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The Economics of Bovine Viral Diarrhea Virus Control in United States Cow-Calf Production

Bailey A. Samper, Jennifer Koziol, and Ryan B. Williams

This study evaluates the costs associated with alternative bovine viral diarrhea virus (BVDV) control strategies for cow-calf producers and aims to identify minimum viable premiums to induce control measures. Monte Carlo simulations were used to estimate the cost of control strategies, risk of BVDV outbreak, and BVDV-attributed production losses. We find that the price premiums needed to induce enhanced BVDV control by cow-calf producers range between \$8.41 to \$35.52 per head. Additionally, larger herds are more likely to adopt rigorous control protocols due to increased likelihood of PI exposure and ability to absorb additional costs with economic profits.

Key words: animal health economics, bovine viral diarrhea virus, cow-calf production, risk analysis

Introduction

Bovine Viral Diarrhea Virus (BVDV) is an infectious pathogen that can cause adverse health effects to beef cattle. BVDV infection falls into three broad categories: transient, fetal, and persistent infection (PI), with the latter being the most harmful. Fetal infection during day 50 to 125 of gestation creates PI animals, and they remain PI their entire life (Grooms et al., 2009). Consequently, PI animals are considered the primary source of BVDV exposure into a cattle operation. For a cow herd, economic losses from BVDV infection have been estimated to be between \$50 to \$100 per cow (APHIS, 2007), stemming from reproductive complications and heightened calf morbidity (Houe, 2003). For stockers and feedlots, the immunosuppressive properties of BVDV increase the likelihood of subsequent respiratory diseases in cattle that are exposed to a PI animal. Loneragan et al. (2005) found that the risk of initial respiratory tract disease was 43% greater in cattle exposed to a PI animal. Correspondingly, the estimated economic losses to the beef cattle industry attributable to PI animals are between \$500 million to 1.5 billion dollars annually (Miles, 2009; Ishmael, 2016).

The prevalence of PI animals in the supply chain is largely determined by the BVDV control practices implemented in the cow-calf sector because these animals are the result of fetal infection. In the U.S., approximately 9% of cow-calf operations have at least one PI animal (Wittum et al., 2001; USDA, 2010b). The within-herd prevalence of PI animals has been estimated to be less

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Table 1. Definition of BVDV Control Strategies Used for Simulations

Control Strategy	Herd Status	Vaccination	Testing
A	Closed	Yes	Yes
B	Closed	Yes	No
C	Closed	No	Yes
D	Closed	No	No
E	Open	Yes	Yes
F	Open	Yes	No
G	Open	No	Yes
H	Open	No	No

than one percent in multiple epidemiological studies of beef cattle (Wittum et al., 2001; USDA, 2010b). In the U.S., increasing BVDV control within the cow-calf sector has the potential to reduce losses to cattle producers and the wider industry. Hurt (2018) concluded that the cow-calf, stocker, and feedlot sectors would each experience net gains due to enhanced BVDV management within the cow-calf sector, with feedlots’ gains substantially outpacing those of the other sectors. However, noninfected herds would experience a net loss due to enhanced BVDV management costs. Since >90% of cow-calf herds fit this category, this constitutes a large barrier to adoption. Furthermore, the uneven distribution of costs and benefits, and the subclinical nature of BVDV infection, make incentivizing BVDV management challenging.

The limited management of PI cattle in the cow-calf sector generates a negative externality for other sectors in the beef cattle market with stockers and feedlots experiencing most of the productivity losses and treatment costs associated with PI cattle. Hence, the cow-calf sector has little incentive to engage in enhanced BVDV control because they do not experience the total costs attributed to PI animals. This negative externality leads to less-than-optimal effort to control BVDV within the cattle industry. This is particularly true, as we will show, of smaller operations; where the risk of loss to the firm is small and the risk can be transferred downstream in the supply chain. A potential solution to the PI externality is rooted in the compensation principle. If the benefit of PI reduction to feed yards is larger than the cost of achieving that level of reduction for cow-calf producers, then feed yards can compensate cow-calf producers for reducing the prevalence of PI cattle, leading to net social gains. In other words, feedlots can provide premiums for tested PI-free cattle to ensure they do not incur losses attributable to PI exposure, potentially constituting net gains for both parties.

While some PI free premiums exist, the volume of producers that market cattle under these programs has been low. According to the USDA (2020a), only 2% of operations marketed calves as PI-free. The 2022 policy book of the National Cattlemen’s Association indicates that the organization encourages efforts to develop economically efficient mechanisms to control and/or eliminate BVDV in beef cattle herds (National Cattlemen’s Beef Association, 2022). Therefore, evaluating necessary PI-free premiums to induce enhanced BVDV management would aid in advancing stakeholders objectives.

Traditionally, BVDV research, among other types of livestock disease research, has been confined to veterinary medicine, epidemiology, and animal science. However, animal health economics is increasingly being incorporated to help develop concepts and models that support the decision-making process in optimizing animal health (Dijkhuizen, Huirne, and Jalvingh, 1995). Most economic studies of BVDV have focused on the cost of disease for the private and public sectors (Bennett, Christianse, and Clifton-Hadley, 1999; Weersink et al., 2002), or the value of eradication programs (Lindberg, 2003; Thomann et a., 2017). These studies estimate the magnitude of the economic cost of disease, but without accounting for the cost and efficacy of control strategies, they do not provide direction for disease management. The few economic studies that do consider the economics of BVDV management are either modeled within dairy production (Chi et al., 2002), or do not account for the natural variability in clinical manifestations

and spread of the disease. Correspondingly, incorporating biological and epidemiological knowledge into an economic evaluation of BVDV management for cow-calf producers would prove beneficial.

The objectives of this study are to: 1) analyze the cost effectiveness of eight BVDV control strategies for three herd sizes in the cow-calf sector, and 2) estimate the PI-free premiums required to induce a PI-testing plus vaccination strategy to be the most cost-effective control option for herds infected and uninfected with BVDV. The aim of a control strategy is to minimize the total cost of BVDV, which is defined as the sum of the control costs and expected production losses. We expect that control inputs exhibit diminishing marginal benefit associated with disease control. Thus, the optimal level of disease is likely to *not* be zero percent. Correspondingly, we first hypothesize that the strategy with the lowest total cost will not minimize the risk of an outbreak nor expected production losses. It is likely that the probability of exposure to a PI animal will differ depending on herd size. Accordingly, our second hypothesis is that the cost-effectiveness of strategies will differ depending on herd size. Lastly, because we expect the cost-effectiveness of strategies to differ conditionally on herd size, we hypothesize that the PI-free premium per head to encourage greater BVDV management will differ depending on herd size.

Conceptual Model

Modelling the impact of disease

Following Chi et al. (2002) and Hennessey and Marsh (2021), we present a model that incorporates the economics of damage control (Lichtenberg and Zilberman, 1986), and a disease management model (McInerney, 1996). The direct effect of a disease is represented by the following production function:

$$(1) \quad Q = f(R)j(C)$$

where:

Q = quantity of output (calves (measured in total cwt))

R = quantity of regular variable inputs used (feed, labor)

C = quantity of disease control inputs used

Disease can lower output by increasing the mortality rate or by reducing the efficiency of the inputs in production, R . The level of disease within a herd depends on the quantity of disease control inputs used, C . The effect of disease on the production function is illustrated in Figure (1), adapted from McInerney (1996), where disease presence in a herd shifts the production function from ‘healthy’ to ‘diseased’ status. In both production functions, the operation is using inputs as efficiently as possible. The downward shift in the “diseased” function is due to reduction in output for a given level of input associated with the presence of disease. The input price, P_R , to output price, P_Q , ratio curve is indicated by the dashed curves. The point where the price ratio curve is tangent to the production function indicates the level of input use that will maximize profits (i.e., where the marginal value of product is equal to the marginal cost of inputs). For a healthy herd and diseased herd, the optimal level of production occurs at point E_h and E_d , respectively.

