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The cost of clinical mastitis in the first 30 days of lactation: An economic modeling tool

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ABSTRACT

Clinical mastitis results in considerable economic losses for dairy producers and is most commonly diagnosed in early lactation. The objective of this research was to estimate the economic impact of clinical mastitis occurring during the first 30 days of lactation for a representative US dairy. A deterministic partial budget model was created to estimate direct and indirect costs per case of clinical mastitis occurring during the first 30 days of lactation. Model inputs were selected from the available literature, or when none were available, from herd data. The average case of clinical mastitis resulted in a total economic cost of $444, including $128 in direct costs and $316 in indirect costs. Direct costs included diagnostics ($10), therapeutics ($36), non-saleable milk ($25), veterinary service ($4), labor ($21), and death loss ($32). Indirect costs included future milk production loss ($125), premature culling and replacement loss ($182), and future reproductive loss ($9). Accurate decision making regarding mastitis control relies on understanding the economic impacts of clinical mastitis, especially the longer term indirect costs that represent 71% of the total cost per case of mastitis. Future milk production loss represents 28% of total cost, and future culling and replacement loss represents 41% of the total cost of a case of clinical mastitis. In contrast to older estimates, these values represent the current dairy economic climate, including milk price ($0.461/kg), feed price ($0.279/kg DM (dry matter)), and replacement costs ($2,094/head), along with the latest published estimates on the production and culling effects of clinical mastitis. This economic model is designed to be customized for specific dairy producers and their herd characteristics to better aid them in developing mastitis control strategies.

1. Introduction

Clinical mastitis has been identified as the most common cause of morbidity in adult dairy cows in the United States (NAHMS, 2007). Based on surveys conducted in 1996, 2002, and 2007, the percentages of cows with clinical mastitis increased over time. These surveys also indicated the top reasons cows were permanently removed from a herd were udder or mastitis problems and reproductive problems. Additionally, mastitis and calving problems were the top reasons identified for cow mortality. Clinical mastitis results in many negative outcomes for the cow including pain, decreased production, culling, and death. The dairy producer incurs the cost of these negative outcomes through reduced quality and quantity of milk, as well as increased production costs. Intramammary infections may be subclinical infections in which the mammary secretions are not visually abnormal in color or consistency, or they may result in clinical mastitis (CM) in which there are abnormalities detectable in the milk, udder, or animal (Ruegg, 2011). Although subclinical mastitis is more prevalent than clinical mastitis, the economic impact of subclinical infections is more difficult to quantify and predict across herds due to the variability in herd level screening intensity and case definition. There is significantly more published information regarding the impact of CM on health, productivity and culling risk as compared to subclinical mastitis; thus, this study focuses on CM. Lactational incidence of subclinical and clinical mastitis varies greatly between herds, but the probability of acquiring an infection is consistently higher during the early dry period (Bradley and Green, 2004). The apparent incidence of mastitis that develops during the dry period is very low due to the lack of daily observation of the mammary secretions. However, the highest risk period for the detection of CM is in early lactation (Ruegg, 2011), and includes the detection of infections acquired during the dry period, as well as infections that occurred

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in early lactation. Clinical mastitis in the periparturient period can have a great impact on lactation performance, affecting both the mammary gland and the overall health of the cow. The dry period and the early fresh period represent the greatest opportunity for management interventions to improve, or potentially worsen, the health of the udder and its ability to produce quality milk throughout lactation, as a large proportion of cases are observed or may be attributed to this time period (Natzke, 1981).

Clinical mastitis can result in a wide spectrum of negative consequences, and its severity is commonly scored based on the extent of tissue involvement (Ruegg, 2011; Oliveira and Ruegg, 2014). Mild CM (grade 1) describes an infection limited to clinically abnormal milk; moderate CM (grade 2) also includes an abnormal udder in its clinical presentation; and severe CM (grade 3) corresponds to abnormal milk, an abnormal udder, and systemic signs of disease. Cows affected with different severities of CM are likely to suffer different short and long term health and production consequences, receive different treatments (Oliveira and Ruegg, 2014), and therefore have different economic impacts. Clinical mastitis has direct economic effects including diagnostic costs, treatment costs, the cost of non-saleable milk, labor and veterinary costs, and death, but CM also has long term health effects that influence future milk production (Wilson et al., 2004; Schukken et al., 2009), future culling risk (Miliansuazo et al., 1988; Beaudeau et al., 1995; Grohn et al., 1998), and future reproductive efficiency (Santos et al., 2004).

