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# Canadian beef and dairy farmers' attitudes towards animal vaccines\*

Albert I. Ugochukwu  and Peter W. B. Phillips<sup>†</sup>

The willingness to pay (WTP) approach is increasingly being used in different disciplines to assess peoples' readiness to accept change. This paper assesses the potential for two subunit vaccines for the prevention and control of bovine tuberculosis and paratuberculosis in cattle. A survey of beef and dairy farmers was conducted across Canada to identify factors that influence their WTP for subunit vaccines. Estimated results of the interval-data model indicate that the size of a farmer's cattle herd, neighbourhood effect, and buyer recommendations for vaccination significantly influence farmers' WTP while veterinarians appear to be the most critical pathway for farmers to source information on new vaccine options. The mean willingness to pay amounts for both vaccines reveals that farmers are likely to use the vaccines if the costs are kept at reasonable level.

**Key words:** bovine tuberculosis, Johne's disease, subunit vaccine, willingness to pay.

## 1. Introduction

Biosecurity has been identified as a major challenge in the livestock sector globally and is vital for improved animal welfare and global health (Anderson 1998; Gunn *et al.*, 2004; Frössling and Nöremark 2016). Vaccination is one of the mechanisms used in the prevention and control of infectious diseases in animals (Cresswell *et al.* 2014), including bovines (Sayers *et al.* 2013; Sarrazin *et al.*, 2014; Sahlström *et al.* 2014). For example, vaccination has been used in preventing and ameliorating the severity and damage of clinical diseases in beef and dairy herds. Vaccines help in improving herd immunity by reducing the amount of pathogen shedding by individual animals and the period of shedding within the herd (Clark, 2015).<sup>1</sup> They also help to avert losses associated with disease outbreak (Stott and Gunn 2008).

Some studies (Heffernan *et al.* 2008; Ritter *et al.* 2017) examine farmer perceptions and attitudes towards biosecurity in the livestock industry and identify incentives that enhance their participation in effective disease

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<sup>1</sup> <https://www.canadiancattlemen.ca/2015/10/28/understanding-the-value-of-vaccines/>

preventive management practices, including vaccination. However, determinants of farmers' decision-making regarding vaccination of animals have not been widely explored in the literature. Results of a recent study in the United Kingdom (Imogen, 2015) indicate that farmers often vaccinate animals in reaction to 'a problem' (p. 3) such as outbreak of a disease. There is need for a proactive approach to reduce negative externalities and costs associated with disease outbreaks.

This paper focuses on an alternate strategy of two new subunit vaccines with companion diagnostics<sup>2</sup> Canadian producers can adopt for the prevention and control of Johne's disease (JD) and bovine tuberculosis (bTB). This study is similar to the experimental study by Doel *et al.* (1994) which demonstrates that vaccination policy can provide effective and rapid protection of animals from foot-and-mouth disease (FMD). Our study explores beef and dairy farmers' willingness to pay and adopt subunit vaccines. This paper identifies *the factors that influence a farmer's willingness to pay for and adopt subunit vaccines for the prevention and control of JD and bTB.*

A subunit vaccine contains a part of the target pathogen that triggers an immune response restricted to the target component alone and consists of bacterial or viral antigens that activate immune response to infectious agents.<sup>3</sup> Given some vaccines such as the BCG (Bacille Calmette-Guerin) for bTB have been found to interfere with other bTB diagnostic tests, including tuberculin skin and gamma interferon tests, any JD vaccine is also likely to show positive in those diagnostics due to similarity between the bacteria that cause the two diseases.<sup>4</sup> The ability to differentiate between vaccinated and infected animals would reduce regulatory difficulties, cross-border rejections, health risks, and economic losses associated with these diseases.

Johne's disease and bTB are among the highest profile, economically important livestock diseases affecting beef and dairy production in Canada and globally. JD, caused by *Mycobacterium avium subspecies paratuberculosis*, is a bacterial disease that affects the small intestines of ruminants and has a long dormant period between infection and manifestation of clinical signs (Tiwari *et al.* 2006; BCRC, 2016). Similarly, bTB is a bacterial disease caused by *Mycobacterium bovis*, which can lie dormant in an animal for a long time before showing clinical signs (CFIA, 2015), and can be transmitted through contact with infected domesticated or wild animals. Studies have shown that these two diseases affect beef and dairy herd productivity and result in economic losses, in the form of low milk production (Wilson *et al.* 1993; Tiwari *et al.* 2008), reduced market value for culled animals (Whitlock *et al.*,

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<sup>2</sup> Companion diagnostics reveal the presence of the disease-causing organism in an infected animal but do not show a positive response in vaccinated animals. Therefore, it can differentiate between vaccinated and infected animals, especially for bTB and JD.

<sup>3</sup> [www.ifst.org/sites/default/files/Livestock%20Vaccines-PN-433\\_0.pdf](http://www.ifst.org/sites/default/files/Livestock%20Vaccines-PN-433_0.pdf)

<sup>4</sup> Ibid.

1985), and reduced fertility (Merkal *et al.* 1975). JD had been estimated to generate \$15.4 m annual costs in England (Chiodini *et al.* 1984), \$54 m in Wisconsin (Arnoldi and Hurley 1983), \$5.4 m in Pennsylvania (Whitlock *et al.*, 1985), between \$200 and \$250 m in U.S. dairy herds (Garry *et al.* 1999), and \$2.1m in Australia (Gill 1989). In Canada, Tiwari *et al.* (2008) reported an economic loss of \$2,500 per 50-cow dairy herd with JD outbreaks, which translates to a total financial loss of approximately \$34.5 m to the estimated 12,529 dairy herd owners in Canada in 2008.

Effective control of some animal diseases, such as swine erysipelas and foot-and-mouth disease (Lombard *et al.* 2007), and rinderpest (Normile 2008) was achieved through vaccination. Although vaccines have been developed for JD and bTB, vaccines for bTB are not used due to its interference with the usual tuberculin skin test used to ascertain whether a herd is free of bTB (Álvarez *et al.*, 2009; Conlan *et al.* 2015). Biosecurity measures in many countries involve testing animals at the borders for the presence of these infectious diseases, particularly animals for cross-border trade.

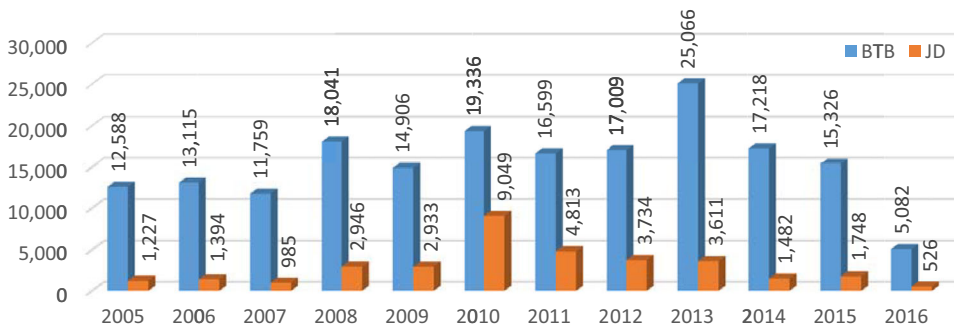
There are existing vaccines (whole-cell based) in the market for JD and bTB but have not been overly effective as animals consistently get infected with bTB by wildlife species (Schiller *et al.* 2010) and still test positive at the border control after receiving the vaccines. Another challenge is the inability to differentiate between vaccinated (disease-free) and infected animals and, in some cases, formation of granuloma (tissue damage) at the injection sites (Patterson *et al.*, 1998; Kohler *et al.* 2001), which results in additional costs.

To answer the research question, an interval-data model was estimated using survey data on Canadian beef and dairy farmers. Information on farmers' willingness to pay for the vaccines would be relevant in developing the subunit vaccines and also decisions on marketing and pricing (Bazzani *et al.* 2018).

This paper consists of five sections. Section two discusses the prevalence and transmission of JD and bTB. Section three describes data and methods data. Section four discusses the results of the analysis and Section five discusses implications and concludes the paper. the concluding

## **2. Prevalence and transmission of Johne's disease (JD) and bovine tuberculosis (bTB)**

One proven pathway of infection is comingling and transmission between wildlife and herds (Walter *et al.*, 2012; Pruvot *et al.* 2014). JD and bTB are among animal diseases that have received less attention in the past, but there is an increasing prevalence rate globally in recent times (OIE, 2009). The incidence and spread of these two diseases are no longer a function of distance between countries; outbreaks are spreading while few countries are free of the diseases. Disease management is becoming a growing challenge



**Figure 1** Global confirmed cases of bTB and JD (January 2005 - June 2016).

Data source: OIE-WAHIS website ([http://www.oie.int/wahis\\_2/public/wahid.php/Diseaseinformation/statusdetail](http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail)). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

with increased movement of animals across borders. Figure 1 shows confirmed cases of JD and bTB globally between 2005 and June 2016. The result shows an increase in the prevalence of bTB and JD in the past decade.<sup>5</sup> The reduction in the number of confirmed cases since 2014 presumably is as a result of national-level control programs instituted in different countries, such as the United States (McKenna *et al.* 2006), Canada (Barker *et al.*, 2012), Australia (AHA, 2012), Denmark (Nielson *et al.*, 2007), and the Netherlands (Kalis *et al.* 1999).

