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# Direct production losses and treatment costs from bovine viral diarrhoea virus, bovine leukosis virus, *Mycobacterium avium* subspecies *paratuberculosis*, and *Neospora caninum*

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**Abstract**

Our purpose was to determine direct production losses (milk loss, premature voluntary culling and reduced slaughter value, mortality loss, and abortion and reproductive loss) and treatment costs (veterinary services, medication cost, and extra farm labour cost) due to four infectious diseases in the Maritime provinces of Canada: bovine viral diarrhoea (BVD), enzootic bovine leukosis (EBL), Johne's Disease (JD), and neosporosis. We used a partial-budget model, and incorporated risk and sensitivity analyses to identify the effects of uncertainty on costs. Total annual costs for an average, infected, 50 cow herd were: JD$ 2472; BVD$ 2421; neosporosis $ 2304; EBL$ 806. The stochastic nature of the proportion of infected herds and prevalence of infection within a herd were used to estimate probability distributions for these ex post costs. For all diseases, these distributions were right skewed. A sensitivity analysis showed the largest effect on costs was due to milk yield effects. For example, changing milk production loss from 0 to 5% for BVD increased the costs for the disease by 266%.


*Keywords:* Bovine viral diarrhoea; Enzootic bovine leukosis; Johne's Disease; Neosporosis; Disease cost; Spreadsheet model; Risk analysis

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## 1. Introduction

Bovine viral diarrhoea (BVD), enzootic bovine leukosis (EBL), Johne's Disease (JD), and neosporosis are contagious diseases found on many dairy farms in Canada. These diseases impose large direct and indirect productivity losses on affected farms. The production losses are mainly from reduced milk production, but other losses can include mortality, weight loss, growth retardation, and abortion/reproductive loss. For example, BVD can have a large negative impact on milk production, abortion and mortality.

Ott et al. (1999) estimated herd-level losses associated with JD on US dairy operations. Those authors estimated the value of production on a per cow basis for each of the farms in a national survey. This net return then was regressed against explanatory variables such as herd size, farm location, and herd classification of JD. The net returns were almost US$ 100 per cow less in JD-positive herds than in JD-negative herds. 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 estimating the economic effects and also provides a means of comparative assessment across factors such as diseases or region. Bennett et al. (1999) also incorporated uncertainties on the incidence of disease, using a range of low and high values for disease parameters. Understanding the probability distribution of costs provides useful information on the likelihood of costs. Although this model serves as a base for our analyses, several adjustments could improve the cost estimates. For example, abortion and reproductive losses of JD could also include costs of increased days open. Furthermore, there have been no economic studies of this type to examine the costs of EBL and neosporosis.

Our objective was to determine costs (and their ranges) of BVD, EBL, JD, and neosporosis in the Maritime dairy industry. The spreadsheet model that we created presents costs of seven components of direct production losses and treatment costs at the herd-level. A probability distribution of the costs represented the stochastic nature of disease prevalence. In addition, a sensitivity analysis was conducted to assess the relative importance of disease parameter values on total disease costs.

Throughout this paper, ''infection prevalence'' refers to the infected proportion of a herd, and ''seroprevalence'' to the proportion of the herd that tests positive (based on a test for antibodies against the infectious agent). Also, for all four diseases, animals can be subclinically infected, with only a portion of all infected cattle developing measurable manifestations of disease. Therefore, disease costs were determined using the risk of showing disease manifestations among the proportion of infected animals, which was calculated from the seroprevalence of infection and test characteristics.

For BVD, ''prevalence of infection'', strictly speaking is a misnomer because tests for antibodies against BVD virus can indicate current or previous infection. Also, unlike the other three diseases in this study, only a small portion of cattle infected with BVD virus will remain permanently infected (shedding virus continuously, leading to future infection of susceptible cattle, and thereby creating an endemically infected herd) (Houe et al., 1995).

Furthermore, there are effective vaccines for preventing many of the disease manifestations of BVD infection (Cortese et al., 1998a,b). Based on the initial survey of Maritime dairy herds, 40% of infected herds were considered to have properly vaccinated cows and heifers ≥6 months old against BVD, and >90% of the infected herds were considered to be endemically infected (no mention of an outbreak at the time of sampling) (VanLeeuwen et al., 2001). Therefore, in this study, infected herds were subdivided into: 10% unvaccinated epidemically infected herds (had a recent introduction of BVD virus leading to an epidemic), 40% vaccinated endemically infected herds (experiencing minimal losses), and 50% unvaccinated endemically infected herds (experiencing periodic but reduced morbidity and mortality). Also, "prevalence of infection for BVD" referred to previously or currently infected cattle.