Modeling disease control

The level of disease in a herd, D , is influenced by the quantity of disease control inputs used in production. Disease control inputs are unique compared to other factors of production in that they do not increase potential output. Rather, the role of such inputs is to reduce the difference between potential output (i.e., the maximum level of output attainable from a given combination of directly productive inputs) and actual output (Lichtenberg and Zilberman, 1986). This characterization

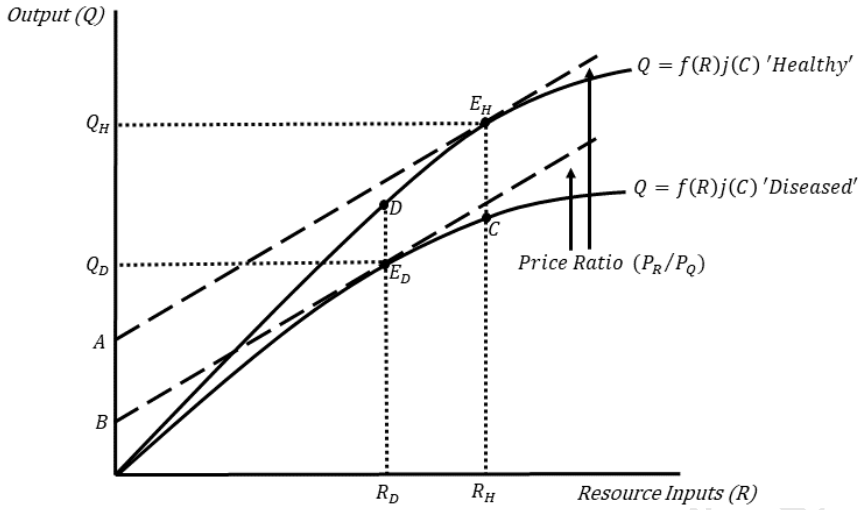


Figure 1. Production Function of a Diseased and Healthy Herd

Notes: Adapted from McInerney (1996)

suggests that the proper way to think about disease control inputs is through a two-step process: (1) the impact of disease control inputs on the level of disease, and (2) how the resulting level of disease influences production and treatment expenditures (Fox and Weersink, 1995).

In the first step, herd level disease (D), depends on the untreated disease prevalence (D_o) and the proportional reduction of disease due to a given level of control inputs, (C). This is summarized by the control function, $\zeta(C)$.

$$(2) \quad D = D_o[1 - \zeta(C)]$$

The control function is assumed to have the same properties as a cumulative probability distribution as it is constrained on the interval $\zeta(C) \in [0,1]$. When $\zeta(C) = 0$, the control inputs have no effect on the level of disease, resulting in $D = D_o$. In contrast, complete eradication ($D = 0$) would be realized if $\zeta(C) = 1$. It is assumed that the proportion of the disease remaining after control inputs are used monotonically decreases with increases in the level of control ($\frac{\partial \zeta}{\partial C} \geq 0$). The rate of change in the marginal product of control inputs is unknown, but is assumed to be concave (Fox and Weersink, 1995).

In the second step, the effect of remaining disease on output is estimated as a fractional reduction in the potential production if disease were not present, $f(R)$. The fraction of this potential production losses is referred to as the damage function:

$$(3) \quad \delta(D)$$

The damage function is assumed to possess the properties of a cumulative distribution function. With no disease ($D = 0$) there is no reduction in output, $\delta(D) = 0$, and actual output will equal potential output, ($Q = Q_o$). As the level of disease approaches infinity ($D \rightarrow \infty$), the proportional losses in output approaches one and actual output approaches some minimum output, Q_{min} , which cannot be less than zero (Fox and Weersink, 1995). It is assumed that the marginal impact of disease on output is nonnegative ($\frac{\partial \delta}{\partial D} \geq 0$) and the damage function could exhibit various curvature properties; but it is assumed to be concave (Fox and Weersink, 1995).

By substituting (2) into (3), the fraction of potential output that is produced is described as:

$$(4) \quad Q = f(R)j(C) = f(R)\{1 - \delta(D_o[1 - \zeta(C)])\}$$

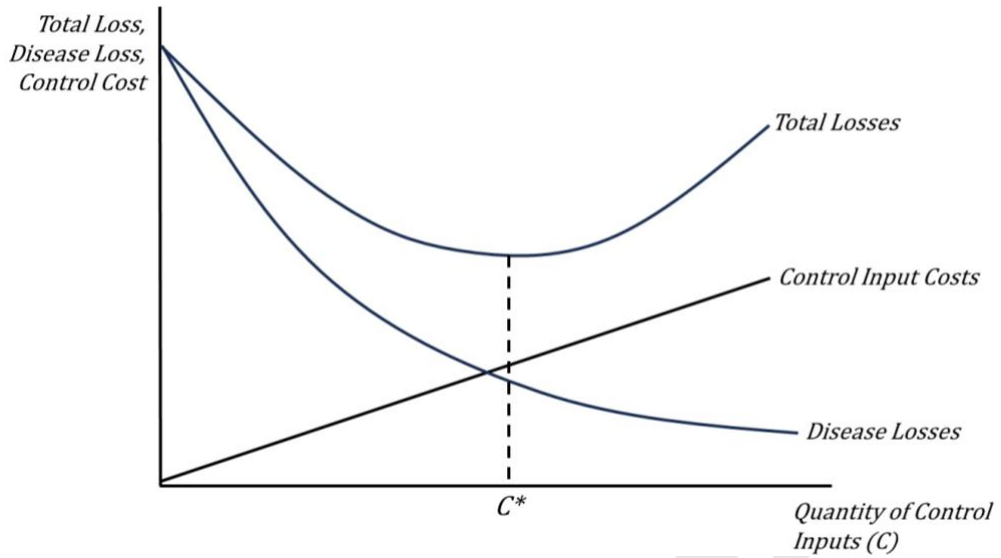


Figure 2. Contribution of Disease Losses and Control Input Costs to the Total Losses of a Disease

Notes: Adapted from Hennessey and Marsh (2021)

With an output price of p , regular input cost of k , and disease control input cost of w , the profit maximization problem becomes:

$$(5) \quad \pi_{max} = p[f(R)\{1 - \delta(D_o[1 - \zeta(C)])\}] - kR - wC$$

The first order optimality conditions are defined as:

$$(6) \quad \pi_R = pf'(R^*)j(C^*) - k = 0$$

$$(7) \quad \pi_C = pD_o f'(R^*)\delta'(D^*)\zeta'(C^*) - w = 0$$

Primes represent the first derivative. The optimal quantity of disease control inputs to use will depend on price of output, initial presence of disease, disease free level of output, the severity of output reduction due to disease, the effectiveness of control inputs in reducing disease prevalence, and the cost of the control input. Following McInerney (1996), if regular inputs are fixed at $R = \hat{R}$, then the problem may be written in terms of cost minimization:

$$(8) \quad Min_C = pf(\hat{R})\delta(D_o[1 - \zeta(C)]) + wC$$

$pf(\hat{R})\delta(D_o[1 - \zeta(C)])$ represents disease loss and wC represents expenditure on disease control. Optimal expenditure on disease control occurs where the marginal cost of control, w , is equal to marginal disease losses, $pD_o f(\hat{R})\delta'(D)\zeta'(C)$. Figure 2 provides an illustration of an interior solution. Increasing disease control inputs used up to C^* decreases the total losses because the marginal reduction in disease losses exceeds the marginal cost of disease control inputs. Past C^* , the marginal cost of disease control inputs exceeds the marginal reduction in disease losses. Hence, employing C^* quantity of disease control inputs minimizes the total cost of a disease.