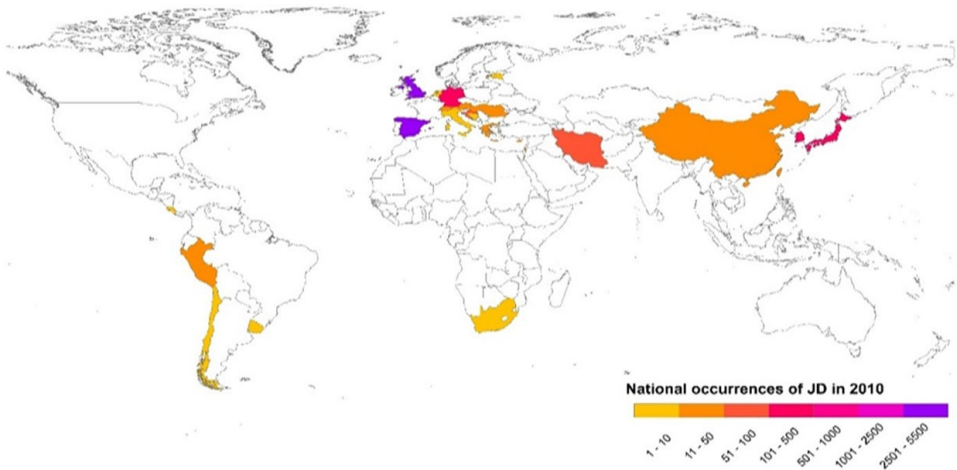
Figure 1 shows the highest incidence of JD and bTB occurred in 2010 and 2013, respectively (OIE 2017). The United Kingdom had the highest number of confirmed JD cases (60 per cent, Figure 2), followed by Spain (27 per cent, Figure 2). Ireland has the highest incidence of bTB cases (35 per cent, Figure 3), followed by Chile (18 per cent, Figure 3).<sup>6</sup> Going by regional distribution of JD prevalence between 2005 and 2016, of the 34,448 confirmed cases globally, 1.8 per cent are in North America, 0.4 per cent in Africa, 0.6 per cent in South America, 18 per cent in Asia, 0.009 per cent in Oceania, and 79 per cent in Europe.<sup>7</sup>

The rate of infection depends on the level of exposure to an infected herd and age of the animal, with younger animals having higher risk of infection (Chiodini *et al.* 1984; Katale *et al.*, 2012). Wildlife species are the major reservoir for bTB (Katale *et al.*, 2012). In contrast, adult animals are most often infected with *Mycobacterium avium* subspecies *paratuberculosis* (MAP),

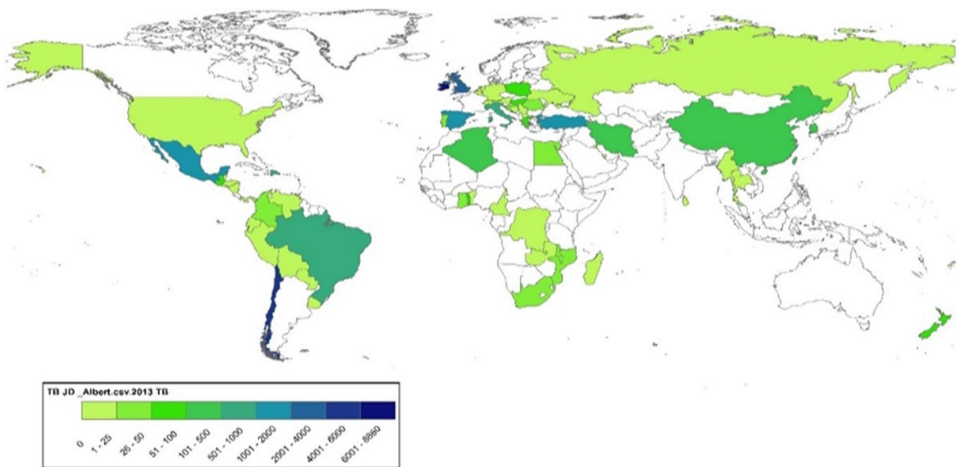
<sup>5</sup> It is important to note that the incidence of these diseases globally, particularly JD, has likely been under-reported due to poor surveillance mechanisms. For example, OIE reported no confirmed case of JD in Ireland between January 2005 and June 2016. However, Good *et al.* (2009) examined individual animal and herd level prevalence of JD in Ireland. They found that of 20,322 animals sampled, 201 were positive for JD. At the herd level, the result shows that of the 639 herds sampled, 137 herds had at least one animal that tested positive to JD.

<sup>6</sup> The percentage numbers show the per cent of herds infected.

<sup>7</sup> Authors' calculations based on data from OIE ([http://www.oie.int/wahis\\_2/public/wahid.php/Diseaseinformation/statusdetail](http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail))



**Figure 2** Global JD occurrence 2010. Data source: [http://www.oie.int/wahis\\_2/public/wahid.php/Diseaseinformation/statusdetail](http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail). [Colour figure can be viewed at [wileyonlinelibrary.com](#)]



**Figure 3** Global bTB occurrence 2013. Data source: [http://www.oie.int/wahis\\_2/public/wahid.php/Diseaseinformation/statusdetail](http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail). Map credit: Savannah Gleim. [Colour figure can be viewed at [wileyonlinelibrary.com](#)]

the cause of JD, through contaminated environments (Rankin 1962), poor nutrition (Kennedy and Benedictus 2001), and feed contaminated by rabbit droppings (McKenna *et al.* 2006). Young animals are more often infected through milk or colostrum from infected cows (Streeter *et al.* 1995). Both young and adult animals can get infected through contaminated faecal shedders (Sweeney *et al.* 1992).

Canada has experienced several animal disease outbreaks in recent years, including bovine spongiform encephalopathy (BSE) in 2003, *E. coli* O157:H7 contamination in beef products traced to XL Foods Inc. in Alberta in 2012



and bovine tuberculosis in 2017. Although JD and bTB are not presently a concern in the United States, Canada's largest trading partner for live cattle and other products, there is need for precautionary measures, especially given Canada's recent increases in import of live cattle from the U.S.<sup>8</sup>

Vaccination for JD has been used and accepted in a number of countries, including Iceland (Fridriksdottir *et al.* 2000), Australia (Reddacliff *et al.* 2006), Spain (Juste and Perez 2011), United States, the Netherlands, and Norway (Singh *et al.* 2015). Subunit vaccines with well-defined recombinant MAP proteins have been shown to avoid some of the problems of whole-cell-based commercial vaccines (Rosseels and Huyge, 2008; Park and Yoo 2016). They offer a real opportunity to reduce health risks and economic losses associated with these diseases, especially in endemic regions, by helping to reduce lesions (Eppleston and Windsor 2007), MAP excretion (bacteria load), productivity loss (Singh *et al.* 2007), and display of clinical signs (Juste 2012; Gupta *et al.* 2015).

### 3. Data and Methodology

#### 3.1. Study area

The study population consisted of Canadian beef and dairy farmers. The choice of beef and dairy farmers stems from the fact that: (i) several studies have shown that cattle farmers have experienced economic losses of varying degrees arising from JD and bTB outbreaks over the years; and (ii) the vaccines are targeted specifically for cattle, although they could be extended to other animals (e.g. sheep and goats). Figure 4 (map of Canada showing number of beef and dairy cattle and farms) is missing here.

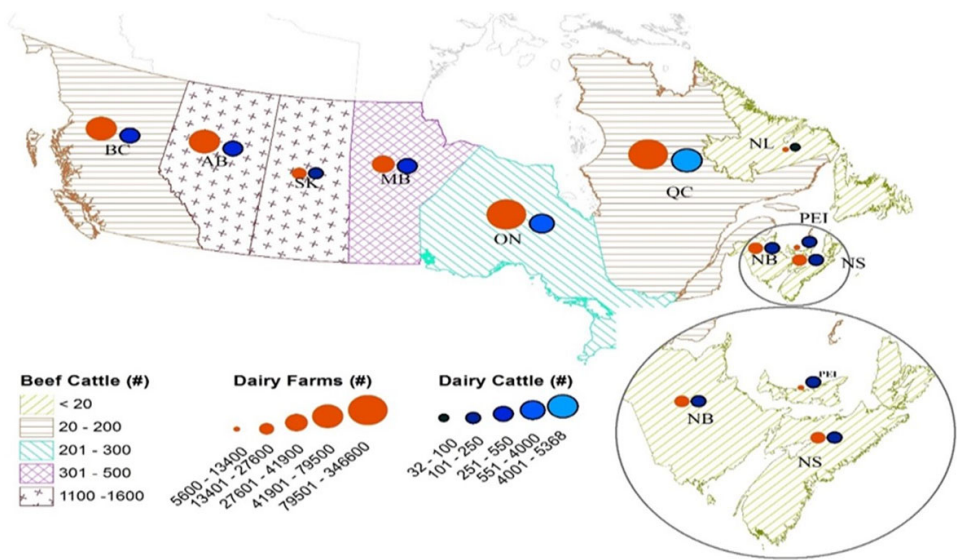
#### 3.2. Data collection procedure

The study used primary data collected through a survey conducted between November 2016 and February 2017. A questionnaire was developed, pretested, and administered face-to-face with paper copies and online through the University's *FluidSurvey*. The objective of the survey was to examine livestock industry readiness and willingness to pay for new subunit vaccines for JD and bTB. The vaccines are still being developed in Canada and are not yet available in the market.

A combination of face-to-face interviews and an online survey were used for data collection following similar studies involving cattle producers (Olynk and Wolf 2008; Cresswell *et al.* 2014; Richens *et al.* 2015). Face-to-face interviews with beef and dairy farmers in western Canada took place during the 2016 *Canadian Western Agribition show* from 20 to 25 November and the 2017 *Saskatchewan beef industry conference* on 24 January 2017. During

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<sup>8</sup> Canada imported 138,348 live cattle from the United States in 2017, a 346% increase from 2016 (AAFC, 2018).



**Figure 4** Map of Canada showing number of beef and dairy cattle, and farms. Note: BC (British Columbia), AB (Alberta), SK (Saskatchewan), MB (Manitoba), ON (Ontario), QC (Quebec), NB (New Brunswick), NL (Newfoundland & Lebrador), NS (Nova Scotia), PEI (Prince Edward Island). #, number. Map Credit: Savannah Gleim. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Agribition, interviews were conducted at individual booths to ensure that we reached the actual farmers. Some questionnaires were completed at the event while other farmers were given addressed envelopes and an email option. In other provinces, some farmers were interviewed one-on-one at their individual farms, while others were interviewed during their provincial meetings.