## 2. Methods and data

### 2.1. Partial-budget model

The ex post losses (direct loss and treatment cost) of the disease were assessed using a partial-budget model adapted from a spreadsheet suggested by Bennett et al. (1999) (Table 1).

#### 2.1.1. Farm characteristics

The 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 per cow per 305-day lactation, milk price, replacement cost of a cow, average slaughter value, heifer value and newborn calf value are representative values for the Maritimes in 2000, based on the ADLIC annual summaries and personal communication with industry personnel.

Information on infection prevalence was obtained from VanLeeuwen et al. (2001) and Keefe and VanLeeuwen (2000a). Using a stratified two-stage random sampling, 90 herds were chosen randomly (using computer-generated random numbers) from all herds enrolled in a monthly milk recording program provided by ADLIC (30 each from 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 dairy cattle in the Maritime provinces had positive tests for antibodies against the agents causing EBL (IDEXX ELISA, Idexx Laboratories, Westbrook, Maine, USA; sensitivity = 98.5%, specificity = 99.9% at *S/P* ratio = 0.50) (Johnson and Kaneene, 1991), JD (IDEXX ELISA; sensitivity = 43%, specificity = 99.2% at *S/P* ratio = 0.25) (Sockett et al., 1992), and neosporosis (Biovet ELISA; sensitivity = 99%, specificity = 98.4% at *S/P* ratio = 0.60) (Bergeron et al., 2000), respectively.

Testing for BVD used a different sampling strategy because vaccination against BVD was commonplace. In herds unvaccinated for BVD, five animals that were part of the 30 cows collected for the other diseases were selected. In vaccinated herds, five unvaccinated heifers >6 months old (so that maternal antibodies were no longer present) were selected.

Table 1
Spreadsheet model to estimate cost of a generic disease in dairy cattle

| Dairy farms characteristics | Notation | Value or calculations (source) |
|---|---|---|
| Total cattle population in Maritimes | $N$ | 88,000 (DFC, 1999) |
| Total number of herds | $H$ | 1135 (DFC, 1999) |
| Average cattle population in herd | $n$ | $N/H = 50$ |
| Milk yield (l per cow per year) | $y$ | 8200 |
| Milk price ($/l) | $p_y$ | 0.55 |
| Replacement cost of cow ($ per head) | $r$ | 2500 |
| Slaughter value of healthy cattle ($ per head) | $s$ | 800 |
| Value of calf ($ per head) | $c$ | 400 |
| Value of heifer ($ per head) | $h$ | 1400 |
| Cost of vet visit ($) | $v$ | 60 |
| Cost of medication ($ per case) | $m$ | 18.26 (NMC, 1991) |
| Cost of extra labour with disease ($ per head) | $l$ | 3.15 (NMC, 1991; Miller et al., 1993) |
| Value of days open loss ($ per day) | $d$ | 5.25 (Kirk, 1999) |
| Prevalence of infection in an infected herd | $d_i$ | See Table 2 |
| Direct losses ($L$) | | |
| Milk yield | | |
| Reduced milk yield (%) | $y_L^d$ | See Table 2 |
| Milk loss ($) | | $nd_i y p_y y_L^d$ |
| 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 ($) | | $nd_i c_L^d[(r-s)(1-s_L^d)]$ |
| Mortality | | |
| Mortality rate in infected cattle (%) | $m_L^d$ | See Table 2 |
| Mortality loss for BVD ($) | | $nd_i 0.5(c+h)(1.2m_L^d) + nd_i r m_L^d$ |
| Mortality loss for the other three diseases ($) | | $nd_i r m_L^d$ |
| Abortion and reproductive loss | | |
| Abortion risk in infected cattle (%) | $a_L^d$ | See Table 2 |
| Loss of milk yield from abortion (%) | $y_L^d$ | See Table 2 |
| Value of reproductive loss ($ per herd) | $a$ | $y p_y y_L^a + c$ |
| Abortion and reproductive loss for Johne's disease ($) | | $nd_i(a_L^d a + 28d)$ |
| Abortion and reproductive loss for the other three diseases ($) | | $(a_L^d nd_i)a$ |
| Total direct loss | $L$ | Milk loss + mortality loss + premature culling + abortion loss |
| Treatment cost ($T$) | | |
| Veterinary services | | $nd_i(a_L^d + m_L^d)v$ |
| Medication cost | | $nd_i 2(a_L^d + m_L^d)m$ |
| Extra labour cost | | $nd_i 2(a_L^d + m_L^d)l$ |
| Total treatment cost | $T$ | Vet cost + treatment + extra labour |
| Herd-level ex post costs | $C_H$ | $L + T$ |

