Direct Production Losses and Treatment Costs due to Four Dairy Cattle Diseases

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Take Home Message

- The direct production losses and treatment costs at the herd level were
  - $2,421 for bovine viral diarrhea (BVD),
  - $806 for enzootic bovine leucosis (EBL),
  - $2,472 for Johne's Disease (JD), and
  - $2,304 for neosporosis in the Maritime provinces of Canada.
- Total costs at the industry level were $1,264,355, $641,061, $842,042, and $1,909,794 for BVD, EBL, JD, and neosporosis, respectively.
- The distributions for all diseases were positively skewed, implying that the average costs reported above were higher than what most farmers experienced.
- The largest effect on costs was due to milk yield effects.

Introduction

Bovine viral diarrhea (BVD), enzootic bovine leucosis (EBL), Johne's Disease (JD), and neosporosis are contagious diseases found on many dairy farms in Canada and elsewhere. These diseases are presumed to impose large direct and indirect productivity losses on affected farms. The production losses are mainly from reduced milk production due to mortality, weight loss, abortion, and growth retardation. BVD, for example, can have a large negative impact on milk production of the infected dairy herds, especially, with an epidemic of the disease. Mortality from BVD, although low in the industry as a whole, can also have devastating effects on infected farms.

A limited number of studies have investigated the economic effects of dairy diseases due to the lack of solid economic and epidemiological data together. Ott *et al*. (1999) estimated herd-level losses associated with JD on US dairy operations. They calculated the value of production on a per cow basis for each of the farms in a national survey. This net return was then regressed against a number of explanatory variables such as herd size, farm location, and herd classification of JD. The returns were almost US$ 100 ($150 Canadian) per cow less in JD-positive herds. When averaged across all herds, JD costs the US dairy industry an average of $25 ($37.50 Canadian) per cow which is similar to the few other studies on JD (i.e. Abbas *et al*. 1993 and Benedictus *et al*. 1987). The regression approach provides useful information on the relative costs of JD but is limited when indicating the extent of the costs to individual herds in varying circumstances. Bennett *et al*. (1999) developed a spreadsheet model that can provide herd-level information on the production losses, plus the treatment costs, from endemic JD and BVD-Mucosal disease (MD) in dairy cattle. The spreadsheet model provides a transparent and standardized approach for calculating the economic effects and also provides a means of comparative assessment across factors such as diseases or region. The results of the model showed that average costs of JD and BVD-MD to the dairy industry in the mainland UK were £2.6 million ($6 million Canadian) and £18.1 million ($41.9 million Canadian) respectively or US$0.47 ($.71 Canadian) and US$1.72 ($2.58 Canadian) per cow respectively. While this model serves as a solid base for the analysis, several adjustments could improve the cost estimates. For example, abortion and reproductive losses of JD could include costs of increased days open. In addition, Bennett *et al*. (1999) incorporated uncertainties on the incidence of disease, using a range of low and high values for disease parameters. Understanding the probability distribution of costs at the herd and regional level provides useful information on the likelihood of costs. In addition, there have been no studies to examine the costs of EBL and neosporosis.

The purpose of this study was to determine current economic costs of four production limiting diseases (BVD, EBL, JD, and neosporosis) in the Maritime dairy industry and the range of possible costs when considering uncertainty. The spreadsheet model in the current study presents costs of seven components of direct production losses and treatment costs at the herd level. The costs were aggregated to a regional level on the basis of the number of herds and proportion of herds infected. The model can be used to estimate costs for other herds and regions with necessary data on variables such as prevalence of infection and size of population at risk, physical effects of the diseases, and values for output losses and inputs used. A probability distribution of the costs was determined, given the stochastic nature of disease prevalence. In addition, a sensitivity analysis is conducted to assess the relative importance of disease parameter values on total disease costs.

▪ Methods and Data

Partial Budget Model

The *ex post* losses (direct loss and treatment cost) of the disease at the regional level were assessed using a partial budget model adapted from a spreadsheet suggested by Bennett *et al*. (1999). The framework for this model (outlined in Table 1) consists of three main sections. The first contains information on dairy farm characteristics such as the size of the population at risk, the prevalence of disease infection, and prices for milk and cattle. The second calculates the direct losses of the diseases associated with milk loss, premature culling and reduced slaughter value, mortality loss, and abortion and reproductive loss. The third section estimates the costs of treatment measures that were undertaken. The components of each section are described in more detail below.

Table 1. Spreadsheet model to estimate cost of a generic disease in dairy cattle ($/animal)

Dairy Farms Characteristics (Notation)	Value or Calculations (Source)
Total cattle population in Maritimes (*N*)	88,000 (DFC, 2000)
Total number of herds (*H*)	1,135 (DFC, 2000)
Average cattle population in herd (*n*)	N/H = 50
Milk yield – litres/cow/yr (*y*)	8,200
Milk price - $/litre ($p_y$)	0.55
Replacement cost of cow - $/head (*r*)	$2,500
Slaughter value of healthy cattle - $/head (*s*)	$800
Value of calf - $/head (*c*)	$400
Value of heifer - $/head *(h)*	$1,400
Cost of Vet Visit - $ (*v*)	$60
Cost of medication - $/case (*m*)	$18.26 (NMC, 1991)
Cost of Extra Labour with Disease - $/head (*l*)	$3.15 (NMC, 1991; Miller *et al*, 1993)
Value of days open loss - $/day (*d*)	$5.25 (Kirk, 1999)
Prevalence of infection in an infected herd (d_i)	See Table 2
Proportion of herd infected (r_d)	See Table 2

