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Lessons from the Australian Johne's disesase control policies and programs

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Lessons from the Australian Johne's disease control policies and programs

by

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Abstract

Bovine Johnes disease (BJD) impacts dairy industries globally. Australia and Canada have low cow-level prevalence with varying herd-level prevalence and recently reviewed control activities. Control strategies using vaccination are lacking, suggesting opportunities for improved efficiencies of regulatory oversight. Aims of this study include identifying characteristics of producers participating in BJD control programs and vaccination, financial benefits of participation, and comparison of control activities in Australia and Canada to inform current and future control policy. An online questionnaire captured knowledge, attitudes, and practices plus demographics from 71 Australian dairy farms. Ordinal choice variable analysis identified several influences on participation, including economic factors. Simulation modelling suggests increased profitability through participation in BJD control programs and vaccination. Financial benefits of BJD control in different countries indicates high likelihood of positive returns for long-term programs, but short-term challenges to adoption and sustainability. Canada's BJD regulatory policies may benefit from Australian experience with BJD control.

Keywords: Johnes Disease, Control Programs, Vaccination Policy

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Dedication

This work is dedicated to my family.

To my wife, Meg for her cornerstone strength, support, and love throughout our journey. Thank you for choosing me.

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Table of Contents

List of Tables

List of Figures and Illustrations

List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
AHA	Animal Health Australia
AHI	Animal Health Ireland
AJDI	Alberta Johne's Disease Initiative
APVMA	Australian Pesticides and Veterinary Medicines Authority
ATQ	Agri-Traçabilité Québec
BJD	Bovine Johne's Disease
BTB	Bovine Tuberculosis
CAHC	Canadian Animal Health Coalition
CAP	Common Agricultural Policy
CattleMAP	National Johne's Disease Market Assurance Program for cattle
CCA	Canadian Cattlemen's Association
CD	Crohn's Disease
CJDI	Canadian Johne's Disease Initiative
CHD	Cattle Health Declaration
CJDPCP	Canadian Johne's Disease Prevention and Control Program
CBP	Cooperative Biosecurity Plan
CVO	Chief Veterinary Officer
DAFM	Department of Agriculture, Food and the Marine
DFC	Dairy Farmers of Canada
ELISA	Enzyme-Linked Immunosorbent Assay
EU	European Union
IJCP	Irish Johne's Disease Control Program
JD	Johne's Disease
JDCAP	Victorian Johne's Disease Calf Accreditation Program
MAP	*Mycobacterium avium ssp. paratuberculosis*
LPA	Livestock Production Assurance
NBJDSP	National Bovine Johne's Disease Strategic Plan
NJDCP	Australian National Johne's Disease Control Program
NPV	Net Present Value
NSW	New South Wales
NT	Northern Territory
NVD	National Vendor Declaration
OIE	World Organization for Animal Health
OJD	Ovine Johne's disease
OJEMAP	Ontario Johne's Disease Education and Management Assistance
PCR	Polymerase chain reaction
RA	Risk assessment
RAMP	Risk Assessment and Management Plan
SA	South Australia
SDR&Gs	Standard Definitions, Rules, and Guidelines
TB	Tuberculosis
TCP	Victorian Test and Control Program
UK	United Kingdom
USA	United States of America
WA	Western Australia

Epigraph

“It is the mark of an educated mind to be able to entertain a thought without accepting it”

Aristotle

Chapter 1 Review of bovine Johne's disease control

1.1 Introduction

Johne's disease (JD) is a debilitating wasting disease primarily affecting domestic ruminants such as cattle, sheep, goats, and camelids but also affects wild ruminants such as deer, elk, and moose. The causative organism, *Mycobacterium avium ssp. paratuberculosis* (MAP) has also been known to affect non-ruminant species such as pigs, horses, and rabbits (OIE, 2014). MAP is primarily faeco-orally transmitted and is disseminated throughout most of the world including Australia, Canada, New Zealand, the Republic of Ireland, United Kingdom (UK), United States of America (USA), and most European countries. There is currently no known cure for the condition.

Cattle are most susceptible to infection as calves through ingestion of colostrum, milk, water, or feed contaminated with MAP-infected faeces. MAP may also be transmitted to calves in-utero or through drinking the milk or colostrum of MAP-infected mothers (Mortier, 2015; Windsor, 2010). The inflammatory reaction induced by MAP causes intestinal thickening, predominantly in the jejunum and ileum resulting in protein leakage and malabsorption of nutrients. Four chronological stages of BJD have been described as the initial "silent infection" in younger animals, "subclinical disease", followed by those adult cattle with "clinical" and "advanced clinical BJD" presenting with chronic wasting and diarrhoea which typically only become visible at 2-10 years of age after lengthy incubation. However, the majority of infected animals remain as silent infections or sub-clinical and prove difficult to detect (Manning, 2010; OIE, 2014; Whitlock, 1996).

Several Mycobacterial diseases affecting animals are known to have public health risks (Thirunavukkarasu, 2016). Given the similar presentation of clinical cases, the link between BJD and Crohn's Disease (CD) in humans has existed for over a century with the zoonotic potential continuing to gather attention by the research community since the isolation of MAP in CD patients in numerous studies (Davis, 2012b; Waddell, 2015). MAP has satisfied neither Koch's postulates nor Hill's criteria for causation of any human diseases yet purported links and isolation of MAP in various dairy products casts public health concerns around dairy consumption as a result (Robertson, 2017b; Stabel, 2000).

Bovine Johne's Disease (BJD) causes economic losses for dairy farms in the form of early culling, decreased milk production, mortality, and reduced fertility (McAloon, 2016; Tiwari, 2008). Trade restrictions imposed on producers with positive herds may contribute to economic loss at the farm level and also limits access to some international markets.

As there is no known cure for BJD, it is important for farmers to apply adequate measures to prevent transmission of MAP into naïve herds and to minimize transmission within already infected herds. Appropriately applied control measures can mitigate the potential negative impacts of BJD such as decreased productivity, trade restrictions, welfare concerns, and any potential public health risks. Control measures available to farmers include testing and culling, hygienic calf management, general biosecurity practices, vaccination, and combinations thereof. Some farmers opt to exercise no specific control measures.

Australia and Canada both have significant dairy industries contributing to the global dairy industry through export trade of high-quality dairy products and genetics. Each having domestic and international export markets to protect, Australia and Canada have a history of various BJD control activities with similar objectives. However, the stakeholders primarily responsible for driving control and control approaches used over time differ significantly. This offers an opportunity to explore different approaches and the potential learnings and implications for other countries formulating new BJD control policy and rolling out control programs.

1.2 **Epidemiological Aspects of Johne's Disease Control**

1.2.1 **Prevalence**

The prevalence of BJD in global dairy cattle populations varies significantly. Several reviews and studies have reported the number of animals within herds infected with MAP (animal-level prevalence) and the number of herds within a region or country infected with MAP (herd-level prevalence) in various countries (Garcia, 2015). Animal-level prevalence in European countries reportedly ranges between 0% in Sweden where BJD has never been detected in dairy cattle, and 1.2% - 8.8% in other European countries (Garcia, 2015; Lombard, 2011). Animal-level prevalence in the USA has been estimated at 2.5% (Lombard, 2011). Herd-level prevalence of BJD in Europe (dairy and beef cattle) has been estimated at greater than 50% (Khol, 2012b; Nielsen, 2009) whereas in the USA this figure is estimated to be as high as 68% (Lombard, 2011).

Although BJD is present in Australia, it is endemic only in a relatively small area in the south-east representing the states of Victoria and Tasmania primarily but also parts of South Australia (SA) and New South Wales (NSW). These areas tend to mirror the distribution of the majority of dairy cattle in Australia. Large areas of Australia are free of BJD or have very few herds known to be infected. Owing to the distinct areas of high, low and zero prevalence, a zoning[1] system was developed in 1997 to assist with the management of BJD (AHA, 2015c). In 2002, dairy herds officially classified as infected in the south-eastern states, formerly known as the Control zone, amounted to a herd-level prevalence of about 14% (Kennedy, 2010). The cow-level prevalence of BJD in Victorian dairy herds is estimated at 1.78% (Jubb, 2004a). As Victoria is a major dairy-producing state and BJD is most prolific in the dairy industry in the south-east of

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[1]Zoning = "Delineation (by regulatory means) of part of a country/territory containing an animal subpopulation with a distinct health status or risk with respect to a specific disease, infection or infestation for which required surveillance, control and biosecurity measures have been applied for the purpose of international trade." http://www.oie.int/wahis_2/wah/help.php accessed 07/01/2019

Australia, the cow-level prevalence across other parts of Australia is likely less than 1.78%. The prevalence of infected beef herds in the same area is less than 1% (Kennedy, 2010).

BJD is present in all dairy farming regions of Canada. Numerous studies have documented the prevalence of BJD in various provinces but have used different test methods to do so. A study conducted in 2003 using serum EISA showed an animal-level prevalence of 1.8% however this study excluded Manitoba and Quebec (Douma, 2010). A more recent study using environmental culture from 362 Canadian dairy farms across the ten provinces revealed a herd-level prevalence ranging across the provinces of 22 – 67% (Corbett, 2018b).

Table 1.1 Cow-level and herd-level prevalence of BJD in dairy and beef herds in Australia and Canada

Prevalence	**Australia**		**Canada**	
	Dairy (%)	Beef (%)	Dairy (%)	Beef (%)
Herd-level prevalence	14.00 [6]	<1.00 [6]	22.00 – 67.00 [2]	11.70 [3]
Cow-level prevalence	1.78 [4]	0.77 [5]	2.00 – 9.00 [1]	1.00 – 2.00 [1, 3]

([1] BCRC, 2018; [2] Corbett, 2018[b]; [3] Douma, 2010; [4] Jubb, 2004[a]; [5] Jubb, 2004[b]; [6] Kennedy, 2010)

1.2.2 **Diagnostic testing**

Evaluation of BJD prevalence studies is challenging owing to different test methods used across different studies, each with varying sensitivity and specificity (Barkema, 2017). BJD can be diagnosed by various methods including clinical examinations and post-mortem examinations to offer a presumptive diagnosis. Laboratory diagnostic testing includes methods rooted in immunology, histology, molecular biology, and bacteriology as described in table 1.2 (AHA, 2017a).

Classification of herds as positive or negative depends on cut-off points for positivity used. For herd testing, individual faecal culture or herd environmental culture is often used where some researchers regard herds as “positive” if there is one positive reactor whereas others regard herds as positive where two or more reactors are present. For individual testing in live animals, Enzyme-Linked Immunosorbent Assays (ELISA) are conveniently and economically performed on individual animal sera with the allocation of positive, negative, or suspect status depending on antibody titre levels measured. ELISA testing can also be performed on individual or bulk milk samples. However, both serum and milk ELISA offer low sensitivity and frequently imperfect specificity. Faecal culture has often been regarded as the reference standard owing to improved sensitivity and near-perfect specificity (100%) for accurate identification of truly BJD negative animals (Barrett, 2011; Garcia, 2015; Pieper, 2014). A major limitation with faecal culture is the long culture period of 12-15 weeks required to obtain a result and the increased cost relative to ELISA. Where faecal culture is deemed inappropriate, faecal PCR has been used but although results are obtained in a shorter time than faecal culture, the cost is often prohibitive. Histopathology and culture on tissue samples from suspect positive animals provide better test sensitivity and specificity compared to the aforementioned tests but the requirement for the slaughter of animals is a major limitation.

Establishing reliable test characteristics for most of these tests is extremely challenging. Sampling techniques such as pooling and location of samples, stage of infection in animals in the sample population can influence accuracy as intermittent shedding presents a challenge for both bacteriological and immunological identification of infection (Table 1.2).

Tests with highly variable sensitivity and specificity, the long incubation period of MAP, inconsistent shedding patterns of infected animals, and persistence of infective organisms in the environment are factors that make BJD a difficult disease to detect and control (Whittington, 2004). The prevalence of MAP in several domestic and wildlife species and lack of effective treatment compounds the already complex epidemiologic factors and renders BJD control a challenging task (Kennedy, 2000b).

Table 1.2 Characteristics of selected diagnostic laboratory tests employed in national Johne's disease control programs in Australia and Canada

Test	Sensitivity (%)	Specificity (%)	Australia (NBJDSP)	Canada (CJDI)
Serum ELISA	7.0 – 94.0	84.9 – 100.0	✓	✓
Milk ELISA	21.0 – 61.1	94.7 – 99.7	✓	✓
Faecal culture	20.0 – 74.0	100	✓	✓
Herd Environmental Culture	71.4 – 76.3	58.8 – 98.6	✓	✓
Faecal PCR	4.0 – 100.0	85.3	✓	✓

(AHI, 2017b; AHA, 2017a; AJDI, 2011; Arango-Sabogal, 2018; Eamens, 2015; Garcia, 2015; Gilardoni, 2012; Nielsen, 2008; Pieper, 2014)

1.2.3 **Risk Factors**

Numerous studies have been conducted over the past few decades which have helped to identify and describe risk factors associated with both the herd-level and cow-level prevalence of BJD. However, some of these studies show conflicting results such as the serial risk factor studies carried out in Australia by Ridge *et al.* where the feeding of waste milk to calves is described first as a risk factor and subsequently as a protective factor (Ridge, 2005; Ridge, 2010). Risk factor studies are designed mostly as cross-sectional studies and case-control studies which are both subject to systematic error such as measurement bias and numerous confounding factors (McAloon, 2015). Studies conducted in the USA which describe important risk factors contributing to BJD transmission between and within herds have helped support the inclusion of risk-based management in BJD control programs in various other countries (Collins, 2010; Johnson-Ifearulundu, 1998; Johnson-Ifearulundu, 1999; Wells, 2000). Table 1.3 highlights some risk factors established in Australia and Canada through research conducted over the past 20 years.

Table 1.3 Studies conducted in Australia and Canada to establish risk factors (host and environmental management) associated with increased herd-level and cow-level prevalence of bovine Johne's disease.

Risk Factor	Australia	Canada
Host factors and herd management		
Breed of cattle (Channel Island)		Sorge, 2011
Contact with beef cattle		Tiwari, 2009
Contact with wildlife		Douma, 2010; Hendrick, 2006
Increased herd ELISA seroprevalence	Ridge, 2010	
Introduction of new animals		Puerto-Parada, 2018; Rangel, 2015; Sorge, 2012; Tiwari, 2009; Wolf, 2012; Wolf, 2016
Lack of rotational grazing		Douma, 2010
Larger herd size	Ridge, 2010	Sorenson, 2003; Wolf, 2016
Presence of other diseases (e.g. BVDV)		Tiwari, 2009
Poor hygiene of feeding equipment		Wolf, 2016
Calf management		
Comingling of young and adult stock		Puerto-Parada, 2018; Tiwari, 2009
Contact of young stock with adult faeces		Barkema, 2018; Doré, 2012: Puerto-Parada, 2018
Feeding concentrates (grain) to calves	Ridge, 2010	
Feeding of waste milk to calves	Ridge, 2005	
Group calf housing		Corbett, 2018[a]
Once-daily calf feeding	Ridge, 2010	
Poor colostrum management		Douma, 2010; McKenna, 2006[a]; Sorge, 2012
Provision of water to neonatal calves	Ridge, 2005	
Calving management		
Group maternity/calving pens	Ridge, 2010	
Poor hygiene of maternity/calving pens		Wolf, 2016

The most consistently identified risk factor for the transmission of MAP between dairy farms is the introduction of animals into the herd without adequate screening and biosecurity (Barrett, 2011; Khol, 2012a; Pillars, 2011; Rangel, 2015; Sorge, 2012; Wolf, 2016). The most important risk factor for transmission of MAP within dairy herds is the contact of young stock with adult faeces (Arango-Sabogal, 2017, Doré, 2012).

Other important risk factors for the increased incidence of MAP on dairy farms include poor hygiene in cattle and calf housing areas, and poor management of colostrum, water, and feed (Wolf, 2016). Investigations into calf rearing and feeding show these to play a key role in the transmission of MAP within infected farms (McAloon, 2017a; Ridge, 2005; Ridge, 2010).

Mitigation of identified risk factors has formed the basis for the risk assessments and the risk-based management approach used as part of BJD control programs in many countries (Collins, 2010).