The survey was posted online and the link sent via email to the Chair, Board members, General Managers, and CEOs of the producer associations for their members' participation. The researchers attended Association meetings and explained the purpose and importance of the study to farmers. Some face-to-face interviews took place during the meetings. Survey awareness was also created through farmers' online fora and social media networking sites (e.g. Facebook and Twitter pages of the Western Beef Development Centre).

The questionnaire included questions that tested farmer attitudes towards existing animal vaccines and factors that are likely to affect their willingness to pay for and adopt the new subunit vaccines. Farmers were asked to list the vaccines they have used in the past and the diseases they were used for. Prior to answering the survey questions, detailed information on these diseases was provided to the participants to control for hypothetical bias. For the dependent variable, willingness to pay and adopt (WTP), contingent valuation questions were used to elicit farmers' valuation of the new vaccines. Farmers were asked to indicate the maximum amount they would be willing to pay for JD and bTB vaccine, respectively, assuming the vaccines are very effective and ready for purchase.



Subunit vaccines examined in this study are still under production and, therefore, not yet available in the market. This prompted the use of stated preference approach, contingency valuation (CV) in particular, in measuring the value of the vaccines (Louviere *et al.* 2000). The use of CV approach in animal disease control has not been widely explored in the literature. However, Bennett and Balcombe (2012) used CV to estimate farmers' WTP for cattle tuberculosis vaccine.

A major challenge in CV studies is the choice of elicitation format, including dichotomous-choice, open-ended and close-ended, multiple-bound, and payment card methods. Open-ended (OE) elicitation has been described as being difficult to answer and less realistic (Terfa *et al.* 2015) and creates avenues for respondents to over and/or under report their WTP values (Hanemann, 1984) unlike in the close-ended (CE) format. Arrow *et al.* (1993) and Carson and Groves (2007) argue that in a hypothetical study, respondents indicate lower WTP values in OE formats particularly when the propensity to afford the good is low or they have experience of the good (Willis 2002) and often overstate their WTP for private or public goods (Balistreri *et al.* 2001). In contrast Arrow *et al.* (1993) maintain that close-ended (CE) estimates are more conservative and realistic as respondents will not have any incentive to answer strategically. However, Cherry *et al.* (2004) found that bidders take into account prices of outside options (substitutes) when bidding, particularly for new products. Given this, a CE iterative bidding process was adjudged to be more incentive compatible (Whittington *et al.* 1990; Carson and Groves 2007); we used market prices (\$5, \$10, \$15, \$20, and > \$20) of existing whole-cell-based animal vaccines (substitutes) specified in double-bounded bidding rounds.

Taking cognisance of these, we used CE format. Following Bennett and Balcombe (2012), our CE design involves three stages: identification of attributes of the subunit vaccines; questionnaire design; and pretesting before actual survey. The idea is to ensure that our assumptions are robust and beef/dairy farmers have a good understanding of the vaccines and provide reliable WTP values.

Although the close-ended format may constrain farmers in choosing their WTP values, the advantage of the chosen double-bound dichotomous iterative bidding approach, in this context, is that it establishes the interval (price range of substitute vaccines) within which the actual WTP amount lies. This helps determine more accurately farmers' latent WTP for the vaccines. These are used to calculate the mean WTP amount for the population. Cummings *et al.* (1986) argue that this approach captures the maximum WTP amount consumers are willing to pay and can be used to trace the demand curve for the good and to measure consumer surplus.

For CV bids, Schnlze *et al.* (1981) suggest four types of biases that may occur, including strategic, information, instrument, and hypothetical bias. This implies that the stated WTP amounts by individual respondents could be adjudged truthful and accurate if these biases, particularly strategic, are

insignificant. To reduce these biases following Bennett (1983, 1987), we ensured: respondents are real farmers who would buy the new vaccines; the sampling size for beef and dairy farmers are large to minimise random error; the bid levels were chosen based on the prevailing market prices of existing whole-cell-based vaccines<sup>9</sup>; and, in addition to detailed explanation about the vaccines in the information statement, it was made clear to farmers that they will pay for the vaccines themselves. This implies that over reporting their maximum WTP would result in personal loss. To control for starting-point bias, different versions of the questionnaire (each having different initial bidding prices) were distributed and used. A total of 129 beef (74 face to face and 55 online) and 125 dairy (40 face to face and 85 online) farmers returned complete questionnaires, which were used for the analysis.

### 3.3. Ethical consideration

Ethical approval for the study was received from the University of Saskatchewan's Ethics Board (Beh 16- 425). To protect farmers' personal information and ensure anonymity, farmers did not indicate their personal information on the questionnaire. The only personal information disclosed by farmers is the province where their operations are located, which enabled the researchers to determine provincial distribution of participating farmers to ensure adequate representation of beef and dairy farmers across Canada.

### 3.4. Analytical technique

#### 3.4.1. Probit analysis

Probit analysis is a parametric technique (Morgan *et al.* 1982) with long-standing applications in the evaluation and characterisation of binomial response variables (Finney, 1978). Commonly applied in social sciences (Maddala, 1983), probit analysis is useful in situations where we have dichotomous or binary outcome variables. The dependent variable of a probit model is binomial and is based on the assumption that the functional form follows a normal (cumulative) distribution (Green and Hensher, 2010, p. 20).

An interval-data model was developed for the analysis. An interval-data model, also referred to as *double-bound* model, can produce robust and efficient estimates while retaining the desirable attributes of the discrete choice survey (Hanemann *et al.* 1991). It is used in modelling results that have interval censoring (i.e. the category in which each observation falls is known but the exact WTP is not known). In this study, each respondent indicated the maximum WTP amount for each vaccine which falls within a known category, justifying the use of an interval-data regression. The dependent variable (WTP) consists of 5 discrete categorical responses.

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<sup>9</sup> Increasing the bids above the existing market prices of substitute vaccines may increase "No" responses or reduce demand for the vaccines. Although vaccine-producing companies are not price takers, they tend to balance the trade-off between the quantities of the vaccines they would offer to sell and the prices beef and dairy farmers are willing to pay.

In this analysis, a farmer's decision to pay for and adopt a subunit vaccine is contingent on a vector of factors,  $\Gamma$ , including the number of cattle in the farmer's operation, risk of disease (JD and bTB) transmission from wild life, source of advice (information pathway) for cattle vaccination, reason (problem) for vaccination and participation in safety management programs.

### 3.4.2. The model

Assume the dependent variable,  $Y$ , represents levels of outcomes (farmers'  $WTP$  thresholds,  $\psi_j$ , for  $j$  categories where  $j = 1, \dots, k$ ) of a latent variable,  $Y^*$ . Assume the observed choice ( $y_i^*$ ) is a linear combination of a vector of predictors ( $\gamma$ ) and an error term ( $\mu$ ) that has normal distribution, we have:

$$y_i^* = \gamma\Gamma_i + \mu_i, \mu_i|\Gamma_i \sim N(0, 1), \quad \forall i = 1, \dots, N \quad (1)$$

If  $y_i = (1, 2, 3, 4, 5)$  for maximum  $WTP$  of (5, 10, 15, 20, > 20) dollars represented by  $\varepsilon_1, \varepsilon_2, \varepsilon_3$ , and  $\varepsilon_4$ , following Green (2002, pp. 736–737), the interval decision rule is given by:

$$y_i = \begin{cases} 1 & \text{if } y_i^* \leq \varepsilon_1 \\ 2 & \text{if } \varepsilon_1 < y_i^* \leq \varepsilon_2 \\ 3 & \text{if } \varepsilon_2 < y_i^* \leq \varepsilon_3 \\ 4 & \text{if } \varepsilon_3 < y_i^* \leq \varepsilon_4 \\ 5 & \text{if } y_i^* > \varepsilon_4 \end{cases} \quad (2)$$

Following the normal distribution assumption of the error term ( $\mu$ ) in probit models (Green, 2008, p. 777), the probabilities for the different thresholds are given by:

$$\begin{aligned} \Pr[y_i = 1|\Gamma_i] &= \Pr[y_i^* \leq \varepsilon_1] = \Pr(\gamma\Gamma_i + \mu_i \leq \varepsilon_1) \\ &= \Pr(\mu_i \leq \varepsilon_1 - \gamma\Gamma_i) \\ &= \Phi(\varepsilon_1 - \gamma\Gamma_i) = 1 - \Phi(\gamma\Gamma_i - \varepsilon_1) \end{aligned} \quad (3)$$

Following the same procedure, we have:

$$\Pr[y_i = 2|\Gamma_i] = \Phi(\gamma\Gamma_i - \varepsilon_1) - \Phi(\gamma\Gamma_i - \varepsilon_2) \quad (4)$$

$$\Pr[y_i = 3|\Gamma_i] = \Phi(\gamma\Gamma_i - \varepsilon_2) - \Phi(\gamma\Gamma_i - \varepsilon_3) \quad (5)$$

$$\Pr[y_i = 4|\Gamma_i] = \Phi(\gamma\Gamma_i - \varepsilon_3) - \Phi(\gamma\Gamma_i - \varepsilon_4) \quad (6)$$

$$\Pr[y_i = 5|\Gamma_i] = \Phi(\gamma\Gamma_i - \varepsilon_4) \quad (7)$$

Thus, the interval-data model for the adoption of a subunit vaccine by a beef or dairy farmer is explicitly stated as:

$$E(Y_i = WTP)_{b,d} = \alpha_0 + \alpha_1 H + \alpha_2 D_{rt} + \alpha_3 P_s + \sum_{l=1}^L \alpha_l AD_v + \sum_{m=1}^M \alpha_m R_v \quad (8)$$

where  $(Y_i = WTP)_{b,d}$  = dependent variable (willingness to pay and adopt a subunit vaccine) by a beef or dairy farmer,  $b$  and  $d$  represent *beef* and *dairy*, respectively,  $\alpha_0$  = constant,  $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_l, \alpha_m$  = coefficients of independent variables,  $H$  = number of cattle (herd size) in the farmers' operation,  $D_{rt}$  = risk of disease (JD and bTB) transmission from wildlife,  $P_s$  = participation in safety programs (e.g. verified beef production and Canadian quality milk),  $AD_v$  = primary source of advice for cattle vaccination, and  $R_v$  = reason for vaccination.