Table 2
Assumptions on disease incidence and effects

| | BVD | EBL | JD | Neosporosis |
|---|---|---|---|---|
| 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 risk of infected cattle, $c_L^d$ (%) | 1.8 | 0 | 20 | 2 |
| Reduced slaughter value, $s_L^d$ (%) | 0 | 0 | 25 | 0 |
| Mortality risk in infected cattle, $m_L^d$ (%) | 0.78 | 2 | 3 | 0 |
| Loss of milk yield from abortion, $y_L^d$ (%) | 28 | 28 | 28 | 28 |
| Abortion risk 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 titres $\geq$ 1:64).
[b] Only applicable to JD-infected cows in $\geq$5th lactation (15% of herd).

This sampling technique was based on Houe (1992) and Houe et al. (1995), that reported $\geq$95% herd-level sensitivity and $\geq$98% herd-level specificity using five unvaccinated animals for detecting herds infected with BVD. 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 (VanLeeuwen et al., 2001). In Table 2, the geometric mean prevalence of infection within an infected herd is given for each disease.

### 2.1.2. Direct losses

The second section in Table 1 on direct losses for each disease consists of four parts, based on losses due to: (1) lower milk production; (2) premature culling and reduced slaughter value; (3) mortality; (4) abortions or reductions in reproductive performance. Direct losses with each component vary depending on the biological characteristics of the disease. Neosporosis, e.g., is primarily vertically transmitted from an infected cow to its fetus in utero, causing higher abortion risks 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.

*2.1.2.1. Milk yield.* Several studies have investigated production losses due to infectious diseases ($y_L^d$). Bennett et al. (1999) measured 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 could only apply to unvaccinated cows in epidemic herds. In unvaccinated endemic herds, most mature cows will be immune due to infection prior to their first lactation. In vaccinated endemic herds, it is assumed that all milking cows will be immune to BVD. VanLeeuwen and Keefe (2001)[1] found that there was no effect of seroprevalence 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); we therefore used a 0% milk yield reduction ($y_L^{BVD} = 0$) for seropositive animals.

[1] "Relationship between milk production and subclinical infection with bovine viral diarrhoea virus at the herd level in Maritime dairy herds", University of Prince Edward Island, Unpublished report.

VanLeeuwen et al. (2000) established that there was no significant effect on 305-day milk yield by infection with the EBL agent (when lactation and linear-score somatic-cell count were controlled). Previous studies found similar results (Johnson and Kaneene, 1991). Therefore, a 0% reduction in milk production due to infection with EBL ($y_L^{EBL} = 0$) was assumed.

For JD, Benedictus et al. (1987) investigated the decrease in milk production for culled animals with clinical paratuberculosis. 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 terminal lactation (compared with the previous lactation). For animals with subclinical paratuberculosis, these decreases were 16 and 6%, respectively. Another study (Abbas et al., 1993) reported that cows subclinically infected with JD produced 15% less milk than culture-negative cows in three California dairy herds.

In contrast, VanLeeuwen et al. (2000) found that, over all lactations, JD seropositivity (based on the IDEXX ELISA) was not significantly associated with projected 305-day milk production in the Maritimes. Only seropositive cows in their fifth or greater lactation had milk effects (loss of ∼15% (1200 lb)). To ensure that this reduction in milk loss ($y_L^{JD} = 0.15$) only applied to the positive cows in the fifth lactation or greater, the geometric mean prevalence for JD of 0.07 was multiplied by the proportion of animals in this older age cohort (which we assumed to be 15%, based on the sample population). Thus, the effective prevalence of JD infection (for milk production effects) within an infected herd was assumed to be 0.011 (=$0.07 \times 0.15$).

*Neospora caninum* seropositive cows produced 2.5 lb per cow per day (760 lb of milk per lactation) less than seronegative cows in one herd (Hietala and Thurmond, 1997). However, this study was limited to first lactation dairy cows in one herd. Keefe and VanLeeuwen (2000b) compared milk production of *Neospora* positive cows with that of seronegative cows for three lactation categories (first, second, and third or more lactations) in 90 Maritime herds. Those authors concluded no impact of infection with *N. caninum* on milk production, although seropositive cows produced marginally more milk than seronegative cows in all three categories. Abortion risk and its associated disease problems cannot be compared between these two studies due to lack of data, but might explain the difference in findings. Results from 25 non-randomly selected Ontario dairy herds showed no significant impact of neosporosis seroprevalence on milk production for the first three test-day evaluations of a group of cow's lactation (Duffield et al., 2001a). In a second Ontario study, milk production was reduced in seropositive herds with high abortion rates, but unaffected in seropositive herds with normal abortion rate histories (Duffield et al., 2001b). With no data on abortion problems among the participating herds, we conservatively assumed that infection with neosporosis had no effect on milk yield ($y_L^{neosporosis} = 0$) in the Maritimes.