1.2.4 **BJD in other livestock species and wildlife**

MAP strains have been isolated from a broad range of species but clinical disease is seen in very few. Strains of MAP can be classified in various ways depending on which characteristics are used for differentiation. Epidemiologically, strains have been differentiated based on phenotypic, genotypic, and taxonomic characteristics, and host predilections (Marsh, 2015). Two main strain types of MAP, namely the Sheep (S) and Cattle (C) strains are commonly used, reflecting the predominant species which they affect. Variants and subtypes have been identified which have been subsequently classified under one of these two strains. C-strains are most commonly isolated in cattle but have a broad range of wild and domestic ruminant and non-ruminant host species. S-strains are more commonly found in sheep and are also known to infect goats with experimental infection described in cattle and deer (Collins, 2002; Stevenson, 2010; Stevenson, 2015). Although strains appear to have host preferences, cross-infection between species has been demonstrated with both strains (Dairy Australia, 2008b; Hutchings, 2010;

Stevenson, 2015). Differentiation of MAP-strains within different livestock populations is important as the different epidemiological characteristics of strains influence diagnostics and control of BJD (Kennedy, 2000a; Kennedy, 2000b). As such, countries such as Australia and New Zealand have included market assurance programs with objectives of minimizing the impact of BJD in other livestock industries such as sheep, goats, alpacas, and deer (Kennedy, 2002).

Ovine Johne's disease (OJD) was first identified in the Australian sheep industry in 1980. As with BJD, the distribution of OJD is focused mostly in the south-eastern states. The Australian Johne's Disease Market Assurance Program for sheep, the component of the NJDCP aiming at reducing the impact of OJD in the Australian sheep industry was initiated in 1997. In addition, the National Ovine Johne's Disease Control and Evaluation Program was launched in 1998 with funding of AUD$40 million from industry and government at both the state and national levels (Allworth, 2000). Control of OJD in Australia has been largely successful with some areas reporting the feasibility of elimination. This success is also attributed to vaccination of infected flocks with Gudair® (Windsor, 2013; Windsor, 2014). A study including millions of vaccinated sheep sampled at the abattoir and evaluated over 10 years, showed that the number of flocks testing positive for OJD remained constant however the number of positive animals was reduced by 67% over the same period (Links, 2012). The current approach to OJD control is industry-driven under the National Ovine Johne's Disease Management Plan (NOJDMP) which was initiated by the Wool Producers Australia and Sheep Producers Australia after a consultative review process with the industry in 2012 (Thompson, 2018). Differences exist regarding regulatory structures in place for OJD with South Australia being the only state currently under regulatory control for OJD (Barwell, 2018).

MAP has been detected in the faeces of various wildlife species around the world with cross-infection between wildlife species and livestock species previously demonstrated. However, the risk of BJD incursions in domestic livestock due to the presence of MAP in resident wildlife populations is deemed to be low (Abbott, 2002; Barkema, 2017; Douma, 2010; Kennedy, 2010; Rangel, 2015). Further studies are required to better quantify MAP prevalence in wildlife populations and the risk of transmission to livestock (Manning, 2010).

1.3 **Bovine Johne's Disease Control Programs and Policy**

Over the years, many countries have mobilized voluntary and involuntary BJD control programs with varied success. Objectives include minimizing the impact of clinical BJD on the dairy industry, maintaining market access, and mitigation of potential public health risks (AHA, 2015b; AHI, 2017b; McKenna, 2006). Elements of national control programs differ concerning testing methods and control measures employed with variation seen across regions within countries (Geraghty, 2014). Evaluation of program outcomes suggests a need for better dissemination of the lessons learned for improving BJD control and thereby benefit the global dairy industry (Barkema, 2017).

In the United States, the approach to BJD control has undergone significant changes over the past 65 years resulting in the current Voluntary Bovine Johne's Disease Control Program (VBJDCP). Change has been prompted due to decreased federal funding of programs. The regulatory environment has evolved such that there are fewer restrictions on producers with positive herds, but restrictions still exist regarding the movement of positive animals (Geraghty, 2014). The VBJDCP is a federal-state-industry initiative implemented in 2002 which provides the guidelines for each state to carry out their own BJD control activities and has been subject to significant revision (Carter, 2011).

Countries in the UK and Europe have BJD control programs demonstrating varied success over the past few decades. Scandinavian countries such as Denmark, Sweden, and Norway have existing programs enabling producers to state test-negativity of beef and dairy herds (Collins, 2014). Sweden is the only country to claim a BJD prevalence of zero (Garcia, 2015; Lombard, 2011). National efforts with a specific focus on BJD in Ireland started in 2004 which has evolved into the current Irish Johnes Control Program (IJCP). The IJCP employs elements of best practice as garnered from the revision of programs in other countries and continues to adjust the program as ongoing revisions reveal areas for improvement (AHI, 2017a; Geraghty, 2014; Graham, 2012).

The Canadian Johne's Disease Initiative (CJDI) operated from 2007 – 2013 and currently there is no nationally unified program directed specifically at BJD control (Barkema, 2018).

Formal BJD control programs in Australia commenced with the National Johne's Disease Control Program (NJDCP) in 1996 (Citer, 2009, Kennedy, 2010). Noteworthy is the evolving regulatory framework for BJD control in Australia. In addition to changes in approach over the years including the most recent in 2016, Australia provides a unique scenario whereby a registered vaccine for BJD control in cattle (Silirum ®, Zoetis) is available to producers as part of their control options.

1.3.1 History of bovine Johne's disease control and current control programs in Australia and Canada

1.3.1.1 Australia

Australia's freedom from many livestock diseases is a major advantage which supports a reputation for high-quality agricultural products and facilitates favorable trade agreements with export partners. Protecting this reputation requires ongoing surveillance and disease control systems to provide assurances that Australia maintains disease freedom or very low-risk status of disease (Australian Government, 2018). As such, animal disease control remains a constitutional responsibility of each state government in Australia.

BJD is most prevalent in the south-east of the country, mostly affecting the high concentration of dairy farms. Many sheep properties in this area are also affected. Despite the challenges posed by BJD to livestock farming in this region, the relatively limited distribution of MAP affords the large majority of the country a livestock farming environment unaffected by the disease. In order to protect this status and maintain market access, control measures are applied in all livestock industries susceptible to MAP (Kennedy, 2010).

Control of BJD in Australia prior to 1996 comprised various State and Territory regulated control activities including test-and-cull programs, vaccination, quarantine, minimal intervention strategies, and market assurance programs which were re-evaluated due to their failure to contain the spread of BJD in endemic areas (Citer, 2009, Kennedy, 2010). The NJDCP, also known as the National Johne's Disease Project, was the first of Australia's nationally cohesive BJD control programs. Following a regulatory control approach, the NJDCP was rolled out in 1996 to coordinate BJD control in all the relevant livestock industries in response to concerns of continued spread of BJD within and between livestock industries, the impact of BJD on livestock productivity, movement restrictions due to infected animals and properties, and public health concerns regarding the purported role of MAP in the aetiology of Crohn's Disease in humans (Citer, 2012; Kennedy, 2000a; Kennedy, 2010).

The NJDCP is managed by Animal Health Australia (AHA), an organization of stakeholders including the Federal, State, and Territory governments, livestock industry organizations, service providers, and associate members serving to coordinate and manage national animal health projects (Citer, 2009; AHA, 2018a). The NJDCP has a set of Standard Definitions, Rules, and Guidelines (SDR&Gs) to guide BJD control in all affected species (AHC, 2012). The National Bovine Johne's Disease Strategic Plan (NBJDSP) oriented by these SDR&Gs support numerous subsidiary programs, such as the National Johne's Disease Market Assurance Program for cattle (CattleMAP) and Beef Only, which previously provided assurance to the market place regarding the risk of BJD in cattle. Various revisions to the NBJDSP between inception and 2015 resulted in changes such as the divergence into separate programs for the beef and dairy industries and the addition of hygienic calf rearing practices to the program (Geraghty, 2014; Kennedy, 2002). Revision of the NBJDSP in 2015 resulted in an amendment to the SDR&Gs, cessation of CattleMAP and Beef Only, and the birth of the current approach referred to as the new BJD Framework. The 2015 revision was a collaborative effort between government and industry resulting in the formulation of the new partially deregulated approach to control (AHA, 2016; Barwell, 2018).

1.3.1.2 ***Canada***

BJD control efforts in Canada commenced in 2001 with the Alberta Johne's Disease Control Program which incorporated multiple ruminant livestock industries. Elements of the program included awareness and education, veterinary accreditation, the Voluntary Herd Status Program, and collaborative research (Mainali, 2002). Initiatives in Alberta progressed to the proposal and coordination of The Canadian Voluntary Johne's Disease Prevention and Control Program (CJDPCP) in 2006 by the Canadian Animal Health Coalition (CAHC), an organization addressing animal health issues through projects involving both industry and government (McKenna, 2006b). The Canadian Johne's Disease Initiative (CJDI) funded by Dairy Farmers of Canada (DFC) and the Canadian Cattlemen's Association (CCA) was thus rolled out in 2009 in response to similar concerns of decreased productivity and increased the susceptibility of herds to other diseases. Additional concerns include impending confirmation of the link between MAP and Crohn's Disease and the subsequent effects on the ability to export cattle (Barker, 2012; Barker, 2013; DFC, 2018a; McKenna 2006b).

Provincial programs supported by the CJDI were subsequently rolled out in each of the 10 provinces (Table 1.4). Funding for the CJDI concluded in 2013 and since then Canada has been without a national control program specifically targeting BJD. There is, however currently a broader quality assurance initiative in place developed by DFC called proAction® which has modules addressing various aspects of dairy production. proAction® employs the BJD risk assessment developed for the CJDI as part of the infrastructure for the biosecurity module of this initiative (Barkema, 2018; DFC, 2018b).

Table 1.4 Provincial BJD Control Programs under the Canadian Johnes Disease Initiative

Province(s)	Control Program	Duration
Alberta	Alberta Johne's Disease Initiative	2010 – 2013
British Columbia	British Columbia Johne's Disease Initiative	2011 – 2013
Manitoba	Manitoba Johne's Disease Initiative	2010 – 2013
New Brunswick Newfoundland and Labrador Nova Scotia Prince Edward Island	Atlantic Johne's Disease Initiative	2011 - 2014
Ontario	Ontario Johne's Disease Education and Management Assistance Program	2010 - 2014
Quebec	Quebec Voluntary Paratuberculosis Prevention and Control Program	2007 – present
Saskatchewan	Saskatchewan Johne's Disease Working Group	Periodic Meetings

(Table adapted from Barker *et al.*, 2012; Barkema *et al.,* 2018.)

1.3.2 **Objectives of programs**

Overarching objectives of control programs around the world are to prevent infection in herds known to be free of BJD and reduction of infection levels in positive herds. This allows local dairy industries to provide quality assurances for products such as milk and genetics to domestic and international trade partners (Barkema, 2017; Garcia, 2015; Geraghty, 2014; McKenna 2006a).

1.3.2.1 Australia

Aims of the NJDCP between 1996 and 2015 were to maintain the favorable low prevalence of BJD in most regions of Australia and to reduce the impact of both the disease itself and the control measures intended to mitigate the risk of BJD, including any inadvertent impacts one industry may have on another (Citer, 2009; Dairy Australia, 2008b; Kennedy, 2010). Learnings from the review to the NBJDSP in 2015 saw new aims of a more comprehensive nature welcomed under the new BJD Framework, creating an approach better suited to the dynamics of the Australian cattle industry and the epidemiology of BJD. These additional aims include a focus on well supported, consistent, cost-effective biosecurity measures which address endemic cattle diseases befitting of the business requirements of individual producers and reduce the regulatory burden of BJD control. (AHA, 2015b). Aims of individual state control programs such as DairyManaJD in South Australia generally reflect those of the national program. Further specific aims of DairyManaJD include engagement of farmers and veterinarians in BJD management, tools to improve biosecurity and facilitation of cattle movement, and reduction of the regulatory burden of BJD control. In addition to being an objective of the program, reduction of infection risk to beef producers served as a motivation for initiation of the program (Rogers, 2012).

1.3.2.2 Canada

The specific aim of BJD control programs in Canada at the outset was to reduce the number of dairy herds infected with BJD and the prevalence of BJD within herds. (DFC, 2018a; Ritter, 2016). Priorities of the CJDI thus focused on the education of dairy industry stakeholders, implementation of collaborative control programs within each province, and funded research programs supportive of BJD control in Canada. (Barker, 2012; Barkema, 2018). Provincial programs rolled out under the CJDI each have objectives aligned with the priorities of the CJDI. Additional objectives of provincial programs included prioritizing animal health within the dairy industry, market assurance, and improved relationships between producers and veterinarians for better general on-farm disease control (Godkin, 2013).

1.3.3 **Features of programs**

Control programs around the world have evolved from a largely test-and-cull based approach to determine BJD herd-status, to a more management-based approach focused on mitigation of known risk factors for transmission of BJD and using status of herds to facilitate trade

(Wolf, 2014a). Testing still forms an important aspect of control programs but owing to poor test characteristics of the currently available tests, less emphasis is placed on testing. A variety of tests are available to be applied under different testing strategies depending on sample origin and the objectives for testing (Table 1.2).

Participation in control programs globally is mostly voluntary with programs having similar features. Common challenges include poor participation rates and poor implementation of best management practices to mitigate established risk factors (Barkema, 2017; Devitt, 2016).

Table 1.5 Elements and features of national Johne's disease control programs in Australia and Canada

Element/Feature	Australia	Canada
Annual auditing	✓	✓
Biosecurity plan	✓	✓
Education (producer and veterinarian)	✓	✓
Enrolment	✓	✓
National herd assurance score/status/certification	✓	✓
Hygienic calf rearing	✓	✓
Individual provincial control programs	✓	✓
Regulatory framework	✓	
Research	✓	✓
Risk Assessment and Management Plan (RAMP)	✓	✓
Regular testing	✓	✓
Vaccination	✓	
Veterinary involvement	✓	✓
Zoning	✓	

(AHA, 2015b; AHA, 2017a; AJDI, 2011; Barkema, 2018; Barker, 212; Barker, 2013)

1.3.3.1 Australia

Substantial reviews to the NBJDSP with development into the current BJD Framework have removed complexities of the previous convoluted SDR&Gs that were inconsistently applied across Australia. Key elements of the CattleMAP and Beef Only control programs have been maintained but the most striking difference is the lack of regulatory features such as quarantine, movement and trade restrictions, and herd depopulation (AHA, 2015a). Participation in the current

BJD Framework is entirely voluntary where farmers are empowered to take measures deemed appropriate to control BJD on their property, framed as part of a broader integrated biosecurity approach, fitting with individual business requirements (AHA, 2017b). As such, various industry and government-supported tools have been made available to farmers and dairy advisors to mitigate the risk of transmission of MAP to BJD-free herds and within BJD-positive herds (AHA, 2015b).

A newer set of definitions and guidelines replacing the previous SDR&Gs is currently available which outline risk-profiling and management schemes assisting herds to acquire a BJD-herd status as classified under the BJD Beef Assurance Score (J-BAS) or National Dairy Bovine Johne's Disease Assurance Score. Approved testing methods as per the Australian and New Zealand Standard Diagnostic Procedure for Paratuberculosis are outlined which can be recorded on Cattle Health Declarations (CHD), forms whereby producers can formally declare the health status of animals under their responsibility to facilitate trade. The definitions and guidelines provide recommendations for investigation, management and identification of positive test reactors, infected animals, and MAP-contaminated land (AHA, 2017a).

Hygienic calf rearing practices have formed an integral part of BJD control programs in Australia over the years with additional BJD-herd status points awarded to herds for employing these practices. The 3-Step Calf Plan is an industry-driven program coordinated by Dairy Australia available for all Australian farmers which is a set of voluntary management practices entailing separation of calves from cows within 12 hours of birth, preventing calves encountering effluent from potentially infected animals, and having pastures for calves younger than 12 months that are separate from pastures used for adult stock in the previous 12 months. This forms part of the Dairy BJD Technotes, a set of best practice recommendations for managing BJD published by Dairy Australia, available to veterinarians and dairy advisors to support producers (Dairy Australia, 2008a; Dairy Australia, 2008b). The Johne's Disease Calf Accreditation Program (JDCAP) is a more rigorous government-driven hygienic calf rearing scheme coordinated by Agriculture Victoria. It is used on dairy farms throughout Victoria and has similar features to the 3-Step Calf Plan but includes additional management, monitoring, review and accreditation procedures. All milk processing companies include hygienic calf rearing practices as part of contractual requirements for on-farm quality assurance (Agriculture Victoria, 2016a; Dairy Australia, 2008a; Rogers, 2012).