Direct Losses (L)	
1. Milk Yield	
Reduced milk yield - % (y_L^d)	See Table 2
Milk loss - $	$= n \times d_i \times y \times p_y \times y_L^d$
2. Premature Voluntary Culling/Reduced Slaughter Value	
Culling rate of infected cattle- % (c_L^d)	See Table 2
Reduced slaughter rate in infected cattle - % (s_L^d)	See Table 2
Premature culling cost - $	$= n\times d_i \times c_L^d \times [r - s\times(1- s_L^d)]$
3. Mortality	
Mortality rate in infected cattle - % (m_L^d)	See Table 2
Mortality loss for BVD - $	$= n\times d_i \times 0.5\times(c + h)\times(1.2 \times m_L^d)$ $+ n\times d_i \times r \times m_L^d$
Mortality loss for the other 3 diseases - $	$= n \times d_i \times r \times m_L^d$
4. Abortion and Reproductive Loss	
Abortion rate in infected cattle - % (a_L^d)	See Table 2
Loss in Milk Yield from Abortion - % (y_L^a)	See Table 2
Value of reproductive loss - $/herd ($a$)	$= y\times p_y\times y_L^a + c$
Abortion & reproductive loss for JD - $	$= n\times d_i \times(a_L^d\times a + 28\times d)$
Abortion & reproductive loss for the other 3 diseases- $	$= (a_L^d\times n\times d_i)\times a$
Total Direct Loss (L)	*= Milk loss+ Mortality loss+ Premature culling + Abortion loss*
Treatment Cost (T)	
1. Veterinary Services	$= n \times d_i \times(a_L^d + m_L^d)\times v$
2. Medication Cost	$= n \times d_i \times 2\times(a_L^d + m_L^d)\times m$
3. Extra labor cost	$= n \times d_i \times 2\times(a_L^d + m_L^d)\times l$
Total Treatment Cost (T)	*= Vet cost + Treatment + Extra labor*
Herd Level Ex Post Costs (C_H)	$= L + T$
Regional Level Ex Post Costs (C_R)	$= H \times C_H \times r_d$

Farm Characteristics. In the first section of Table 1, the total number of cows (N=88,000) and farms (H=1,135) indicates the potential size of the population that could be affected. These estimates were collected from Dairy Farmers of Canada (1999). Average cattle population in a herd (n=50) was calculated as the total number of dairy cows on the Atlantic Dairy Livestock Improvement Corporation (ADLIC) divided by total number of herds enrolled in the ADLIC in 1997. Estimates of milk yield (y=8,200 litres) per cow per 305 day lactation, milk price (p_y=$0.55/litre), replacement cost of a cow (r=$2,500), average slaughter value (s=$800), heifer value (h=$1,400) and newborn calf value (c=$400) are representative values for the Maritimes, based on the ADLIC annual summaries and personal communication with industry personnel.

Information on infection prevalence was obtained from VanLeeuwen *et al*. (2001). Using a stratified 2-stage random sampling, 90 herds were randomly chosen from all herds enrolled in a monthly milk recording program provided by ADLIC, with 30 from each of the provinces of New Brunswick, Nova Scotia, and Prince Edward Island. Blood samples were collected on each surveyed farm from 30 randomly selected cows. VanLeeuwen *et al.* (2001) found that 20.8, 2.6 and 20.3% of a random sample of dairy cattle in the Maritime provinces had positive tests for infection with the agents causing enzootic bovine leukosis (IDEXX ELISA, Idexx Laboratories, Westbrook, Maine, USA - sensitivity 98.5%, specificity 99.9% S/P ratio≥0.50) (Johnson and Kaneene, 1991), Johne's Disease (IDEXX ELISA - sensitivity 43%, specificity 99.2% S/P ratio≥0.25) (Sockett *et al*., 1992), and neosporosis (Biovet ELISA – sensitivity 99%, specificity 98.4% S/P ratio≥0.60) (Bergeron *et al*., in press), respectively.

Testing for BVD employed a different sampling strategy because vaccination against BVD was commonplace. In unvaccinated (for BVD) herds, 5 animals that were part of the 30 cows collected for the other diseases were selected. In vaccinated herds, 5 unvaccinated heifers over six months of age, so that maternal antibodies were no longer present, were selected. This sampling technique was based on Houe's studies (1992, 1995), that reported excellent sensitivity and specificity for detecting herds infected with BVD using 5 unvaccinated animals. The animal level prevalence of infection with BVD in the Maritime study was 28%, a crude estimate of BVD prevalence because of the small number of animals tested.

The average values for the proportion of the herds infected (r_d) and the average prevalence of infection within an infected herd are listed in the first two rows of Table 2.

Table 2. Assumptions on disease incidence and effects.

	BVD	EBL	JD	Neo-sporosis
Proportion of herds infected (r_d)	0.46	0.7	0.30	0.73
Prevalence of infection in an infected herd (d_i)	0.67[a]	0.31	0.07	0.24
Loss of milk yield in infected cattle (y_L^d)	0 %	0 %	15 %[b]	0 %
Culling rate of infected cattle (c_L^d)	1.8%	0 %	20 %	2 %
Reduced slaughter value (s_L^d)	0 %	0 %	25 %	0 %
Mortality rate in infected cattle (m_L^d)	0.78%	2 %	3 %	0 %
Loss of milk yield from abortion (y_L^a)	28 %	28 %	28 %	28 %
Abortion rate in infected cattle (a_L^d)	1.05%	0 %	0 %	10 %

a. This is the average within herd infection prevalence in unvaccinated animals in the herd based on recent infection with titres ≥ 1:64

b. Only applicable to JD-infected cows in their 5th lactation or greater (15% of herd)

Direct Losses. The second section in Table 1 on direct losses consists of four parts based on losses due to: 1) lower milk production; 2) premature culling and reduced slaughter value; 3) mortality; and 4) abortions or reductions in reproductive performance. Direct losses with each component vary depending on the biological characteristics of the disease. Neosporosis, for example, is primarily vertically transmitted from an infected cow to its fetus in utero, causing higher abortion rates in infected cows than in uninfected cows. In contrast, EBL is primarily horizontally transmitted by blood and it is not directly associated with abortion losses. The means of determining the four components of direct losses are discussed below.

1. Milk Yield Average annual productivity level per cow (y) and milk price (p_y) were multiplied together along with herd size (n) to get milk revenue per farm. The potential milk revenue reduction on infected farms was found by multiplying this total herd revenue ($y \times p_y \times n$) by the prevalence of infection within the infected herd (d_i) and the percentage reduction in milk production from infection with disease d (y_L^d), listed in Table 2.