*2.1.2.2. Premature voluntary culling and reduced slaughter value*. One of the components of the direct loss calculation was premature voluntary culling, which can include reduced slaughter values; the cost of a premature cull was the replacement cost less than the slaughter value ($r - s$). The slaughter value can be reduced by a percentage due to disease factors that lower body weight. 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 that the cull value would be 0 and the cost of a premature cull would be the value of a healthy replacement. The opportunity cost of replacement due to premature culling was $((r - s)(1 - s_L^d))$.

*2.1.2.2.1. Culling risk*. David et al. (1994) investigated epidemics of acute clinical BVD infection in three dairy herds in England and found that 11% of cows were culled prematurely because of this chronic illness. Another study (Pritchard et al., 1989) reported that 15 (8%) cows died and 20 (11%) were culled (mainly because of acute infection) because of BVD in a 183 cow dairy herd in Norfolk, England. Bennett et al. (1999) suggested minimum, average, and maximum values of premature culling risks from BVD of 2, 8, and 11%, respectively. These categories represent different severities of epidemics of BVD in recently infected unvaccinated herds. In endemically infected unvaccinated herds, the premature culling risk is likely to be in the lower range of 2% (Meyling et al., 1990).

Conversely, the impact of BVD is likely minimal in vaccinated endemically infected herds. Based on virus-isolation tests for six BVDV unvaccinated and 12 vaccinated heifers, only two calves from the vaccinated heifers were persistently infected with BVDV although all of the six unvaccinated heifers had positive results (Cortese et al., 1998a,b). Those authors also showed that vaccination with a modified-live type-I isolate of BVDV could protect young calves from infection with BVD. Therefore, we assumed no effect of BVDV in vaccinated herds.

Using these findings and the results of Bennett et al. (1999), an annual premature culling risk of 2% was used for endemic herds and 8% for epidemic herds. A premature voluntary culling risk per year was calculated by summing the effects on the remaining 60% in unvaccinated infected herds having epidemic ($0.1 \times 8\%$) and endemic ($0.5 \times 2\%$) BVD. Therefore, a 1.8% premature culling risk per year was assumed for animals infected with BVD in the current study.

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, and 13.8% of seropositive cows and 4.3% of seronegative cows that aborted more than one time were culled in the 3-year period. Because we did not have data on abortions, we used the first comparison. There was a difference in culling of 5.2% (35.8–30.6%) between seropositive and seronegative cows over the 3 years. Thus, we assumed a 2% premature voluntary culling risk per year for cows infected with neosporosis.

There were no previous studies on which to base premature voluntary culling risk estimates for cows infected with EBL. We assumed that this risk was 0% because there did not seem to be any milk production impact among seropositive cows for BLV (VanLeeuwen et al., 2000) that might lead to premature culling. Seropositive cows developing lymphosarcoma are considered in the mortality section below.

For JD, a recent study (Goodell et al., 2000) reported differences in culling risk between seropositive and seronegative cows 1 year later. Using the IDEXX ELISA *S*/*P* ratio, those authors divided the cows into four groups: 0–0.09, 0.1–0.24, 0.257–0.39, and 0.4–10 and found the removal risks of these groups were 30.4, 35.8, 50.0, and 48.1%, respectively. Thus, the difference in culling risk between seropositive and seronegative animals was ~20% (50–30), which we used for $c_L^{JD}$ for seropositive cows.

*2.1.2.2.2. Reduced slaughter value*. For Holstein cows that were clinically affected by JD in the Netherlands, Benedictus et al. (1987) found that slaughter value of infected cows was 30% lower than usual slaughter value, and that day value (sum of usual slaughter value and the usual loss at culling) of infected cows was 20% lower than usual day value. Johnson-Ifearulundu et al. (1999) found that a 10% 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, USA. Therefore, we assumed a 25% decrease in slaughter value ($s_L^{JD}$) for a cow affected with JD.

Due to lack of data to support an effect of seropositivity on slaughter value, a conservative value of 0% was assumed for BVD, EBL, and neosporosis.

*2.1.2.3. Mortality*. Cow value at death was set equal to the cost of replacement because no carcass value was assumed for dead animals from any of the four diseases (Nix, 1996).