Biosecurity checklists and biosecurity plan templates are available for farmers to implement and improve on-farm biosecurity in support of BJD control as part of an integrated biosecurity approach. The new BJD Framework provides guidelines for producers to set up groups having a Cooperative Biosecurity Plan (CBP) as appropriate. This tool enables producers within a distinct geographic location or with common interests to form a recognized group using a compartment approach to managing various diseases, including BJD (AHA, 2017b)

Tools that were available to support enrollment in the former CattleMAP included state-specific control programs such as the Test and Control Programs (TCP) rolled out in Victoria for infected farms to reduce infection within the herd and overcome trade restrictions imposed by prevailing regulations at the time. TCP included whole herd serum ELISA testing with the culling of positive reactors and management plans to control BJD thereby providing a pathway to join the market assurance program (CattleMAP). Similarly, the South Australian industry-government BJD control program, DairyManaJD was launched in 2005 entailing testing, case investigation, and hygienic calf rearing to aid producers in acquiring a BJD-herd risk status as per the National Dairy Bovine Johne's Disease Assurance Score. (Dairy Australia, 2008b; Jubb, 2000; Rogers, 2012; AHC, 2012).

Zoning is a tool previously used whereby Australia was divided geographically into zones based on the prevalence of BJD and control infrastructure available. The four zones were classified in order of increasing BJD-risk as the Residual, Control, Protected, and Free zones each with an associated level of BJD risk-assurance (Dairy Australia, 2008b). Active surveillance for BJD in Western Australia (WA) contributed to the region's status as a former Free zone after no evidence of BJD was found in high-risk cattle populations (Kennedy, 2000a; Kennedy, 2000b). The former Residual and Control Zones cover Tasmania, Victoria, and parts of New South Wales and South Australia, thereby encompassing most of the dairy industry. Beef Protected Areas were a feature of the control framework prior to 2016 where beef farms in the higher prevalence south-east were compartmentalized and received the same status as farms in the Protected and Free Zones. Beef Protected Areas were designated as part of the separate control program rolled out for beef producers called Beef Only.

Under regulatory control, enforcement of regulatory control measures and movement restrictions within each state varied. Initially any positive herds or suspected positive herds were subject to mandatory testing, culling, and quarantine. Producers with infected herds enrolled in the South Australian DairyManaJD control program were exempt from quarantine. Early revisions to the SDR&Gs rendered regulatory control measures applicable only to herds outside of the control and residual zones (AHC, 2012, Dairy Australia, 2008b; Geraghty, 2014; Kennedy, 2000a; Rogers, 2012). Further revisions to BJD control in Australia lead to partial deregulation of BJD control effective from 2016. Zones are no longer in place however some low prevalence jurisdictions such as NT and WA have maintained regulatory control at the behest of the local livestock industries to maintain a competitive advantage for exports of livestock and livestock products. (AHA, 2015b; Barwell, 2018). The state of Queensland, part of the former Protected Zone with a low BJD prevalence, is currently undertaking a Surveillance Program for BJD whereby diagnostic tests are offered free of charge by the Queensland government. Follow up investigations carried out on suspected cases are also done at no financial cost to the producer (Queensland Government, 2018a; Queensland Government, 2018b).

Livestock Production Assurance (LPA) is an additional voluntary on-farm quality assurance program in Australia managed by Meat and Livestock Australia (MLA). The elements of the LPA include risk assessments, good stewardship of animal feeds and therapeutics, management of livestock movement, biosecurity, and animal welfare. Participating producers may be audited and those complying with all requirements receive LPA certification. National Vendor Declaration (NVD) forms are available for participants whereby producers can disclose information about on-farm practices relevant to LPA program requirements (MLA, 2018). Although not BJD focused, LPA certification provides additional assurance that producers are addressing quality aspects of livestock production.

A tool available to beef producers with infected farms enrolled in the former Beef Only market assurance program was a package consisting of financial and non-financial components. The non-financial component entailed counselling and management advice provided to complement the financial component which funded the testing and removal of suspect animals. The financial component was subsidized by the Cattle Council of Australia which paid out AUD$2,000,000 in funding to eligible producers between 2004 and 2007 (Citer, 2007; Keatinge, 2009).

Collaborative research was identified as a key feature of the NJDCP at inception in 1996 with a focus on applied research and the persistence of MAP in the environment and transmission of BJD between species (Kennedy, 2000a; Kennedy, 2000b; Kennedy 2010). Research priorities have not been emphasized explicitly under the new BJD framework.

The demographic profiles and characteristics of Australian dairy farmers participating in control programs have not been described in the literature.

1.3.3.2 Canada

The different provincial control programs under the CJDI in Canada vary in certain aspects but common elements include education of producers, consumers, and veterinarians, on-farm risk assessments with appropriate management plans to remediate problem areas, environmental and individual cattle testing, applied research, and voluntary participation (Barker, 2012; Barkema, 2018).

The educational feature of the CJDI was carried out through various channels of printed media and presentations accessible to producers and veterinarians. In some provinces, the educational component was used not only to improve awareness of BJD and control but also to inform better approaches to disease control and other priority matters on farms based on individual farmers different knowledge and attitudes (Kelton, 2011b; Ritter, 2017; Roche, 2015).

Annual risk assessment questionnaires standardized across the provinces and conducted by accredited veterinarians form the basis for directing change within herds by identifying areas that contribute to increased transmission of MAP and allocation of scores accordingly. Practical and attainable changes in management practices are then agreed upon by the producer and veterinarian as part of the risk assessment and management plan (RAMP) to improve problem areas identified thereby improving the RAMP score within a relevant time frame. RAMPs have been deemed an integral part of BJD control and serve as a valuable tool in Canadian control programs as RAMP scores are generally higher on farms infected with BJD than those that are test-negative (Barkema, 2018; Devitt, 2016; Pieper, 2015a, Pieper, 2015b; Ritter, 2015; Sorge, 2010a).

Testing is another key aspect of the CJDI however test methods used and frequency of testing across the different provincial programs are inconsistent. Testing in Alberta and the Atlantic provinces consists of annually obtaining 6 environmental samples for culture from 6 strategic locations around the farm to test for the presence MAP. Herds with MAP-positive environmental cultures then undergo individual cow serum and/or milk ELISA testing to identify test-positive animals for removal from the herd (AJDI, 2011; Godkin, 2009; Keefe, 2012; Kelton, 2011a; Wolf. 2012). This differs from testing methodology employed in Ontario where no environmental testing is used however farmers were incentivized to have all cattle individually tested once-off using serum or milk ELISA on a specified test day (Godkin, 2009; Godkin, 2013b). Testing in conjunction with the on-farm risk assessments forms the foundation for classifying and assigning herds a BJD-risk status to facilitate trading and provide market assurance. Some provincial programs included the publication of herds online with test-negative status. Herd status and classification across provinces are however not standardized nor reciprocally recognized owing to differing execution of risk assessments and testing methods (Barkema, 2018; Geraghty, 2014).

Characteristic features of CJDI participants in some provinces were those farmers having larger herds, those using a herd veterinarian more often, and those having more knowledge about the CJDI and in other provinces characteristic features included farmers having better production figures and management practices than non-participants (Kelton, 2011a; Ritter, 2015).

The research component of the CJDI contributed to the production of numerous peer-reviewed papers by researchers, most notably at the University of Guelph and the University of Calgary through collaboration with their respective provincial programs. The involvement of academia played a key role in driving some provincial programs and allowed elaboration on risk factors and disease control dynamics under Canadian dairy industry conditions as literature pertaining to the epidemiology, economics and management of BJD in Canada prior to the CJDI is lacking.

1.3.4 **Sources and allocation of funding**

Funding sources for BJD control programs vary from country to country with the majority of funding generally coming from those stakeholders primarily responsible for driving BJD control. National disease control programs around the world are having to rely more on the industry for funding as government priorities change (Kennedy, 2011).

1.3.4.1 Australia

Facilitation and coordination of the NBJDSP by Animal Health Australia is funded by annual subscriptions received from its stakeholder members. Activities at the national level such as the former CattleMAP were funded largely by producers with annual funding from producer levies reaching AUD$1,700,000 in some years. Funding was also provided by the government and industry organizations such as Cattle Council of Australia and Australian Dairy Farmers Association. Initial costs to cover testing and fees associated with veterinary services are anticipated at around AUD$10 per head (Geraghty, 2014; Kennedy, 2010). Subsidies for testing and veterinary advice for BJD control within each state vary.

DairyManaJD participants through the South Australian Cattle Advisory Group and TCP participants through the Cattle Compensation Fund, receive funding for testing and veterinary advice pertaining to BJD control. Annual costs of TCP in Victoria were estimated at AUD$2,000,000 per year funded mostly by industry. Government funding for Victorian TCP participants was also available through the Department of Natural Resources and Environment. Industry funding for DairyManaJD between 2004 and 2011 amounted to approximately AUD$450,000 annually. Producers in both SA and Victoria received additional compensation for investigation of suspect clinical cases and culling positive ELISA test reactors (Jubb, 2000; Jubb, 2004a; Kennedy, 2000a; Rogers, 2012). Eligible producers in SA and Victoria have access to a subsidy if opting to use a BJD vaccine. Beef and dairy producers in Victoria with BJD-positive herds wanting to make us of Silirum ® Vaccine to control BJD have access to a subsidy of AUD$12.50 per dose. Producers engaging in JDCAP and meeting all program criteria are eligible for a maximum rebate of AUD$356 for initial enrollment and AUD$250 per annum thereafter. Both the vaccine and JDCAP subsidies are available until 31 December 2019 (Agriculture Victoria, 2016b; Rogers, 2012).

Annual BJD surveillance in Western Australia (WA), the former Free Zone, amounts to about AUD$86,000 per year however this may increase depending on the level of regulatory control imposed and the number of BJD incursions that require eradication. Modelled over a 30-year period, the costs of a state regulatory control program under a scenario where no control measures are in place at the state or farm level have been estimated at AUD$6,140,000 Net Present Value (NPV) which is likely much greater than costs associated with losses due to BJD (Government of Western Australia, 2016).

In Queensland, additional state-specific funding includes the state government-funded AUD$5,000,000 Queensland Biosecurity Fund established in 2013 which was used to partially compensate each Queensland producer affected by regulatory control measures up to AUD$100,000 (Queensland Government, 2014). A 2014 report estimates the cost to industry and government of managing BJD-positive herds identified through trace-forward and trace-back under regulatory control at AUD$24,000,000 (Queensland Government, 2014). Although deregulated in 2016, The Queensland Government conducts ongoing monitoring for BJD by the provision of free testing at the Biosecurity Queensland veterinary laboratory as part of the Surveillance Program (Queensland Government, 2018a).

Diminishing funding from both industry and government contributed to the development of the new BJD Framework to control BJD in Australia (AHA, 2015b; Kennedy, 2011; Rogers, 2012). Appropriate funding available under the new BJD Framework will be allocated to research and development of tools to assist producers in the management of endemic diseases however costs associated with the use of tools by producers are not subsidized (AHA, 2015b).

1.3.4.2 Canada

Total funding for the CJDI across all provinces amounted to CAD$6,600,000 from 2007 – 2014. Initially, funding was provided by the government, the dairy industry (DFC) and the beef industry (CCA) (Barkema, 2018; Barker, 2012; Barker, 2013; Geraghty, 2014). Additional funding for individual provincial programs came from government, industry, and academia with the majority coming from public sources.

In Ontario, industry served as the major source of additional funding for the OJEMAP (Barker, 2013; Kelton, 2011b; Pieper, 2014). Funding allocated to testing ranged from partial reimbursement of farmers for some tests carried out, to all testing being covered fully without farmers having to pay upfront. Initial testing costs per animal in various provinces ranged from CAD$6-8 per head. Veterinary fees for risk assessments and other program-associated work were covered in full in some programs and only partially in others. Some programs also offered partial compensation for the culling of cows with high titre ELISA test results such as in the OJEMAP where producers were paid CAD$500 per cow culled as per program specifications. A survey of producers in Ontario revealed that most producers would be willing to share costs if control programs became mandatory in Canada (Sorge, 2010a).

Funding allocated to the research component of the provincial programs differs in that some provinces factored funds for research into the program budget whereas other provinces allocated funding to researchers which had also secured funding through other channels. Funding was also allocated to the administration of programs (Barkema, 2018; Kelton, 2011b).

1.3.5 **Monitoring and evaluation of control programs**

Efficacy of BJD control programs in the short term is contentious as tangible benefits are not apparent to producers. Empirical evidence for control programs successfully eradicating BJD and long-term efficacy of BJD control is lacking however simulation of program benefits over the longer term are promising (Barkema, 2017; Cho, 2013; Rasmussen & Hall, 2018; Shephard, 2016). Numerous indicators can be used to gauge the impact that control programs may have.

Indicators such as a change in prevalence can be difficult to quantify especially when a variety of classification and test methods exist each with different test sensitivity and specificity. This presents a challenge when trying to objectively assess changes in true and apparent prevalence across regions. A field trial conducted as part of control programs in the US demonstrated a 6% reduction in apparent prevalence over 6 years in herds (Collins, 2010; Garcia, 2015). Changes over time in parameters such as RAMP scores, participation rates, knowledge, attitudes, practices toward BJD control, and net financial benefits are some of the other measurable progress indicators of control programs.

1.3.5.1 Australia

The number of participants in CattleMAP showed an initial increase from 180 participants in 1996, to 1623 participants over a seven-year period (McKenna, 2006a). Factors attributed with the initial increase in participation include easier navigation of movement requirements within Australia, better prices received for the livestock from participating herds, provision of quality assurance to buyers of stud animals, and financial support for program costs in some states (Kennedy, 2002). Thereafter, the CattleMAP experienced a decline in program participation. The decline has been attributed to factors such as frustration with false-positive reactors, difficulty for herds to graduate to “test-negative” after complying with program standards, social stigma and risk of decreased land value for infected properties, reduced ability to trade cattle under regulatory constraints, and lack of perceived benefit to participation especially for commercial producers in areas where testing was not subsidized (Davis, 2012a; Kennedy, 2000a; Kennedy, 2002; Kennedy, 2011; Shephard, 2014b; Westacott, 2012).

DairyManaJD in South Australia had a very high participation rate with 97% of all herds in the state enrolled between 2004 and 2011 with 28 infected herds achieving test-negative status (Rogers, 2012). Evaluation of the Test and Control Programs (TCP) in Victoria showed a successive reduction in BJD prevalence in enrolled dairy herds, evident through a significant reduction in the number of clinical cases and test reactors. Although the reduction in reactors among younger animals was significant, only 6% of participating herds achieved a resolution to a negative BJD status following 3 successive negative herd tests. The inclusion of hygienic calf rearing practices in control programs in Australia is deemed to reduce transmission of BJD within infected herds. However, the presence of reactors in many participating herds after the commencement of the TCP suggest that eradication is questionable in the short term. (Davis, 2012a; Jubb, 2000; Jubb, 2004a; Ridge, 2010).

1.3.5.2 Canada

Producers participating in the former CJDI represented more than 35% of all Canadian dairy farms at the time with some provincial programs having 70% of producers enrolled. Provinces using RAMPs as part of control programs all showed an improvement in RAMP scores over time. More than 60% of veterinarians consulting to the dairy industry dairy were trained over the period of the CJDI. Impact on the reduction in true prevalence due to the CJDI is difficult to ascertain owing to the variation in test methods applied across provincial programs. Herds in Western Canada and Ontario reported a decreased cow-level prevalence based on milk ELISA testing (Sorge, 2011a). Despite lowered cow-level prevalence and many farms showing negative test results for all animals, the associated nomenclature of herd status proved a source of frustration for farmers wanting to claim freedom from BJD as opposed to the technically correct term “test-negative” being used to satisfy the limitations of poor diagnostic test characteristics and complexities of a herd certification system (Barkema, 2017; Roche, 2014). Many producers disengage from control programs when no animals in the herd test positive due to a lack of perceived value of continuation. In addition, withdrawal of participation for fear of false-positive test results can result in the propagation of BJD infection (Cho, 2013; Kelton, 2011; Sorge, 2010a).