Empirical Model

Three Monte Carlo stochastic simulation models were combined to estimate the total cost of eight BVDV control strategies over a 1-year horizon. A 1-year horizon was chosen as multiple

epidemiological studies have found that herds of susceptible cattle that come into contact with a PI animal seroconvert within 6 months of exposure (Wentink et al., 1991; Moerman et al., 1993; Houe, 1999). Total cost of BVDV was defined as the sum of control costs and expected BVDV losses. Expected BVDV losses were defined as the product of the risk of a BVDV outbreak and losses if a BVDV outbreak were to occur. The model was applied to herd sizes 50, 100, and 500. From these results, the required PI-free premium needed for more intensive control strategies to become the most cost effective was estimated. The simulation conducted 1,000 iterations to obtain an “average case” scenario over a distribution of variables. All simulations were conducted in R Studio (Boston, MA) using a fixed random seed.

Model baselines for calving percentage, weaning weight, and replacement rate are provided in Table 2. The model assumed each herd was naïve to BVDV and that PIs were the only source of viral exposure. Each herd shared fence line contact with one neighboring herd and faced no risk of BVDV exposure from wildlife. Revenue was generated through selling calves at weaning and each control strategy was mutually exclusive from one another. Because our intention is to provide a general framework from which to build upon for herds in specific regions, nationally representative data sources were used for the analysis.

The eight BVDV control strategies considered were various combinations of three BVDV control components: maintaining a closed herd, vaccination, and testing for PI cattle. Because PI introduction commonly occurs through the importation of replacement animals, we defined closed herd status as all replacements being raised on farm, open herd status was defined as all replacements being imported. Vaccination is used to protect animals against transient BVDV infection. For strategies that included vaccination, we assumed that the cow herd was vaccinated annually, and calves are vaccinated twice before sale. Testing involves virus isolation from serum, blood, or tissue to identify PI animals. Examples of PI tests include antigen-capturing ELISA, immunohistochemistry, and polymerase chain reaction. For strategies that included testing, we assumed all new replacements and calves are tested for PI. Combining these control components formed eight BVDV control strategies, which are presented in Table 2.

Data Sources

All cattle price data was accessed through the USDA Agricultural Marketing Service (AMS) using the custom report feature. Ten-year historical data from June 2012 – June 2022 was used for the analysis. Data from all locations were retained to generate nationally representative data distributions.

Calf price mean and standard deviation were estimated from steer and heifer price data for 400 – 500 pounds, medium and large frame size, muscle score 1 and 2 cattle. Data for only 400 – 500 pound cattle were used to control for the negative correlation between calf price and weight. Weaning weight was matched with price data to be truncated within 400 – 500 pounds. Normal distribution of prices and weaning weight was assumed, and data were truncated within two standard deviations from the mean to control for outliers.

Cull cow prices were obtained from breaker, boner, and lean categories within the weight range of 1,200 to 1,400 pounds. A normal distribution was assumed, and data were truncated within 2 standard deviations away from the mean. Cull cow weights were matched with price data and truncated within 1,200 to 1,400 pounds.

The cost of raising a replacement heifer on farm was the sum of the forgone revenue associated with marketing the heifer at weaning plus the two-year costs of raising her to a fall pregnancy check. The forgone revenue was estimated by multiplying heifer price (as described above) by weaning weight. The two-year costs of maintaining the heifer were estimated following the budget approach developed by South Dakota State University Extension and reported in FarmProgress (2016). To account for the known variation in feed, labor and veterinary costs, these costs were allowed to vary by 25% from the mean. The cost of purchasing a replacement heifer is

Table 2. Input Distributions for Control Costs, Risk of BVDV Outbreak, and Losses of BVDV Outbreak

Parameter description		Distribution	Source
cp	Calving percentage (%)	Pert(84.4, 89.5, 95.6)	USDA (2020a)
r	Replacement rate (%)	15%	Thomas (2021)
w_c	Weaning weight (cwt)	Tnorm(4.5, 0.3, 4, 5)	USDA-AMS (2022); USDA (2020)
P_f	Cost of raising replacement heifer over 2 years (\$/hd)	Tnorm(1,728, 118, 1490, 1965)	FarmProgress (2016); USDA-AMS (2022)
P_i	Cost of purchasing replacement heifer (\$/hd)	Tnorm(1,363, 186, 989, 1736)	Prevatt (2020); USDA-AMS (2022)
p_t	Cost of BVDV-PI test (\$/hd)	Poisson(1000, 7.25)	OADLL (2021); KSVDL (2022); TVDML (2022)
p_v	Cost of vaccine (\$/dose)	Pert(2.00, 3.58, 4.20)	Dr. Koziol, DVM ; Riley et al. (2019); ValleyVet (n.d.)
HP	Prevalence of herds having at least one PI animal (%)	Pert(4%, 9%, 12%)	Wittum et al. (2001) ; USDA (2010b)
p	Within-herd prevalence of PI animals in positive herds (%)	U(0.01%, 5.00%)	Wittum et al. (2001) ; USDA (2010b)
h	Number of herds replacements are imported from (n)	U(1,8)	Dr. Koziol, DVM
T_{ef}	Reduction in risk of exposure from testing (%)	Pert(0, 42%, 66%)	Smith et al. (2009)
V_{ef}	Vaccine efficacy (%)	Pert(40%, 88%, 99%)	Fairbanks et al. (2004); Ficken, Ellsworth, and Tucker (2006)
d	Within-herd prevalence of BVDV (%)	Bin(1,000, 45.14%)	Scharnbock et al. (2018)
cp_{rd}	Reduction in calving percentage (%)	Gamma(1000, 2%, 0.5%)	Taylor, Janzen, and Donkersgoed (1997) ; Waldner and Kennedy (2008)
w_{rd}	Reduction in weaning weight (lbs)	Gamma(1000, 28.6, 1)	Taylor, Janzen, and Donkersgoed (1997) ; Waldner and Kennedy (2008)
m_c	Increased preweaning mortality (%)	Gamma(1000, 1%, 0.5%)	Taylor, Janzen, and Donkersgoed (1997) ; Waldner and Kennedy (2008)
pc_{cow}	Premature culling rate of infected cows (%)	Gamma(1000, 1.8%, 0.5%)	Bennett, Christiansen, and Clifton-Hadley (1999); Weersink et al. (2002)

w_c	Weaning weight (cwt)	Tnorm(4.50, .27, 4, 5)	USDA (2020b); USDA-AMS (2022)
p_c	Calf price (\$/cwt)	Tnorm (174.78, 45.47, 83.82, 265.74)	AMS (2022)
p_r	Replacement cost (\$/hd)	N(1,363, 124)	Prevatt (2020); USDA- AMS (2022)
p_s	Cull cow value (\$/cwt)	Tnorm (75.59, 20.46, 34.65, 144.91)	USDA-AMS (2022)
c_w	Cull cow weight (cwt)	Tnorm(13.39, 0.47, 12.00, 14.00)	USDA-AMS (2022)
c_v	Veterinary cost (\$/case)	Pert(50, 60, 70)	Weersink et al. (2002); Dr. Koziol, DVM
c_m	Medication cost (\$/case)	Pert(10, 15, 20)	Weersink et al. (2002); Dr. Koziol, DVM
c_l	Extra labor cost (\$/case)	Pert(3, 5, 7)	Weersink et al. (2002); Dr. Koziol, DVM

Notes: Parentheses represent numbers describing each distribution. Tnorm(mean, standard deviation, lower bound, upper bound), Poisson(number of trials, lambda) Pert(minimum, most-likely, maximum), U(minimum, maximum), Bin(number of trials, probability of success), Gamma(number of trails, shape, rate). Within herd prevalence is defined as proportion of antibody positive animals in herd.

estimated to be roughly 1.5 times the average price of a 550-pound feeder steer (Prevatt, 2020); therefore, the 10-year historical price of a 550-pound feeder steer was multiplied by 1.5 to obtain the estimated cost of purchasing a replacement heifer. For the cost of raising versus purchasing a replacement heifer, data were truncated within 2 standard deviations from the mean. It is important to note the cost of raising versus purchasing a replacement heifer will significantly vary depending on regional differences, economic factors, weather conditions, and forage availability. Hence, the decision to raise versus purchase replacement heifer depends not only on BVDV risk, but also economic factors, forage availability, and operational objectives. Costs of testing, vaccination, veterinary, medication, and extra labor costs were acquired from clinical diagnostic labs (OADDL, KSVDL, TVDML), journal articles, or co-author Koziol's professional experience as a food animal veterinarian.