David et al. (1994) examined BVD-infected cows in severe epidemics of acute clinical cases in three sample dairy herds of England and found that the average mortality from BVD across the herds 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, we used 5.25% [0.5(0.5 + 10)] for unvaccinated epidemic herds. In unvaccinated herds with endemic BVD, the additional mortality for BVD-infected cows was assumed to be 0.5% because of low disease incidence through herd immunity from natural exposure. A 0% mortality was used for properly vaccinated herds (Ellis et al., 2001). Given the 0% mortality for infected cows in the 40% of infected herds that were vaccinated properly, the 5.25% mortality risk for the 10% of unvaccinated epidemic herds, and the 0.5% mortality for the remaining 50% of unvaccinated endemic herds, the annual mortality risk for BVD-infected animals in the current study was 0.78% ($=0.1 \times 5.25\% + 0.5 \times 0.5\% + 0.4 \times 0\%$).

Unlike the other three diseases, young stock that contract a BVD infection also could die. We assumed that the mortality 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. The value of young animals was the mean of the value of a calf and the value of a heifer.

For EBL control in Virginia, USA, Pelzer (1997) estimated that 1–2% of BLV-infected cows would develop tumours 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 risk per year for infected cattle was assumed.

In 121 dairy herds in Michigan, USA (Johnson-Ifearulundu et al., 1999), mortality risk among herds positive for paratuberculosis was 3% higher than among negative herds and this increase was associated with JD or disease secondary to JD. We used 3% mortality risk per year for infected cattle.

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 mortality risk estimate of 0% per year was assumed.

*2.1.2.4. Abortion and reproductive losses*. Bennett et al. (1999) estimated the cost of dairy cow abortions as the reduction in milk yield plus the value of the calf lost. We used the 28% loss in milk yield due to abortion from Bennett et al. (1999) (this was not included in milk production losses above).

Caldow et al. (1996) reported that abortion due to BVD was diagnosed in 6.5% of abortion cases in Scotland. In England, Murray (1990) showed that 26% of abortions were associated with BVDV. In Denmark, 4.8% of abortions were related to BVDV infection (Meyling et al., 1990). These proportional morbidities demonstrate the frequency with which BVD is diagnosed as the cause for bovine abortions. Bennett et al. (1999) assumed 5% abortion risk per year in unvaccinated infected herds with 50% infection-and-disease incidence per year in susceptible animals. Therefore, in epidemically infected herds in our study, 2.5% ($=5\% \times 50\%$) of cattle were assumed to be infected and abort annually. Because all cattle have an annual abortion risk due to BVD of 0.2% (Bennett et al. (1999), we assumed an abortion risk among infected cattle of 8% ($=0.2\% \times 100\%/2.5\%$).

For unvaccinated endemic herds, the low abortion risk of 0.5% was assumed. A 0% abortion risk for BVD-infected cows in properly vaccinated herds was assumed. Thus, the study used an average abortion risk for infected cows of 1.05% ($=0.5 \times 0.5\% + 0.1 \times 8\% + 0.4 \times 0\%$).

For EBL and JD, we assumed a 0% annual abortion risk in infected cattle because there have been no studies investigating abortion due to these diseases. However, even subclinically infected cattle for JD appear to have increased days open (Johnson-Ifearulundu et al., 2000). In a sample of 533 animals from 7 Michigan, USA dairy herds, ELISA-positive cows had a 28-day increase in days open compared with negative herd-mates. We adopted this 28-day increase for JD-infected cows. Kirk (1999) stated that a cost of increased days open during early pregnancy is at least US$ 2.00–5.00 per day. A mean value of US$ 3.50 was assumed, which converted to CDN$ 5.25 per day by using an exchange rate of 1.5.

For neosporosis, the economic cost of disease is mainly from abortion. One study in California, USA 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. Nineteen of 145 (13.1%) congenitally infected heifers aborted during the initial pregnancy, 5 of 104 (4.8%) aborted during the first lactation, and 6 of 49 (12.2%) aborted during the second lactation aborted. We used an average annual abortion risk 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 and reproductive loss).

*2.1.3. Treatment cost*

Treatment costs were assumed to consist of veterinary visits for diagnosis, medication costs, and extra farm labour cost due to disease and/or infection. We assumed that all clinical and no subclinical cases were treated.

The cost of a veterinary service visit ($ 60 per visit) was based on personal communication with Maritime veterinarians. The herd cost of veterinary services to diagnose clinical

cases of disease assumed one case was assessed per visit. We used the proportion of animals aborting or dying due to disease as representative of the proportion of animals receiving veterinary attention. We believe this will balance underestimation (from not including repeat visits and clinical cases) and overestimation (because not all cows that abort or die receive veterinary services, some animals will be examined at herd-health visits, and many clinically sick animals are treated by the farmer without receiving veterinary care).