The educational component of the CJDI improved producers’ awareness of BJD and risk factors for disease thereby recognizing the merits of risk-based trading and assisting the transition from a misplaced reliance on testing and culling (Barkema, 2018; Barker, 2013; Roche, 2015; Wolf, 2012). The OJEMAP reported the implementation of only 33% of recommendations made by veterinarians following completion of on-farm RAMPs. Improvement of RAMP scores has been associated with the implementation of recommendations however a decrease in management improvements has been noted as programs progress. A reason suggested for this is that easily rectifiable changes are implemented earlier on in programs with less feasible management changes addressed later or not at all (Sorge, 2011; Wolf, 2015).

1.3.6 The role of beef cattle in BJD control

Australia and Canada have prominent beef industries which play an important role in disease control in cattle populations. Dairy herds typically have a higher BJD prevalence compared to beef herds due to management factors that allow transmission of BJD during early calf-hood such as high-density calving areas and feeding of pooled colostrum. (Good, 2009). Although equally erosive to both beef and dairy cattle, BJD has been seen by some as a problem primarily of the dairy industry with dairy cattle populations serving as a repository for infection (Douma, 2010; Keatinge, 2009; Kennedy, 2010).

Table 1.6 Profiles of the Australian and Canadian beef industries (2016)

Characteristic	Australia	Canada
Number of beef cattle ('000) [¥]	25,000 [3]	9,683 [1]
Number of farms	47,021 [3]	63,245 [1]
Average cows per farm	532 [*]	153 [1]
Annual volume of beef produced (tonnes)	2,070,000 [3]	1,300,000 [2]
Volume of beef exported (tonnes)	962,983 [3]	359,600 [2]
Live cattle exports	907,965 [3]	640,477 [1]
Value of total annual beef product exports [#]	AUD$7.1 Billion [3]	CAD$3.6 Billion [2]
Main beef export trade partners (Most to least)	Japan, USA, Korea, China [3]	USA, China, Japan, Mexico, Korea [1]

* Derived; ¥ Cows and followers; # Including live exports
([1] AAFC, 2018; [2] CCA, 2018; [3] MLA, 2017)

Preservation of the low BJD prevalence in Australia, particularly in the beef industry has been one of the major drivers of the NBJDSP. Freedom from BJD in most of Australia facilitates both domestic and international market access for live cattle exports and other beef products. The previous government-driven approach to BJD imposed significant regulatory penalties on infected beef and dairy herds. One of the aims of this approach was to help maintain assurance of low risk for BJD in the Australian livestock industries but made the movement of cattle between different zones challenging. Beef producers with infected herds within the former Control Zone were particularly affected by movement restrictions and thereby had reduced market access. Initiation of the Beef Only control program compartmentalized beef herds within the south-east thereby allowing movement of cattle into lower prevalence areas and facilitating trade (Citer, 2007; Keatinge, 2012; Kennedy, 2010). To encourage beef farmers to participate in the CattleMAP program (Beef Only) during its tenure, a rebate of AUD$220 was made available to cover the costs of testing and a further AUD$300 allocated to external audits done by the Cattle Council of Australia (Geraghty, 2014).

The Beef Only program accompanied by deregulation of BJD control in the south-east dairy regions alleviated some regulatory burden on beef producers in the south-east wishing to move cattle interstate. However, inconsistent application of the SDR&Gs across the states and territories and ongoing regulatory control in the beef industry maintained a restrictive trading environment for producers with positive reactors, particularly beef stud breeders and those wishing to export live cattle. In addition to the financial effects such as production loss, reduced market access, and decreased land value, social and psychological impacts on producers with positive BJD herds has been documented (AHA, 2018b; Citer, 2007; Gavey, 2016; Gavey, 2018; Keatinge, 2009).

Owing to the status as a former Protected Zone with low apparent BJD prevalence and predominantly beef cattle, BJD control in Queensland before 2016 was managed through a regulatory approach as per the SDR&Gs. BJD incursions on several Queensland beef properties in 2012 and 2013 resulted in regulatory actions imposed on approximately 280 beef farms through trace-forward and trace-backwards procedures to resolve the infection and establish risk status of farms. Affected producers were not able to trade cattle other than directly to slaughter or to other infected properties until resolution of the herd's BJD status. Although the resolution of the risk status of most of the properties was achieved before the 2015 NBJDSP review, the regulatory impact of these incursions contributed significantly to the movement for revision and deregulation of BJD control (Queensland Government, 2014; Gavey, 2016).

Queensland dairy producers enjoyed the protection of low BJD prevalence in the state afforded by the Protected zone status under the previous regulatory approach. Deregulation of BJD control in Queensland was initially opposed by dairy producers but is being progressively embraced as a way of maintaining the low BJD prevalence in all Queensland's livestock industries. Producers are responding to market-driven incentives for the uptake of BJD control measures such as the mandatory LPA certification requirement by red-meat processors and specific movement requirements for animals into other states and territories. Aligned with the new BJD Framework, mandatory biosecurity planning for all livestock producers has recently been included in Queensland legislation which allows producers to comply with LPA requirements more readily (Barwell, 2018; Gavey, 2018; Queensland Country Life, 2016).

Although less affected by cases of clinical BJD, the beef industry in Australia has generally been supportive of the need to control BJD in the dairy industry. Active participation of beef producers in BJD control preserves the competitive advantage that a low prevalence affords regarding international trade requirements to provide livestock products with a high assurance of BJD freedom. This is especially beneficial and, in some cases, necessary for stud herds where regulatory control has led to severe business disruption (Webb-Ware, 2012). For example, the DairyManaJD program in South Australia was funded by the local beef industry and proved mutually beneficial as relatively few trade restrictions accompanied mitigation of the risk of BJD in both the local beef and dairy industries in South Australia (Dairy Australia, 2008b; Rogers, 2012).

Prior to its conclusion, the CJDI included objectives for BJD control in Canadian beef herds however the individual provincial programs appear to have been more focused on the dairy industry.

The previous regulatory approach to BJD control in Australia and the dynamics of the Australian beef industry provide an example of the unintended consequences of regulatory control. It also allows insight into how control activities in one livestock industry can be unintentionally influenced by control activities of another.

1.3.7 **The role of veterinarians in control programs**

Veterinarians have been identified as an important and respected source of information for the livestock industries and as such are able to significantly influence the uptake of BJD control activities on dairy farms. Private veterinarians involved in control programs in Australia and Canada are all required to undergo further training and accreditation to deliver relevant aspects of programs (Agriculture Victoria, 2016; AHI, 2017a; Arrango-Sabogal, 2017; Barkema, 2018; Hendrick, 2006; Rogers, 2012). A survey of Canadian veterinarians enumerating perspectives on BJD control revealed most veterinarians were supportive of farms being subject to compulsory BJD testing and felt that elements such as risk assessments are valuable tools (Sorge, 2010b). Veterinarians play an integral part in the risk assessments used in control programs, especially in the implementation of management practices to address risk factors identified (Barkema, 2017; Ritter, 2015). Aside from the technical expertise provided on BJD control, control programs can foster veterinarian-farmer collaboration on general animal management and disease control matters (Godkin, 2013a).

Variation in the level of veterinary involvement and standards applied across control programs in Canada and within provincial control programs has been identified as problematic (Barkema, 2017; Pieper, 2015a). Ineffective communication between veterinarians and farmers has also been identified as a potential barrier to uptake of control measures recommended by veterinarians (Ritter, 2015).

Veterinary associations and schools are involved in BJD control programs in various ways. The Australian Veterinary Association and the veterinary schools of Australia and New Zealand are members of AHA which are consulted and engaged in the process of formulating approaches to animal health issues such as the current BJD framework (AHA, 2018a). Similarly, Veterinary Ireland is a stakeholder in Animal Health Ireland (AHI) and has been involved in the consultative process of developing the Irish Johne's Control Program (IJCP) (AHI, 2018).

1.3.8 **The role of vaccination in BJD control**

Vaccination has been an option available to livestock producers to control BJD in various species since the 1920s (De Lisle, 2010). France was the first country to effectively control BJD by means of vaccination but soon experienced interference with TB control programs (Benedictus, 2000). Owing to similarities in taxonomic classification *between Mycobacterium bovis* and *Mycobacterium avium ssp. paratuberculosis*, BJD-vaccinated animals have been shown to cross-react to intradermal tuberculin testing used in many countries as part of TB control programs. Increased numbers of false-positive TB reactors effectively reduce test specificity which has subsequent economic effects (Brett, 1995; Coad, 2012; Garcia, 2015; Groenendaal, 2014; Price, 2011).

Vaccinated animals are also likely to test-positive to ELISA tests for BJD thus threatening BJD status of herds. Although Australia is officially recognized as TB-free by OIE standards, false-positive reactions to both TB and BJD pose a risk to export markets where trade partners require certification for freedom from these diseases. Potential strategies to mitigate this risk include suitable identification of BJD-vaccinated animals, exclusion from export markets requiring test freedom for BJD and TB, and individual animal testing able to differentiate vaccinated animals from animals infected with TB and BJD (APVMA, 2014; Barkema, 2017; Sergeant, 2012; Shephard, 2014b).

Both live and inactivated (killed) vaccines for BJD are available around the world. In the USA, a killed vaccine is available, Mycopar®, which is administered subcutaneously to calves less than 35 days old. There are currently no BJD vaccines registered for use in Canada.

Since 2002, Gudair® has been registered and commercially available in Australia and has shown to be of great benefit in the successful control of ovine Johne's disease in the sheep industry (Windsor, 2013). Silirum®, a killed BJD vaccine based on the same MAP-strain (316 F) as Gudair® was registered in 2014 for use in cattle in Australia as a once-off sub-cutaneous dose administered from 3 weeks of age. Silirum® is registered for use in all Australian states except in WA. Prior to the new BJD framework roll out in 2016, vaccination was only permitted under the approval of the Chief Veterinary Officer (CVO) however the requirement for CVO approval currently varies from state to state (Agriculture Victoria, 2016b; AHC, 2012).

Silirum® and Gudair® vaccines have both shown to reduce shedding of MAP from infected animals however the immunity provided is incomplete and still allows infection of some animals which raises concerns over the efficiency of vaccine use in low prevalence populations. Despite success shown in minimizing clinical disease and controlling BJD with vaccines, additional concerns about potential adverse reactions, occupational health and safety risks, and lack of producer awareness has cast vaccination in an unfavorable light relative to other BJD control options (Barkema, 2017; Queensland Government, 2014; De Lisle, 2010; Kennedy, 2000; Shephard, 2014a; Shephard, 2016; Windsor, 2006; Windsor, 2013). The high cost of vaccination is also a barrier to use with some higher prevalence areas in Australia receiving a subsidy for vaccination of up to AUD$12.50 per dose to encourage ongoing control (Agriculture Victoria, 2016b).

Despite current vaccines being unable to completely prevent infection, the reduction of clinical BJD cases and decreased shedding of MAP makes vaccination in endemic herds a useful tool to reduce environmental contamination with MAP-infected faeces and minimize production losses (Bastida, 2011; Caldow, 2005). Vaccination has been shown to be cost-effective over the long term and if it can be shown to fit appropriately into existing frameworks of BJD and TB control, acceptance as an additional tool to control BJD would be enhanced. This would be more beneficial on high prevalence farms provided farmers do not forego other best management practices for BJD control in lieu of a misplaced reliance solely on vaccination (Brett, 1995; Garcia, 2015; Groenendaal, 2014; McKenna, 2006a; Shephard, 2016).

1.3.9 **Position of stakeholders**

Stakeholders may be involved to varying degrees to control BJD in the dairy industry, each prioritizing control objectives differently. BJD control programs around the world typically involve varying levels of responsibility and costs borne by government and industry. Programs dependent on government-driven initiatives have more regulatory elements supported by policy while industry-driven programs have more market-related incentives for participation.

Uptake of BJD control activities by producers depends on numerous factors such as behavioral, economic, legal, social, and welfare factors. Poor engagement in BJD control by producers has been observed in both government-driven and industry-driven programs and more recently in government-industry partnership approaches. Tangible benefits of control programs are not easily seen in the short-term which contributes to poor uptake (Garcia, 2015; Rasmussen, 2018; Westacott, 2012).

Control programs can have significant benefits to government, industry, and consumer stakeholders but there are also drawbacks to control programs which manifest as lack of funding and reduced support of control activities. Although responsibility for the control of animal diseases in many countries falls under government departments, disease control programs are perceived to benefit industry more than government and consumers thus forcing the industry to take responsibility and fund its own control initiatives independently or through intermediary partnership organizations such as AHA and AHI (Sergeant, 2012).

Other factors impacting participation and subsequent success of control programs relate to the epidemiology of BJD such as the long incubation period, subclinical nature of the disease, lack of effective treatment, the persistence of MAP in the environment, poor test characteristics, and lack of protective vaccines (Kennedy, 2000b; Whittington, 2004).

1.3.9.1 ***Government***

Australia has an advantage over many countries regarding biosecurity and disease control owing to isolation from other landmasses with different endemic disease profiles and disease management approach. Although BJD is present in Australia, it is endemic only in a relatively small area in the south-east which mirrors the distribution of dairy cattle. Thus, from a government perspective, successful BJD control programs can maintain and improve on the favorable low prevalence status, protect the significant livestock produce export market, and enhance Australia's reputation for high-quality livestock products (Dairy Australia, 2008b; Kennedy, 2010).

1.3.9.2 Industry

From an industry perspective, reduced losses due to BJD and improved market access are very tangible benefits of control programs (Caldow, 2005; Citer, 2007; Hoogendam, 2009; Kennedy, 2000a; McKenna, 2006a; Rogers, 2012). Control programs have a positive impact on producer awareness of BJD and potential impacts on the dairy industry (Citer, 2007; Citer, 2009). However, to garner support from farmers and justify expenses incurred by control programs, the benefits of programs need to be realized, especially in commercial dairy herds where benefits are less tangible than for stud breeders (Brett, 1995; Garcia, 2015; McAloon, 2017b).

Various studies have shown economic benefit to dairy farmers controlling BJD however, this benefit is mostly seen over the longer term (Cho, 2013; Rasmussen, 2018; Shephard, 2016).

Aside from costs due to regulatory conditions, cost-benefit analyses suggest that infected Australian dairy herds engaging in BJD control can be financially justified where clinical disease is significantly reduced at a cost of less than AUD$50/cow/year (Shephard, 2014a). Evaluation of the financial aspects of the AJDI showed a net benefit of $74 per cow for program participants however this benefit was 2-3 times less if program costs were covered by the producer (Wolf, 2014b).

Despite the relatively low cost of ELISA testing, the weak test specificity resulting in false-positive animals being removed from herds without compensation at times, threat of regulatory restrictions imposed on positive herds, resultant social stigma and discrimination against those with infected properties, excessive paperwork, and lack of tangible financial benefits are major deterrents to producers participating in control programs (Barkema, 2018; Devitt, 2016; Kennedy, 2002; Kennedy, 2011; Larsen, 2012; Rogers, 2012; Shephard, 2014a; Shephard, 2014b).

Submissions by industry bodies to the 2015 NBJDSP review suggest a view held by many that the proposed solution to BJD is costlier and more onerous than the disease itself. This arose out of voiced frustration with Inconsistently applied SDR&Gs which resulted in some producers being deemed compliant with program specifications afforded relatively unimpeded market access owing to low-risk herd status whereas other equally compliant producers being allocated a lower herd status and being disadvantaged through reduced market access (AHA, 2015a). Owing to the lengthy incubation period of BJD, infected herds attempting to regain negative status don’t realize the resolution of herd-status and accompanying market access benefits for many years (Jubb, 2000).

Market access has generally improved for Australian producers through the recent partial deregulation of BJD which means that producers can now engage in BJD testing and control without fear of regulatory penalty for infected herds. This is especially true for beef producers as BJD control was already deregulated for the dairy industry prior to the 2015 review.

The change to risk-based trading over time which eventually evolved into the new BJD Framework in Australia aims to address this disparity in benefits realised among participating producers whereby those engaging in BJD control activities can do so in accordance with their own business objectives without incurring any regulatory penalty should positive animals be identified. This facilitates trade within an environment that provides tools and support for positive herds to minimize infection (Citer, 2009).

Canadian dairy producers perceive value in attaining a meaningful herd status owing to efforts to control BJD through programs, especially those affording trade advantages (Barkema, 2018; McKenna, 2006b). Although the CJDI was initiated primarily by industry, there was significant involvement of academia in driving the control programs to meet the objectives of research output from the program.