The economic impact of CM is typically much larger than that of many other clinical diseases of dairy cattle, and much work has been done to estimate losses at the cow level, the herd level, and the industry level. Several methods have been used to estimate the economic effects of mastitis, including partial budgeting (Kossaibati and Esslemont, 1997), dynamic optimization programming (Bar et al., 2008), and decision tree analysis (Pinzon-Sanchez et al., 2011). The differences in these methods, along with different inputs used in the models, result in wide ranges in the published estimates of the economic effects of mastitis (Halasa et al., 2007). Most published work has focused on mastitis that occurs throughout lactation, but little has been done to evaluate the specific impact of mastitis occurring within the first 30 days in milk (DIM). Cows that experience early lactation infections have the potential for greater negative impact due to the preponderance of lactational time remaining. Accurate economic analysis of the disease, and more specifically, a good understanding of the corresponding costs as they relate to early lactation mastitis, is important so the dairy producer can make informed decisions pertaining to the prevention and management of CM on the farm.

The purpose of this study was to create an accurate and customizable tool to be used by dairy veterinary consultants to help their clients assess the economic effects of CM during the first 30 days of lactation in order to better guide decision making and management interventions during the transition period.

2. Materials and methods

2.1. Overview

A deterministic partial budget was created using spreadsheet software (Microsoft Excel, Redmond, WA) to estimate the economic impact of CM that is diagnosed within the first 30 DIM. Model inputs (Table 1 and Table 2) were selected from the available literature based on their scientific merit and applicability, or, when none were available, from clinical experience with actual herd data. In some instances, there was considerable variation in the published impact (most commonly risk ratios or odds ratios) associated with CM. In these cases, a blended mean estimate was used to smooth the impact of a very low or very high estimate. When actual herd data were used, the estimates were derived from a convenience sample of dairy herds assimilated by one of the authors (Overton) from U.S herds that were consistent in size and management approach as described in the model. The cows represented by this compilation include over 30,000 animals from average to above average managed herds that utilized DairyComp305 on-farm management software, were primarily free stall housed, fed total mixed rations balanced by a professional nutritionist, and were located in the upper Northeast, Midwest, Northwest, West or Southwest regions of the U.S.

The economic impact per case of CM was divided into direct and indirect costs. Direct costs include diagnostic testing, therapeutics, non-saleable milk, veterinary service, labor, and death loss. Indirect costs include future milk production loss within the remainder of the current lactation, cost associated with premature culling and replacement, and reproductive loss during the current lactation that is attributable to early lactation mastitis.

Model inputs were based on a typical large Holstein dairy herd using modern production practices in the United States of America with 1000 animals calving per year; 38% of the calvings were assumed to be primiparous animals. The milk price of $0.461 per kilogram of milk was a 3-year average of net pay prices received by dairy farmers for their milk, including all payments received for milk sold and all costs associated with marketing the milk (i.e., mailbox prices) from January 2012 to December 2014 as reported by the USDA Agricultural Marketing Service (USDA, 2014).

Within the model, non-saleable milk could either be discarded or used to feed replacement heifers. This non-saleable milk includes milk from cows with CM, cows being treated with therapies that require milk withdrawal, and milk from cows following therapy but before milk is cleared for human consumption and sale. It was assumed that feeding non-saleable milk to calves would allow producers to displace purchased milk replacer powder. Since historical prices for commercial milk replacer are not typically published by any public information source, the authors obtained the historical monthly price of a commercial 28% protein and 15% fat milk replacer from a U.S. national manufacturer and distributor. The 3-year (January 2012 to December 2014) average price on a fluid basis was $0.426 per kilogram (92.3% of the value of milk). While the cost of milk replacer reflects the value of non-saleable milk that is used to displace purchased milk replacer, this value was discounted to 85% of its cost, since not all non-saleable milk is suitable to be fed to calves, and the supply of non-saleable milk may be greater than the need for calves. Based on this substitution approach, non-saleable milk used to feed calves was assumed to have a value of $0.362 per kg of liquid milk. Thus, the economic loss of a kilogram of non-saleable milk was equal to $0.461 minus $0.362, or $0.099 of lost potential value if the milk had been traditionally marketed.

First lactation fresh animals were valued at $2094 per head, based on a 3-year average of reported prices from January 2012 to December of 2014 (Livestock Marketing Information Center, 2014). The value of older animals was calculated based on a curvilinear depreciation model that accounted for lactation-specific culling risk and expected future salvage value and was equal to $1973 per head. Relative to straight line depreciation, where the market value of a cow depreciates a constant amount per year from the beginning value to the ending value, the model depreciates cows slower in the initial years and then faster in the last years (i.e., market value decreases at an increasing rate from beginning value to ending value). Market price for culled animals was $1.84 per kg live weight, which was a 3-year average of reported prices from January 2012 to December of 2014 (USDA, 2014); the income received for an animal sold was adjusted for the risk of condemnation (White and Moore, 2009). Lactational culling risk, including deaths and animals sold, was 25% for first lactation animals (20.5% sold and 4.5% died), and 46% for mature animals (36% sold and 10% died), as derived

Table 1
Deterministic model inputs to estimate the cost of clinical mastitis in the first 30 days of lactation.