Baseline distributions (i.e., non-BVDV associated) for management, health and performance parameters were obtained from the U.S. Department of Agriculture 2017 Beef Cow-calf Management Practices in the United States Report 1 (USDA, 2020a). Epidemiological data on the prevalence of herds containing at least one PI animal and the within herd prevalence of PI animals was obtained from the USDA 2007-2008 report of the Prevalence and Control of BVDV on U.S. Cow-Calf Operations (USDA 2010b) and from Wittum et al. (2001). Data for within herd prevalence of transient infections of BVDV was obtained from a meta-analysis of BVDV prevalence in cattle populations reported in Scharnböck et al. (2018). Data pertaining to the efficacy of testing, vaccination, and the production impacts of BVDV infection were acquired from various peer reviewed journal articles (Fairbanks et al., 2004; Ficken, Ellsworth, and Tucker, 2006; Smith, 2009).

Cost of BVDV Control

The first simulation estimated the costs of each BVDV control strategy. The cost of maintaining a closed herd, C_c , was calculated as:

$$(9) \quad C_c = r \cdot n \left(\frac{(P_f - P_i)}{2} \right)$$

where r is the replacement rate, n is herd size, P_f is the two-year cost of raising a replacement heifer, and P_i is the cost of importing a replacement heifer. The cost of raising a replacement heifer was the sum of the forgone revenue associated with marketing the heifer at weaning, plus the two-year costs of raising the animal. The forgone revenue was estimated by multiplying heifer price (as described above) by weaning weight. The two-year costs of maintaining the heifer were estimated following the budget approach developed by South Dakota State University Extension which includes feed costs, veterinary costs, marketing and shipping, breeding feeds, and indirect costs. These values are divided by 2 to set costs on a yearly basis. The price of purchasing a replacement heifer was estimated following the approach of University of Florida Extension and assumed that the cost of a replacement heifer is roughly 1.5 times the average price of a 550-pound feeder steer (Prevatt, 2020). The 10-year historical price of a 500 pound feeder steer was multiplied by 1.5 to obtain the estimated cost. The cost of vaccination, V_c , was calculated as:

$$(10) \quad V_c = p_v \cdot n(2 \cdot cp + 1)$$

where p_v is the per-head cost of vaccination and cp is the calving percentage. The scalar of 2 is included because calves are vaccinated twice prior to sale. The herd level cost of PI testing, T_c , was calculated as:

$$(11) \quad T_c = p_t \cdot n(r + cp)$$

where p_t is the per-head cost of testing. The distribution of inputs for simulating the cost of control strategies is provided in Table 2. No adjustment to costs were made to account for the ability to negotiate bulk transactions by larger firms.

BVDV Outbreak Risk

The second simulation estimated the risk of a BVDV outbreak for each control strategy. The model for BVDV risk was adapted from Morley (1993), where the risk of an outbreak is defined as the product of the probability of exposure to at least one PI animal and the probability of infection given exposure. For each control strategy, the risk of a BVDV outbreak, R , was defined as:

$$(12) \quad R = \left\{ P(E) - \left[\begin{array}{l} 0 \text{ if } T = 0 \\ T_{ef} \text{ if } T = 1 \end{array} \right] \right\} \cdot \left[\begin{array}{l} 1 \text{ if } V = 0 \\ 1 - V_{ef} \text{ if } V = 1 \end{array} \right]$$

where $P(E)$ is the probability of exposure to at least one PI animal, T_{ef} is the proportional reduction in the probability of exposure due to testing, T , and V_{ef} is the proportional reduction of probability of infection due to vaccination, V , or vaccine efficacy.

We assumed PI exposure could only occur from the importation of a PI animal or fence-line contact with neighboring herds infected with BVDV. Closed herds faced risk from fence line contact while open herds faced risk from fence line contact and importation. The probability of exposure was modeled using the multilevel binomial probabilistic model from Murray (2004), because it can account for potential clustering of PI animals from an infected herd. The probability of exposure to at least one PI animal was defined as:

$$(13) \quad P(E) = 1 - [1 - HP(1 - (1 - p)^i)]^h$$

where HP is the prevalence of herds with at least one PI animal, p is the prevalence of PI animals within herds that have at least one PI animal, i is the number of animals being imported, and h is the number of herds animals are being imported from. For fenceline contact, we assumed a firm faced potential exposure from one neighboring herd of the same size. No additional management behavior (e.g., established trust and reputation, type and quality of cattle purchased, etc.) is

considered in the model. The distribution of inputs for simulating the risk of BVDV outbreak is provided in Table 2.

BVDV Outbreak Losses

The third simulation estimated the losses associated with a BVDV outbreak. The model followed the framework of Bennett, Christiansen, and Clifton-Hadley (1999) and was employed in Weersink et al. (2002), where the losses are the sum of production losses and treatment expenditure. Production losses were further subcategorized as reproductive, preweaning morbidity, preweaning mortality, and premature culling losses. Reproductive losses, L_r , were calculated as:

$$(14) \quad L_r = n \cdot d \cdot cp_{rd} \cdot p_c \cdot w_c$$

where n is herd size, d is the prevalence of antibody-positive animals in the herd¹, cp_{rd} is the reduction in calving percentage due to abortion, reduced conception rates, and congenital defects, p_c is the calf price measured in dollars per hundredweight, and w_c is calf weaning weight measured in hundredweight. Preweaning morbidity losses, L_b , were calculated as:

$$(15) \quad L_b = n \cdot cp \cdot d \cdot w_{rd} \cdot p_c$$

where w_{rd} is the reduction in the weaning weight of infected calves. Preweaning mortality losses, L_m , were calculated as:

$$(16) \quad L_m = n \cdot cp \cdot d \cdot m_c \cdot p_c \cdot w_c$$

where m_c is the percentage increase in preweaning mortality due to exposure to a PI animal. Premature culling losses, L_p , were calculated as:

$$(17) \quad L_p = n \cdot d \cdot pc_{cow} \cdot (p_r - (p_s \cdot c_w))$$

where pc_{cow} is the percentage increase in premature culling, p_r is the cost of purchasing a replacement heifer and p_s is the price of a cull cow, measured in dollars per hundredweight, and c_w is cull cow weight, measured in hundredweight.