The medication value was based on the value of $ 12.17 (US in 1991) from the National Mastitis Council (NMC) (Crist et al., 1998). 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. We 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.

Miller et al. (1993) measured annual treatment costs of clinical mastitis in 50 monitored Ohio, USA dairy herds and found that labour costs for treating cows were $ 1.19 per cow ($ 1.79 per cow in Canadian dollars). We used the average value ($ 3.15) of this converted cost ($ 1.79) and the extra labour cost in the NMC data ($ 4.50 in Canadian dollars).

### 2.2. Risk and sensitivity analysis

Farms differ regarding the percentage of animals with a given infection. The stochastic nature of prevalence of infection in a herd was accounted for within the spreadsheet model.

The first step was to determine the appropriate probability distributions for infection prevalence within the 90 monitored herds (VanLeeuwen et al., 2001) (Keefe and VanLeeuwen, 2000a,b) for each of the four diseases. BestFit[2] (Version 4.0, Palisade Corporation) was used to fit the survey data and rank the fit among 37 possible probability distributions. The expected frequency for each fitted distribution was compared to the actual frequency of a histogram from the observed survey data using a chi-squared test statistic; the distribution with the highest $P(\chi^2)$ was selected (Vose, 2000).

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 (2000) (Version 4.0, Palisade Corporation). @RISK used a Latin Hypercube simulation with 1000 iterations. The range and probabilities of the possible economic costs due to infection were determined.

### 2.3. Sensitivity analysis

Uncertainty due to the stochastic nature of infection prevalence is accounted for in the risk analysis section, but there is 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 risk; (3) reduced slaughter risk; (4) mortality risk; (5) abortion risk. The impacts of altering these five parameters on the effects of total cost estimates was determined by adding 5 and 10% to the base effects.

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

Table 3
Results of distribution tests of disease infection within-herd using BestFit

| Disease | Type of distribution | Minimum | Median | Maximum | $P(\chi^2)$ |
|---|---|---|---|---|---|
| BVD | Uniform | 0.18 | 0.60 | 1.02 | 0.04 |
| EBL | Inverse Gaussian | 0 | 0.19 | $\infty$ | 0.52 |
| JD | Triangle | 0.03 | 0.07 | 0.17 | 0.05 |
| Neosporosis | Inverse Gaussian | 0.03 | 0.18 | $\infty$ | 0.63 |

## 3. Results

### 3.1. Probability distributions of disease

The Uniform distribution BestFit the within-herd BVD infection prevalence (Table 3). All infection risks between the 0.18 and 1 were assumed to have the same likelihood of occurrence. An Inverse Gaussian distribution best described the probability distribution of within-herd prevalence for both EBL and neosporosis. This distribution is right skewed (as indicated by the larger mean than median values for infection prevalence). A triangular distribution BestFit the probability distribution for the within-herd prevalence of infection for JD. The triangular distribution was defined for seroprevalence for JD in the Maritimes by 0.03 (minimum), 0.07 (most likely value), and 0.17 (maximum). Many of the surveyed 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.

### 3.2. Direct losses and treatment cost

The direct losses to infected herds (Table 4) for BVD, EBL, JD, and neosporosis were much greater than average total treatment costs. Average herd costs were higher for JD than

Table 4
Annual ex post costs (CDN$) of dairy disease in positive herds (50 cow herd size)

| Costs | BVD | EBL | JD | Neosporosis |
|---|---|---|---|---|
| Direct losses ($L$) | | | | |
| Milk yield | 0 | 0 | 355 | 0 |
| Premature culling/reduced cull value | 1025 | 0 | 1330 | 408 |
| Mortality | 935 | 775 | 263 | 0 |
| Abortion and reproductive loss | 406 | 0 | 514 | 1774 |
| Total direct loss | 2366 | 775 | 2462 | 2182 |
| Treatment costs ($T$) | | | | |
| Veterinary services | 32.2 | 18.6 | 6.3 | 72.0 |
| Medication cost | 19.6 | 11.3 | 3.8 | 43.8 |
| Extra labour | 3.4 | 2.0 | 0.66 | 7.6 |
| Total treatment costs | 55.2 | 31.9 | 10.8 | 123.4 |
| Herd-level ex post costs ($L+T$) | 2422 | 807 | 2473 | 2305 |