	Input			Source[a]
Income	Milk price	$0.461	/kg	USDA (2014)
	Market cow price	$1.845	/kg	USDA (2014)
Reproduction	21-day pregnancy rate (50-day VWP[b])	22	%	Norman et al. (2009); Dairy Metrics (2015)
Non-saleable milk value	Feed calves	$0.362	/kg	Milk replacer manufacturer[c]
	Discarded	$0.00	/kg	
Nutrition	Feed price (lactating cow TMR[d])	$0.279	/kg DM[e] feed	USDA (2014)
	Energy density of feed	1.70	Mcal NE_L[f]/kg DM feed	
	Energy required to produce marginal milk[g]	0.71	Mcal of NE_L/kg milk	National Research Council (2001)
	Marginal milk value	$0.346	/kg	Calculated value

[a] Data entered into the model as inputs may be adjusted or calculated from referenced sources.
[b] VWP = voluntary waiting period.
[c] Non-saleable milk value was calculated from the cost of milk replacer provided by an anonymous milk replacer manufacturer and distributor.
[d] TMR = total mixed ration.
[e] DM = dry matter.
[f] NE_L = net energy for lactation.
[g] Marginal milk = incremental milk resulting from increasing nutrient intake over and above maintenance requirements.

Table 2
Lactation group specific deterministic model inputs to estimate the cost of clinical mastitis in the first 30 days of lactation.

	Input	Overall	Lact = 1	Lact > 1	Source[a]
Calving	% of calvings/year by lactation		38%	62%	Compiled herd data[b]
	# of animals calving per year	1000	380	620	
Culling	Average value of cows in lactation		$2094	$1973	Livestock Marketing Information Center (2014)
	Culling risk over complete lactation	38%	25%	46%	Compiled herd data
	Average body weight (kg)	662	544	735	
	Market value if sold	$1173	$964	$1301	USDA, 2014
Fresh cows	Avg. milk production/cow at 1–30 DIM (kg)	28.3	22.7	31.8	Compiled herd data
Mastitis	Mastitis incidence during first 30 DIM	6%	6%	6%	Wilson et al. (2014)
	Mild mastitis (% of all mastitis)	50%			Oliveira and Ruegg (2014)
	Moderate mastitis (% of all mastitis)	40%			
	Severe mastitis (% of all mastitis)	10%			
	% First cases gram positive	35%			Schukken et al. (2009)
	% First cases gram negative	35%			
	% First cases "other[c]"	30%			
	Recurrence risk (% of cases with 2nd case)	33%	26%	38%	Hertl et al. (2011); Cha et al. (2013)
	Recurrence risk (% of cases with 3rd case)	13%	8%	16%	

[a] Data entered into the model as inputs may be adjusted or calculated from referenced sources.
[b] Compiled herd data estimates were derived from a convenience sample of dairy herds assimilated by one of the authors (Overton) from U.S herds.
[c] "Other" includes included no growth, yeast, *Trueperella pyogenes*, and other organisms.

Table 3
Culling risks[a] across lactation by lactation group to estimate the cost of premature culling and death per case of clinical mastitis.

	Lact 1		Lact > 1	
DIM category	Sold	Died	Sold	Died
1–30	2.6%	3.2%	4.1%	4.0%
31–60	1.7%	1.3%	2.5%	1.3%
61–90	1.6%	0.7%	1.9%	0.9%
91–120	2.4%	0.5%	2.4%	0.7%
121–150	1.2%	0.2%	2.0%	0.8%
151–180	0.9%	0.2%	2.6%	0.5%
181–210	0.9%	0.3%	2.4%	0.5%
211–240	0.8%	0.2%	2.4%	0.4%
241–270	0.8%	0.2%	3.0%	0.1%
271–300	0.8%	0.2%	2.7%	0.3%
301–330	0.9%	0.4%	2.2%	0.2%
>330	5.5%	1.1%	7.9%	0.5%
Overall	20.5%	4.5%	36.0%	10.0%

[a] Risks are presented as cows culled as a percentage of those that calved, and rounded to one decimal point.

from the previously described herd data set. These parity specific overall lactation culling risks were used to model proportion sold and died in 30-day increments across the entire lactation based upon compiled data from herds across the U.S and are presented in Table 3. Animals that died on the farm incurred a $50 cost for disposal. Lactating cows were fed a balanced total mixed ration (TMR) with an energy density of 1.70 Mcal of Net Energy for lactation per kg of dry matter valued at $0.279 per kg of dry matter, based on reported prices of monthly feed costs from January 2012 to December 2014 (USDA, 2014).

Maintenance feed requirements are essentially constant whether a cow has CM in the first 30 days or not; however, total feed required will vary if milk production varies due to the energetic requirements of milk production. The difference between total milk production over the lactation with and without CM in the first 30 days is referred to in this case as marginal milk. Given fat, protein, and lactose levels in the milk of 3.7%, 3.1%, and 4.85%, respectively, the Mcal of Net Energy for lactation per kg of marginal milk is 0.71 (National Research Council, 2001). This energetic feed requirement, along with the previously mentioned feed cost and fluid milk price, result in the value of a marginal kilogram of milk of $0.346. This value is then used to estimate the lost value of milk that is not produced over the remainder of the lactation as a result of CM.