Several studies have investigated production loss due to dairy diseases (y_L^d). Bennett *et al*. (1999) attempted to measure milk loss due to a BVD outbreak in the United Kingdom and estimated that milk yield dropped by 30% in affected dairy cows over a 3 week period. This loss would only apply to unvaccinated cows in infected herds, based on the assumption that proper vaccination gives protection against disease. Also, in endemic herds, a large majority of cows will become immune due to infection prior to their first lactation, and therefore likely less than 5% of cows in any given year will become infected as cows and thus suffer any short term milk production losses directly from clinical disease, such as pneumonia or diarrhea (Houe *et al*., 1995). However, VanLeeuwen and Keefe (2001) found that there was no effect of subclinical infection with BVD on milk production at the herd level in Maritimes dairy herds (based on the endemicity of infection in infected herds, and the common use of BVD vaccine) and therefore a 0% reduction (y_L^{BVD}=0) in milk production was used in the current study.

VanLeeuwen *et al*. (2000) determined that there was no significant negative effect on 305 day milk yield by infection with the agents causing EBL when lactation and linear score somatic cell count were controlled. Therefore, a 0% reduction in milk production due to infection with EBL (y_L^{EBL}=0) was assumed for the current study.

For JD, Benedictus *et al*. (1987) investigated the decrease in milk production for culled animals showing clinical signs of *paratuberculosis*. According to their results, milk production fell by 19.5% for the lactation in the year of culling, compared with the lactation 2 years before culling, and by 5% for the last lactation, compared with the previous lactation. For animals without clinical *paratuberculosis*, these decreases were 16% and 6%, respectively. Another study (Abbas *et al*., 1983) reported that cows subclinically infected with JD produced 15% less milk than culture-negative cows in three California dairy herds. In contrast to these previous studies where JD infection pressure was higher, VanLeeuwen *et al*. (2000) found that for all lactations JD infection, based on the IDEXX ELISA, was not significantly associated with 305 day milk production in the Maritimes. Only positive cows in the 5th lactation or greater showed significant negative milk production of approximately 15% (1200 pounds). This reduction in milk loss ($y_L^{JD}=0.15$) only applied to the positive cows in the 5th lactation or greater so the prevalence for JD of 0.07 was multiplied by the proportion of animals in this older age cohort which was assumed to be 15%. Thus, the effective prevalence of JD infection within a herd was assumed equal to 0.011 (= 0.07*0.15).

For neosporosis, *N. caninum* seropositive cows have been shown to produce an average of 2.5 lbs/cow per day or 760 lbs of milk per lactation less than seronegative cows in one herd (Hietala and Thurmond, 1997). Although the study was limited to first lactation dairy cows in one herd, the results showed a significant milk loss associated with neosporosis infection. Keefe and VanLeeuwen (2000) compared milk production of neospora positive cows with that of seronegative cows in 3 lactation categories. Surprisingly, seropositive cows produced marginally more milk than seronegative cows in all of the 3 categories. Seropositive cows projected 7,318, 8,244, and 8,848kg of 305-day milk production in the 1st, 2nd, and 3rd or more lactations, respectively while seronegative cows projected 7,165, 8,034, and 8,504kg, respectively. They concluded no impact of infection with *Neospora caninum* on milk production. The level of abortion and its associated disease problems cannot be compared between these two studies due to lack of data, but may explain the difference in findings. For the current study, it was assumed that infection with neosporosis had no effect on milk yield ($y_L^{neosporosis}$=0) in the Maritimes.

2. Premature Voluntary Culling and Reduced Slaughter Value One of the components of the direct loss calculation was premature voluntary culling, which may include reduced slaughter values. The potential number of affected cows in a herd was again found by multiplying cow numbers (n) by the prevalence of infection for each disease in the herd (d_i). Of those cows with the infection, a percentage will be culled before normal replacement (c_L^d). The dollar value associated with premature culling was measured by multiplying the number of affected animals culled prematurely ($n \times d_i \times c_L^d$) by the cost of a premature cull, which was the replacement cost less the slaughter value (r–s). The slaughter value can be reduced by a percentage, denoted by s_L^d due to disease factors that lower body weight. Thus, the opportunity cost of replacement due to premature culling was ($r - s \times (1 - s_L^d)$). Note that in extreme cases (e.g. lymphosarcoma in BLV positive cows), there would be a complete reduction in the slaughter value ($s_L^d = 1$) so the cull value would be zero and the cost of a premature cull would be the value of a healthy replacement.

Culling rate - Several studies have determined cull rates caused by these production limiting diseases (c_L^d). Using these findings of Pritchard et al. (1989), David et al. (1994), Cortese et al. (1998) and Bennett et al. (1999), a premature culling rate of 2% was used for BVD endemic herds and 8% for BVD epidemic herds. Because over 90% of infected herds in this study were likely endemic (no mention of an outbreak at the time of sampling) and 40% of infected herds were considered to be effectively protected against BVD (using proper vaccination protocol for their cows and heifers over 6 months of age), a premature voluntary culling rate per year was calculated by summing the effects on the remaining 60% in unvaccinated infected herds having epidemic (0.1×8%) and endemic (0.5×2%) BVD. Therefore, a 1.8% premature culling rate per year was assumed for animals infected with BVD in the current study.

There were no previous studies to base premature voluntary culling rate estimates for cows infected with EBL. It was assumed that this rate was relatively low because there did not seem to be any milk production impact among seropositive cows for BLV (3). Therefore, 0% of infected cows were assumed prematurely culled annually.

For JD, a recent study (Goodell et al., 2000) reported differences in culling risk between seropositive and seronegative cows one year later. The difference in culling risk between seropositive and seronegative animals was approximately 20% (50%-30%). Therefore, the current study had a 20% per year culling rate (c_L^{JD}) for seropositive cows.

Thurmond and Hietala (1996) estimated culling risk for *N. caninum* infection in 442 Holstein cows in a commercial dairy herd in California. In their study, 35.8% of seropositive animals and 30.6% of seronegative animals were culled after 3 years (1991-1993) of their first calving, while 13.8% of seropositive cows and 4.3% of seronegative cows that aborted more than one time were culled. Because we did not have data on abortions, the first comparison was utilized in the current study. There was a difference in culling of 5.2% (35.8%-30.6%) between seropositive and seronegative cows over the three years. Thus, the current study assumed a 2% premature voluntary culling rate ($c_L^{neosporosis}$) per year for cows infected with neosporosis.