Following Equation (8), four different models were estimated based on *type of farmer and disease*. These include: beef farmer TB vaccine (model 1); beef farmer JD vaccine (model 2); dairy farmer TB vaccine (model 3); and dairy farmer JD vaccine (model 4). The idea is to separate the effect of the independent variables on beef and dairy farmers' WTP for the JD and bTB vaccines, having indicated different price points for each of the vaccines. The data were first sorted based on farmer type (i.e. beef and dairy farmers). Each dataset was subsequently sorted based on disease type (i.e. JD and bTB). The four different models were run separately.

Each beef and dairy farmer has five possible choices (WTP amounts) to choose for each vaccine. Following Prillaman (2014), the probability that a farmer's WTP amount ( $y_i^*$ ) will fall into category  $j$  is given by:

$$\pi_{ij} = \Pr[y_{ij} = 1] = \Pr(\psi_{j-1} < y_i^* < \psi_j) \quad (9)$$

where  $\pi_{ij}$  is an indicator variable, and equal to 1 if  $y_i = j$  and zero otherwise.

Integrating Equation (9) within the limits of  $\psi_{j-1}$  and  $\psi_j$ , we have:

$$\int_{\psi_{j-1}}^{\psi_j} f(y_i^* | \mu_i) dy_i^* = \int_{\psi_{j-1}}^{\psi_j} f(y_i^* | \gamma \Gamma_i) dy_i^* = F(\psi_j | \gamma \Gamma_i) - F(\psi_{j-1} - \gamma \Gamma_i) \quad (10)$$

Therefore, Equation (9) becomes:

$$\pi_{ij} = \Phi(\psi_j - \gamma \Gamma_i) - \Phi(\psi_{j-1} - \gamma \Gamma_i) \quad (11)$$

where  $F$  is the cumulative density of  $y_i^*$  and  $\Phi$  is the cumulative density function of the standard normal distribution.

The likelihood function used to estimate the parameters, following Green (2002, p. 698), is derived by taking the log of Equation (11) as follows:

$$L(\psi, \gamma|y) = \ln \left( \prod_{i=1}^N \left\{ \prod_{j=1}^K [\Phi(\psi_j - \gamma\Gamma_i) - \Phi(\psi_{j-1} - \gamma\Gamma_i)]^{y_{ij}} \right\} \right) \quad (12)$$

Solving, we have:

$$L(\psi, \gamma|y) = \sum_{i=1}^N \sum_{j=1}^K y_{ij} \ln [\Phi(\psi_j - \gamma\Gamma_i) - \Phi(\psi_{j-1} - \gamma\Gamma_i)] \quad (13)$$

Therefore, the likelihood function is given by:

$$L(\psi, \gamma|y) = \prod_{i=1}^N \left\{ \prod_{j=1}^K [\Phi(\psi_j - \gamma\Gamma_i) - \Phi(\psi_{j-1} - \gamma\Gamma_i)]^{y_{ij}} \right\} \quad (14)$$

Drawing from Green (2008, p. 833), the marginal probability effects (MPEs) which measure the partial effects of each independent variable on the mean WTP were estimated as follows:

$$MPE_{Y_i=1} = \frac{\partial \Pr[Y_i = 1|\Gamma_i]}{\partial \Gamma_{ij}} [\Phi(-\gamma\Gamma_i) - \Phi(\epsilon_1 - \gamma\Gamma_i)] \alpha_j \quad (15)$$

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$$MPE_{Y_i=J} = \frac{\partial \Pr[Y_i = J|\Gamma_i]}{\partial \Gamma_{ij}} = \Phi(\epsilon_{j-1} - \gamma\Gamma_i) \alpha_j \quad (16)$$

The definitions and measurement of the variables included in the model (Equation 8) are presented in Table 1. Selection of the variables in the model was based on a review of animal vaccine adoption studies in different jurisdictions.

Of the 129 responses from beef farmers, 29.5 per cent were from Alberta, 23.3 per cent from Saskatchewan, 14 per cent from Manitoba, 9.3 per cent from British Columbia (BC), and 8.5 per cent from Ontario. This reflects the distribution of beef cows and number of beef farms across Canada. The average herd per farm for beef cows stood at 255, 191, 167, and 117 for Alberta, Saskatchewan, Manitoba and BC, respectively, while the Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland) have an average herd size of 55 beef cows per farm (CBI, 2017). The provincial distribution of beef and dairy cattle, and farms in terms of numbers in Canada is shown in Figure 4 above (Table 2).

**Table 1** Definition and measurement of variables

Variable	Abbreviation	Definition	Measurement
Farmers' willingness to pay and adopt a subunit vaccine	<i>WTP</i>	Defined as the amount a farmer would be willing to pay for JD and bTB vaccines assuming the vaccines are very effective	Interval variable with five discrete categories: 1 = $0 < WTP \leq 5$ ; 2 = $5 < WTP \leq 10$ ; 3 = $10 < WTP \leq 15$ ; 4 = $15 < WTP \leq 20$ ; 5 = $WTP > 20$
Herd size	<i>H</i>	Number of cattle in farmer's operation/farm in 2016	Measured as the actual number of cattle (including the young stock) in the farm
Disease transmission	<i>D<sub>rt</sub></i>	Farmer's perception of risk of disease (JD and TB) transmission from wildlife	Dummy variable: Yes = 1, 0 = otherwise (No)
Safety programs	<i>P<sub>s</sub></i>	Farmers' participation in safety programs (e.g. verified beef production, Canadian quality milk)	Dummy variable: Yes = 1, 0 = otherwise (No)
Advice for vaccination	<i>AD<sub>v</sub></i>	Farmers' primary source of advice for cattle vaccination	Dummy variable: 1 for a chosen source, 0 = otherwise. Options include: veterinarian; producer associations; neighbour; regulatory agencies; opinion leaders; and others. ' <i>Regulatory agencies</i> ' was used as the base source of advice for the regression.
Reason for vaccination	<i>R<sub>v</sub></i>	Farmers' major reason for vaccinating their cattle	Dummy variables are used for each reason (1 = reason, 0 = otherwise). Options include: disease control; prevention; elimination; buyer recommendation; vet recommendation; and other. ' <i>Disease control</i> ' was used as the base reason for the regression.

For dairy farmers, 28 per cent of the responses were from Quebec, 21.6 per cent from Ontario, 12.8 per cent from Alberta, 12 per cent from BC, and 8.8 per cent from Manitoba. Again, this reflects the distribution of provinces based on the number of dairy farms and cows (see Figure 4).

#### 4. Empirical findings

##### 4.1. Information pathway (source of advice) and reason for cattle vaccination

Even if farmers are open to consider risks, it is important to deliver information and options through recognised and respected pathways. We



**Table 2** Provincial distribution of respondents (beef and dairy farmers')

Province	Beef			Dairy		
	Frequency	%	Source pop (%)*	Frequency	%	Source pop (%)
Alberta	38	29.5	40.49	16	12.8	8.41
British Columbia	12	9.3	5.11	15	12.0	8.41
Manitoba	18	14.0	30.19	11	8.8	4.43
New Brunswick	3	2.3	0.39	4	3.2	2.03
Newfoundland & Labrador	2	1.5	0.005	2	1.6	0.59
Nova Scotia	5	3.9	0.45	6	4.8	2.38
Ontario	11	8.5	7.17	27	21.6	32.73
Prince Edward Island	3	2.3	0.27	3	2.4	1.42
Quebec	7	5.4	4.48	35	28.0	36.68
Saskatchewan	30	23.3	30.19	6	4.8	2.92
Total	129	100.0	100.0	125	100.0	100.0

Note: \*Source population (%) refers to the percentage number of beef and dairy cattle according to province reported by Statistics Canada on 1 July 2017. Sources: Survey data, 2016/2017; StatCan. 2017 (CANSIM Table 003-0032; 004-0221).

tested to see how livestock farmers receive information and advice concerning vaccination and other disease control and management strategies, and examine their reasons for vaccination. This provides important information on the potential and/or critical pathways through which information on the efficacy of the subunit vaccines could be passed to farmers for timely adoption and use.

Results in Table 3 indicate that more than 65 per cent of the surveyed beef and dairy farmers in Canada receive advice on the availability and use of cattle vaccines through veterinarians. In addition, 16.3 per cent and 12 per cent of beef and dairy farmers' source information on cattle vaccines through their producer associations while neighbourhood effect accounts for about 8 per cent of information.

Farmers vaccinate their cattle for different reasons, including disease control, prevention, or elimination, often based on recommendations by the veterinarian or as a precondition of buyers. Survey results in Table 3 show that the single most important reason for farmers to vaccinate is to prevent disease from entering their herds. Disease control and veterinary recommendation are the next most important reasons farmers vaccinate their animals.

To enhance quality, meet industry standards, and secure individual farmer's and industry-wide collective reputation, beef and dairy farmers across Canada participate in on-farm food safety and quality assurance programs. Results in Table 3 show that more than 70 per cent of the farmers participate in food safety and quality assurance programs. This suggests that beef and dairy farmers are most interested in disease prevention and control as a liability management response. It appears to be a good signal for the uptake of the subunit vaccines as a complementary approach to disease prevention and control.

**Table 3** Farmers' information pathways, reasons for vaccination and safety program participation

Variable	Beef (%)	Dairy (%)
Source of advice		
Veterinarian	67.5	65.6
Producer associations	16.3	12.0
Neighbour	8.5	8.0
Regulatory agencies	2.3	4.8
Opinion leaders	2.3	3.2
Others (specify)	3.1	6.4
Total	100.0	100.0
Reason for vaccination		
Disease control	11.6	8.0
Disease prevention	61.2	52.0
Disease elimination	4.7	4.8
Buyer recommendation	5.4	12.8
Recommendation from veterinarian	10.1	16.8
Others (specify)	7.0	5.6
Total	100.0	100.0
Safety program participation		
Yes	74.4	78.9
No	25.6	21.1
Total	100.0	100.0

Note: Total number of respondents: beef (129); and dairy (125). Source: Survey data, 2016/2017.