Treatment costs were the sum of veterinary, medication, and extra labor costs. The cost of veterinary care, C_v , was calculated as:

$$(18) \quad C_v = n \cdot d \cdot cp_{rd} \cdot c_v$$

where c_v is the cost of veterinary care per case. Veterinary costs were only incurred for clinical cases, which we defined as reproductive complications. Medication, C_m , and extra labor costs, C_l , were calculated as:

$$(19) \quad C_m = n \cdot d \cdot 2 \cdot cp_{rd} \cdot c_m$$

$$(20) \quad C_l = n \cdot d \cdot 2 \cdot cp_{rd} \cdot c_l$$

where c_m is the cost of medication per case and c_l is the cost of extra labor per case. Following Weersink et al. (2002) medication and labor were applied to clinical and subclinical cases, and subclinical cases were assumed to be twice the number of clinical. The distribution of inputs for simulating the losses of a BVDV outbreak is provided in Table 2.

¹ Antibody positive animals represent animals that are transiently infected with BVDV, which is the outcome of exposure of PI animals.

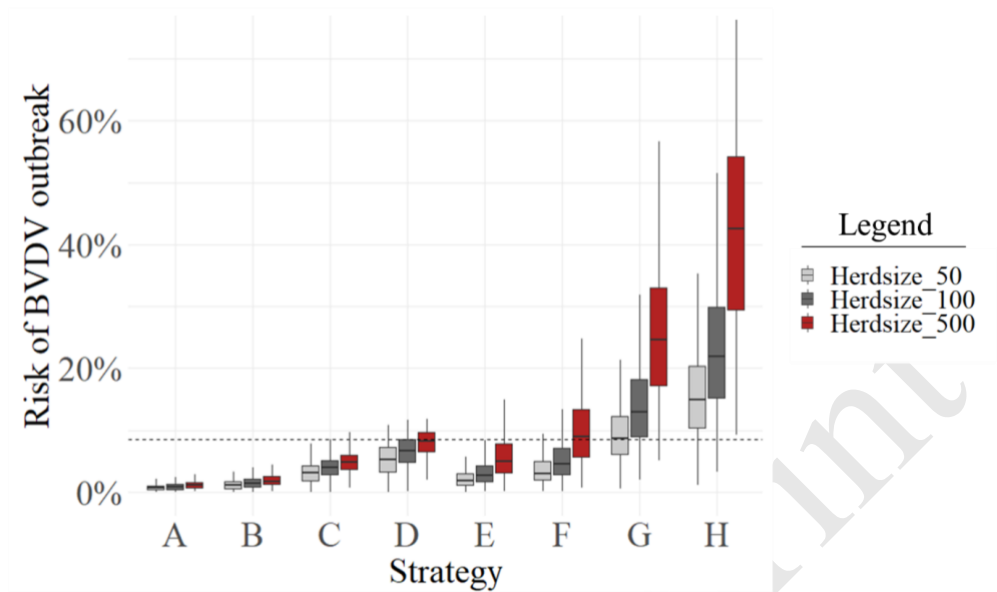


Figure 3. Risk of BVDV Outbreak under each Control Strategy for Herd Sizes 50, 100, and 500

Notes: Box plots represent minimum and maximum (whiskers), first and third quartiles (box), and median (line within the box). Strategies A-D are closed herd, A and E are vaccination and testing, B and F are vaccination only, C and G are testing only, and D and H are no additional control strategies.

Sensitivity analysis

The sensitivity of model output to the risk of BVDV outbreak was examined for all herd sizes. The impact of altering BVDV risk was determined by adding 10% and 20% from the average outbreak risk estimated from the simulation model. The changes in total cost for all control strategies under the three herd sizes were evaluated on a per-head basis. Differences in risk and costs among control strategies within herd size stratum were assessed using the Wilcoxon Ranked Sum test.

Incentives for enhancing BVDV control

Following identification of the most cost-effective strategy for each herd size, the required PI-free premium needed for a testing plus vaccination strategy (strategy E) to become the most cost-effective control option was estimated for infected and non-infected herds. The testing plus vaccination strategy was chosen as the enhanced control strategy because vaccination protects a herd from transient infection and testing and removal of PI animals reduces their flow into the supply chain. Maintaining a closed herd was excluded from the enhanced control strategy because the decision to maintain a closed herd does not depend solely on disease risk, but also market conditions, forage availability, and genetic objectives. Hence, for simplicity, the testing plus vaccination strategy was chosen as employing these disease control inputs is more directly influenced by BVDV risk.

For noninfected herds, the required PI-free premium per head was estimated as the difference in the control costs of the most cost-effective strategy and the testing plus vaccination strategy, divided by the number of calves marketed. For infected herds, the PI-free premium per head was estimated as the difference in the control costs of the most effective strategy and the testing plus

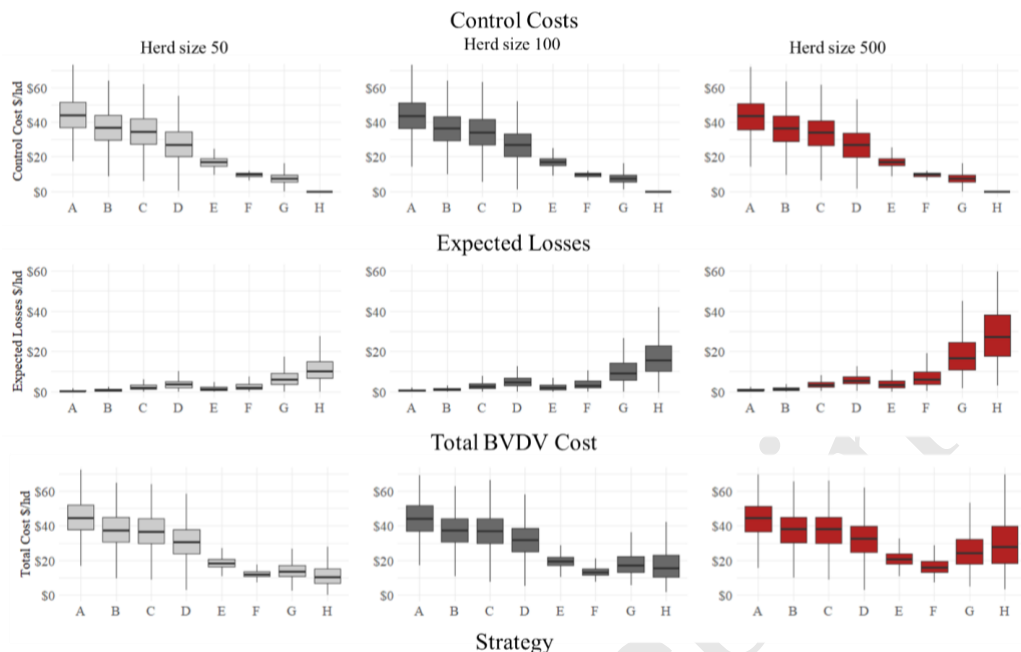


Figure 4. Control Costs, Expected Losses, and Total Cost of BVDV Control Strategies for Herd Sizes 50, 100, and 500

Notes: Box plots represent minimum and maximum (whiskers), first and third quartiles (box), and median (line within the box). Strategies A-D are closed herd, A and E are vaccination and testing, B and F are vaccination only, C and G are testing only, and D and H are no additional control strategies.

vaccination strategy and the forgone revenue of marketing PI animals, divided by the total number of non-PI calves marketed. For infected herds, it was assumed that 2% of the calf crop is PI, following estimates of within herd prevalence of PI animals of infected herds from (USDA, 2010b).

Results

The effect of control strategies on BVDV outbreak risk are shown in Figure 3. Within each herd size stratum, the risk of outbreak for each BVDV control strategy was statistically different from one another ($P < 0.01$). The simulation model predicted that the average BVDV risk for herd sizes 50, 100, and 500 was 5.22%, 7.41%, and 12.88%, respectively. The dashed line across Figure 3 represents the overall average risk for all herd sizes considered, which was estimated to be 8.51%.