Modern risk-based control approaches founded on decreasing the probability of infection have eliminated many of the threats to business continuity for farmers presented by a regulatory approach. However, without appropriate market drivers even modern control approaches may fail to garner support (AHA, 2015b; Citer 2009; Kennedy, 2012). The general integrated biosecurity approach is beneficial in mitigating numerous diseases in addition to BJD thereby promoting healthier, more productive herds. Inclusion of hygienic calf rearing requirements in quality assurance agreements between milk processors and producers initiates this general disease control benefit through prevention of calf diseases (Barkema, 2018; Dairy Australia, 2008a).

1.3.9.3 Consumers

Consumers as stakeholders also benefit from government and industry engagement in BJD control activities. Australian health authorities and the dairy industry believe causal links between MAP and Crohn’s Disease are unsubstantiated, as voiced through submissions to the BJD review in 2015 and is seemingly not a motivating factor for uptake of control activities in Australia. It has been hypothesized that should the purported links become more robust, countries with comprehensive BJD control programs will have a competitive market advantage (Garcia, 2015; Good, 2009).

Regardless of any verifiable causal links between MAP and human health issues, BJD control activities on farms encourage husbandry of healthier animals and naturally invoke quality assurance of farm produce. Thus, national BJD control programs can help address the increasing awareness and concerns that consumers of livestock products may have about the transmission of zoonotic diseases (AHA, 2015c; Garcia, 2015; Kennedy, 2000a). Further research is required to accurately establish the efficacy that control programs may have on consumer attitudes and perceptions toward disease control and the livestock industries.

1.3.10 **Governance**

1.3.10.1 Policy formulation

Classification of BJD as a notifiable disease varies from country to country. Notification of disease cases forms a key role in the management and control of diseases where notification may be accompanied by policies that stipulate control measures to be taken when disease occurs. This allows animal health authorities to be prepared in the event of increased incidence of the disease and to perform ongoing surveillance in support of national control programs and providing assurance to international trade partners.

1.3.10.1.1 Australia

The development and implementation of disease control policy at the government level in Australia are driven by the Animal Health Committee, a sub-committee of the National Biosecurity Committee under the Department of Agriculture (AHC, 2018). BJD in all species is classified as a notifiable disease in Australia as it is deemed to pose a significant threat to relevant local livestock industries and export markets. Any persons that suspect or confirm animals to be infected MAP are legally obligated to notify the relevant animal health authority in their state or territory (Australian Government, 2018).

Initial attempts at national BJD control in Australia formed part of routine constitutional disease control responsibilities of state or territory governments. However, this proved insufficient to control the spread of BJD within endemic areas and other parts of Australia. The NJDCP was thus initiated by industry in 1996 to meet specific control objectives. Despite industry involvement with a more structured control framework, the government was primarily accountable and thus maintained a regulatory approach underpinned by regulatory disease control standards as per the SDR&Gs accepted and agreed upon across the states and territories by both the dairy and beef industries. (Citer, 2009; Citer, 2012).

Control activities suitable to each state and territory were then formed in accordance with the SDR&Gs giving rise to variation regarding movement restrictions, funding, and quarantine across regions (Kennedy, 2000a). Notification of BJD incursions as per legal obligations thus attracted regulatory control measures such as quarantine and movement restrictions.

Numerous revisions to the SDR&Gs in subsequent years resulted in regulatory control measures in the endemic south-east dairy areas being repealed in favor of a more risk-based, market-driven approach. This transferred responsibility for BJD control on dairy farms primarily to the dairy industry and individual producers to manage the impact of the disease. During this time, regulatory control was maintained through government administration of the former BJD zones, particularly in low prevalence regions such as NT, Queensland, WA, and parts of SA to prevent the spread of infection into these regions (AHC, 2012; Citer, 2012; Gavey, 2016; Kennedy, 2010). The program and policies encompassed by “Beef only” provides an example of policy formulation led by industry whereby the Cattle Council of Australia, the peak producer organisation for the beef industry, used the existing NBJDSP to establish the low-risk BJD compartment in the south-east of the country (Keatinge, 2012).

Further significant revisions in 2015 transitioned BJD control to the current partially deregulated, industry-driven approach supported and administered by the government-industry partnership organization, AHA. Through inclusion and consultation with industry, the regulatory structures such as zoning and associated movement and control specifications are largely no longer applicable. Regulatory control measures have been repealed for both the beef and dairy industries in all states and territories except NT and WA where local livestock industries requested continuation of regulatory control to protect the favorable low BJD prevalence in these regions. Except for regions maintaining regulatory control, notification of BJD incursions does not trigger a regulatory response. Records of notification are maintained indefinitely for trade and surveillance purposes (Australian Government, 2018; AHA, 2015b; AHA, 2017a; AHA, 2018b; Barwell, 2018).

The new approach affords producers the flexibility to manage BJD in accordance with individual business priorities within the broader boundaries as directed by legislation and trade regulations (AHA, 2015b).

1.3.10.1.2 Canada

BJD in Canada is classified as an “Annually Notifiable Disease” at the federal level. This refers to a group of endemic diseases occurring in Canada that need to be documented and submitted in an annual report to the OIE. This contrasts with other diseases classified as “Reportable” or “Immediately Notifiable” in Canada which are those diseases deemed to pose a significant threat to human and animal health and may have major economic implications (CFIA, 2018). Each province has a parallel list of diseases classified into similar categories with variation as to the inclusion or exclusion of BJD.

There is no national policy addressing BJD control in Canada but there are some provincial policies that indirectly support BJD control. Quebec is the only province currently with regulatory movement restrictions imposed on farms with BJD which is supported by Agri-Traçabilité Québec (ATQ), an animal traceability system implemented by the provincial government in 2001. The traceability module of proAction® aims to implement a similar traceability system nationally across all provincial dairy industries (Barker, 2012; CDN, 2018).

As of 2013, the Ontario Milk Act includes a stipulation that all dairy producers in Ontario are legally required to complete an annual Animal Health Risk Assessment under the guidance of an appropriately licensed and trained veterinarian. The risk assessment is structured such that it favors evaluation of BJD transmission risks, but the process also includes a cattle health declaration and a review of responsible veterinary medicine usage on farms (Kelton, 2011b; Ontario Government, 2018).

*1.3.10.2 **Timelines/Horizons***

1.3.10.2.1 Australia

The change to the current BJD New Framework in Australia was implemented as part of a scheduled review to the NBJDSP mandate from 2012-2020.

1.3.10.2.2 Canada

Since the end of the funded mandate of the CJDI in 2013, there has been no formal national program addressing BJD specifically although some of the provincial programs have continued. A need has been identified for a national program that employs a standardised herd status system for various livestock diseases across Canada, ideally lead and driven by industry (Barker, 2012). Elements of the CJDI, specifically the Risk Assessment, have transitioned to form part of the biosecurity module of proAction®, a broader industry-driven initiative addressing quality assurance in Canada’s dairy industry (Barkema, 2018).

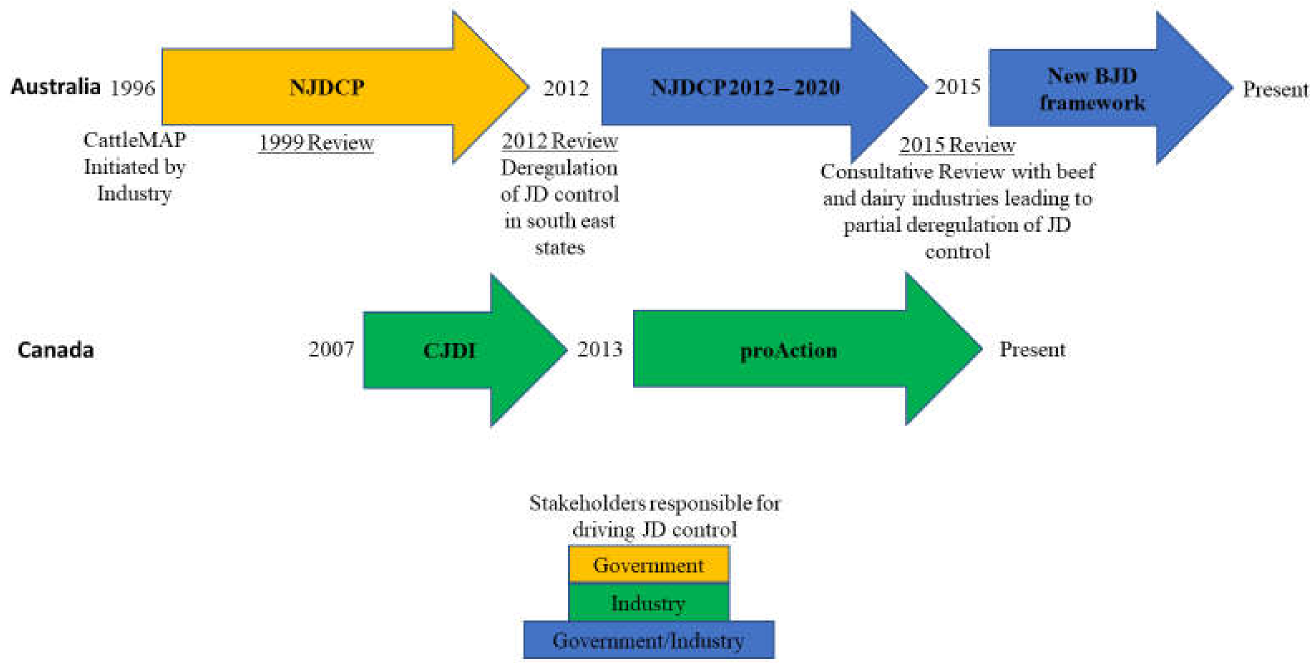

Figure 1.1 Timelines of national BJD control programs in Australia and Canada

1.3.10.3 Acceptance of policy

1.3.10.3.1 Australia

The different approaches to BJD control in Australia have been met with opposing views and preferences over time. Submissions to the review process of the NBJDSP revealed some producers voicing that a regulatory approach is neither effective nor appropriate to control BJD, especially where uniformity of control policies across the country is lacking. Producers with farms placed under quarantine due to animals testing positive for MAP have been particularly outspoken against regulatory control ascribed to the significant financial, social, and psychological costs of regulatory control (AHA, 2015c). Concerns about potential human health implications linked to BJD are dismissed as unsubstantiated by many producers and industry bodies and deemed inappropriate to warrant the need for stringent control policy for a disease not regarded as a priority in the dairy industry (AHA, 2015a; Gavey, 2016; Latter, 2015; Westacott, 2012).

There are however also producers that see merit in maintaining regulatory control, especially those producers wishing to protect livestock farming areas with favorably low BJD prevalence. This is evident in WA and NT where, after deregulation of BJD control in the rest of Australia following the 2015 review, regulatory control is still in place at the behest of the local livestock industries (Barwell, 2018; Whittington, 2019).

Discrepancies in the control environments between states and territories in Australia currently are purportedly due to poor communication of the tangible benefits of the new BJD Framework and the time lapse between the decision to change the approach in 2015, and actual implementation of the new BJD framework in 2017 (AHA, 2018b). Insufficient time has lapsed since the rollout of the new control policy in Australia to ascertain the effects it is having on uptake of control activities and any changes in stakeholders' attitudes toward BJD.

1.3.10.3.2 Canada

The regulatory requirements of BJD as an annually notifiable disease in Canada are comparatively relaxed and as such, there has been no national policy for BJD control. There has however been support from producers and veterinarians for mandatory BJD control implementation on Canadian dairy farms. Some producers have stated that they would be willing to share costs if control programs became mandatory (Sorge, 2010a; Sorge, 2010b).

1.3.10.4 Supporting policy

Policies that influence animal health, animal movement and marketing of livestock products may indirectly play a role in BJD control even if they aren't specifically directed at BJD. Ideally, policies need to be supportive of BJD-specific control directives and elements of programs are compatible with existing policy.

1.3.10.4.1 Australia

Examples of policies supportive of BJD control in Australia include the mandatory biosecurity planning in Queensland where all livestock producers have obligations under the state

Biosecurity Act of 2014 to mitigate disease risk on their property (Queensland Government, 2016; Gavey, 2018).

Since deregulation in 2000/2001, there is no longer legislative control over the milk price that Australian dairy farmers receive. Currently, market-forces determine the price farmers are paid for milk (Dairy Australia, 2018).

1.3.10.4.2 Canada

Similarly, Ontario Regulation 761 (the Milk Act) describes mandatory completion of an annual Cattle Health and Veterinary Medicine Use Declaration for all dairy producers in Ontario, Canada. A risk assessment covering biosecurity is recommended as part of this process (Ontario Government, 2018). The DFC initiative, proAction ®, provides quality assurance for Canadian dairy products by the implementation of 6 modules addressing key aspects of responsible dairy farming and milk production. These modules include Milk Quality, Food Safety, Animal Care, Livestock Traceability, Biosecurity, and Environment which are being rolled out in stages with a goal for all modules to be active by 2023. As of September 2019, the biosecurity module which includes the Risk Assessment used in the CJDI will be mandatory for all Canadian dairy farmers. All 6 modules of proAction ® will be mandatory once the staged roll-out is complete (DFC, 2017).

The ATQ system in place since 2001 addresses traceability of animals in Quebec which requires that movement restrictions be placed on farms with cases of BJD (CDN, 2018).

Compared to a free-market situation, the use of supply management by some dairy industries to match domestic production and consumption helps stabilize producers' revenue but may also differentially influence producers' decisions to implement certain disease control measures. Supply management in Canada has been a contentious issue for many years and is currently employed in the poultry, egg, and dairy industries. This is achieved in the dairy industry through the management of milk prices, farm quotas, and import restrictions. Many dairy farmers in Canada are under supply management which is administered by the Canadian Dairy Network

(Tasker, 2018). Some benefits of supply management include a stable supply of milk at stable prices for consumers and a stable income for farmers. Aspects of supply management that have come under scrutiny include lack of access to the Canadian dairy market for other countries, and fostering complacency among Canadian producers. A detailed discussion of supply management is beyond the scope of this study however through the mechanisms of the supply management system, there is the potential to facilitate and enforce disease control policy.

1.4 **Thesis rationale**

Many producers acknowledge that BJD is a problem for the dairy industry but not necessarily for their farm (Sorge, 2010a). The economic benefits of participation in both BJD control program and vaccination have been well described (Shephard, 2016; Wolf, 2014b). However, poor participation remains a problem. Research suggests that prior to actual participation in control activities based on sound, evidence-based epidemiologic principles, control strategies need to be amenable to producers' knowledge, attitudes, practices, and preferences regarding BJD control (Barkema, 2017; Roche, 2015). Thus, in addition to economic reasons, these factors determining the level of engagement in BJD control need to be better understood to allow the formulation of more inclusive and supportive control programs.

The characteristics of BJD control program participants have previously been described in some countries (Ritter, 2015; Ritter, 2017; Sorge 2010a). However, no studies describe the characteristics of producers by varying levels of engagement in different BJD control strategies, particularly vaccination. The role of vaccination within BJD control programs has not clearly been defined. Reasons for this may include cross-reactivity, cost, and safety concerns. A better understanding of this will be valuable as industry dynamics and policy environments shift.

It is evident for certain diseases that a regulatory approach can be effective with the government as the stakeholder bearing most of the responsibility and cost of control. However, control measures applied unilaterally without considering the objectives of all stakeholders can inadvertently create barriers to compliance. Government-industry partnership approaches to BJD control may foster better stakeholder engagement and uptake of control activities through market-driven incentives and improving the perceived benefit of controlling BJD (Citer, 2007; Citer 2012; More, 2008; More, 2010; Westacott, 2012). An improved understanding of the influence that regulatory policy has on uptake of BJD control activities on dairy farms would be valuable for the design of future control programs and to better inform policy formulation supportive of control objectives.

Considering the moderate success of Australian BJD control programs admixed with some pitfalls over time, this evolution and availability of a vaccine present a valuable research opportunity to better understand the factors influencing a successful participatory approach and the regulatory policy opportunities to improve BJD control. The hypothesis central to this thesis is that farmers engaged in BJD control have more profitable dairy farms than those not engaged.

1.5 Research objectives

1. To determine the association between farm factors, farmer perceptions on BJD, policy environment, and level of engagement in BJD control strategies on Australian dairy farms.
2. To determine differences in profitability between Australian dairy farms engaged in BJD control activities and those not engaged.
3. To determine the implications on current and future BJD control policy and how this may translate into benefits applicable to Canada.