Potentially, adoption and use of a new subunit vaccine for animals would largely depend on farmer attitudes and prior use of animal vaccines. Survey results indicate that all respondents are familiar and have used different vaccines for the prevention and control of different diseases. Examples of such vaccines and the diseases they are used for (in bracket) include the following: Bovi-Shield Gold FP 5 (diarrhoea); Vista Once Sub Q (IBR, BVD, Haemophilus), Somubac, Tasvax 8 (Tetanus) and Vision 7 (Blackleg); Scour BOS 4 & 9 (*Escherichia Coli*, diarrhoea, rota virus, corona virus); and BioMycin 200 or oxytetracycline (Foot rot). Veterinarians and producer associations appear to be critical and efficient pathways to create awareness and promote adoption of the subunit vaccines under production for JD and bTB.

#### 4.2. Willingness to pay (WTP) for the new subunit vaccines

Awareness and latent need for vaccines are important considerations, but actual uptake and use critically depend on a number of factors, including the safety and efficacy of the vaccines, compatibility with other vaccines, and ease of administration. The livestock industry worldwide has experienced economic losses of varying degrees due to outbreaks of several diseases. High efficacy vaccines only exist for some diseases. Hence, farmers were asked to indicate the maximum amount they would be willing to pay for each of the new vaccines assuming they are very safe and effective.

Summary statistics of WTP thresholds for the vaccines are shown in Tables 4 and 5, respectively, while that of farmers' WTP for each vaccine is shown in Table 6.

Comparing the WTP amount for the vaccines, results in Tables 4 and 5 show that dairy farmers' indicate higher WTP amounts for JD vaccine relative to beef farmers. For each of the bidding categories above \$5 (Tables 4, 5), dairy farmers' maximum WTP amount for JD vaccine is at least 11 per cent higher than the corresponding maximum amounts indicated by beef for each category. A potential explanation is that JD has more negative economic effect on dairy cattle as they are confined and kept on the farm for longer periods than beef cattle and are more likely to show clinical signs for JD than beef cattle which are often sold or slaughtered before clinical signs for JD emerge.

**Table 4** Summary of WTP thresholds for bTB subunit vaccine

WTP Threshold	Beef farmers					Dairy farmers				
	N	Mean	Min	Max	Std. Dev.	N	Mean	Min	Max	Std. Dev.
$0 < \text{WTP} \leq 5$	27	3.24	0	5	1.39	40	3.41	2	5	1.27
$5 < \text{WTP} \leq 10$	49	7.60	6	10	1.28	44	7.51	6	9	1.23
$10 < \text{WTP} \leq 20$	28	15.60	11	18	1.84	22	15.45	11	18	1.84
$20 < \text{WTP} \leq 30$	15	24.81	21	28	2.52	10	24.70	21	26	2.57
$\text{WTP} > 30$	10	36.22	33	39	2.28	9	35.56	32	37	1.33
Total	129	N/A	N/A	N/A	N/A	125	N/A	N/A	N/A	N/A

**Table 5** Summary of WTP thresholds for JD subunit vaccine

WTP Threshold	Beef farmers					Dairy farmers				
	N	Mean	Min	Max	Std. Dev.	N	Mean	Min	Max	Std. Dev.
$0 < \text{WTP} \leq 5$	50	3.38	1	5	1.34	21	4.00	3	5	0.71
$5 < \text{WTP} \leq 10$	39	7.20	6	8	1.30	36	7.57	6	10	1.35
$10 < \text{WTP} \leq 15$	18	15.40	11	17	2.15	41	15.56	13	19	2.15
$15 < \text{WTP} \leq 20$	13	24.42	20	24	2.08	15	25.00	22	28	2.75
$\text{WTP} > 20$	9	33.13	32	35	2.16	12	36.25	32	43	2.80
Total	129	N/A	N/A	N/A	N/A	125	N/A	N/A	N/A	N/A

**Table 6** Summary Statistics of farmers' WTP for bTB and JD vaccines per animal per year

Type of farmer	N	bTB			JD		
		Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Beef	129	11.99	8.00	9.44	9.99	6.25	9.27
dairy	125	11.04	8.00	9.36	14.45	13	9.79

Note: The WTP values in Table 4, 5, 6 are in 2016 Canadian dollars.

Source: Survey data, 2016/2017.

For the bTB vaccine, the WTP amounts (Table 4) indicated by beef farmers (for bid categories above \$5) are slightly higher than that of dairy farmers. Beef cattle are not well confined and, therefore, usually come in contact with wild animals (e.g. bison) that serve as potential hosts for tuberculosis. For this reason, beef farmers are expected to be more concerned about tuberculosis infection, which could be an incentive for high WTP for bTB vaccine by beef farmers.

The beef farmers' mean WTP amount per animal per year for bTB and JD vaccines (Table 6) stood at \$8 and \$6.25, respectively. On the other hand, dairy farmers (on average) are willing to pay \$14.45 for JD vaccine per animal per annum and \$11.04 for bTB vaccine.

#### 4.3. Interval-data analysis results

To identify the factors that significantly influence a farmer's decision to pay for and adopt new subunit vaccines for JD and bTB, four interval-data models were estimated based on the type of farmer (beef and dairy) and disease (bTB and JD). The parameter estimates and marginal effects are shown in Table 7 and 8 for beef and dairy farmers, respectively.

Some of the explanatory variables are expressed as dummies. A dummy (binary) variable used in regression analysis refers to a numerical variable used to represent categorical data (e.g. gender), and is usually dichotomous. It takes the value 1 or 0 to show the presence or absence of a categorical effect, with 1 representing presence of a qualitative attribute and 0 represents absence (Draper and Smith 1998). The number of values a categorical variable can assume determines the number of dummy variables required to represent the categorical variable. For example, a categorical variable with ' $n$ ' values requires ' $n - 1$ ' dummy variables. To avoid the problem of *dummy variable trap* (collinearity between explanatory dummy variables), one of the dummies in each category is dropped during regression, with that category becoming the reference or base category against which other categories are assessed. Failure to do this results in multicollinearity. While the choice of the base category is arbitrary, the estimated coefficient of the reference dummy variable is used as a comparative benchmark (i.e. coefficient of other dummy variables within the same category are interpreted relative to the base category; Ling and Lockshin 2003; Gujarati and Porter 2009).

The marginal effects of the explanatory variables measure the effect of a change in each explanatory variable ( $X_i$ ) on the expected change in the dependent variable ( $Y$ ). To check for the presence of correlation between two or more independent variables, pairwise correlation analysis was carried out for beef and dairy models. A correlation coefficient indicates the degree and direction of linear relationship between two variables (Rumsey 2011, p. 116). The results on Tables A1 and A2 suggest that there is no multicollinearity among the independent variables in the models.

**Table 7** Interval-data regression results (beef farmers)

Variable	Level	TB Model			JD Model		
		Coef. ( $\beta$ )	Std. error	Marginal effects	Coef. ( $\beta$ )	Std. error	Marginal effects
Constant				n/a	0.4264*	0.5397	n/a
Cattle herd		0.4544**	0.5475	0.1113**	0.1663**	0.6929	0.0091*
Risk of dis. transmission		0.4309**	0.6529	0.1704*	0.1472	0.3132	0.0643
Source of advice for vaccination		0.3136*	0.9503	Base	Base	Base	Base
	Reg. Agencies	Base	Base	0.5316	0.3109**	0.5653	0.0861**
	Producer association	0.6543	1.0553	0.2267***	0.4407**	0.5374	0.2933**
	Veterinarian	0.4137***	0.6464	0.1356	-0.2725	0.9397	-0.0658
	Opinion leaders	0.2163	1.1384	0.1467**	0.1913	0.8317	0.1157
	Neighbour	0.3281**	1.0584	Base	Base	Base	Base
Reason for vaccination		Base	Base	0.0953*	0.3402	0.9195	0.1743
	Disease control	0.2932*	0.7716	0.0034	0.0965	0.5676	0.0249
	Disease prevention	0.0571	0.5191	0.5769	0.5041***	0.7877	0.2015***
	Disease elimination	0.8844	0.9118	0.1567***	0.6273**	1.0816	0.1864**
	Buyer recommendation	0.5140***	0.7041	-0.0313	-0.0877	0.3508	-0.0542
	Veterinarian recommendation	-0.0829	0.3768	-0.1440**	-0.3932**	0.5174	-0.2166**
Safety program participation		-0.4615**	0.5366	78	51		
Cost of vaccine				-35.04	-28.24		
Number of observations				24.32	26.21		
Log likelihood				0.0026	0.0019		
Log-likelihood ratio $\chi^2$				0.3697	0.6140		
Prob.> $\chi^2$							
Pseudo- $R^2$							

Note: Significance level and codes of  $P$ -values:

\*10%, \*\*5%, \*\*\*1%

McFadden's pseudo- $R^2$  shows the level of improvement of the full model relative to the intercept model. A lower value is an indication that the full model has a better fit than the intercept model ([http://www.ats.ucla.edu/stat/mult\\_pkg/faq/general/Pseudo\\_RSquareds.htm](http://www.ats.ucla.edu/stat/mult_pkg/faq/general/Pseudo_RSquareds.htm)). Source: Survey data, 2016/2017.