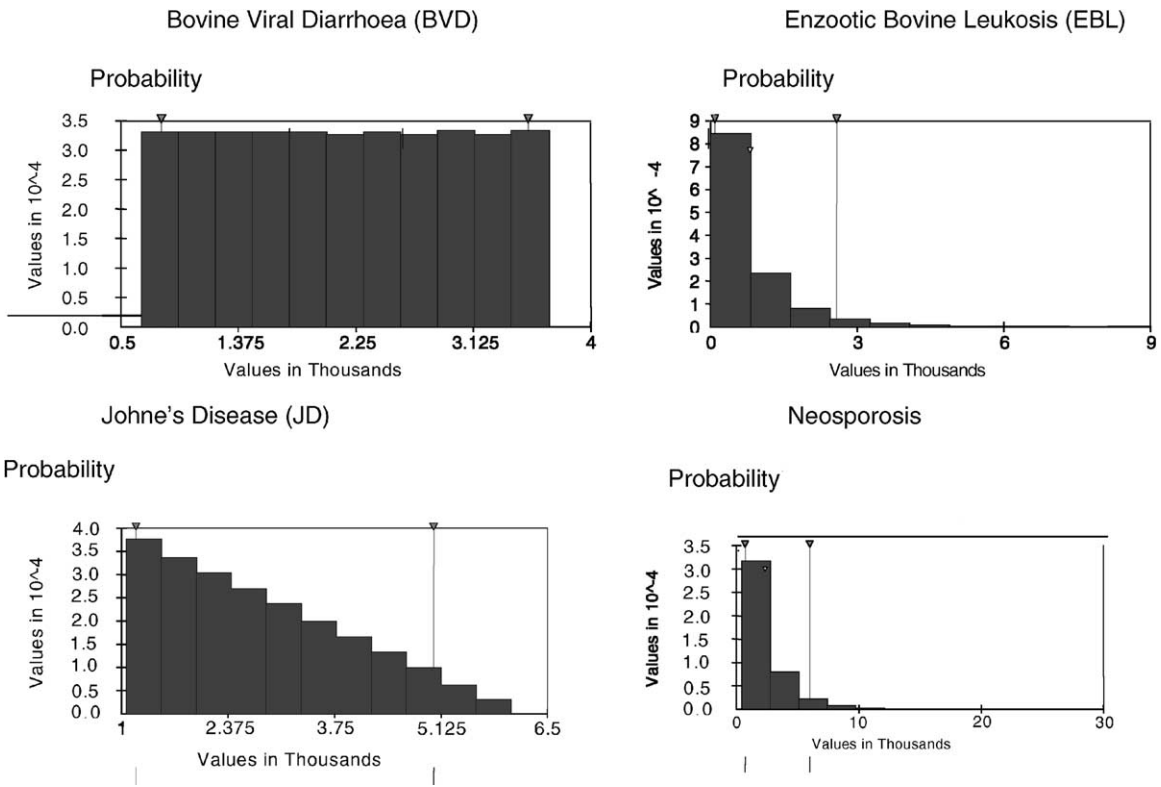


Fig. 1. Distributions of annual ex post costs (CDN$ 000) for 50 cow herd due to the four diseases.

the other three diseases despite JD having the lowest apparent prevalence of infection in a positive herd (7%) because of high premature voluntary culling (20%) and reduced slaughter value (25%) in JD-infected animals. 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 than EBL because of abortions.

The largest component of the costs from epidemic BVD and JD was associated with premature culling and reduced cull value ($ 1025 and 1330 annually per 50 cow herd, respectively). For EBL, mortality costs of $ 775 were the highest component of its annual total costs at the herd-level. Abortion represented the largest cost ($ 1774) for neosporosis.

### 3.3. Distributions of disease costs

The expected distributions of ex post costs due to disease prevalence within a herd are shown in Fig. 1. The shapes of the cost distributions at the herd-level for each disease are the same as the shapes of the probability distributions for the within-herd infection prevalences. (The 5th and 95th percentiles are shown by vertical lines.)

The highest median cost ($ 2556) was for JD (Fig. 1). JD also had a high annual maximum ex post cost which consisted of $ 6001 in direct losses ($ 841 of milk yield + $ 3256 of premature culling/reduced slaughter value + $ 642 of mortality + $ 1259 of abortion and reproductive loss) and $ 26 in treatment costs ($ 15 of vet service + $ 9 of medication cost + $ 2 of extra labour cost). The median and maximum ex post costs associated with an epidemic of all cows in the herd infected with BVD were $ 2165 and 3684, respectively. Because the maximum (1.02) of the uniform distribution overestimates the actual bounds of 0 and 1 for disease prevalence, the cost was truncated at $ 3614. Similarly, the maxima of the distributions for EBL and neosporosis were truncated at costs of $ 2602 and 9604, respectively. The maximum cost for neosporosis is higher than for JD, showing the large potential impact of abortion in infected herds.