Reproductive performance was described using herd average 21-day pregnancy rate which is defined as the number of cows eligible for pregnancy that actually became pregnant divided by the number of eligible 21-day cycles at risk. The annual average whole herd 21-day pregnancy rate following a 50-day voluntary waiting period was input as 22%. This value reflects the mean of the multi-herd U.S. data set used for the culling estimates as previously described and is below the values presented by Norman et al. (2009), and above the mean value (21%) derived from a data pull with Dairy Metrics (Dairy Metrics, 2015), using data from 2184 herds containing 200 cows or more in all U.S. states. Average milk production in the first 30 days of lactation was 22.7 kg per cow per day for primiparous cows and 31.8 kg per cow per day for multiparous cows.

The incidence risk of clinical mastitis in the first 30 days of lactation was input as 6% for both first lactation animals and for second and greater lactation animals (Wilson et al., 2004). This means that 6% of all cows calving experienced one or more cases of clinical mastitis within the first 30 DIM. While other estimates describe incidence levels within the first 30 DIM that were significantly higher (17% and 15% in housed and pasture-based herds, respectively) (Green et al., 2007), we chose to use the 6% estimate from Wilson et al. due to the corresponding milk loss estimates that were included and due to the closer fit to the herd performance represented by the data set used to estimate culling risks across time. To estimate the long term consequences of CM, the distribution of CM severity and causal organisms was built into the model. Mild CM (grade 1) accounted for 50% of all CM cases, moderate CM (grade 2) accounted for 40%, and severe (grade 3) accounted for the remaining 10% of cases of CM (Oliveira and Ruegg, 2014). Gram positive pathogens accounted for 35% of all cases of clinical mastitis, gram negative pathogens accounted for 35%, and the remaining 30% were grouped as "other causes", which included no growth, yeast, *Trueperella pyogenes*, and other organisms (Schukken et al., 2009). Primiparous animals with a first case of CM had a 26% risk of having another case within the same lactation, and an 8% risk of having a third case (Hertl et al., 2011; Cha et al., 2013). Multiparous animals with a first case of CM had a 38% risk of having another case within the same lactation, and a 16% risk of having a third case (Hertl et al., 2011; Cha et al., 2013). Days to recurrence has been reported to range from 15 to 86 days with a mean time to recurrence of approximately 7 to 8 weeks, and recurrence of CM in this model was input as an interval of 8 weeks between cases (Hertl et al., 2011; Pinzon-Sanchez et al., 2011; Oliveira et al., 2013). Mastitis increased the risk of culling (sold for slaughter) throughout lactation by a factor of 1.8 (Miliansuazo et al., 1988; Beaudeau et al., 1995; Grohn et al., 1998), and increased the risk of death by a factor of 1.2 (Seegers et al., 2003).

2.2. Direct costs

The cost of diagnostics per case was determined by the cost of milk microbiological culture done at a local veterinary clinic; all cases of CM incurred the cost of microbiological culture. The therapeutic cost per case of mastitis was calculated using common treatment protocols for cases of mild, moderate, and severe mastitis, and are described in Table 4. The medications, route of administration, dosage, and number of treatments are not intended to be treatment recommendations but rather to reflect treatment protocols commonly used on large, commercial US dairies (Oliveira and Ruegg, 2014). Mild mastitis cases received only intramammary therapy that resulted in a total of six days of non-saleable milk. Moderate cases of CM received intramammary therapy, an intravenous anti-inflammatory drug, and an oral electrolyte solution; these treatments resulted in six days of non-saleable milk. Severe cases were treated with intramammary antimicrobials, parenteral antimicrobials, an anti-inflammatory drug, intravenous hypertonic saline solution, and one treatment with an oral electrolyte solution. Severe cases of CM incurred a total of seven days of non-saleable milk. Some of the treatments described represent extra-label drug use (ELDU) in the US, and should only be performed following the rules of the US Food and Drug Administration Animal Medicinal Drug Use Clarification Act within the context of a valid veterinary client patient relationship. The cost of milk withdrawal was calculated based on the difference in the values of non-saleable milk and saleable milk which were impacted by the decision made by the farm to either feed or discard the waste milk. The inclusion of the option to feed the waste milk in the model is not intended to be an endorsement of this practice but rather to reflect the management practices in place on many US dairies. According to the NAHMS (2002) report, 87.2% of operations fed non-saleable milk to replacement heifers (NAHMS, 2002). Based on common practice on large conventional dairies in the US and published data (Richert et al., 2013), the cost of veterinary service was only incurred for 30% of the severe cases of mastitis, and included 30 min of professional time at \$130 per hour and a trip fee of \$30. The cost of treatment labor was calculated based on the treatments given, the estimated amount of time required for each, and a cost of labor of \$14 per hour.