Strategies A through F resulted in mean BVDV risk values at or below the national average. Maintaining a closed herd was particularly effective at reducing risk. For all herd sizes considered, strategies that included closed herd status (A – D) resulted in an average risk of 3.32%. For open herd strategies that included vaccination (E and F) the simulated average risk for all herd sizes considered was estimated to be 5.21%. Strategies G and H results in an average risk that was greater than the national average for each herd size.

The simulation model resulted in substantial differences in the variability of BVDV risk. Strategies that included closed herd status (A – D) resulted in less variability of risk outcome relative to open herds. For open herds, not only did G and H result in the highest average risk, but they also resulted in the greatest uncertainty in risk outcome. The results also indicate a positive relationship between herd size and BVDV risk due to the potential for greater spread of disease amongst the larger herd. This relationship is particularly evident for open herds strategies. The

mean BVDV risk for open herd strategies was 7.79%, 11.47%, and 21.80% for herd sizes of 50, 100, and 500, respectively.

Figure 4 illustrates the control costs, expected losses, and total BVDV cost for each strategy under the three herd sizes considered. The first panel depicts control costs, the second depicts expected losses, and the last depicts total BVDV cost.

The top panel of Figure 4 depicts the control costs of each strategy. The average control costs for all herd sizes and strategies considered was \$22/head. Within each herd size stratum, each strategy's control costs were statistically different from one another ($P < 0.01$). As expected, strategies that included more disease management inputs had higher control costs relative to the average. On average, maintaining a closed herd was considered the most expensive disease control input due to expenditure on capital and labor required to raise replacement heifers internally, along with the forgone revenue of marketing the heifer at weaning. Consequently, closed herd strategies resulted in control costs that were above the average level across strategies. However, this result will vary significantly depending on region, economic factors, and forage availability. Because of this variability, closed herd strategies faced greater variation in control costs due to the variation of year-to-year operational costs. In contrast, open herd strategies experienced relatively less variation in control costs because vaccination and testing constituted a smaller proportion of total expenditure on control costs. Additionally, they experienced less variation in total BVDV costs. Summary statistics of the control costs for each herd size are provided in the Appendix.

The center panel of Figure 4 depicts the expected losses of each strategy. Average expected losses across all control strategies were \$3.87, \$5.71, and \$9.20, for herd sizes 50, 100, and 500, respectively. Within each herd size stratum, the expected losses for each control strategy were statistically different from one another ($P < 0.01$). For all herd sizes considered, strategies A-F resulted in expected losses at or below the mean for a given herd size. Furthermore, strategies that included more disease management inputs reduced the variability in expected losses. Under open herd strategies, larger herds faced a higher probability of BVDV outbreak. Correspondingly, larger herds had greater expected losses due to BVDV. For example, for herd sizes of 50 and 500, strategy H yielded expected losses of \$11.76 and \$31.04, respectively.

Production losses and treatment expenditure constituted 93% and 7% of expected BVDV losses, respectively. Within production, reproductive losses were the largest contributor (39.7%), followed by morbidity (39.1%), preweaning mortality (12.3%), and premature culling (8.9%). Within treatment expenditure, veterinary cost was the largest contributor (61%), followed by medication cost (30%), and extra labor cost (9%). Additional information about the losses associated with a BVDV outbreak is provided in the Appendix.

The bottom panel of Figure 4 illustrates the total BVDV cost for each control strategy stratified by herd size. For a herd size of 50, all total BVDV costs were statistically different from one another ($p < 0.01$) except for strategies B and C ($P = 0.24$). For a herd size of 50, strategies that required little to no BVDV management resulted in the lowest total BVDV cost. Strategies F, G, and H resulted in the lowest cost at \$12.45, \$14.62, and \$11.76, respectively. There are tradeoffs among the three options. Strategy H resulted in the average lowest total cost but has greater outcome variability. Strategies F and G resulted in slightly higher total costs but reduced outcome uncertainty. The added control costs associated with closed herd strategies were not offset by reduced expected BVDV losses. Consequently, these strategies were predicted to be the less cost-effective.

Similarly, for a herd size of 100, less management-intensive options resulted in lower total BVDV costs. All total BVDV were statistically different from one another ($P < 0.01$), aside from strategies B and C ($P = 0.48$). Like the results from a herd size of 50, strategies F, G, and H resulted in the lowest total BVDV cost at \$13.307, \$18.33, and \$18.06, respectively. Among these alternatives, the model predicted vaccination (strategy F) to have the lowest total cost and the least outcome variability. Relative to strategies that included open herd status, closed herd strategies increased the average total BVDV cost by \$23.34 per head. Because larger herds face greater risk

Table 3. Sensivity analysis comparison of the total economic impact when the probability of BVDV outbreak is increased by 10% and 20% (\$/head)

Change in Outbreak Risk	Control Strategies							
	A	B	C	D	E	F	G	H
Herd size: 50								
10%	\$0.05	\$0.07	\$0.24	\$0.38	\$0.17	\$0.27	\$0.72	\$1.18
20%	\$0.11	\$0.18	\$0.48	\$0.76	\$0.33	\$0.54	\$1.43	\$2.35
Herd size: 100								
10%	\$0.07	\$0.11	\$0.31	\$0.50	\$0.25	\$0.41	\$1.11	\$1.81
20%	\$0.14	\$0.23	\$0.61	\$1.00	\$0.51	\$0.83	\$2.21	\$3.61
Herd size: 500								
10%	\$0.08	\$0.14	\$0.36	\$0.59	\$0.43	\$0.74	\$1.91	\$3.10
20%	\$0.17	\$0.28	\$0.72	\$1.18	\$0.87	\$1.47	\$3.81	\$6.21

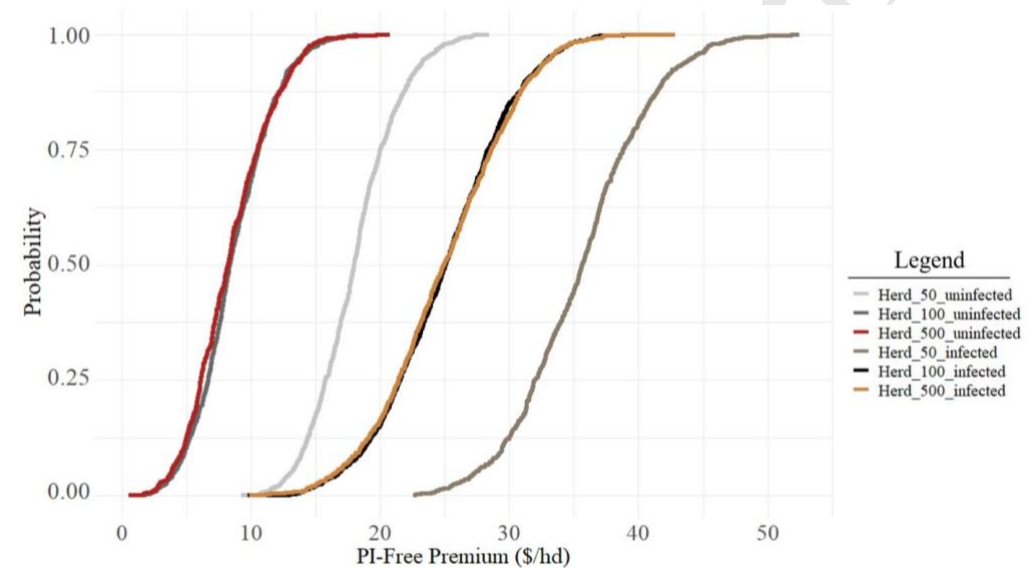


Figure 5. Cumulative Density Function of PI-free Premiums Needed for Testing Plus Vaccination to be the Most Cost-Effective Strategy for Infected and Non-Infected Herds

of exposure, their expected losses are greater. Consequently, incurring a larger amount of control costs to mitigate the substantially large expected losses makes some expenditure on BVDV control more cost effective.