Reduced Slaughter Value - Benedictus *et al*. (1987) found that slaughter value of JD infected cows was 30% lower than normal slaughter value and day value of infected cows was 20% lower than normal day value. Another study (Johnson-Ifearulundu *et al*., 1999) found that a 10 percent increase in proportion of cows positive for paratuberculosis was associated with a 33.4 kg decrease in mean weight of culled cows in 121 dairy herds of Michigan. Using these previous studies, a 25% decrease in slaughter value (s_L^{JD}) for a cow affected with JD was adopted in the current study. Due to lack of data to support an effect on slaughter value, 0% of a reduction for BVD, EBL, and neosporosis was assumed.

3. *Mortality* Another component affecting direct cost is death loss. The value of the herd that could be affected by death through a disease was found by multiplying together individual cow value (r) by the average herd size (n) and the prevalence of infection within a positive herd (d_i). Cow value was set equal to the cost of replacement because no carcass value was assumed with dead animals from any of the four diseases (Nix, 1996). The mortality losses within a herd were calculated by multiplying the value of the herd that could be affected by death ($r \times n \times d_i$) by the mortality rate in infected animals (m_L^d) per year.

David *et al*. (1994) found that the average mortality from BVD across three sample herds in severe epidemic outbreaks of acute clinical cases was 5%. Bennett *et al*. (1999), in determining the impacts of BVD in the United Kingdom, used 0.5% and 10% estimates for low and high mortality of adult dairy cows, respectively. However, these estimates were from previously unvaccinated herds experiencing an epidemic of BVD. Therefore, the mean value of 5.25% [i.e. 0.5×(0.5+10)] was applied for epidemic infected herds in the current study.

In herds unvaccinated for BVD, experiencing an endemic occurrence of BVD, the mortality for BVD infected cows was assumed to be 0.5% due to the low level incidence in endemic herds through herd immunity from natural exposure, as explained earlier. A 0% mortality was used for properly vaccinated herds as supported by a recent paper by Ellis *et al*. (2001) that showed only mild or no disease in properly vaccinated cattle that did not have blocking maternal antibodies. Given the 0% mortality for infected cows in the 40% of infected herds that were properly vaccinated, the 5.25% mortality rate for the 10% of infected herds (unvaccinated) experiencing epidemics, and the 0.5% mortality rate for the remaining 50% of herds that were infected (unvaccinated) experiencing endemics, the adopted annual mortality rate for BVD infected animals in the current study was 0.78% (0.78% = 0.1×5.25% + 0.5×0.5% + 0.4×0%).

Unlike the other 3 diseases, young stock that contract a BVD infection could die as well. The current study assumed that the mortality rate of BVD-infected young stock was 20% higher than in adult cows due to their immature immune system (Tizard, 2000) and the waning protection of maternal antibodies as the young stock get older. Therefore, the average mortality loss for BVD infection can be calculated by summing the mortality loss of young animals [$=n \times d_i \times 0.5 \times (c+h) \times (1.2 \times m_L^d)$] and mortality loss of adult cows ($=n \times d_i \times r \times m_L^d$). The value of young animals was used as the mean of the value of a calf (c = \$400) and the value of a heifer (h = \$1,400).

For EBL, Pelzer (1997) investigated the costs and benefits of EBL control in Virginia. He estimated that an average of 1 or 2% of BLV-infected cows would develop tumors in the lymph glands annually. Once clinical signs develop or tumours are detected in more than one internal organ, the carcass is likely to be condemned. Consequently, a 2% mortality rate per year (m_L^{EBL}) was assumed in the current study for animals infected with BLV.

In 121 dairy herds in Michigan (Johnson-Ifearulundu *et al*., 1999), mortality rate among herds positive for *paratuberculosis* was 3 percent higher than among negative herds and this increase was associated with JD or secondary disease to JD. Thus, a 3% annual mortality rate was used in the current study for herds infected with JD.

No previous studies were found that estimated the effect of neosporosis on mortality, although there is a small risk of death post-abortion due to metritis. Therefore, a conservative estimate of 0% per year was assumed for herds infected with this disease.

4. Abortion and Reproductive Losses The fourth and final component of direct loss in the partial budget model (Table 1) is associated with abortion and reproductive losses. The abortion and reproductive losses were calculated by multiplying together the number of aborted cows due to the disease ($a_L^d \times n \times d_i$) by the value of abortion and reproductive loss (a). Bennett et al. (1999) estimated the cost of dairy cow abortions (a) as the reduction in milk yield ($y \times p_y \times y_L^a$) + value of calf lost (c) where y_L^a is the reduction in milk yield associated with an abortion. Using the 28% loss in milk yield due to abortion from Bennett et al. (1999) along with the other parameters in Table 1, the total cost of a dairy cow abortion (a) would be $1,478 (7000×0.55×0.28 + 400).

Various studies have estimated abortion rates (a_L^d) associated with the four diseases. The current study used the low value (0.5%) for endemically infected unvaccinated herds (50% of infected herds) and the high value (8%) for epidemically infected unvaccinated herds (10% of infected herds). A 0% abortion rate for BVD-infected cows in properly vaccinated herds was assumed. Thus, the study employed an average abortion rate for infected cows of 1.05% (1.05% = 0.5×0.5% + 0.1×8% + 0.4×0%).

For EBL and JD, the current study assumed a 0% annual abortion rate in infected cattle because there have been no studies investigating abortion due to these diseases. However, there is another reproductive impact of JD infection due to increased days open. Johnson-Ifearulundu *et al*. (2000) found that ELISA-positive cows had, on average, a 28-day increase in days open compared with negative herd-mates and the result was statistically significant. This 28-day increase of JD-infected cows was adopted in the current study. Kirk (1999) stated that a cost of increased days open during early pregnancy is at least US$2.00 to $5.00 per day. A mean value of $3.50 was converted to Canadian dollars of $5.25 per day by using an exchange rate of 1.5. Using a 28-day increase, the study calculated days open loss due to JD infection by multiplying the number of infected animals ($n \times d_i$) by the $147 or annual reproductive loss associated with increased days open ($147 = $5.25×28).