### 3.4. Sensitivity analysis

Because the same general 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 show the influence of the five parameters (Table 5). The most significant impacts on the estimated costs resulted

Table 5
Effect of changing BVD cost parameters on annual ex post costs (CDN$)

| Cost parameter | Base impact (%) | Effect on total ex post costs | | | |
|---|---|---|---|---|---|
| | | Add 5% to base impact | | Add 10% to base impact | |
| | | $ | % change | $ | % change |
| Reduced milk yield | 0 | 6449 | 266 | 12,898 | 532 |
| Cull risk | 1.8 | 2848 | 117 | 5,695 | 235 |
| Reduced slaughter risk | 0 | 24 | 1 | 48 | 2 |
| Mortality risk | 0.78 | 6169 | 254 | 12,337 | 509 |
| Abortion risk | 1.05 | 2648 | 109 | 5,296 | 218 |

from increases in the milk reduction associated with BVD and in the risk of mortality. Altering the slaughter risk had little effect on total ex post costs to the herd from BVD.

## 4. Discussion

A major difficulty in estimating the direct and treatment costs was the lack of consistent results on some of the losses. Impacts on milk production, culling, mortality and reproduction were only included if consistent and statistically significant impacts were documented in the literature. As a result, conservative values were used for some of the impact estimations producing underestimates. However, we felt that solid scientific evidence was necessary before impacts were included into the total costs so that the estimates could not be criticized as ''propaganda of overestimates'', and therefore discarded. For example, with conflicting reports on the milk production effect of being seropositive for neosporosis, we assumed no effect. Treatment effects were also likely to be underestimates due to the lack of published data on the drug and milk withdrawal costs of treating the manifestations of these diseases. Future studies will clarify the impacts, providing more accurate estimates.

Sensitivity analysis demonstrated the effects of altering specific 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.

One could also argue that because the milk yield impacts were determined using a percentage reduction from the average 305-day milk yield in the region, this average milk yield is a composite of all cattle in the region—both infected and non-infected cattle. Therefore, the base estimate of production for cows not infected by the agents causing these diseases would likely be higher than the regional average. On the contrary, when we determined the average 305-day milk yield for cows that were test negative for BLV, JD and neosporosis, this average was slightly lower than the regional average that we used in the study. Producers are unlikely to cull high-producing cows from a herd, even if they are test-positive for one of these infectious diseases. With vertical transmission, these test-positive cows can propagate further test-positive high-producing cows (particularly for neosporosis and BLV, for which the evidence of a seropositivity impact on milk production is weak).

As with any predictive model, certain assumptions are required, and these assumptions might be appropriate for one particular country or region or set of circumstances—but inappropriate for others. Furthermore, costs do not generalize well across time and space to other jurisdictions and times because input and output prices, monetary values and production systems are quite variable over time and among different locations. Therefore, the external validity of the numerical results from this study might not be representative of populations outside of the Maritime provinces of Canada. However, the methodology of integrating management and biologic parameters in this study to determine total costs of the diseases can be utilized by other jurisdictions at different times. We feel that the developed methodology is the real strength of this study, which can be modified to adjust for more appropriate assumptions, cost structures, and production systems for a particular area of concern, providing useful information regarding the absolute and relative costs of

these four diseases in that area. These cost estimates may assist decision-makers at the herd and regional/national level to prioritize efforts where costs are determined to be highest.

The methodology developed in this paper clearly builds upon the cost estimates developed by Bennett et al. (1999) for BVD and JD in dairy cattle in Britain. However, our methodology has also included other costs (such as increased days open), and used infection prevalence data as a basis for determining the variable incidence levels of the clinical manifestations of the diseases in infected animals. Infection prevalence data can lead to more-precise estimates of infectious disease costs and are becoming much more-commonly available with herd-health veterinarians attempting to determine and reduce the impacts of infectious diseases on the production of dairy herds. In addition, we expanded our developed methodology to include two other diseases, neosporosis and EBL, diseases not included in the work of Bennett et al. (1999). Our cost estimates certainly could be refined even further as future research produces better estimates of the impacts of the disease manifestations.

## 5. Conclusions

Total annual costs for an average, infected, 50 cow herd were: JD$ 2472; BVD$ 2421; neosporosis $ 2304; EBL$ 806. The stochastic nature of the proportion of infected herds and prevalence of infection within a herd were used to estimate probability distributions for these ex post costs. For all diseases, these distributions were right skewed. A sensitivity analysis showed the largest effect on costs was from milk yield.

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