For a herd size of 500, the heightened risk of BVDV outbreak resulted in moderately intensive control strategies being the most-cost effective. All strategies were statistically different from one another ($P<0.01$), aside from strategies B and C ($P=0.17$). Strategies E, F, and G resulted in the lowest expected total BVDV cost of \$21.08, \$16.49, and \$26.64, respectively. In addition to resulting in the lowest total cost, the results suggest that strategy F has the lowest variability in outcome. Relative to smaller herds, the considerable BVDV risk faced by large herds resulted in strategy H having a higher expected total BVDV cost and greater variability.

The results of the sensitivity analysis are given in Table 3. The ranking of strategies by cost-effectiveness from the simulation output was not altered given changes in the risk of BVDV. Strategies for which total BVDV cost is primarily comprised of expected BVDV losses were more

sensitive to changes in BVDV risk. For example, for a herd size of 50, a 20% increase in the risk of a BVDV outbreak increases the total cost of strategy H by \$2.35 per head versus strategy E by \$0.33. The largest changes in total cost due to changes in risk happen when the herd size is 500. Under this scenario, a 20% increase in BVDV risk is predicted to increase total BVDV cost within the range of \$0.17 to \$6.21, depending on the control strategy.

Figure 5 illustrates the cumulative density functions of PI-free premiums required for the testing plus vaccination strategy (Strategy E) to be the most cost-effective control option. PI-free premiums were considered for infected and uninfected herds of size 50, 100, and 500.

The most cost-effective strategy for a herd size of 50 was the no control option (H). In order for testing plus vaccination to become the most cost-effective strategy for an uninfected herd, the PI-free premium must cover the costs of testing and vaccination for the entire herd. For the infected herd, the PI-free premium must cover the cost of testing, vaccination, and the forgone revenue associated with marketing PI calves, assuming 2% of calves are PI. For herd sizes of 100 and 500, strategy F (vaccination) was the most cost-effective strategy. For testing plus vaccination to become the most cost-effective strategy for an uninfected herd, the PI-free premium must cover the costs of testing. For an infected herd, the PI-free premium must cover the costs of testing and the forgone revenue associated with marketing PI calves.

For noninfected herds, the average required PI free premium to induce the testing plus vaccination strategy to be the most cost-effective strategy was \$18.10, \$8.64, and \$8.41 for herd sizes of 50, 100, and 500, respectively. The variation in these values largely depends on the cost of testing and vaccination for a producer. For infected herds, the average required PI free premium to make testing plus vaccination the most cost-effective strategy was \$35.95, \$25.32, and \$25.28 for herd sizes of 50, 100, and 500, respectively. In addition to the variability due to control costs, the required PI-free premiums for infected herds can significantly vary depending on the within herd prevalence of PI animals. For example, if the within herd prevalence of PI calves was 10%, the required PI-free premium for a herd size of 50 would be \$110.75 per head.

Discussion

BVDV and PI animals cause economic losses for the beef industry. This paper develops a stochastic simulation model to assess the total costs of BVDV control strategies for U.S. cow-calf producers based on herd size. Additionally, it assesses the required PI-free premium to incentivize greater BVDV management for infected and uninfected herds. Despite multiple economic studies suggesting that industry-wide adoption of BVDV control would yield positive net benefits, the adoption of BVDV management has been low, particularly for small herds. Our findings suggest that the low prevalence of PI cattle along with diminishing marginal returns to BVDV control inputs results in less-intensive BVDV control strategies becoming more cost-effective for cattle producers. Furthermore, our results suggest that current PI-free premiums may not be sufficient to incentivize the combination of testing and vaccination for uninfected or infected herds, particularly for herds of less than 50 head.

An important finding from the study was that minimizing expected BVDV losses never minimized the total economic impact of BVDV for a cow herd. This supports our first hypothesis. Two underlying bio-economic processes drive this finding. The first is the effect of untreated disease incidence on the marginal value of a disease control input. The second is the two-step method of control and damage function used to describe the marginal value of a disease control input.

From our conceptual model and as reported in Fox and Weersink (1995), the marginal value of a disease control input depends on the price of output, the untreated disease incidence, the disease-free level of output, the severity of output reduction due to disease, and the effectiveness of control inputs in reducing disease prevalence. Because most herds are PI-free, the untreated disease incidence is zero, or close to zero. Hence, for PI-free herds, the marginal value of BVDV

control inputs is low due to the negligible levels of untreated disease incidence. In other words, because most herds are not infected with BVDV, there is little value in engaging in BVDV management for the producer.

As reported in Lichtenberg and Zilberman (1986), the two-step mechanism of evaluating the effect of a disease control input on the production function underscores the importance of the damage function when determining the marginal value of disease control inputs. At high levels of disease incidence, the marginal value of a disease control input will be sizable. This is because, at high levels of prevalence, the proportional reduction of disease prevalence due to each additional unit of a disease control input applied is substantial. This will correspond to large reductions of disease incidence within the damage function, leading to large increases in realized output. Hence, the marginal value of a disease control input is relatively large when high levels of disease is present. When disease prevalence is low, the marginal effect of a disease control input on the proportional reduction of disease incidence is relatively smaller. Correspondingly, the proportional reduction within the damage function may be negligible, and the marginal value of a disease control input smaller. Therefore, as we increase the quantity of disease control inputs used, the prevalence of a disease is reduced, and the marginal value of a disease control input diminishes.

To demonstrate, for a herd size of 50, our results suggest increasing from no control to vaccination solely (strategy H to F), reduced the average level of risk by 12.59%; whereas increasing control from maintaining a closed herd and vaccination to maintaining a closed herd, testing, and vaccination (B to A), reduces the average level of risk only by 0.49%. Correspondingly, the value (in terms of reducing BVDV expected losses) of moving from H to F is \$9.96 per head, whereas moving from B or A is only \$0.36 per head. Similar results have been noted in the dairy sector when evaluating the cost effectiveness of including introduction checks, vaccination, and producer sourcing for dairy heifers in Canada (Chi et al., 2002). The combination meager levels of untreated PI-BVDV incidence and diminishing marginal returns to disease control inputs suggests that it is rational for a producer to not engage in PI animal eradication. This conclusion has critical implications for the stocker and feed yard sectors. Because cow-calf producers are not likely to enhance BVDV management given the current set of incentives, the financial losses attributed to PI cattle will persist.

For the cow-calf producer, the model suggested that the majority of expected losses from BVDV were due to reproductive complications. This agrees with previous research using the same model in the dairy sector (Weersink et al., 2002; Houe, 2003). However, our model predicted a larger portion of losses to be attributed to reduced performance (increasing preweaning morbidity), relative to the above publications production losses of reduced milk yield. Additionally, our estimates of BVDV production losses fall within the range of a recent meta-analysis. Pinior et al. (2019) estimated mean annual production losses due to BVDV infection to fall within the range of €42.14 – €67.19, or \$49.72 - \$79.28 per head depending on viral circulation intensity. Our model predicted mean annual production losses due to BVDV infection to be \$73.58 per head. However, our model predicted greater variation in the expected losses due to BVDV infection, largely dependent on the reproductive and biological impacts of a BVDV infection. Assuming 9% of cow-calf herds have at least 1 PI animal, and cattle are naïve to BVDV, the estimated U.S. cow-calf sector production losses due to BVDV would fall within the range of \$29 million to \$65 million annually.