For neosporosis, the economic impacts of the disease are mainly caused from abortion. One study in California found between 5 and 15% of pregnancies ended in abortions each year and about one third of the abortions were caused by *N. caninum* (Barr *et al*., 1998). Thurmond and Hietala (1997) also investigated abortion risk due to *N. caninum* in 468 Holstein cattle in California and found that during the first lactation, 5 of 104 (4.8%) infected first calf heifers aborted their calf. For the second lactation, 6 of 49 (12.2%) infected cows had abortions. Given these estimates, the current study used an average annual abortion rate for Neosporosis of 10% for infected cows.

Total annual direct losses for each disease at the herd level were obtained by summing all four components of the *ex post* direct losses (Milk loss + Premature voluntary culling/reduced slaughter value + Mortality loss + Abortion & reproductive loss).

Treatment Cost. Treatment costs were assumed to consist of veterinary visits for diagnosis, medication costs, and extra farm labor cost due to disease and/or infection. The present study assumed that all clinical cases were treated, but subclinical cases were not treated.

The cost of a veterinary service visit ($60/visit) was based on personal communication with Maritime veterinarians. The herd cost of veterinary services to diagnose clinical cases of disease was equal to the number of animals in the herd infected ($n \times d_i$) multiplied by the $60 per visit (assuming one cow is assessed per visit) multiplied by the proportion of infected animals that received veterinary services (i.e. clinical case). The current study used the proportion of animals aborting or dying due to disease as representative of the proportion of animals receiving veterinary attention. Therefore, the sum of the abortion and mortality rates ($a_L^d + m_L^d$) was considered as the proportion of animals affected by clinical disease in the study. This was considered to be an appropriate balance between underestimation due to not including repeat visits and clinical cases, and overestimation because not all cows that abort or die receive veterinary services, and many clinically sick animals are treated by the farmer without receiving veterinary care.

The medication cost was calculated by multiplying the number of infected animals ($n \times d_i$) by medication cost per case (m) and proportion of infected animals requiring medication. The medication value (m = $18.26) was based on the value of $12.17 (US in 1991) from the National Mastitis Council (NMC) (Crist *et al*., 1998) in the United States and converted to Canadian dollars using an exchange rate of 1.5. The proportion of infected animals that were given medication was assumed to be higher than the proportion receiving veterinary services but no studies have estimated this number. Therefore, the current study used the proportion receiving veterinary services ($a_L^d + m_L^d$) multiplied by 2, assuming that farmers will be giving medication to twice as many cows as they will have examined by veterinarians.

Extra labor costs to the farmer of treating the disease was estimated by multiplying the extra labor cost (l) by the number of infected cattle ($n \times d_i$) and the proportion of animals given medication. Miller *et al*. (1993) measured treatment costs of clinical mastitis by monitoring 50 Ohio dairy herds for 1 year and they found that labor costs for treating cows were $1.19/cow ($1.79/cow in Canadian dollars). For the current study, the average value ($3.15) of this converted cost ($1.79) and the extra labor cost in the NMC data ($4.50 in Canadian dollars) was adopted for extra labor costs for treating the four diseases in the study.

Aggregation of Costs. The costs of direct losses (L) and treatment costs (T) calculated to this point were for an average herd per year. Because the four diseases to be examined were mostly enzootic, the impacts could be estimated at the individual farm level and aggregated to a regional level without significant effect on market prices. The aggregate costs in the current study considered only infected herds. Thus, the costs were aggregated to the regional level (C_R) by multiplying the herd level costs (C_H) by the number of herds (H) and by the proportion of the herds infected by the given disease (r_d).

Risk and Sensitivity Analysis

Not all farms have the diseases present on their operation, nor do all infected farms have the same percentage of animals with a given infection or disease. Thus, the proportion of herds infected and the prevalence of infection in a herd are stochastic variables with a probability distribution. The stochastic nature of these two variables was accounted for within the spreadsheet model by simulating the model under the observed probability distributions.

The first step in the risk analysis was to determine the appropriate probability distributions for both proportion of herds infected and infection prevalence within herds for each of the four diseases. BestFit[1] (version 4.0, Palisade corporation) was used to fit the survey data and rank the fit among 37 possible probability distributions. The second step was to determine the distribution of *ex post* costs of the four diseases, given the uncertainty in infection prevalence estimated in the first step. The fitted probability distribution for the infection prevalence parameters were incorporated into the partial budget model using @RISK (version 4.0, Palisade corporation). The range and probabilities of the possible economic costs due to infection with disease were subsequently determined.

▪ Results

Direct Losses and Treatment Cost

The *ex post* costs associated with each of the four diseases using the partial budget model from Table 1 are given in Table 3. The direct losses at the herd level for BVD, EBL, JD, and neosporosis were $2,366, $775, $2,462, and $2,181 respectively. Based on average infection levels per herd, these productivity losses were much greater than average total treatment costs, which were $55 for BVD, $31 for EBL, $10 for JD, and $123 for neosporosis for clinical cases of the diseases. Thus, total *ex post* costs for an average herd were highest for herds with JD ($2,472), followed closely by BVD ($2,421) and neosporosis ($2,304). Average herd costs were higher for JD than the other three diseases despite JD having the lowest apparent prevalence of infection at

[1] BestFit is a companion program of the @RISK for probability analysis

7%. High premature voluntary culling (20%) and reduced slaughter value (25%) in JD infected animals led to the largest culling cost among the four diseases. EBL had a higher prevalence of infection (31%) in a positive herd than neosporosis (24%), but the total *ex post* costs at the herd level were higher for neosporosis ($2,304) than EBL ($806) due to the high economic impacts from abortions.