Chapter 2 Factors associated with Australian dairy farmers' choice of Johne's disease control strategy

2.1 Introduction

2.1.1 Conceptual model

Producers want to optimize profits as this assumes cost reduction and increased production efficiency. Active producer participation in BJD control activities, including basic disease surveillance, formal control programs, and vaccination, can contribute to lowering production costs associated with losses due to BJD. Simultaneously this demonstrates to consumers that dairy farmers have a pro-active approach to disease management and production of safe food for consumption. Overall, this results in a beneficial scenario for all cattle industry stakeholders where dairy farms can provide assurances of animal welfare, disease freedom, and food safety to local and international consumers while improving production efficiency and enabling profit optimization.

Understanding producers' perceptions of BJD and control strategies employed on dairy farms in Australia, given the recent change in the JD control framework and policy environment, will help us understand how attitudes toward BJD, BJD control strategies, and the regulatory environment governing it influence participation in various control activities.

2.1.2 Theoretical model

Microeconomic theory assumes dairy farms as business firms aim to optimize profitability in the short and long term (Pindyck, 2013). In economic terms, profit is the difference between total revenue and total costs. As BJD is known to be a disease having an economic impact on dairy farms, efficient mitigation of the risk posed by BJD requires the implementation of an optimal control approach factoring in available control options. Profit optimization provides a useful framework for decision making by dairy farmers where management of BJD forms part of the efficient management of resources to optimize profits and ensure the viability of the dairy operation. Using this model will allow increased profitability to reflect optimal efficient utilization of resources in farm management with JD control forming part of the management plan.

The Health Beliefs Model (HBM) has been used in numerous studies investigating the uptake of health care programs which rely on human behavior. The HBM is based on the understanding that a person will take specific health-related action (i.e., implement a BJD control program) based on that person's perceived susceptibility, perceived severity, perceived benefits, perceived barriers, the necessary cues to action required to implement such change and their own ability to successfully execute the change. (Denison, 1996).

The HBM can be extrapolated to the animal health industry (Figure 2.1) where farmers take behavioral actions to improve the health of their animals, and ultimately their businesses. In the context of controlling BJD on dairy farms, farmers without adequate disease management may or may not realize their vulnerability to the negative impact of BJD on production and animal welfare (perceived susceptibility and severity). Through investing time to understand BJD and the implications of different control activities such as biosecurity measures, vaccination, and testing under the consultation of their veterinarian (perceived barriers), they will ensure optimal productivity and minimize trade restrictions, thus improving business efficiency (perceived benefits). Farmers' decisions to implement BJD control activities may depend on individual motivating factors such as scheduled monthly herd visits from consulting veterinarians, awareness of public health concerns, and maintaining a sound social standing (cues to action). Ongoing monitoring and evaluation of herd productivity and animal welfare combined with testing that shows a reduction in herd prevalence would further motivate farmers to maintain participation in BJD control programs (self-efficacy).

Based on the above scenario, the HBM would be an appropriate model to support an investigation into the factors motivating Australian dairy farmers to partake in BJD control activities.

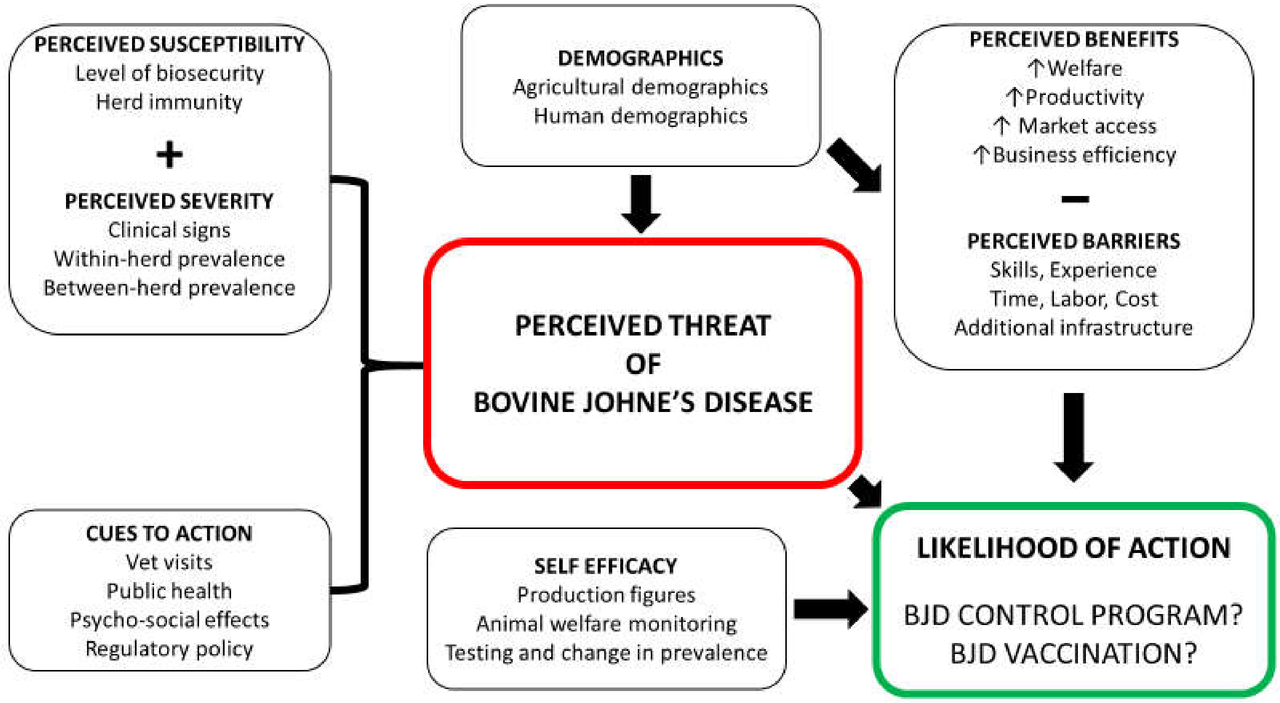

Figure 2.1 Health Beliefs Model *(Adapted from Janz and Becker, 1984)

Similarly, the Technology Acceptance Model (figure 2.2) offers a useful framework to focus on the knowledge, attitudes, and perceptions of farmers to represent their stated preferences and relate this to the exercised preferences regarding actual participation in BJD control activities. This has been deemed especially useful where evolving animal health programs need to be assessed for their suitability to meet industry objectives and satisfy both consumers' and producers' preferences (Morris, 1997). The Health Beliefs Model, Technology Acceptance Model, and constructs of profit optimization thus offer a complementary framework to investigate the complexity of BJD control.

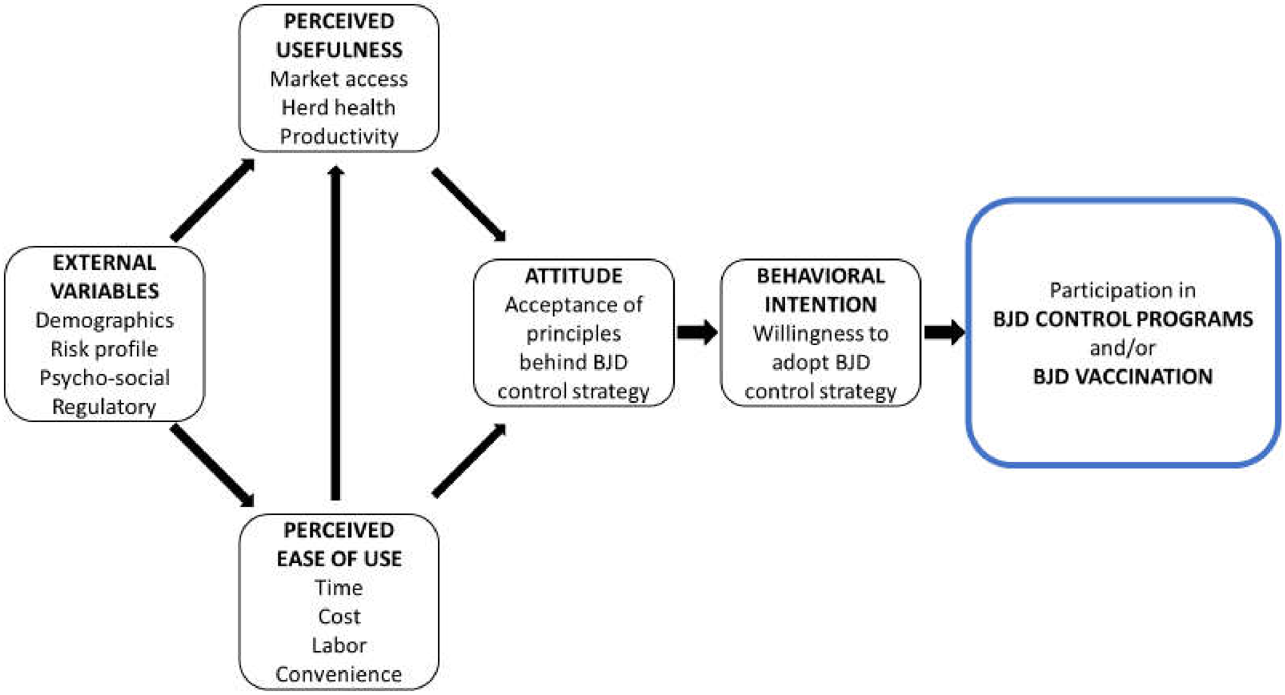

Figure 2.2 Farmer Technology Acceptance Model *(Adapted from Davis, 1989; Lima, 2018; Morris, 1997; Holden, 2010)

2.2 Materials and Methods

2.2.1 Study area and population

The study population is dairy farmers located in all states and territories in Australia who are currently farming or who have farmed with dairy cattle within the last 3 years.

2.2.2 Sample size calculation

A sample size of 384 farmers was calculated using the following formula as shown in Dohoo, 2003:

$$n = Z^2 \ \frac{p(1-p)}{e^2}$$

Where:
Z (Level of confidence) = 1.96
P (Estimated baseline prevalence) = 0.5
e (Margin of error, α) = 0.05

$$n = 1.96^2 \times \frac{0.5(1-0.5)}{0.05^2} = 384.16$$

The following adjustments are factored in:

Groups (based on herd size) = 1
$\mathrm{n} = 384.16 \times 1 = 384.16$

Design effect = 1.0
$\mathrm{n} = 384.16 \times 1.0 = 384.16$

The anticipated response rate from prospective participants is 15%
$\therefore \mathrm{n} = \frac{384.16}{0.15} = 2561$
Thus, it was estimated that a total of 2561 farmers need to be reached in order to achieve the desired sample size.

2.2.3 **Ethics statement**

The Conjoint Faculties Research Ethics Board (CFREB), University of Calgary reviewed and approved this study protocol on 17 September 2018 with the unique ethics identity code REB18-1407.

2.2.4 **Study design and survey procedure**

This cross-sectional study was conducted using an online questionnaire designed to capture information on variables necessary to meet the research objectives as stated in chapter 1. Clusters of variables for which information was captured include human and farm demographics, economics, animal health and production, regulatory affairs, and knowledge, attitudes, and practices. Types of questions include closed-ended, open-ended, Likert-scale, dichotomous, and multiple-choice questions.

Attitudes toward BJD, BJD control strategies, and BJD control policy were captured by asking participants' level of agreement (5-point Likert scale) with statements regarding BJD, control programs, vaccination, and two different regulatory scenarios.

Prior to distribution, the questionnaire was trialed by graduate students, Australian dairy farmers, Dairy Australia, Animal Health Australia, Australian government veterinarians, and private dairy industry consultants with the objective to assess the clarity of questions, the flow of questions, and completion time. Based on this trial, the time commitment for completion suggested to prospective participants was 15 – 20 minutes. The questionnaire was posted online by Survey Monkey (SurveyMonkey Inc., San Mateo, California, USA) and was compatible with multiple device types.

In November 2018 the link to the online questionnaire was distributed to Australian dairy farmers through several channels including large animal veterinary clinics, cattle breed societies, and state dairy associations through their respective social media sites. The link was reposted on some sites up to 3 times during the recruitment period. In addition, the survey was advertised on various popular dairy media platforms and at the Australian Dairy Conference 2019 in Canberra. Participation was entirely voluntary and whether or not subjects with access chose to complete the questionnaire was indiscernible by the distributing channel and the researcher. Data collected was completely anonymous and did not include personally identifiable information. The final response was collected in March 2019.

2.2.5 **Statistical analysis**

Statistical analyses were all performed using Stata 15.0 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC). Summary statistics were conducted to describe the dataset and are represented by four clusters of variables designated as demographics, animal health and production, regulatory affairs, and knowledge, attitudes, and practices. Outliers were identified as values more than 1.5 X interquartile range below the first quartile and values more than 1.5 X interquartile range above the third quartile. Outliers were scrutinized and were included in all analyses. String variables were recoded to numeric format and stored as float variables in Stata. Likert-scale variables were recoded as dichotomous where appropriate. All missing observations remained as missing after recoding.

Dependent variables for three aspects of BJD control strategy uptake were identified; favorability of attitudes, stated preferences, and exercised preferences.

- Favourability of attitude toward BJD control programs
  Favourability of attitude toward BJD vaccination
- Stated willingness to adopt BJD control programs
  Stated willingness to adopt BJD vaccination
- Ever participated in BJD control programs
  Ever participated in BJD vaccination

Variables within clusters were independently tested for a significant association with each of 6 binary dependent variables respectively using 3 separate univariate analyses. Cross-tabulation was performed and Fisher's exact test for independence used to assess significance ($p<0.2$) of the association between each independent variable and dependent variable respectively. In addition, univariate logistic regression was performed by regressing each independent variable on the dependent variables to assess significance ($p<0.2$) of the relationship between each independent variable and the dependent variables respectively. T-tests (parametric data) and Wilcoxon Rank Sum Tests (non-parametric data) were then performed to test if the group means of independent variables classified by categories of the dependent variable were significantly different ($p<0.2$). The associations between favorability of attitudes, stated preferences, and exercised preferences were assessed and is included in this analysis.

Potential explanatory variables for each of the six models were tabulated and ranked by significance ($p<0.2$) to ascertain candidate models for multiple logistic regression. Of the higher-ranked variables, those containing the greatest number of observations and those with higher standard deviations were prioritized for inclusion in each model. Variables with an intuitively plausible effect on the dependent variable, as informed by the conceptual and theoretical frameworks earlier mentioned, were also considered for inclusion. Following the abovementioned approach, various binary choice variable regression models were explored however no strong candidate models were identified. The trial analysis alluded to a discrepancy between farmers' stated preferences and their exercised preferences.

Focusing on stated preferences, ordinal logistic regression was then performed using the dependent variables re-coded as “stated willingness to accept, stated willingness to adopt, and stated willingness to pay” as the sequentially interdependent categories representing the level of engagement in BJD control programs and BJD vaccination. Univariate logistic regression was performed to assess statistical significance ($p<0.2$) of associations between all potential explanatory variables and the two dependent ordinal variables respectively. Explanatory variables were selected for inclusion in the models as per the approach outlined for binary logistic regression. In the final models, explanatory variables were regarded as significant at $p<0.1$.

Goodness-of-fit and the proportional odds assumption for each model was tested using approximated likelihood-ratio tests as part of the OMODEL module (Wolf, 1997) followed by the Brant test. Multicollinearity was tested using the “collin” command (Ender, 2010) with variance inflation factors (VIF) greater than 10 considered indicative of multicollinearity.

Prior to analysis, location of the dairy farm (state) was identified as an extraneous variable with potential effect-modifying and/or confounding capacity on the relationship between the explanatory variable “attitude toward regulatory control policy” and dependent variable “level of engagement in BJD control strategies”. Similarly, the effect of annual farm milk production on the relationship between self-perceived health of farmers’ herds and level of engagement in BJD control strategies, and the effect of beef cattle presence on the relationship between farm biosecurity and level of engagement in BJD control strategies were identified as potential effect-modifying and/or confounding factors.

Firstly, these extraneous variables were individually assessed as effect modifiers by including them and their interaction terms (extraneous variable X explanatory variable) in the model. Interaction terms with a significant p-value ($p<0.1$) suggested the respective extraneous variable was an effect modifier. Upon exclusion of extraneous variables as effect modifiers, assessment for confounding was then conducted by inclusion of the variable in the model one at a time. In the adjusted model, a change in the odds ratio of the explanatory variable greater than 15% was indicative the extraneous variable had a confounding effect. Extraneous variables deemed to have a confounding effect were included in the final model.

The probabilities of observations occurring within each of the four categories of the dependent variables were predicted using the “margins” command in Stata at specified values of significant explanatory variables while holding the values of other variables at their means.