Table 8 Interval-data regression results (dairy farmers)

Variable	Level	TB Model			JD Model		
		Coef. ( $\beta$ )	Std. error	Marginal effects	Coef. ( $\beta$ )	Std. error	Marginal effects
Constant		0.3427*	0.9262	n/a	0.3958**	0.4498	n/a
Cattle herd		0.2565**	0.7773	0.0102**	0.2435***	0.9019	0.0971***
Risk of dis. transmission		0.4983*	0.6471	0.1962	0.5767*	0.7033	0.2266*
Source of advice for vaccination	Reg. Agencies	Base	Base	Base	Base	Base	Base
	Producer association	0.2631	0.8487	0.0321	0.4654	0.7052	0.1753
	Veterinarian	0.6097*	0.8352	0.1960*	0.5989**	0.8093	0.3394**
	Opinion leaders	-0.1391	0.7321	-0.0115	0.2062	0.7110	0.0806
	Neighbour	0.0423	0.5288	0.0026	-0.3744	0.4992	-0.1485
Reason for vaccination	Disease control	Base	Base	Base	Base	Base	Base
	Disease prevention	0.4885**	0.7080	0.2146**	0.8731**	0.9595	0.2761**
	Disease elimination	-0.0601	0.2504	-0.0254	0.3809*	0.8280	0.1780*
	Buyer recommendation	0.4586*	0.5662	0.1571**	0.4956	0.8125	0.2425
	Veterinarian recommendation	0.5758*	0.8345	0.2403*	0.6028***	0.8736	0.3601***
Safety program participation		-0.1392	0.7733	-0.0555	0.2009	0.7441	0.0794
Cost of vaccine		-0.4481***	0.5335	-0.2417***	-0.4664***	0.6478	-0.1931***
Number of observations		44			81		
Log likelihood		-31.77			-43.85		
Log-likelihood ratio $\chi^2$		26.16			24.11		
Prob > $\chi^2$		0.0016			0.0039		
Pseudo- $R^2$		0.3765			0.3283		

Note: Significance level and codes of  $P$ -values:  
\*10%, \*\*5%, \*\*\*1%.  
McFadden's pseudo- $R^2$  shows the level of improvement of the full model relative to the intercept model. A lower value is an indication that the full model has a better fit than the intercept model ([http://www.ats.ucla.edu/stat/mult\\_pkg/faq/general/Pseudo\\_RSquareds.htm](http://www.ats.ucla.edu/stat/mult_pkg/faq/general/Pseudo_RSquareds.htm)).Source: Survey data, 2016/2017.



The results show that estimates of the coefficients differ for both beef and dairy farmers, and the diseases under consideration. The statistical significance of the estimated likelihood-ratio chi-square ( $P < 0.01$ ) indicates that all the models are a good fit. The estimated coefficient for cattle herd size is positive and significant at the 5 per cent level for beef farmers in the TB and JD models and in dairy farmer TB model; and 1 per cent level for dairy farmers in the JD model, indicating that the number of cattle on a farm would significantly influence willingness to pay for and use a subunit vaccine. This is consistent with the result of Ma *et al.* (2018) who found herd size to be positively and significantly influencing dairy production. The marginal effects suggest that increasing the herd by one unit increases beef and dairy farmers WTP for bTB subunit vaccines by 11 and 0.01 per cent, respectively, and 0.01 and 0.1 per cent for JD subunit vaccine. This further implies that farmers with large herd sizes have a higher propensity to pay for and use the subunit vaccines given the potential magnitude of economic losses they would have in the event of JD or bTB disease outbreak.

The estimated coefficient for veterinarians as a source of advice is positive and significant in all the models. The marginal effects indicate that, holding other variables constant, receiving advice on vaccine use from a veterinarian increases a beef farmers' WTP for bTB and JD subunit vaccines by 23 and 29 per cent, respectively, relative to advice from regulatory agencies (the base category). On the other hand, dairy farmers' WTP for JD and bTB subunit vaccines increases by 34 and 20 per cent, respectively, following veterinarian advice. This suggests that dairy farmers have higher willingness to pay for JD vaccine relative to bTB vaccine. This is not surprising given the negative effect of JD on milk production. The neighbourhood effect is positive and significant at 5 per cent level and increases beef farmers WTP for a new subunit vaccine for bTB by 15 per cent relative to advice from regulatory agencies.

Similarly, the estimated coefficient for veterinarian recommendation for vaccine usage is significant in beef and dairy models. This is consistent with Cresswell *et al.* (2014) who reported that 95 per cent of beef and dairy farmers surveyed in the United Kingdom rely on veterinarians as their major source of information concerning vaccination of animals. In addition, Enticott *et al.* (2012) and Ruston *et al.* (2016) found that livestock farmers are closer to veterinarians and have more confidence in their advice on disease control and management practices. The result further shows that relative to disease control, disease prevention positively and significantly influences dairy farmers' willingness to pay for JD and bTB subunit vaccines. For the beef farmers' model, the estimated coefficient for disease prevention is positive for JD and bTB models, but only significant at 10 per cent for the bTB model. The marginal effects suggest that recommendations for vaccination by a veterinarian increases beef farmers' willingness to use a subunit vaccine by 16 and 18 per cent, respectively, for bTB and JD. The estimated coefficient for a buyer recommendation for vaccine use for JD by beef farmers is positive and

significant at the 1 per cent level and at the 10 per cent level for a bTB vaccine for dairy farmers. However, a farmer's decision to pay for a vaccine could also depend on whether the vaccination is voluntary or mandatory. In some jurisdiction (e.g. UK), the cost of mandatory vaccination is usually covered by the state.

## 5. Implications and Conclusions

The study examined an alternate strategy of two subunit animal vaccines for bovine tuberculosis and Johne's disease in cattle and farmers' willingness to pay for the vaccines. Although vaccination has been identified as a widely accepted strategy for disease control and prevention in many countries, albeit complemented by efficient management practices, such as testing, culling, and pre-emptive slaughter, studies have not widely explored what drives farmers' decision to use cattle vaccine. JD infection occurs in three stages with the animal showing clinical signs at the third stage, suggesting that the practice of testing, culling and pre-emptive slaughter is only effective for animals with late-stage infections that are shedding MAP (Bastida and Juste 2011). This implies that eradication and prevention can only be achieved if all the infected animals are detected during the early stage of infection, which is difficult (Gumber *et al.* 2009).

The results of the study have implications for the livestock industry. Increased participation of beef and dairy farmers in food safety and quality assurance programs to prevent animal diseases is a good signal for potential uptake of the new subunit vaccines. The mean WTP amounts for both vaccines imply that beef and dairy farmers have high likelihood of using the vaccines if the costs are kept at reasonable level. Results of the analyses show that veterinarians play a crucial role as a major pathway for vaccine information, advice, and dissemination to farmers. Hence, it is important to engage veterinarians to raise awareness and facilitate the adoption and use of subunit vaccines for JD and bTB prevention and control. The fact that the size of a cattle herd and buyers' recommendation or requirements for vaccination significantly influence beef and dairy farmers' willingness to pay and adopt a subunit vaccine suggest additional variables to consider in a rollout strategy.

The cost of acquiring a new technology is a critical factor that influences adoption. There may be an opportunity for the public sector to create incentives for the private sector to adopt new vaccines through subsidies and public-private partnerships. An appropriate program might reduce the cost burdens on farmers, improve animal health and safety, generate high returns to innovators, and cushion the effects of market volatility.

The study only examines Canadian beef and dairy farmers. Future studies could expand the scope to other bovine animals or use a larger sample size to examine the uptake and adoption rate of subunit vaccines in Canada and potential uptake in other countries and regions of the world. The results of

such studies will be useful for designing appropriate vaccination adoption strategies in the livestock sector.

### Conflict of Interest

None.

### References

- Agriculture and Agri-Food Canada (2018). Livestock imported from the United States. Available from URL: <http://www.agr.gc.ca/eng/industry-markets-and-trade/canadian-agri-food-sector-intelligence/red-meat-and-livestock/red-meat-and-livestock-market-information/imports/livestock-imported-from-the-united-states/?xml:id=1415860000006> [accessed 26 July 2018].
- Álvarez, J., de Juan, L., Bezos, J., Romero, B., Sáez, J.L., Marqués, S., Domínguez, C., Mínguez, O., Fernández Mardomingo, B., Mateos, A., Domínguez, L. and Aranaz, A. (2009). Effect of paratuberculosis on the diagnosis of bovine tuberculosis in a cattle herd with a mixed infection using Interferon-Gamma Detection Assay, *Veterinary Microbiology* 135, 389–393.
- Anderson, J. (1998). Biosecurity: a new term for an old concept: how to apply it, *Bovine Practitioner* 32, 61–70.
- Animal Health Australia (2012). Cattle MAP. Available from URL: <https://www.animalhealthaustralia.com.au/what-we-do/endemic-disease/market-assurance-programs-maps/cattle-map/> [accessed on 4 September 2017].
- Arnoldi, J.M. and Hurley, S. (1983). Johne's disease in Wisconsin cattle - A survey of cull cows, *Proceedings of the first international colloquium of research in paratuberculosis*; 16–21.
- Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R. and Schuman, H. (1993). Report of the NOAA panel on contingent valuation, *Federal Register* 58, 4601–4614.
- Balistreri, E., McClelland, G., Poe, G. and Schulze, W. (2001). Can hypothetical questions reveal true values? A laboratory comparison of dichotomous choice and open-ended contingent values with auction values, *Environmental Resource Economics* 18, 275–292.
- Barker, R.A., Barkema, H.W., Fecteau, G., Keefe, G.P. and Kelton, D.F. (2012). Johne's disease control in Canada – coordinated nationally – delivered provincially, *Proceedings of the 3rd ParaTB Forum* 2012, 45–51. Available from URL: [http://www.paratuberculosis.info/web/images/paratbforum/proc\\_pf\\_2012.pdf](http://www.paratuberculosis.info/web/images/paratbforum/proc_pf_2012.pdf). [accessed 2 December 2017].
- Bastida, F. and Juste, R.A. (2011). Paratuberculosis control: A review with a focus on vaccination, *Journal of Immune Based Therapies and Vaccines* 9, 8.
- Bazzani, C., Palma, M.A. and Nayga Jr, R.M. (2018). On the use of flexible mixing distributions in WTP space: an induced value choice experiment, *Australian Journal of Agricultural and Resource Economics* 62, 185–198.
- BCRC (Beef Cattle Research Council) (2016). *Johne's disease*. Available from URL: <http://www.beefresearch.ca/research-topic.cfm/johnes-disease-51> [accessed 6 November 2017].
- Bennett, J.W. (1983). Validating revealed preference, *Economic Analysis and Policy* 13, 2–17.
- Bennett, J.W. (1987). Strategic behaviour: Some experimental evidence, *Journal of Public Economics* 32, 355–368.
- Bennett, R. and Balcombe, K. (2012). Farmers' willingness to pay for a tuberculosis cattle vaccine, *Journal of Agricultural Economics* 63, 408–424.
- Carson, R.T. and Groves, T. (2007). Incentive and informational properties of preference questions, *Environmental Resource Economics* 37, 181–210.
- CBI (Canada's Beef Industry). (2017). Fast facts. June 2017. Available from URL: <http://www.cattle.ca/assets/CBIfastfactsENGAug3b-WEB.pdf>. [accessed 9 November 2017].