Table 3. *Ex post* costs of dairy disease in positive herds at herd and regional levels

Costs	BVD	EBL	JD	Neo-sporosis
Direct Losses (L)				
1. Milk Yield	0	0	355.16	0
2. Premature Culling-Reduced Cull Value	1,025.10	0	1,330.00	408.00
3. Mortality	935.45	775.00	262.50	0
4. Abortion & Reproductive loss	406.01	0	514.50	1,773.60
Total Direct Loss	2,366.56	775.00	2462.16	2,181.60
Treatment Costs (T)				
1. Veterinary Services	32.16	18.60	6.30	72.00
2. Medication cost	19.57	11.32	3.83	43.82
3. Extra labour	3.38	1.95	0.66	7.56
Total Treatment Costs	55.11	31.87	10.80	123.38
Herd Level *Ex Post* Costs (L+T)	2,421.67	806.87	2,472.96	2,304.98
***Ex Post* Costs for Maritime Region**	1,264,355	641,061	842,042	1,909,794

The largest components of the *ex post* costs for all four diseases, representing more than half of total costs, were associated with premature voluntary culling and reduced slaughter values, mortality, or abortion. The largest component of the costs due to epidemic BVD infection and JD was associated with premature culling and reduced cull value ($1,025 and $1,330 respectively). For EBL, mortality costs of $775 were the most significant component of its annual total costs of $806 at the herd level. Abortion represented the largest cost ($1,773) among all tested components of total costs for neosporosis.

At the regional level, relative costs of the diseases changed due to the differences in the likelihood of herds infected. For example, 30% of the 1,135 herds in the Maritimes were estimated to be infected with JD as opposed to approximately 70% of the herds infected with EBL and neosporosis. Neosporosis had the largest aggregate costs ($1,909,794). Although neosporosis, JD and BVD had similar costs at the herd level, the aggregate costs of JD ($842,042) for the Maritime dairy sector was less than half of the aggregate cost of neosporosis and the aggregate cost of BVD ($1,264,355) was less than two-thirds of the cost of neosporosis. EBL had the smallest overall cost ($641,061) but its relative effect was increased at the aggregate level due to the high number of herds infected with the disease.

Probability Distributions of Disease

The Beta General distribution was used for the proportion of herds infected by all four diseases. The Beta General distribution is described in part by the minimum value and the maximum value, which were 0 and 1 respectively for all four diseases. The Uniform distribution best fit the within-herd BVD infection prevalence. All infection rates between the minimum of 0.18 and the maximum of 1 are assumed to have the same likelihood of occurrence. An Inverse Gaussian distribution best described the probability distribution of within herd prevalence for both BLV, and neosporosis. This distribution is positively skewed as indicated by the difference between the mean and median values for infection rate. A triangular distribution best fit the probability distribution for the within herd prevalence of infection for JD. The triangular distribution is defined by its minimum, most likely and maximum values which in the case of prevalence of JD infection in the Maritimes were given by 0.03 (minimum), 0.03 (most likely value), and 0.17 (maximum). A large number of the herds had only a few cows infected and the number of herds with more cows infected, declined in a linear fashion consistent with a triangular distribution.

Distribution of Disease Costs

Herd Level. The mean and median value of the total costs at the herd level along with the values at the 5th and 95th percentiles are reported in Table 4 for a normal distribution and for the distribution determined to best fit the data as discussed in the previous section. The highest mean cost ($2,767) and maximum cost ($6,027) were for JD. This maximum ex post cost consisted of $6,001 in direct losses ($841 of milk yield + $3,256 of premature culling/reduced slaughter value + $642 of mortality + $1,259 of abortion & reproductive loss) and $26 in treatment costs ($15 of vet service + $9 of medication cost + $2 of extra labor cost). The mean and maximum ex post costs associated with an epidemic of all cows in the herd infected with BVD were $2,168 and $3,684, respectively. The maximum cost for neosporosis is higher than for JD, showing the large potential impact of abortion in infected herds, especially if an epidemic were to occur, causing a high within-herd infection prevalence.

Table 4. Distribution of herd level costs of 4 diseases under a normal and fitted probability distribution for prevalence of disease infection.

Disease	Normal Distribution				Fitted Distribution			
		Percentile				Percentile		
	Average	5%	50%	95%	Average	5%	50%	95%
BVD	$2,421	-$3,526	$2,421	$8,357	$2,168	$799	$2,165	$3,533
EBL	$806	-$3,475	$803	$5,081	$803	$87	$489	$2,582
JD	$2,464	-$55,684	$2,413	$60,431	$2,767	$1,187	$2,556	$5,030
Neo-sporosis	$2,307	-$13,524	$2,301	$18,081	$2,348	$717	$1,738	$5,986

The distribution for BVD (Uniform) was symmetric so there was no difference between the mean and median as would occur with a normal distribution. However, the use of a normal distribution would imply a much larger confidence interval (-$3,526 to $8,357) than with the best fit distribution ($799 to $3,533). The difference between the estimated confidence intervals for a normal distribution and the probability distribution determined to best fit the prevalence of infection (see Probability Distributions of Disease section) were exaggerated further for the other 3 diseases. Those fitted distributions were positively skewed.

The skewness of the distributions for the diseases other than BVD has another impact aside from distorting the confidence intervals if a normal distribution was incorrectly assumed. It means the average value is significantly higher than the median value (50th percentile). For example, the mean herd level costs for EBL was $803 and the median value was $489. Thus, a typical farmer is likely to experience herd level costs lower than the average reported for EBL, JD, and neosporosis.

Aggregate Industry Level. Neosporosis, which had the second highest mean cost ($2,348) at the herd level, showed the highest mean cost at $2,874,299 for the Maritime dairy sector due to the highest proportion of infected herds (73%). The mean values of total aggregate costs for JD and BVD were $1,427,122 and $1,177,565, respectively. The lowest average cost at the regional level among the four diseases was for EBL at $578,470. EBL also had the lowest average cost at the herd level ($803).

The probability distributions of *ex post* costs of the diseases at the aggregate industry level were determined on the basis of the probability distributions for prevalence of infection with disease and proportion of infected herds. The estimates of skewness and kurtosis at the industry level were increased for BVD, EBL, and JD as compared to the distribution of costs at the herd level. As a result, the 50th percentile values were significantly different from the mean values of the associated distribution. This effect was particularly distinct for BVD and JD. The mean values of aggregate total costs due to infection with BVD and JD were $1,177,565 and $1,427,122, respectively, while the 50th percentile values were $750,083 and $902,651, respectively. The difference between the mean and 50th percentile value was not distinct at the infected herd level. The mean values of herd total costs of infection with BVD and JD were $2,168 and $2,767, respectively, and 50th percentile values were $2,165 and $2,556, respectively. For EBL and neosporosis, the 50th percentile values for regional costs were $243,147 and $1,142,002, respectively, while mean costs were $578,470 and $1,638,894.