2.3 **Results**

During the recruitment period, 71 responses were received with participants completing 63.82% of all questions on average. Responses collected by participants accessing the link via social media channels accounted for 51% of all responses. The remaining responses were collected by distributing a web link to the survey to dairy farmers via large animal veterinary clinics, breed societies and various media channels (49%). The survey was distributed in all known dairy farming regions within Australia based on areas as recognized by Dairy Australia (Dairy Australia, 2018). The average time farmers spent answering the questionnaire was 16 minutes and 57 seconds.

2.3.1 **Descriptive statistics**

2.3.1.1 Demographics

Table 2.1 Demographics of Australian dairy farmers participating in an online questionnaire on BJD control

Characteristic	n	Category	Frequency	%
Age (years)	38	≥ 50	20	52.6
		< 50	18	47.4
Gender	37	Male	26	70.3
		Female	11	29.7
Experience in the dairy industry (years)	39	≥ 20	27	69.2
		< 20	12	30.8
Role on farm	61	Owner/Co-Owner	45	73.8
		Manager	7	11.5
		Share Farmer	8	13.1
		Other	1	1.6
Highest education level	37	Completed High School	11	29.7
		Certificate II	2	5.4
		Certificate III	3	8.1
		Certificate IV	4	10.8
		Diploma	4	10.8
		Assoc. degree. / Adv. Dipl.	4	10.8
		Bachelor’s degree	6	16.2
		Grad. dipl. / Bach. Hons. degr.	2	5.4
		Master’s degree	1	2.7
Mean percentage of household income derived from dairy (%)	39	≥ 85	30	76.9
		< 85	9	23.1

Table 2.2 Farm demographics of Australian dairy farmers responding to an online questionnaire on BJD control (2019)

Characteristic	n	Category	Frequency	%
State		New South Wales	6	9.8
		Queensland	4	6.6
		South Australia	16	26.2
		Tasmania	3	4.9
		Victoria	32	52.5
Total Farm size (Ha)	61	≥ 245	26	42.6
		< 245	35	57.4
Land allocated to cropping (Ha)	58	≥ 200	41	70.7
		< 200	17	29.3
Predominant breed	52	Holstein/Friesian	40	76.9
		Illawarra	3	5.8
		Jersey	6	11.5
		Other	3	5.8
Number of cows ≥ 1st lactation [1]	60	Small (<150 cows)	12	20.0
		Medium (150 - 300 cows)	27	45.0
		Large (300 - 500 cows)	14	23.3
		X-large (500 - 700 cows)	5	8.3
		XX-large (>700 cows)	2	3.3
Annual milk production (x 10^6 L)	53	≥ 1.63	31	58.5
		< 1.63	22	41.5

([1] Herd size classification as per Dairy Australia Herd Genetics & Animal Husbandry Survey, 2016)

Subjects answering the questionnaire largely identified as male (70.27%), were mostly farm owners or co-owners (73.77%) of dairy farms with a mean age of 49.89 years and had spent a mean time of 29.59 years in the dairy industry. Most questionnaire participants had obtained some form of post-secondary qualification (70.27%) and had a group mean for household income derived from dairy of 87.51%.

The most frequently stated reasons for participants being involved in the dairy industry were “Lifestyle” (74.36%), “Family legacy” (66.67%), and “Business management” (46.15%).

Other reasons cited as motivating factors for being involved in the dairy industry were "Profit" (33.33%), "Love of cattle" (23.08%), "It's a job" (15.38%), and "Breeding and genetics" (5.13%).

The geographic distribution of participants was reflective of the population in many of the identified dairy states in Australia. South Australia had a significantly higher ($p<0.05$) proportion of respondents (26.23%) relative to the actual proportion of farms (4.24%) in that state. There was a significantly lower ($p<0.05$) proportion of participants (52.46%) from Victoria than actual farms (67.86%) in that state (Dairy Australia, 2018). There were no participants from Western Australia.

The mean total farm size among participants was 367.77 hectares of land with a mean allocation of 217 hectares to cropping. The predominant breed of cattle among herds was Holstein/Friesian (76.92%) with other breeds such as Jersey, Ayrshire, Illawarra, and cross-bred cattle making up the minority. Although the modal value for the size of participating herds was 150 – 300 cows, the mean herd size as designated by the number of cows in their first lactation was 325 owing to the presence of several X-large herds and 2 XX-large herds with more than 1300 cows in the sample. The mean annual production of participant herds was 2.42 million litres as reflected by the volume of milk shipped to milk processors per annum. The derived mean annual milk production per cow equates to 6793.99L. 38.60% of dairy farmers kept beef animals (excluding dairy animals reared for beef) with a mean of 15 beef animals per respective property.

Table 2.3 Comparison of select characteristics of Australian dairy farmers in the sample frame and the population of all Australian dairy farmers

Parameter	Sample	Population	p-value
Mean Time in Dairy Industry (years)	27.50	20.00 [2]	0.001***
Mean Total Farm Size (Ha)	200.00	246.00 [2]	0.046**
Mean Herd size (cows ≥ 1st lactation)	304.00	273.00 [1]	0.208
Mean Annual Milk Production/cow (L)	6793.99	6070.00 [1]	0.001***
Percentage Holstein/Friesian in Herd (%)	75.00	75.00 [1]	0.746
Closed Herds (%)	24.10	49.00 [1]	0.000***
JD Herd Prevalence (%)	19.23	14.00 [3]	0.348

(***$p<0.01$; **$p<0.05$) ([1] Dairy Australia, 2018; [2] Cockfield, 2016; [3] Kennedy, 2010)

2.3.1.2 Animal health and production

The majority of farms (98.33%) operate dairies on a pasture-based system with 35% practicing seasonal calving, 38.33% calving at two distinct periods of the year, and 26.67% having a year-round calving system. Farmers selling livestock within Australia account for 58.93% whereas those selling livestock to buyers outside of Australia account for 38.33% of participants.

Table 2.4 Animal health and husbandry practices on Australian dairy farms (2019)

Characteristic	n	Farm practice	Frequency	%
Housing system	60	Pasture-based	59	98.3
		Free-stall	1	1.7
Calving system [1]	60	Seasonal	21	35.0
		Split	23	38.3
		Year-round	16	26.7
Livestock trading practices	56	Sells within Australia	33	58.9
		Sells outside Australia	19	33.9
		Sells within and outside Australia	13	23.2
Beef animals kept on the property	57	Yes	22	38.6
		No	35	61.4
Maintains closed herd	56	Yes	13	23.2
		No	43	76.8
Requests vendor declarations when bringing in livestock	43	Yes	34	79.1
		No	9	20.9
Receives routine veterinary visits	55	Yes	33	60.0
		No	22	40.0
Emergency veterinary visits/month	55	≥ 1	20	36.4
		< 1	35	63.6
Has a biosecurity plan signed by a veterinarian	56	Yes	20	35.7
		No	36	64.3
Currently using vaccines (Any)	56	Yes	48	85.7
		No	8	14.3

([1] Calving system classification as per Dairy Australia Herd Genetics & Animal Husbandry Survey, 2016)

There were more herds receiving routine veterinary visits (60.00%) than those not receiving a visit at least once every 3 months (40.00%). The mean number of unscheduled/emergency veterinary visits across all farms was less than one visit per month (0.91 visits/month). Herds with a high level of biosecurity accounted for 26.32% of all participants. These herds were identified as farms maintaining closed herds, requesting vendor declarations when purchasing livestock, having a veterinary certified biosecurity plan, and using any vaccines or having at least three of these four biosecurity practices in place.

Participants currently using a vaccine (85.71%) stated the three most important attributes sought when choosing a vaccine to control a disease are “prevention of new infections” (80.00%), “prevention of shedding in already infected animals” (80.00%), and “ease of administration” (40.00%). Other attributes considered of subsequent importance are “cost” (37.78%), “safety for animals” (26.67%), “improvement of herd health” (13.33%), “return on investment” (6.67%) and that the vaccine should cover multiple diseases in a single product (6.67%).

The modal value of reported bulk milk cell count (BMCC), an aggregate of individual cow somatic cell counts as measured in milk vats, was 150,000 – 200,000 cells/ml (34.55%) indicative of good mastitis control. The current target for farmers to receive a premium from most dairy processors in Australia is 150,000 – 250,000 cells/ml (Dairy Australia, 2019).

The modal value of reported body condition score (BCS) at calving for participant herds was 5 on an 8-point scale (24.07%). The current target for BCS at calving is fewer than 15% percent of cows within a herd scoring 4.5 or less and fewer than 15% of cows scoring 5.5 or more (Dairy Australia, 2015).

The majority of participants classified the health of their herd relative to dairies in their region as “Good” (50.91%) (Figure 2.5). Cattle health problems that producers are most concerned about are mastitis (85%) followed by infertility (76%), lameness (49%), and metabolic disorders such as hypocalcaemia, ketosis, displaced abomasa (left and right), fatty liver etc.

(40%). Sixteen percent of participants were concerned about calf diseases such as pneumonia and diarrhea (etiology not specified) and less than ten percent of participants were concerned about internal parasites (9%) and external parasites (5%). Only nine percent of participants viewed BJD as an important health concern for their herd.

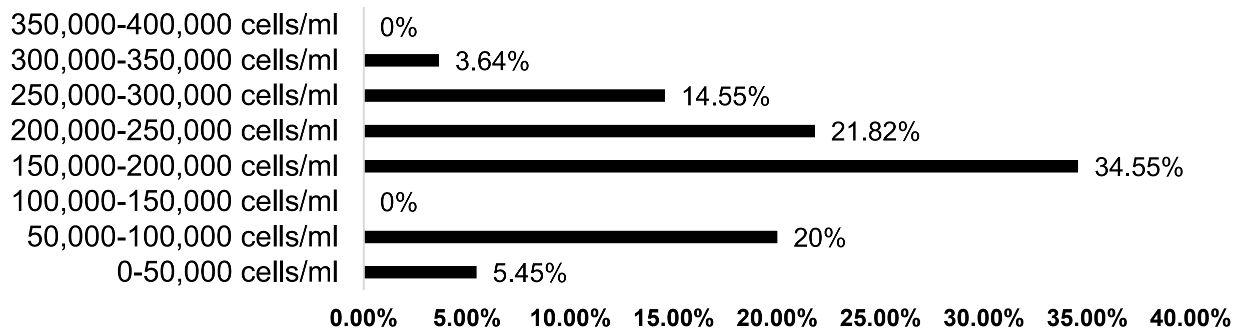

Figure 2.3 Reported bulk milk cell counts of Australian dairy herds (n=55) (2019)

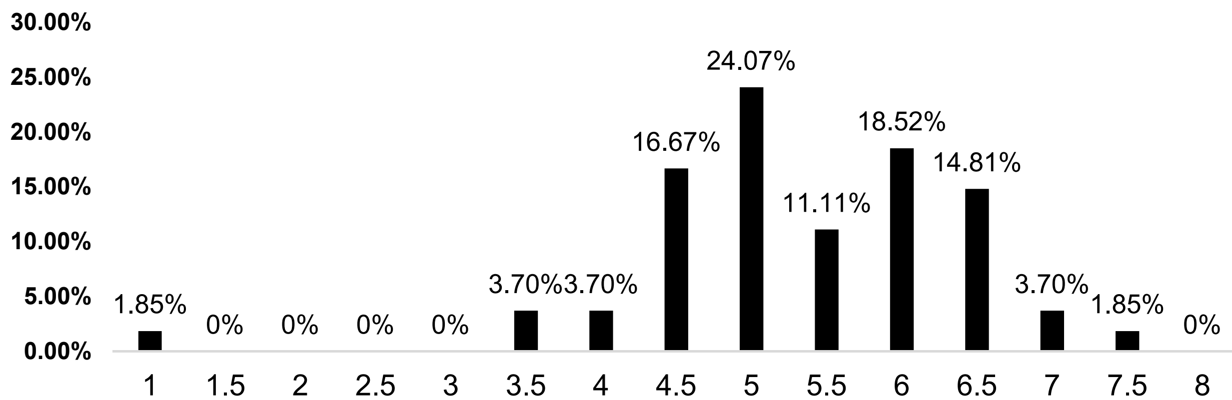

Figure 2.4 **Reported body condition scores of cows at calving in Australian dairy herds (n=54) (2019)**

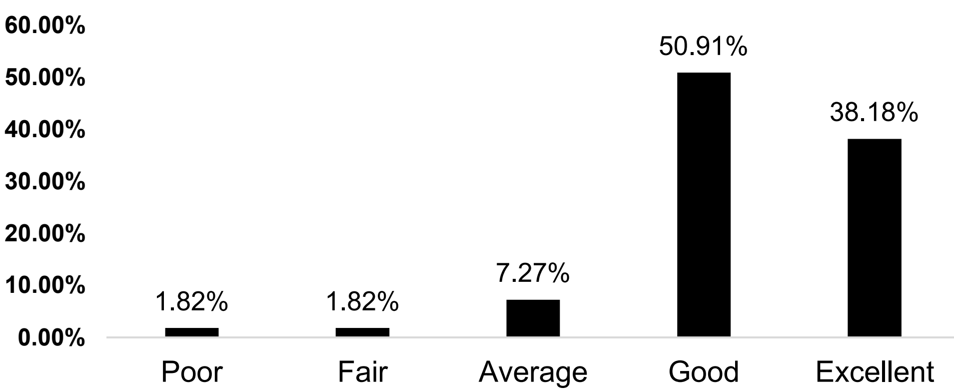

Figure 2.5 Self-perceived health of Australian dairy herds (n=55) (2019)

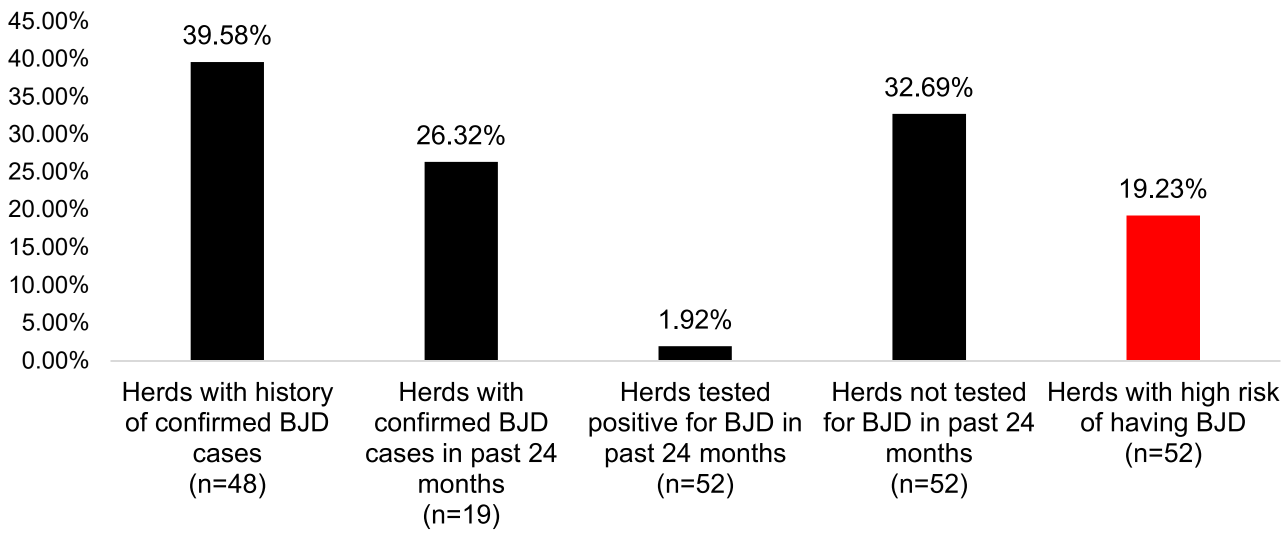

Figure 2.6 BJD status of Australian dairy herds (2019)

Based on historical BJD incidence, recent cases of BJD, and testing activities within the previous 24 months 19.23% of herds in this sample are at high risk of being positive for BJD. There were 32.69% of farmers that had not tested for BJD in their herds within 24 months prior to answering the questionnaire.

Veterinarians were identified as an important source of animal health information by 96.23% of participants. Other important sources of information cited include Government/Primary industries (60.38%), industry associations (37.74%), Feed and Drug companies (26.42%). Up to 5% of the participants relied upon other sources such as dairy consultants, discussion groups, internet, milk processors, peers, personal experience and stock agents for information regarding animal health and production.