The number of deaths that were attributable to CM was calculated using population attributable fraction (AF_p) using the following formula (Dohoo et al., 2003):

$$AF_p = \frac{P_e \times (RR_e - 1)}{1 + P_e \times (RR_e - 1)}$$

where P_e is the incidence of the exposure (incidence of mastitis) and RR_e is the relative risk of death due to that exposure. Since the incidence of mastitis is 6% and the RR of death due to mastitis is 1.2 (Seegers et al., 2003), then the AF_p is equal to 1.19%. For the first lactation group, since the overall risk of death was 4.5% of 380 cows that calved, the number of deaths attributed to CM was 0.20 animals. For the multiparous group, since the overall risk of death was 10% of 620 cows that calved, the number of deaths attributed to CM was 0.73 animals. Cows that died as a result of mastitis incurred a cost of disposal as well as the loss of current estimated value (i.e., market value of lactating cow). This calculation was performed for each lactation group, and the number and cost of deaths attributed to CM were then assigned to all cases of CM to estimate a cost per case.

2.3. Indirect costs

Milk production loss was calculated using the average of two estimates in the literature (Wilson et al., 2004; Schukken et al., 2009). From Schukken's work, the proportion of gram positive, gram negative and other bacteria were used to calculate future losses. The milk loss was calculated by monthly intervals, taking into account the culling risk for each of the monthly periods, as well as the recurrence risk of mastitis from the model inputs. As cows that had mastitis were culled or died, their predicted subsequent milk production losses were removed from the model. The same method was used with the weekly milk production losses reported in the Wilson et al. study, although pathogen prevalence was not considered in those estimations. The estimate of milk production loss was multiplied by the marginal milk value to estimate the cost of the milk production loss by parity group.

Using a relative risk of culling (sold for slaughter) of 1.8 for cows with CM (Miliansuazo et al., 1988; Beaudeau et al., 1995; Grohn et al., 2005), the total number of cows culled throughout lactation attributable to CM that occurred in the first 30 days of lactation was calculated for each parity group using the population attributable fraction equation presented previously. For the first lactation group, using the relative risk above, an incidence of CM of 6%, and a baseline culling risk of 20.4%, the AF_p was equal to 4.58% of culled animals, or 3.55 attributable culled animals. For the multiparous group, using the same inputs and a baseline culling risk of 36%, the AF_p was equal to 4.58% of culled animals, or 10.23 attributable culled animals. This estimate of attributable culls was then multiplied by the difference in the current estimated value (i.e., market value of lactating cow) and the net income received from culling to calculate the cost of premature culling and replacement for all cases. The cost of culling and replacement for all cases

Table 4
Model inputs for therapeutic options for CM by severity score[a] used to estimate the therapeutic cost per case of clinical mastitis.

Severity score	Therapy	Minutes of labor[b]	Days of treatment	Days of withdrawal following treatment	Days of non-saleable milk[c]
1	IMM[d] hetacillin K	10	3	3	6
	IMM ceftiofur HCl	10	3	3	6
2	IV[e] NSAID[f]	15	1	1.5	
	Oral electrolyte solution	15	1	0	
	IMM ceftiofur HCl	10	4	3	7
	SQ[g] ceftiofur HCl	3	4	0	
3	IV NSAID	15	2	1.5	
	IV hypertonic saline	10	1	0	
	Oral electrolyte solution	15	1	0	

[a] Some of the treatments described represent extra-label drug use (ELDU) in the US, and should only be performed following the rules of the US Food and Drug Administration Animal Medicinal Drug Use Clarification Act within the context of a valid veterinary client patient relationship.
[b] Labor is presented as minutes of farm labor required to perform the described treatment for each administration.
[c] Days non-saleable milk reported for therapy with highest sum of treatment and withdrawal.
[d] IMM = intramammary infusion.
[e] IV = intravenous injection.
[f] NSAID = non-steroidal anti-inflammatory drug.
[g] SQ = subcutaneous injection.

was then averaged over the number of cows with CM to determine the cost of culling and replacement per case of CM.

The economic impact of CM in the first 30 days of lactation on reproductive performance was modeled using the assumption that a case of mastitis would lead to a four day delay in time to first service and a 25% reduction in first service conception risk (Santos et al., 2004). These data, as well as the baseline inputs from the model were entered into a spreadsheet based model (Overton, 2009) to estimate the expected impact on 21-day pregnancy rate and profitability. The reproductive model considers annualized replacement costs, the marginal feed consumed by cows producing marginal milk, the change in marginal milk produced based upon a change in expected DIM, feed consumed by additional non-lactating cows, additional costs for housing, labor or medical expenses, and extra costs associated with the change in reproductive management and efficiency. Due to the higher culling risk associated with the occurrence of CM in the first 30 days of lactation, only 39% of affected cows survived the lactation (not sold or died). Those surviving animals incurred the cost associated with a change in reproductive performance, but the total cost for the survivors was averaged over all cases such that all cases diagnosed with a case of mastitis in the first 30 days of lactation incurred a reproductive loss cost. Direct and indirect costs were calculated on an incident case basis for both first lactation and older animals, and then the direct costs, excluding death loss, were adjusted for the cost of recurrence of clinical mastitis for the duration of that lactation. The overall average cost of a case of clinical mastitis for all cows is based on the cost per case for each lactation category, and it is adjusted for the herd parity distribution and the mastitis risk for each lactation category.