Sensitivity Analysis

Uncertainty due to the stochastic nature of infection prevalence was accounted for in the previous risk analysis section but there was also uncertainty surrounding five key parameters that have considerable influence on the *ex post* costs in the spreadsheet model: 1) reduced milk yield, 2) cull rate, 3) reduced slaughter rate, 4) mortality rate, and 5) abortion rate. The impacts of altering these five parameters on the effects of total cost estimates were determined by adding 5% and 10% to the base effects. Because the same formula was used to estimate costs of the four diseases, a herd with an epidemic of BVD, which had the largest cost, was selected to distinctively show the influence of the five parameters. The results are summarized in Table 5.

Table 5. Effect of changing BVD disease parameters on total *ex post* costs.

Disease Parameter	Base Impact	Effect on total ex post costs: Add 5% to base impact	Effect on total ex post costs: Add 10% to base impact
Reduced milk yield	0%	+$6,448.75 (266%)	+$12,897.50 (532%)
Cull rate	1.8%	+$2,847.50 (117%)	+$5,695.00 (235%)
Reduced slaughter rate	0%	+$24.12 (1%)	+$48.24 (2%)
Mortality rate	0.78%	+$6,168.72 (254%)	+$12,337.45 (509%)
Abortion rate	1.05%	+$2,647.87 (109%)	+$5,295.75 (218%)

* Estimates represent positive changes ($) in the *ex post* costs due to BVD

Values in parentheses are the percentage increase in total *ex post* costs for BVD from base model

The base model had assumed that BVD had no negative impact on milk yield. If a reduction in milk productivity of 5% was used, the total *ex post* costs at the herd level would have increased 266% from $2,421.67 to $8,870.42. Increasing the impact on milk yield to 10% would have further increased total costs to $15,319.17. Increasing the cull rate from 1.8% for BVD to 6.8% increased herd level costs by $2,847.50 or 117%. However, both 5% and 10% increases of reduced slaughter rate did not have important impacts on total costs (less than 5%). Herd level *ex post* costs for BVD would increase by $6,168.72 (254%) if mortality rate rose to 5.78% from 0.78%, and would increase by $2,647.87 (109%) if the abortion rate was increased to 6.05% from 1.05%.

▪ Discussion and Conclusion

This study has determined the *ex post* losses at the herd level and at the regional level for four dairy diseases in the Maritimes. A partial budget model was developed to account for the direct production losses and treatment costs. The largest costs were found for a herd with JD ($2,472 for an average herd), due largely to it having the highest premature culling and reduced cull value. In contrast, the *ex post* costs for an average herd was lowest for EBL at $806 because no effects of the disease on milk yield, culling value, and abortion loss were assumed.

Of the four components of direct costs in the study, premature culling and reduced cull value showed the most significant effect on total costs of BVD ($1,025) and JD ($1,330). Mortality and abortion/reproductive loss had the largest costs for EBL ($775) and neosporosis ($1,773), respectively. Of the three components of treatment costs, veterinary service costs were the highest for all of the four diseases: BVD ($32), EBL ($18), JD ($6), and neosporosis ($72). However, direct losses were much higher than treatment costs for all the four diseases.

A major difficulty in estimating the direct and treatment costs was the lack of conclusive data on some of the losses associated with each of the four diseases. Conservative parameter values were assumed but the sensitivity analysis demonstrated the effects of altering the estimates. For example, changing the effect of BVD on milk yield from 0 to negative 5% increased total *ex post* costs at the herd level by over 266%. Thus, there is a need for more research on the effects of the diseases before a more accurate picture of their impacts can be estimated.

The probability distributions of the total *ex post* costs, generated on the basis of the probability distributions for the prevalence of the diseases, were used in the current study. Because these distributions were generally positively skewed, the majority of farms were likely to have herd level costs less than the calculated average level. This effect on the distribution of costs was more significant at the regional level.

▪ References

@RISK. Guide to using @RISK4.0: risk analysis and simulation add-in for Microsoft Excel. Palisade Corporation, 2000.

Abbas, B., Reimann, H.P. and Hird, D.W. 1993. Diagnosis of Johne's disease (paratuberculosis) in northern California cattle and a note on its economic significance. California Veterinary, 8:20-24.

Barr, B.C., Dubey, J.P., Lidsay, D.S., *et al*. 1998. Neosporosis: its prevalence and economic impact. Veterinary Exchange, Supplement to Compend. Cont. Educ. Pract. Vet., 20:1-16.

Benedictus, G., Dijkhuizen, A.A. and Stelwagen, J. 1987. Economic loss due to paratuberculosis in dairy cattle. Veterinary Record, 121:142-146.

Bennett, R.M., Christiansen, K. and Clifton-Hadley, R.S. 1999. Modelling the impact of livestock diseases on production: case studies of non-notifiable diseases of farm animals in Great Britain. Animal Science, 68:681-689.

Bennett, R.M., Christiansen, K. and Clifton-Hadley, R.S. 1999. Preliminary estimates of the direct costs associated with endemic diseases of livestock in Great Britain. Preventive Veterinary Medicine, 39(3):155-171

Bergeron, N., Fecteau, G., Pare J., Martineau R. and Villeneuve, A. In press. Vertical and horizontal transmission of *Neospora caninum* in dairy herds in Quebec. Can Vet J.

Caldow, G.L., Buxton, D., Spence, J.A. and Holisz, J. 1996. Diagnoses of bovine abortion in Scotland. In: XIX World Buiatrics Congress, 8-12 July 1996, Edinburgh, 191-194.

Cortese, V.S., West, K.H., Hassard, L.E., Carman, S. and Ellis, J.A. 1998. Clinical and immunologic responses of vaccinated and unvaccinated calves to infection with a virulent type-Π isolate of bovine viral diarrhea virus. JAVMA, 213(9):1312-1319.

Cortese, V.S., Grooms, D.L., Ellis, J., Bolin S.R., Ridpath, J.F. and Brock, K.V. 1998. Protection of pregnant cattle and their fetuses against infection with bovine viral diarrhea virus type 1 by use of a modified-live virus vaccine. AJVR, 59(11): 1409-1413.

