX)	Friesian/Holstein	152**	90
Hortet & Seegers	1998	France	Literature Review	NA***	NA***	NA***
Ostergaard & Grohn[a]	1999	Denmark	Linear regression model	Danish Red, Danish B&W, Danish Jersey, Danish R&W, & crossbreds	2,120	3
Seegers, et al.	2003	United Kingdom	Literature Review	NA***	NA***	NA***
Swinkels, Hogeveen, & Zadoks	2005	Netherlands	Simulation model using partial budgeting	NA****	NA****	NA****
Hagnestam et al.	2007	Sweden	Repeated-measures mixed model	Swedish Red & Swedish Holstein	506	1
Bar, et al.	2008	New York State/US	Custom-constructed optimization and simulation model	Holstein	4,300	5
Hultgren & Svensson	2009	Sweden	Generalized linear mixed model	Swedish Red & Swedish Holstein & Crossbreds	28-94**	122
Hagnestam & Ostergaard	2009	Sweden	Repeated-measures mixed model & simulation	Swedish Red & Swedish Holstein	150	1
Hagnestam-Nielsen et al.	2009	Sweden	Mixed linear model	Swedish Red & Swedish Holstein	497	1
Geary, et al.	2012	Ireland	Budgeting simulation model	NA****	22,879	357
Heikkila, Nousainen, & Pyorala	2012	Finland	Dynamic optimization model	Ayrshire & Holstein	40**	1,749

*Lactation records from March 1985-March 1986

**Average cows/herd

***Missing information due to literature review article

****Unspecified information due to a simulation model

[a] Losses are underestimated because they do not include the loss occurring >5 weeks after diagnosis

Table 2. Milk Loss and Cost Estimates Due to Mastitis

Study	**Year**	**Milk Lost (kg/ lactation)**	**Milk Lost (kg/day)**	**Milk Lost-1st Lactation (kg)**	**Milk Lost-2nd Lactation (kg)**	**Milk Lost (% of 1st Lactation)**	**Milk Lost (% of 2nd Lactation)**	**Cost/ lactation ($)**	**Cost/case of mastitis ($)**	**Cost/cow/ year ($)**
Barlett et al.	1990		1.17							
Kossaibati & Esslemont	1997	183.37-622.64						357.52		
Hortet & Seegers	1998			31-749	155-860					
Ostergaard & Grohn	1999			65	117					
Seegers, et al.	2003	375*						195.08		
Swinkels, Hogeveen, & Zadoks	2005			161	242				16.43	
Hagnestam et al.	2007					0-9%	0-12%			
Bar, et al.[a]	2008			247	348				170.00	71.00
Hultgren & Svensson[b]	2009					0-9%	0-11%	735.00		95.00
Hagnestam & Ostergaard[c]	2009	797**							572.19	
Hagnestam-Nielsen et al.	2009					3-9%	4-18%			
Geary, et al.[d]	2012									
Heikkila, Nousainen, & Pyorala	2012					0-9%	0-11%	138.44-1,169.344****		

*Loss per case of clinical mastitis

**Energy Corrected Milk

***$566.13 average cost/lactation

[a] 64% of mastitis losses due to reduced milk yield

[b] $103/lactation for all cows in the herd

[c] Max avoidable costs: $129.68

[d] 62% loss in profit when bulk tank SCC levels rise from <100K to >400K

Table 3. Ordinary Least Squares Regression Results

	Model 1		Model 2	
Variable	Coefficient (kg/day)	Standard Error	Coefficient (kg/day)	Standard Error
NY	-2.1069***	0.2416	-2.1106***	0.2412
IL	-1.9072***	0.6259	-1.9511***	0.6250
MI	-9.5021***	2.4875	-9.5278***	2.4838
L2	5.6448***	0.2805	6.1942***	0.3017
L3	7.8879***	0.3295	9.0981***	0.4115
L4P	8.1617***	0.3464	10.6468***	0.6142
DIM	-0.0282***	0.0012	-0.0279***	0.0012
LNSCC	-4.2828***	0.7509	-3.8776***	0.7544
LNSCC2	0.1891*	0.2437	0.2207**	0.2434
LNSCC3	0.0189*	0.0233	0.0200*	0.0232
LNSCC*S	--	--	-0.2540***	0.0519
Constant	47.1575***	0.7148	46.5476***	0.7245
R^2	0.2412		0.2389	

Base case is a cow located in Wisconsin in its first lactation

Significance at 1% (***), 5% (**), and 10% (*)