- CFIA (Canadian Food Inspection Agency) (2015). Bovine tuberculosis – fact sheet. Available from URL: <http://www.inspection.gc.ca/animals/terrestrial-animals/diseases/reportable/tuberculosis/fact-sheet/eng/1330208938232/1330209051950> [accessed 5 November 2017].
- Cherry, T.L., Frykblom, P., Shogren, J.F., List, J.A. and Sullivan, M.B. (2004). Laboratory testbeds and non-market valuation: the case of bidding behavior in a second-price auction with an outside option, *Environmental & Resource Economics* 29, 285–294.
- Chiodini, R.J., Van Kruiningen, H.J. and Merkal, R.S. (1984). Ruminant paratuberculosis (Johne's disease): the current status and future prospects, *Cornell Veterinarian* 74, 218–262.
- Clark, R. (2015). Understanding the value of vaccines. The Canadian Cattlemen Beef Magazine, October 28, 2015. Available from URL: <https://www.canadiancattlemen.ca/2015/10/28/understanding-the-value-of-vaccines/> [accessed 6 November 2017].
- Conlan, A.J.K., Brooks, P.E., McKinley, T.J., Mitchell, A.P., Jones, G.J., Vordermeier, M. and Wood, J.L. (2015). Potential benefits of cattle vaccination as a supplementary control for bovine tuberculosis, *PLoS Computational Biology* 11(2), e1004038.
- Cresswell, E., Brennan, M., Barkema, H.W. and Wapenaar, W. (2014). A questionnaire-based survey on the uptake and use of cattle vaccines in the UK, *Veterinary Record Open* 2014, e000042.
- Cummings, R.G., Brookshire, D.S. and Schulze, W.D. (1986). *Valuing Environmental Goods: A State of the Arts Assessment of the Contingent Valuation Method*. Rowman and Allanheld, Totowa, NJ.
- Doel, T.R., Williams, L. and Barnett, P.V. (1994). Emergency vaccination against foot-and-mouth disease: the rate of development of immunity and its implications for the carrier state, *Vaccine* 12, 592–600.
- Draper, N.R. and Smith, H. (1998). *Applied Regression Analysis*. Wiley, Hoboken, NJ. ISBN 0-471-17082-8 (Chapter 14).
- Enticott, G., Franklin, A. and Van Winden, S. (2012). Biosecurity and food security: spatial strategies for combating bovine tuberculosis in the UK, *Geographical Journal* 178, 327–337.
- Eppleston, J. and Windsor, P.A. (2007). Lesions attributed to vaccination of sheep with gudair for the control of ovine paratuberculosis: post farm economic impacts at slaughter, *Australian Veterinary Journal* 85, 129–133.
- Finny, D.J. (1978). *Statistical Method in Biological Assay*. Charles Griffin, London.
- Fridriksdottir, V., Gunnarsson, E., Sigurdarson, S. and Gudmundsdottir, K.B. (2000). Paratuberculosis in Iceland: epidemiology and control measures, past and present, *Veterinary Microbiology* 77, 263–267.
- Frössling, J. and Nöremark, M. (2016). Differing perceptions—Swedish farmers' views of infectious disease control, *Veterinary Medical Science* 2, 54–68.
- Garry, F., Wells, S., Ott, S. and Hansen, D. (1999). Info sheet: APHIS veterinary services: who can afford a \$200 loss per cow? Or Johne's disease - what do I need to know? Available from URL: [https://www.aphis.usda.gov/animal\\_health/nahms/dairy/downloads/dairy96/Dairy96\\_is\\_Johnes.pdf](https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy96/Dairy96_is_Johnes.pdf) [accessed 23 July 2018].
- Gill, I.J. (1989). The economic impact of johne's disease in cattle in Australia, in: Milner, A. and Wood, P. (eds), *Johne's Disease*, Commonwealth Scientific and Industrial Research Organization, East Melbourne, pp. 41–45.
- Good, M., Clegg, T., Sheridan, H., Yearsely, D., O'Brien, T., Egan, J. and Mullowney, P. (2009). Prevalence and distribution of paratuberculosis (Johne's disease) in cattle herds in Ireland, *Ireland Veterinary Journal* 62, 597–606.
- Green, W.H. (2002). *Econometric Analysis*, 5th edn. Prince Hall, USA, New Jersey, p. 1026.
- Green, W.H. (2008). *Econometric Analysis*, 5th edn. Prentice Hall, London, p. 828.
- Green, W.H. and Hensher, D.A. (2010). *Modeling Ordered Choices: A Primer*, 1st edn. Cambridge University Press, Cambridge.
- Gujarati, D.N. and Porter, D.C. (2009). *Basic Econometrics*, 5th edn. MacGraw-Hill Publishers, New York, 946 pp.

- Gumber, S., Taylor, D.L. and Whittington, R.J. (2009). Valuation of the immunogenicity of recombinant stress-associated proteins during mycobacterium avium subsp. paratuberculosis infection: implications for pathogenesis and diagnosis, *Veterinary Microbiology* 137, 290–296.
- Gunn, G., Stott, A. and Humphry, R. (2004). Modelling and costing BVD outbreaks in beef herds, *Veterinary Journal* 167, 143–149.
- Gupta, S., Chaubey, K.K., Singh, S.V., Bhatia, A.K., Kumar, N., Goel, A., Sachan, T.K., Rawat, K.D., Sohal, J.S. and Dhama, K. (2015). Immunoreactivity to culture filtrate proteins of mycobacterium avium subspecies paratuberculosis in naturally infected goat and sheep sera, *Advances in Animal and Veterinary Sciences* 3(6), 347–353.
- Hanemann, W.M., Loomis, J.B. and Kanninen, B. (1991). Statistical efficiency of double-bounded dichotomous choice contingent valuation, *American Journal of Agricultural Economics* 73, 1255–1263.
- Heffernan, C., Nielson, L., Thomson, K. and Gunn, G. (2008). An exploration of the drivers to biosecurity collective action among a sample of UK cattle and sheep farmers, *Preventive Veterinary Medicine* 87(3–4), 358–372.
- Imogen, R. (2015). Implementation of vaccination strategies on British dairy farms: understanding challenges and perceptions. Report prepared for AHDB dairy, December 2015. Available from URL: [https://dairy.ahdb.org.uk/media/1311037/411098\\_ah4\\_report\\_richens\\_phd\\_vaccination\\_branded.pdf](https://dairy.ahdb.org.uk/media/1311037/411098_ah4_report_richens_phd_vaccination_branded.pdf). [accessed 20 January 2018].
- Juste, R.A. (2012). Slow infection control by vaccination: Paratuberculosis, *Veterinary Immunology and Immunopathology* 148, 190–196.
- Juste, R.A. and Perez, V. (2011). Control of paratuberculosis in sheep and goats, *Veterinary Clinics of North America: Food Animal Practice* 27, 127–138.
- Kalis, C.H., Hesselink, J.W., Russchen, E.W., Barkema, H.W., Collins, M.T. and Visser, I.J. (1999). Factors influencing the isolation of *Mycobacterium avium* subsp. paratuberculosis from bovine fecal samples, *Journal of Veterinary Diagnostic Investigation* 11, 345–351.
- Katale, B.Z., Mbugi, E.V., Kendal, S., Fyumagwa, R.D., Kibiki, G.S., Godfrey-Faussett, P., Keyyu, J.D., Van Helden, P. and Matee, M.I. (2012). Bovine tuberculosis at the human-livestock-wildlife interface: Is it a public health problem in Tanzania? *Journal of Veterinary Research* 79, Art. #463.
- Kennedy, D.J. and Benedictus, G. (2001). Control of *Mycobacterium avium* subsp. paratuberculosis infection in agricultural species, *Revue Scientifique et Technique de l'Office International des Epizooties* 20, 151–179.
- Kohler, H., Gyra, H., Zimmer, K., Drager, K.G., Burkert, B., Lemser, B., Hausleithner, D., Cubler, K., Klawonn, W. and Hess, R.G. (2001). Immune reactions in cattle after immunization with a mycobacterium paratuberculosis vaccine and implications for the diagnosis of *M. paratuberculosis* and *M. Bovis* infections, *Journal of Veterinary Medicine, Series B* 48, 185–195. <https://doi.org/10.1046/j.1439-0450.2001.00443.x>.
- Ling, B.-H. and Lockshin, L. (2003). Components of wine prices for Australian wine: how winery reputation, wine quality, region, vintage, and winery size contribute to the price of varietal wines, *Australian Marketing Journal* 11, 19–32.
- Lombard, M.F., Pastoret, P.P. and Moulin, A.M. (2007). A brief history of vaccines and vaccination, *International Office of Epizootics* 26(1), 29–48.
- Louviere, J.D., Hensher, M. and Swait, J. (2000). *Stated Choice Methods: Analysis and Application*. Cambridge University Press, Cambridge.
- Ma, W., Bicknell, K. and Renwick, A. (2018). Feed use intensification and technical efficiency of dairy farms in New Zealand, *Australian Journal of Agricultural and Resource Economics* 63(1), 1–19.
- Maddala, G.S. (1983). *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge University Press, New York.