Crist, W.L., Harmon, R.J. and O'Leary, J. 1998. McAllister AJ. Mastitis and its control. On-line electronic publications of the College of Agriculture at the University of Kentucky (site: http://www.uky.edu/Agriculture/AnimalSciences/extension/pubpdfs/asc140.pdf)

Dairy Farmers of Canada. Dairy Facts & Figures at a Glance. 1999. Dairy Farmers of Canada.

David, G.P., Crawshaw, T.R., Gunning, R.F., Hibberd, R.C., Lloyd, G.M. and Marsh, P.R. 1994. Severe disease in adult dairy cattle in three UK dairy herds associated with BVD virus infection. Veterinary Record, 134:468-472.

Ellis, J., West, K., Cortese, V., Konoby, C., and Weigel, D. 2001. Effect of maternal antibodies on induction and persistence of vaccine-induced immune responses against bovine viral diarrhea virus type Π in young calves. JAVMA, 219(3):351-356.

Goodell, G.M., Hirst, H., Garry, F. and Dinsmore, P. 2000. Comparison of cull rates and milk production of clinically normal dairy cows grouped by ELISA *Mycobacterium avium paratuberculosis* serum antibody results. Proceeding of the International Symposium of Veterinary Epidemiology and Economics. Breckenridge. Colorado, USA.

Hietala, S.K. and Thurmond, M.C. 1997. *Neospora caninum* infection in cattle. United States Animal Health Association (USAHA) Proceedings.

Houe, H. 1992. Serological analysis of a small herd sample to predict the presence of animals persistently infected with bovine virus diarrhea virus (BVDV) in dairy herds. Res. Vet. Sci., 53:320-323.

Houe, H., Baker, J.X., Maes, R.K., *et al*. 1995. Prevalence of cattle persistently infected with bovine viral diarrhea virus in 20 dairy herds in two counties in central Michigan and comparison of prevalence of antibody positive cattle among herds with different infection and vaccination status. J. Vet. Diag. Invet., 7:321-326.

Johnson-Ifearulundu, Y., Kaneene, J.B. and Lloyd, J.W. 1999. Herd-level economic analysis of the impact of paratuberculosis on dairy herds. JAVMA, 214:822-825.

Johnson-Ifearulundu, Y., Kaneene, J.B., Sprecher, D.J., Gardiner, J.D. and Lloyd, J.W. 2000. The effect of subclinical Mycobacterium paratuberculosis infection on days open in Michigan, USA, dairy cows. Preventive Veterinary Medicine, 46:171-181.

Johnson, R. and Kaneene, J.B. 1991. Bovine leukemia virus. Part 1. Descriptive epidemiology, clinical manifestations, and diagnostic tests. Compend Contin Educ Pract Vet, 13:315-325.

Keefe, G. and VanLeeuwen, J. 2000. *Neospora caninum*: influence on 305-day milk production in eastern Canadian herds. The American Association of Bovine Practitioners Proceedings, 33:150

Kirk, J.H. 1999. Infectious abortions in dairy cows. On-line electronic publications of the Veterinary Medical Extension, Veterinary Medicine Teaching and Research Center, University of California.

(site: www.vetmed.ucdavis.edu/vetext/INF-DA_InfexAbortions.html)

Meyling, A., Houe, H. and Jensen, A.M. 1990. Epidemiology of bovine virus diarrhoea virus. Rev. Sci. Tech. Off. Int. Epiz., 9:75-93.

Miller, G.Y., Bartlett, P.C., Lance, S.E., Anderson, J. and Heider, L.E. 1993. Costs of clinical mastitis and mastitis prevention in dairy herds. Food Animals Economics, 202:1230-1236.

Murray, R.D. 1990. A field investigation of causes of abortion in dairy cattle. Vet. Rec., 127:543-547.

Nix, J. 1996. Farm Management Pocketbook, 27th edition. Wye College, University of London, Ashford, Kent.

Ott, S.L., Wells, S.J. and Wagner, B.A. 1999. Herd-level economic losses associated with Johne's disease on US dairy operations. Preventive Veterinary Medicine, 40:179-192.

Pelzer, K. 1997. Report of the Committee on Bluetongue and Bovine Retrovirus. United States Animal Health Association (USAHA) 1997 Committee Reports.

Pritchard, G.C., Borland, E.D., Wood, L. and Pritchard, D.G. 1989. Severe disease in a dairy herd associated with acute infection with bovine virus diarrhoea virus, Leptospira hardjo and Coxiella burnetii. Vet. Rec., 124:625-629.

Sockett, D.C., Conrad, T.C., Thomas, C.B. and Collins, M.T. 1992. Evaluation of four serological tests for bovine paratuberculosis. J Clin Microbiol, 30:1134-1139.

Thurmond, M.C. and Hietala, S.K. 1996. Culling associated with *Neospora caninum* infection in dairy cows. American Journal of Veterinary research, 57:1559-1562.

Thurmond, M.C. and Hietala, S.K. 1997. Effect of congenitally acquired *Neospora caninum* infection on risk of abortion and subsequent abortions in dairy cattle. American Journal of Veterinary research, 58:1381-1385.

Tizard, I.R. 2000. Veterinary Immunology: an Introduction. Philadelphia, P.A., W.B. Saunders. 482pp.

VanLeeuwen, J.A. 1999. Development of a National Dairy Cattle Health Assurance Program. Unreported project proposal.

VanLeeuwen, J.A., Keefe, G.P., Tremblay, R., Power, C. and Wichtel, J.J. 2001. Seroprevalence of infection with *Mycobacterium avium subspecies paratuberculosis*, bovine leukemia virus, and bovine viral diarrhea virus in Maritime Canada dairy cattle. Canadian Veterinary Journal, 42:193-198.

VanLeeuwen, J.A., Keefe, G.P., Tremblay, R., Power, C. and Wichtel, J.J. 2000. Seroprevalence, spatial distribution and productivity effects of infection with Johne's Disease and bovine leukosis in Maritime Canadian dairy cattle. Proceeding of the International Symposium of Veterinary Epidemiology and Economics. Breckenridge. Colorado, USA.

Vose, D. 2000. Risk Analysis: A quantitative guide. John Wiley & Sons, LTD.