Within the cow-calf population, our results suggest that it is likely that larger herds are more likely to be exposed to a PI animal. This is particularly true for herds that are importing replacement heifers. For example, for open herd strategies, our study found that the average level of BVDV outbreak risk is 7.96%, 11.54%, and 20.53% for herd sizes 50, 100, and 500, respectively. Our findings suggest that because larger herds face greater risk and thereby greater expected losses, adopting some level of BVDV management becomes more cost effective. This finding supported our second hypothesis. Correspondingly, we would expect larger herds to adopt more rigorous BVDV management protocols, such as regular vaccination for calves and the cow

herd. This claim is reinforced when model outputs are compared to BVDV management practices seen in cow-calf production. For example, the USDA (2020b) reported that 52.6%, 68.3%, and 84.8% of operations with cowherds of 1-49, 50-100, and 200+ vaccinated cattle against BVDV, respectively.

For the beef industry, our results suggest that the eradication of PI animals is unlikely to occur given the current incentive structure. While vaccination protects cow herds against infection, it does not generally eliminate PI animals². Consequently, disease caused by PI animals is likely to continue. Our model suggested that for a herd size of 50, it was cost-effective to not engage in BVDV control. Given that roughly 40% of the U.S. beef cow inventory reside in herds of 50 cows or less (USDA, 2010a), these small herds are the likely source of PI cattle that enter the supply chain. While our model predicts that it is cost effective to engage in vaccination for herds larger than 100, vaccination is not completely efficacious in preventing BVDV infection. Hence, PI animals can still be generated. If the beef industry aims to reduce the prevalence and economic impact of PI animals, increasing incentives for BVDV control within the cow-calf sector is required.

PI-free premium compensations from feeder cattle buyers to feeder cattle sellers is a potential mechanism to incentivize greater BVDV control. While PI-free premiums exist, the volume of cattle marketed under these premiums has been low. Our model predicts that current PI-free premiums may not be sufficient to incentivize enhanced BVDV management amongst small herds, nor medium to large herds that may be infected with BVDV. Our model predicted that in order for a testing plus vaccination strategy to be the most cost effective for uninfected herds, the PI-free premiums must be, on average, \$18.06, \$8.63, and \$8.41 per head for herd sizes 50, 100, and 500 respectively. The estimates of these premiums depend on the cost of control inputs and labor costs. The required PI-free premiums are larger for herds less than 50 relative to larger herds because our model predicted that not engaging in BVDV control was cost effective for small herds. Hence, to incentivize switching to a vaccination plus testing strategy, premiums need to be large enough to cover the costs of employing both disease control inputs. In contrast, the model predicted the vaccination was the most cost-effective strategy for medium and large sized herds, and therefore PI-free premiums need to only cover the costs of testing and labor.

The required PI-free premiums for infected herds are significantly larger due to forgone revenue of marketing PI animals. For infected herds, the average required PI-free premiums for the testing plus vaccination strategy to be the most cost effective was \$35.52, \$24.90, and \$24.86 per head for herd sizes of 50, 100, and 500, respectively. These values will depend on the cost of control strategies, prevalence of PI animals, calf price, and forgone revenue of marketing PI animals. When input costs and calf prices are high, the cost of testing and the forgone revenue of marketing PI cattle increase. Hence, the required PI free premiums to incentivize greater BVDV control likely outpace the available PI free premiums on the market. Consequently, during inflationary periods, it is possible that less cattle are marketed as PI free.

Martinez et al. (2021) found that lots that were PI tested were associated with a \$1.19/cwt premium, or about \$10 per head premium. While this estimate is larger than the PI-free premiums needed for medium and large uninfected herds, it is important to note that without testing, the infection status of a herd is unknown. Hence, because current PI-free premiums are not sufficient to cover the forgone revenue of marketing PI animals, producers may be disincentivized to test calves for PI status. Additionally, knowledge gaps among producers may inhibit the adoption of testing. Among small operators, 48% do not know if removing PI calves affects the value of calves in the remaining herd (USDA, 2020b). Consequently, providing sufficient compensation for enhanced BVDV control and improved education about the value of PI testing is warranted to encourage enhanced BVDV control.

² A small exception can occur when females are vaccinated against BVDV during a specified period of gestation (Zimmer et al., 2002)

As with any simulation model, the applicability of results depends on the suitability of the model structure and input distributions. While veterinary knowledge of BVDV is extensive, economic and epidemiological data about BVDV specific to cow-calf production is limited. Accordingly, the greatest limitation of this research was the assumptions made about the distributions of epidemiological parameters in the model. The risk of outbreak could have potentially been underestimated given the model does not consider risk of BVDV exposure due to the presence of cervids and transiently infected cattle. Additionally, the differences in attitude toward risk among producers were not considered. While generalizations can be made, the most cost-effective BVDV control strategy will depend on farm characteristics unique to each operation.

Conclusion

For most herds, vaccination was found to be the strategy that minimizes the total cost of BVDV for a cow-calf producer. A strategy's total cost was determined by its level of BVDV risk, cost of disease control inputs, and losses due to an outbreak. The positive relationship between herd size and BVDV risk suggests that larger herds are more likely to adopt rigorous BVDV management programs. The estimated PI-free premium required to induce a testing plus vaccination strategy to be the most cost effective largely exceeds current PI-free premiums on the market. Hence, if BVDV control is a priority for the cattle industry, greater incentives must be relayed to cow-calf producers. Future research should: 1) investigate the cost of PI exposure to feedlots, 2) assess mechanisms of reducing transactions costs associated with buying and selling cattle in a PI-free market.

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Appendix A

Table 4. Summary statistics of the 1,000 iterations of cost of BVDV control strategies and BVDV outbreak losses

Variable	Herd size 50				Herd size 100				Herd size 500			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Control Costs												
Maintaining closed herd	\$1,347	\$516	-\$159.2	\$2,824	\$2,694	\$1,042	-\$277	\$3,400	\$13,432	\$5,112	- \$5095	\$28,717
Herd vaccination	\$476	\$57	\$314	\$593	\$916	\$161	\$566	\$1,189	\$4,568	\$790	\$2,838	\$5,951
BVDV-PI testing	\$371	\$141	\$0	\$853	\$728	\$278	\$0	\$1,600	\$3,793	\$1,462	\$0	\$10,670
BVDV Outbreak Losses												
Reproductive losses	\$1,389	\$887	\$42	\$6,491	\$3,017	\$1,926	\$269	\$12,395	\$13,981	\$9,178	\$595	\$78,363
Morbidity Losses	\$1,369	\$434	\$425	\$3,502	\$2,755	\$833	\$966	\$6,524	\$13,386	\$4,186	\$4,412	\$29,117
Mortality Losses	\$431	\$447	\$0.00	\$3,316	\$826	\$834	\$0.94	\$4,905	\$4,193	\$4,263	\$0.92	\$41,134
Premature Culling Losses	\$311	\$511	-\$160	\$3,809	\$744	\$1,238	-\$502	\$15,913	\$3,512	\$5,308	- \$11178	\$41,706
Veterinary Cost	\$106	\$63	\$3.50	\$416	\$228	\$132	\$18	\$819	\$1,088	\$675	\$52	\$5,321
Medication Cost	\$53	\$32	\$1.59	\$211	\$115	\$67	\$11	\$401	\$544	\$338	\$27	\$2,810
Extra Labor Cost	\$18	\$11	\$0.58	\$72	\$38	\$23	\$2.28	\$165	\$182	\$117	\$9	\$1,037
Total BVDV Outbreak Losses	\$3,679	\$1,419	\$14	\$9,190	\$7,727	\$2,986	\$2	\$22,736	\$36,888	\$14,301	\$8,348	\$125,173