- McKenna, S.L., Keefe, G.P., Tiwari, A., VanLeeuwen, J. and Barkema, H.W. (2006). Johne's disease in Canada Part II: disease impacts, risk factors, and control programs for dairy producers, *The Canadian Veterinary Journal* 47, 1089–1099.
- Merkal, R.S., Larsen, A.B. and Booth, G.D. (1975). Analysis of the effects of inapparent bovine paratuberculosis, *American Journal of Veterinary Research* 36, 837–838.
- Morgan, K.T., Swenberg, J.A., Hamm, T.E., Wolkowski-Tyl, R. Jr and Phelps, M. (1982). Histopathology of acute toxic response in rats and mice exposed to methyl chloride by inhalation, *Fundamental Applied Toxicology* 2, 293–299.
- Nielson, S.S., Jepsen, O.P. and Aagaard, K.. (2007). Control programme for paratuberculosis in Denmark. In: Bull. Intern. Dairy Fed. 410/207: Proc. 1st Paratuberculosis Forum, 23–29.
- Normile, D. (2008). Rinderpest driven to extinction, *Science* 319(5870), 1606–1609. <https://doi.org/10.1126/science.319.5870.1606>.
- OIE (Office International des Epizooties - World Organisation for Animal Health) (2009). *Cost of national prevention systems for animal diseases and zoonoses in developing and transition countries*. Report prepared by Civic Consulting, Berlin Germany, October 2009.
- OIE (2017) WAHIS interface: animal health information. Availbale at: [http://www.oie.int/wahis\\_2/public/wahid.php/Diseaseinformation/statusdetail](http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail).
- Olynk, N.J. and Wolf, C.A. (2008). Economic analysis of reproductive management strategies on U.S. commercial dairy farms, *Journal of Dairy Science* 91, 4082–4091.
- Park, H.-T. and Yoo, H.S. (2016). Development of vaccines to *Mycobacterium avium* subsp. paratuberculosis infection, *Clinical Experimental Vaccine Research* 5, 108–116.
- Patterson, C.J., LaVenture, M., Hurley, S.S. and Davis, J.P. (1998). Accidental self-inoculation with mycobacterium paratuberculosis bacterin (johnes' bacterin) by veterinarians in Wisconsin, *Journal of the American Veterinary Medical Association* 192, 1197–9.
- Prillaman, S. (2014). *GOV 2001/ 1002/ E-2001 Section 8 Ordered Probit and Zero-Inflated Logit (March 2014)*. Available at: [https://projects.iq.harvard.edu/files/gov2001/files/section8\\_2014\\_print.pdf](https://projects.iq.harvard.edu/files/gov2001/files/section8_2014_print.pdf) [accessed 10 September 2018].
- Pruvot, M., Kutz, S., Van der Meer, F., Musiani, M., Barkema, H.W. and Orsel, K. (2014). Pathogens at the livestock-wildlife interface in western Alberta: does transmission route matter?, *Veterinary Research* 45, 18.
- Rankin, J.D. (1962). The Experimental infection of cattle with mycobacterium *johni*. IV: adult cattle maintained in an infectious environment, *Journal of Comparative Pathology and Therapeutics* 72, 133–117.
- Reddacliff, L., Eppleston, J., Windsor, P., Whittington, R. and Jones, S. (2006). Efficacy of a killed vaccine for the control of paratuberculosis in Australian sheep flocks, *Veterinary Microbiology* 115, 77–90.
- Richens, I.F., Hobson-West, P., Brennan, M.L., Lowton, M.L. and R., Kaler, J. and Wapenaar, W., (2015). Farmers' perception of the role of veterinary surgeons in vaccination strategies on British dairy farms, *Veterinary Record* 177, 465.
- Ritter, C., Jansen, J., Roche, S., Kelton, D.F., Adams, C.L., Orsel, K., Erskine, R.J., Benedictus, G., Lam, T.J.G.M. and Barkema, H.W. (2017). Invited review: determinants of farmers' adoption of management-based strategies for infectious disease prevention and control, *Journal of Dairy Science* 100, 3329–3347.
- Rosseels, V. and Huyge, K. (2008). Vaccination against Paratuberculosis, *Expert Review of Vaccines* 7, 817–832.
- Rumsey, D.J. (2011). *Statistics Essentials for Dummies*, 2nd edn. Ohio State University. Wiley Publishing Inc., Hoboken 195 pp.
- Ruston, A., Shortall, O., Green, M., Brennan, M., Wapenaar, W. and Kaler, J. (2016). Challenges facing the farm animal veterinary profession in England: a qualitative study of veterinarians' perceptions and responses, *Preventive Veterinary Medicine* 127, 84–93.
- Sahlström, L., Virtanen, T., Kyyrö, J. and Lyytikäinen, T. (2014). Biosecurity on Finnish cattle, pig and sheep farms—results from a questionnaire, *Preventive Veterinary Medicine* 117, 59–67.



- Sarrazin, S., Cay, A.B., Laureyns, J. and Dewulf, J. (2014). A survey on biosecurity and management practices in selected Belgian cattle farms, *Preventive Veterinary Medicine* 117, 129–139.
- Sayers, R.G., Sayers, G.P., Mee, J.F., Good, M., Bermingham, M.L., Grant, J. and Dillon, P.G. (2013). Implementing biosecurity measures on dairy farms in Ireland, *Veterinary Journal* 197, 259–267.
- Schnlze, W.D., d'Argeand, R.C. and Brookshire, D.S. (1981). Valuing environmental commodities: some recent experiments. *Land Economics* 57(2), 151–172.
- Schiller, I., Oesch, B., Vordermeier, H.M., Palmer, M.V., Harris, B.N., Orloski, K.A., Buddle, B.M., Thacker, T.C., Lyashchenko, K.P. and Waters, W.R. (2010). Bovine tuberculosis: A review of current and emerging diagnostic techniques in view of their relevance for disease control and eradication, *Transboundary and Emerging Diseases* 57(4), 205–220. <https://doi.org/10.1111/j.1865-1682.2010.01148.x>.
- Singh, S.V., Singh, A.V., Singh, R., Sandhu, K.S., Singh, P.K., Sohal, J.S., Gupta, V.K. and Vihan, V.S. (2007). Evaluation of highly sensitive indigenous milk elisa kit with fecal culture, milk culture and fecal-PCR for the diagnosis of bovine johne's disease (BJD) in India, *Comparative Immunology, Microbiology and Infectious Disease* 30, 175–186.
- Singh, S.V., Singh, P.K., Kumar, N., Gupta, S., Chaubey, K.K., Singh, B., Srivastav, A. and Yadav, S. (2015). Evaluation of goat based 'indigenous vaccine' using novel 'Indian bison type' biotype of mycobacterium avium subspecies paratuberculosis for the control of bovine johne's disease in endemic herds of native Indian cattle, *Indian Journal of Experimental Biology* 52, 16–24.
- Stott, A.W. and Gunn, G.J. (2008). Use of a benefit function to assess the relative investment potential of alternative farm animal disease prevention strategies, *Preventive Veterinary Medicine* 84, 179–193.
- Streeter, R.N., Hoffsis, G.F., Bech-Nielsen, S., Shulaw, W.P. and Rings, D.M. (1995). Isolation of mycobacterium paratuberculosis from colostrum and milk of sub-clinically infected cows, *American Journal of Veterinary Research* 56, 1322–1324.
- Sweeney, R.W., Whitlock, R.H. and Rosenberger, A.E. (1992). Mycobacterium paratuberculosis isolated from fetuses of infected cows not manifesting signs of the disease, *American Journal of Veterinary Research* 53, 477–480.
- Terfa, Z.G., Garikipati, S., Dessie, T., Lynch, S., Wigley, P., Bettridge, J.M. and Christley, R.M. (2015). Farmers' WTP for a village poultry vaccine service in Ethiopia: Prospects for enhancing rural livelihoods, *Food Science* 7, 905–917.
- Tiwari, A., VanLeeuwen, J.A., McKenna, S.L., Keefe, G.P. and Barkema, H.W. (2006). Johne's disease in Canada Part I: clinical symptoms, pathophysiology, diagnosis, and prevalence in dairy herds, *Canadian Veterinary Journal* 47, 874–882.
- Tiwari, A., Vanleeuwen, J.A., Dohoo, R.I., Keefe, G.P. and Weersink, A. (2008). Estimate of the direct production losses in Canadian dairy herds with subclinical *Mycobacterium avium* subspecies paratuberculosis infection, *Canadian Veterinary Journal* 49, 569–576.
- Walter, W.D., Anderson, C.W., Smith, R., Vanderklok, M., Averill, J.J. and VerCauteren, K.C.. (2012). On-farm mitigation of transmission of tuberculosis from white-tailed deer to cattle: Literature review and recommendations, *Veterinary Medicine International* 2012, 1–15. 616318.
- Whitlock, R.H., Hutchinson, L.T. and Merkal, R.S.. (1985). Prevalence and economic consideration of Johne's disease in the northeastern U.S. *Proceedings of the United States Animal Health Association* 89, 484–490.
- Whittington, D., Briscoe, J., Mu, X. and Barron, W. (1990). Estimating the willingness to pay for water services in developing countries: a case study of the use of contingent valuation surveys in southern Haiti, *Economic Development and Cultural Change* 38, 293–311.
- Willis, K.G. (2002). Iterative bid design in contingent valuation and the estimation of the revenue maximising price for a cultural good, *Journal of Cultural Economics* 26, 307–324.

Wilson, D.J., Rossiter, C., Han, H.R. and Sears, P.M. (1993). Association of mycobacterium paratuberculosis infection with reduced mastitis, but with decreased milk production and increased cull rate in clinically normal dairy cows, *American Journal of Veterinary Research* 54, 1851–1857.

### Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table A1.** Pairwise correlation matrix for independent variables – beef farmers’ model.

**Table A2.** Pairwise correlation matrix for independent variables – dairy farmers’ model.