In order to show how sensitive the cost of mastitis is to varying economic assumptions, the effect of changing key price and cost variables was performed within the observed ranges of prices (mean +/− one or two standard deviations) within the time period used (January 2012 to December 2014).

3. Results and discussion

Based on the model inputs, the overall cost per case of clinical mastitis during the first 30 days in lactation is presented in Table 5. Direct costs account for only 29% of the total costs of a case when non-saleable milk is used to feed calves, whereas indirect costs account for the remaining 71%. Therapeutic costs, which are often the most visible cost to producers, represent only 8% of the total costs of a case of clinical mastitis in this scenario.

The cost of non-saleable milk is dependent on how the farm utilizes this potential feed. Discarding non-saleable milk results in a total loss of its value. The practice of feeding non-saleable milk to replacement heifers is common in the United States (NAHMS, 2002) and has been shown to be an effective and economical method of raising heifers (Godden et al., 2005). Based on this model in which non-saleable milk is fed to calves, the cost of non-saleable milk due to a case of CM is $25, which represents 5.7% of the total cost per case. If the non-saleable milk is discarded, the cost increases by $92 bringing the total cost per case to $536, and increases the cost of non-saleable milk to 22% of the total cost per case. Based on this, the decision to feed or discard non-saleable milk must be carefully evaluated, taking into account not only its value, but also its availability, nutritional quality, bacterial quality, day-to-day variation in solids level, and the potential for contributing to antimicrobial resistance.

The cost of veterinary service of $4 represents a small amount of the cost (1% of total costs per case) in this example, but this impact may be greater on farms that rely more heavily on veterinarians, where veterinary service is more costly, or on farms with a higher incidence of severe mastitis. Our calculations are in contrast to the economic assessment by Heikkila et al. (2012), in which veterinary service and drugs represented from 24% to 31% of the cost of CM. This difference may be attributed to differences in veterinary labor and drug costs between the United States and Finland, or in the estimations of the other component costs of CM. In our model, if the veterinarian's presence is required on the farm to confirm the diagnosis and perform treatments on the first day with the producer performing the follow up treatment, the cost of veterinary service increases to $106, which represents 19% of the total cost, and brings the total cost per case to $551. If in this same scenario, non-saleable milk is discarded instead of fed to calves, the total cost per case rises to $644.

The economic impact of death represents only 7% of the total cost per case. Even though each death represents a large economic loss, the low incidence of severe mastitis in this model and the relative risk of death help to dilute that loss across all cases of CM. The cost per case is greater for multiparous animals ($40) compared to primiparous animals ($19), because of the higher baseline incidence of death in these animals and an equivalent relative risk of death due to CM.

Future milk production loss is a substantial fraction of the economic impact of CM (28% of total cost per case, or $125). Previous studies that estimate milk production loss as a consequence of CM have a wide range of estimates, especially as they estimate pro-

Table 5
Breakdown of estimated cost per case of clinical mastitis in the first 30 days of lactation.[a]

		Lact = 1	Lact > 1	Overall	
		Cost per incident case	Cost per incident case	Cost per incident case	% of total cost
Direct costs	Diagnostics	$9	$11	$10	2.3
	Therapeutics	$30	$40	$36	8.1
	Non-saleable milk	$18	$30	$25	5.7
	Veterinary service	$4	$4	$4	0.9
	Labor	$19	$22	$21	4.7
	Death loss	$19	$40	$32	7.2
	Direct cost/case	$100	$146	$128	28.9
Indirect costs	Future milk production loss	$149	$111	$125	28.2
	Premature culling loss	$176	$185	$182	40.9
	Future repro. loss	$9	$9	$9	2.0
	Indirect cost per case	$333	$305	$316	71.1
Average cost per case				$444	

[a] Results are rounded to the nearest whole US dollar.

Table 6
Sensitivity analysis of cost per incident case of CM for key economic variables.[a]

Baseline cost per case of clinical mastitis[b]	Mean	Std dev	$444 Impact of + 1 std dev change
Milk price, $/kg	$0.461	$0.061	+$39.22
Non-saleable milk, $/kg	$0.362	$0.025	−$6.40
Feed price, $/kg	$0.279	$0.032	−$4.85
Value of lactation 1 cows	$2094	$426	+$95.65
Market cow price, $/kg	$1.845	$0.301	−$45.52

[a] Other major model inputs include parity breakdown (38% primiparous, 62% multiparous), 21-day pregnancy rate (22%), culling risk (25% for primiparous, 46% for multiparous), body weight (544 kg for primiparous, 735 kg for multiparous), average milk production in the first 30 DIM (22.7 kg for primiparous, 31.8 kg for multiparous), clinical mastitis incidence in the first 30 DIM (6% for primiparous, 6% for multiparous), clinical mastitis severity breakdown (50% mild, 40% moderate, 10% severe), recurrence risk for a second case of CM during the lactation (26% for primiparous, 38% for multiparous), recurrence risk for a third case of CM during the lactation (8% for primiparous, 16% for multiparous).
[b] Based on non-saleable milk being fed to calves. If milk is discarded cost is $536 per case.

duction loss several months after the clinical episode. This range in estimates can be partly attributed to the control group to which mastitic cows are compared. In the Wilson et al. (2004) estimation, cows diagnosed with mastitis were higher producing cows before the clinical episode, and the authors compared production after clinical mastitis to a predicted lactation curve for those higher producing cows, not an average lactation curve for cows not affected by CM. Taking this into account approximately doubles their estimate of milk loss. In the Schukken et al. (2009), the milk production effects of clinical mastitis were stratified by pathogen groups, which allows for more accurate modeling to match herd pathogen prevalence. In this study, we used a blended estimation of milk loss based on the two cited studies. Another item to consider is the timing of the clinical mastitis episode. Most studies consider any case of mastitis during lactation for inclusion. Wilson's study estimated a median onset of clinical mastitis of 22 DIM for first lactation animals and of 81 DIM for second-plus lactation animals. Our study focused on clinical mastitis in the first 30 DIM, a time when mastitis may have a greater impact on the future milk production over the rest of the lactation (Hagnestam-Nielsen and Ostergaard, 2009). Better estimations of long term milk production loss for CM that occurs during the first 30 DIM would strengthen the milk loss estimates in our model.

Because milk production is the main driver for an individual cow's profitability, and mastitis can have such a large impact on production, mastitis is one of the leading reasons for culling by dairy producers (NAHMS, 2002, 2007). Culling due to mastitis can occur at various times within the lactation based upon the other associated reasons for removal. For example, a cow that is in early lactation and significantly fails to regain her expected level of milk production is more likely to be culled earlier and closer to the early lactation mastitis event. Other cows that regain varying portions of their projected level of milk production may be culled in mid to late lactation after a subsequent case of mastitis or other disease issue. In this situation, the reduction in milk production due to the early mastitis contributes to, but may not intrinsically necessitate the culling of the cow. Other cows may be culled later due to a failure to become pregnant that was at least partially attributed to early lactation reproductive challenges associated with mastitis. Using the relative risk of culling due to CM and the attributable fraction allows us to estimate the cost of incremental culling and replacement that is due to exposure to a CM event. This model reveals that the cost of premature culling and replacement represents the greatest cost of all categories examined (41% of total costs, or $182). This finding agrees with the report by Down et al. (2013) which found that "the most influential financial input was the cost of a cull".

The cost of reduced reproductive efficiency ($9) due to CM represents a small cost relative to other indirect costs. Mastitis may have several potential effects on reproductive efficiency, including direct effects of mastitis-associated inflammation, as well as effects on feed intake and energy balance. Effects of systemic inflammation, including that related to CM, have been implicated in the abnormal function of the corpus luteum (Santos et al., 2004), but this may not have clinically observable effects when CM occurs very early in lactation, when the likelihood of cows having a corpus luteum is low. Clinical mastitis in the first 30 DIM is more likely to exert its negative impact on reproduction via a negative impact on feed intake and energy balance, which has a direct effect on the interval to first ovulation (Walsh et al., 2007). However, the distribution of CM severity, the delay between a case of CM that occurs before 30 DIM and the first breeding, as well as hormonal interventions to stimulate cyclicity may negate some of those effects on cyclicity and risk of conception, resulting in a relatively small effect as described by Santos et al. (2004).

The incidence of CM in the first 30 DIM and the cost per case of CM can vary greatly between herds or management systems. This

Table 7
Sensitivity analysis. Cost per incident case of CM by replacement cost and milk price.[a]

	Replacement heifer cost, $/head	Milk price, $/kg				
		$0.34	$0.40	$0.46	$0.52	$0.58
Feed non-saleable milk[b]	$1668	$276	$309	$348	$388	$427
	$2094	$371	$405	$444	$483	$522
	$2520	$467	$500	$540	$579	$618
Discard non-saleable milk[c]	$1668	$362	$402	$441	$480	$519
	$2094	$458	$497	$536	$576	$615
	$2520	$554	$593	$632	$671	$711

[a] Other major model inputs include parity breakdown (38% primiparous, 62% multiparous), market cow price ($1.845/kg), 21-day pregnancy rate (22%), marginal milk value ($0.342/kg), culling risk (25% for primiparous, 46% for multiparous), body weight (544 kg for primiparous, 735 kg for multiparous), average milk production in the first 30 DIM (22.7 kg for primiparous, 31.8 kg for multiparous), clinical mastitis incidence in the first 30 DIM (6% for primiparous, 6% for multiparous), clinical mastitis severity breakdown (50% mild, 40% moderate, 10% severe), recurrence risk for a second case of CM during the lactation (26% for primiparous, 38% for multiparous), recurrence risk for a third case of CM during the lactation (8% for primiparous, 16% for multiparous).
[b] Non-saleable milk fed to calves has a value of 85% of milk replacer price ($0.426).
[c] Discarded non-saleable milk has a value of $0.000/kg.

analysis was based on an incidence of CM, culling risk, and management protocols representative of a typical large dairy herd in the U.S. and used a published RR describing the relationship between mastitis and culling. More importantly, the analysis was based on the interrelationships of these factors to estimate attributable cases. If the herd incidence of CM is changed, but culling risk is not, all costs per case remain the same other than small changes in death loss and culling and replacement loss. For example, if we hold all other inputs the same, but increase CM incidence from 6% to 12%, then the cost per case decreases from $444 to $438. On the other hand, if CM incidence is changed and culling risk is simultaneously changed such that RR and proportion of attributable cases remain constant, the cost per case for all the direct and indirect costs of mastitis remains the same. When economic models are used to evaluate the effect of management changes, one must be cognizant of the relationships between inputs. The economic tool based on this model considers this relationship and modifies the herd culling risk as the CM incidence changes so that the cost per case for all the direct and indirect costs are not a function of incidence of CM.

In order to show the effects of variation in some of the most influential and volatile model inputs, sensitivity analyses are presented in Tables 6 and 7. Table 6 shows the impact of a one standard deviation change of key economic variables on the cost per incident case of CM. Table 7 shows the cost per case of CM for all lactation groups at various milk prices (mean +/− two standard deviations) and replacement heifer costs (mean +/− one standard deviation) for a herd that uses non-saleable milk for calf feed, as well as for a herd that discards non-saleable milk. The remainder of the inputs for this analysis are as described in Tables 1 and 2. From Table 6 it can be seen that the price of replacement cows has the largest impact on the cost of a case of CM where one standard deviation increase ($426) increases costs $95.65 per case. The second largest impact is the price of cull cows, where a one standard deviation increase in price ($0.30/kg) decreases the cost per case of CM by $45.52. An increase in the price of milk of one standard deviation ($0.06/kg) increases the cost per case of CM by $39.22. Table 7 shows the costs per case of CM over a range of milk and replacement cow prices when waste milk is either fed or discarded. Discarding non-saleable milk results in an increase of $92 across the milk prices and replacement heifer costs examined.

One facet of the epidemiology of CM in dairy herds that is not considered in this model is the risk of transmission of contagious pathogens to herdmates (Down et al., 2013). While this can be a concern, the authors feel that transmission of pathogens is highly dependent on the individual herd's mastitis control strategies. In this model, it is assumed that the common practice of segregating or culling animals with contagious mastitis organisms is performed to reduce the risk of transmission. It has also been reported that in large herds in the United States, the proportion of CM caused by contagious organisms is much lower than that in smaller herds or in decades past (Oliveira et al., 2013).

This model represents an average case of CM in a hypothetical herd and uses deterministic model inputs. As more data become available to provide a better understanding of the true distribution of key inputs, a stochastic approach to this model may provide more information on the variation surrounding each of the components and the total cost of CM in the first 30 days of lactation. However, for the major drivers of the cost of CM, currently there are insufficient data available to completely and accurately estimate the precise variation of effects of a case of CM.

4. Conclusions

This study examined the cost of clinical mastitis during the first 30 days in milk by using recent estimates of its effects, and reflects current market conditions and management practices in the United States. The findings show that a majority of the costs associated with clinical mastitis in the first part of lactation are indirect costs that occur over the remainder of that lactation. There is a large opportunity to mitigate these costs by managing udder health during the transition period to prevent clinical mastitis. Based on the results of this work, and using the assumption that non-saleable milk was fed to calves and using minimal veterinary involvement in treatment, the cost of each incident case of clinical mastitis that occurs during the first 30 days of lactation was estimated to be $444. The majority of this cost (71%) is comprised of indirect costs that are more difficult for producers to "see" because they do not require a direct cash outlay (e.g., future milk production, premature culling and replacement, and reproductive losses). However, these indirect costs reflect lost opportunity and impact the economic viability of the dairy and thus it is important for producers to recognize these costs.

This method of cost estimation is highly adaptable to individual farms and allows for evaluation of specific management interventions. The concepts described and discussed in this modelling project help to improve our understanding of the full economic impact of early lactation mastitis. The model inputs can be customized to specific situations and updated to current economic conditions. The model structure also allows for future adjustment of the effects of mastitis as more data become available. However, since most of the references cited and all of the herd data and major inputs used were from built from a US production perspective, caution must be exercised when using this or any model in situations where actual data inputs vary considerably from those used in the assumptions for model construction.

Conflict of interest

Two of the authors (K.C. Dhuyvetter and M.W. Overton) are employees of Elanco Animal Health, which owns the rights to the economic model.

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