2.3.1.3 Knowledge, attitudes and practices toward BJD and BJD control strategies

In contrast to asking participants to state the three most important animal health concerns for their herds, when asked about it specifically, BJD was perceived as detrimental to the dairy industry by 48.08% of producers. This was based on a composite of variables indicating level of agreement with the statements "BJD increases culling" (71.15%), "BJD reduces profitability" (69.23%), "BJD is a trade risk to the dairy industry" (57.69%), and "BJD is zoonotic" (9.62%).

Currently, there are fewer farmers (71.11%) participating in BJD control programs than previously (78.38%). Conversely, there are currently more BJD vaccine users (15.0%) compared to the past (11.43%). There was no time period specified for previous participation in BJD control activities.

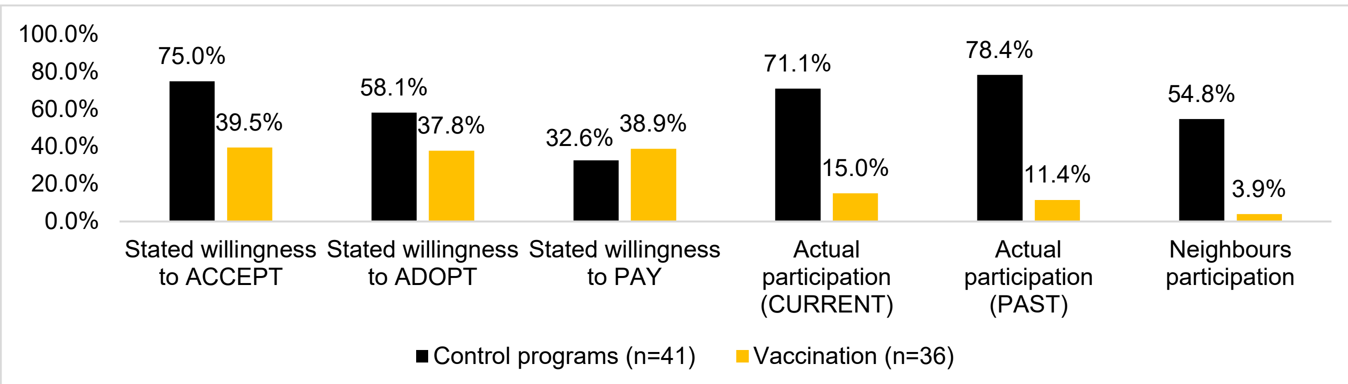

Figure 2.7 Stated willingness to accept, willingness to adopt, willingness to pay for BJD control strategies, and participation in BJD control activities on dairy farms in Australia

Of those farmers who had participated in control programs in the past, 89.28% are still engaged which indicates a 10.72% attrition. All of those farmers who were not previously participants in control programs remained so, indicating no new converted control program participants. All farmers who previously used a BJD vaccine continue to do so. In addition, among farmers who previously were not vaccinating, 3.23% have subsequently started.

Farmers were more willing to accept the principles and concepts behind control programs (75.00%) than vaccination (39.47%). The number of farmers stating willingness to adopt control programs (58.14%) was again higher than for vaccination (37.84%) however there were fewer farmers with stated willingness to pay for control programs (32.56%) than for vaccination (38.89%). There was a sequential interdependence between farmers' willingness to accept, adopt, and pay for both control programs and vaccines.

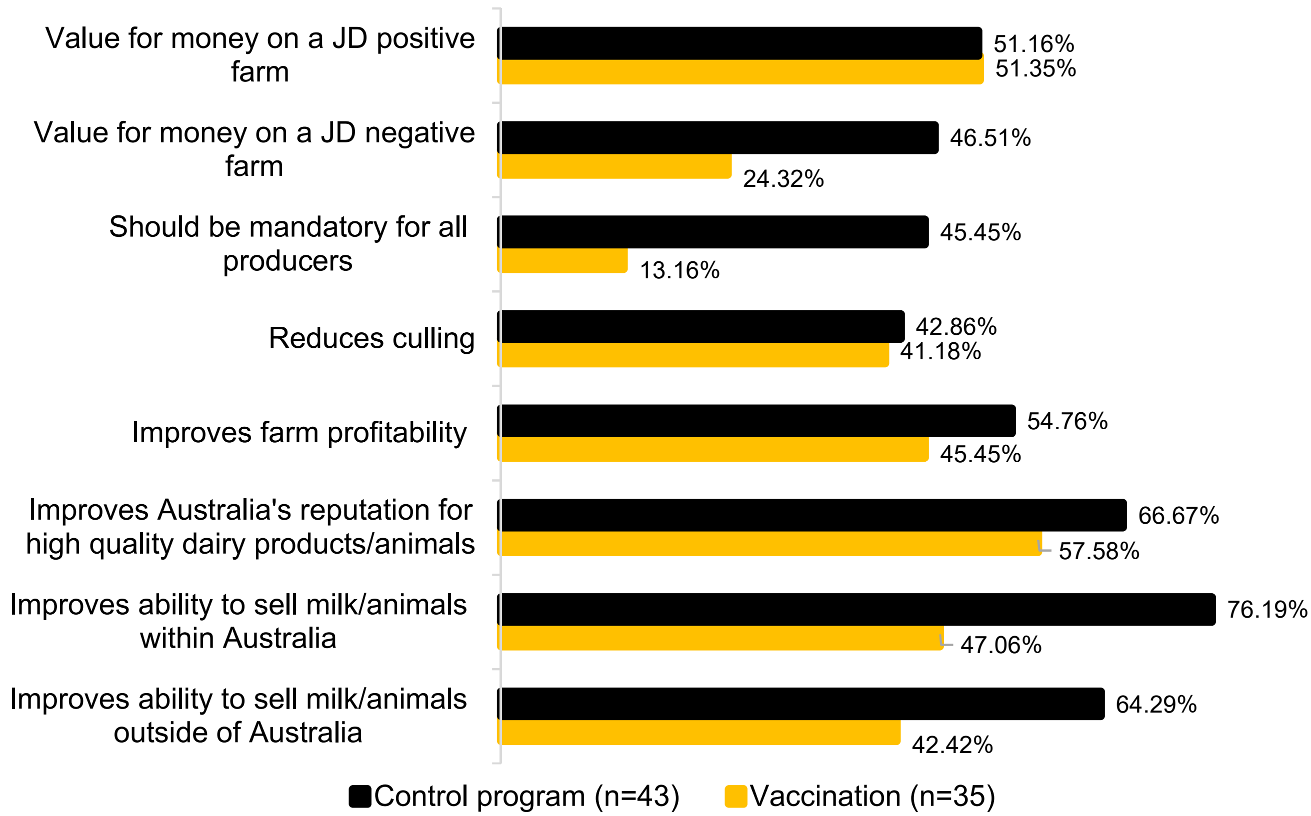

Figure 2.8 Attitudes of Australian dairy farmers toward various aspects of BJD control

Favorability of attitudes toward different BJD control strategies was captured by aggregating the attitudes toward the proposed positive effects of each control strategy (Figure 2.8). As a result, 47.73% of farmers were identified as having a favorable attitude toward control programs compared to 31.58% having a favorable attitude toward vaccination (Figure 2.11).

Table 2.5 Crude odds ratios from univariate logistic regression showing association between BJD control attitudes, stated preferences, and exercised preferences of Australian dairy farmers

Exercised Preference	Stated Preference	Odds Ratio	95% Confidence Interval	p-value
Control programs	Ordinal - Level of engagement (stated)	1.29	(0.66 - 2.54)	0.456
	Binary - Stated willingness to accept	2.03	(0.4 - 10.38)	0.397
	Binary - Stated willingness to adopt	6.27	(1.09 - 36.25)	0.040**
	Binary - Stated willingness to pay	0.80	(0.16 - 3.95)	0.781
	Binary - Favorability of attitude	1.76	(0.36 - 8.55)	0.480
Vaccination	Ordinal - Level of engagement (stated)	1.55	(0.75 - 3.20)	0.241
	Binary - Stated willingness to accept	9.00	(0.92 - 88.16)	0.059*
	Binary - Stated willingness to adopt	10.00	(1.01 - 98.88)	0.049**
	Binary - Stated willingness to pay	4.64	(0.43 - 50.44)	0.208
	Binary - Favorability of attitude	6.00	(0.9 - 40.14)	0.065*

(**p<0.05; * p<0.1)

There was no statistically significant association between the stated level of engagement in either BJD control activity (ordinal) and actual participation. However, when looked at individually, a significant association between stated willingness to adopt control programs and actual participation existed ($p<0.05$). This suggested that the odds of a farmer with stated willingness to adopt control programs actually participating were 6.27 times that of a farmer stating they were unwilling ($p<0.05$). There were no significant associations between other stated preferences, attitudes and actual participation in control programs.

Significant associations existed between various stated preferences and actual participation in BJD vaccination ($p<0.1$). The odds of farmers willing to accept concepts behind BJD vaccination and actually participating were 9.00 times the odds of farmers not willing to accept ($p=0.059$). The odds of farmers with stated willingness to adopt BJD vaccination actually participating were 10.00 times that of farmers not willing to adopt ($p=0.049$). Farmers with favorable attitudes toward BJD vaccination had 6.00 times greater odds of actually participating than those with unfavorable attitudes ($p=0.065$).

Albeit a small percentage, there are some producers that have previously participated and are currently participating in BJD control strategies that do not even accept the principles nor have a favorable attitude toward the respective activities. The sequential independence between levels of stated engagement for both control strategies was however evident by cross-tabulating levels by one another which showed that 100% of farmers with a stated willingness to adopt had a stated willingness to accept. Similarly, 100% of farmers with a stated willingness to pay also had a stated willingness to accept and adopt.

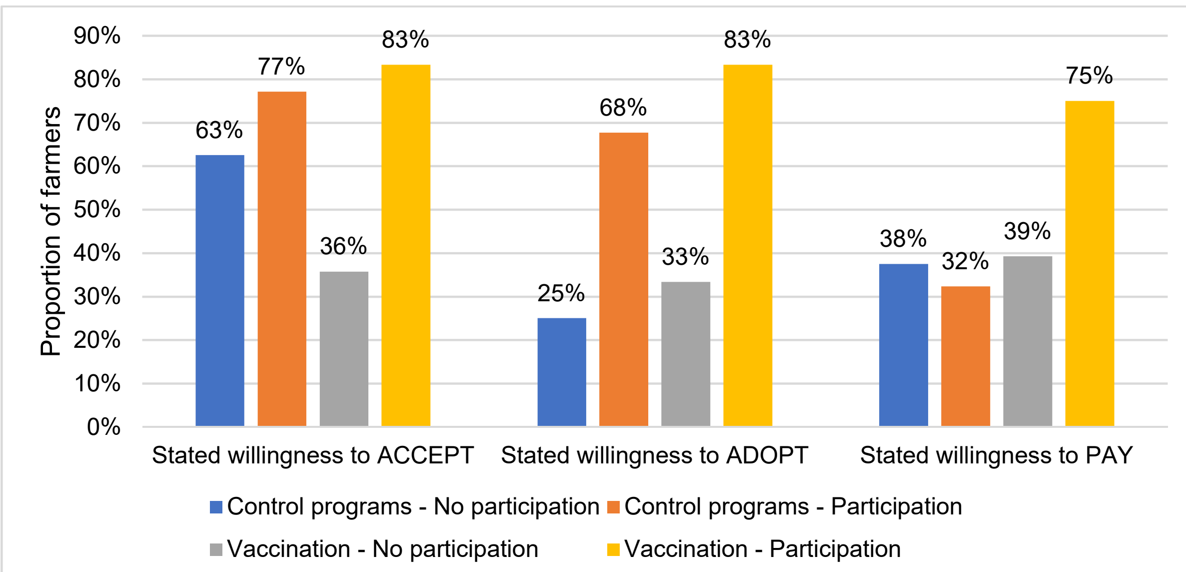

Figure 2.9 Participation rates of Australian dairy farmers in BJD control activities relative to stated preferences

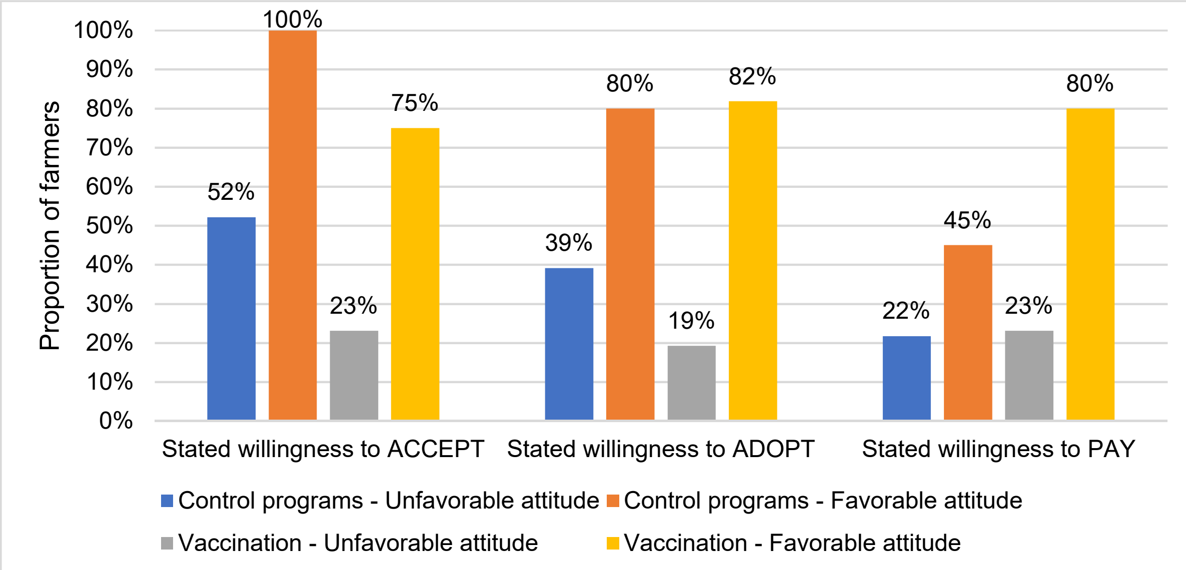

Figure 2.10 Favorability of Australian dairy farmers' attitudes (aggregated) toward BJD control activities relative to stated preferences

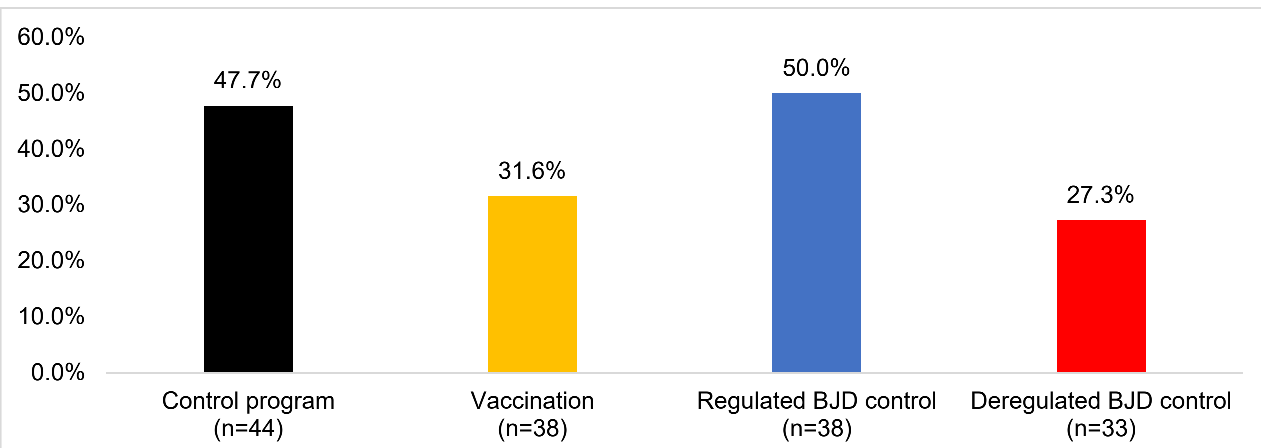

Figure 2.11 Favorability of Australian dairy farmers attitudes (aggregated) toward aspects of BJD control on dairy farms

2.3.1.4 Regulatory affairs

There was a higher proportion of farmers with favorable attitudes toward a policy environment where BJD control is regulated (50%) compared to deregulated (27.27%). This was as a result of the aggregated attitudes toward potentially beneficial outcomes of policy structures (Figure 2.12).

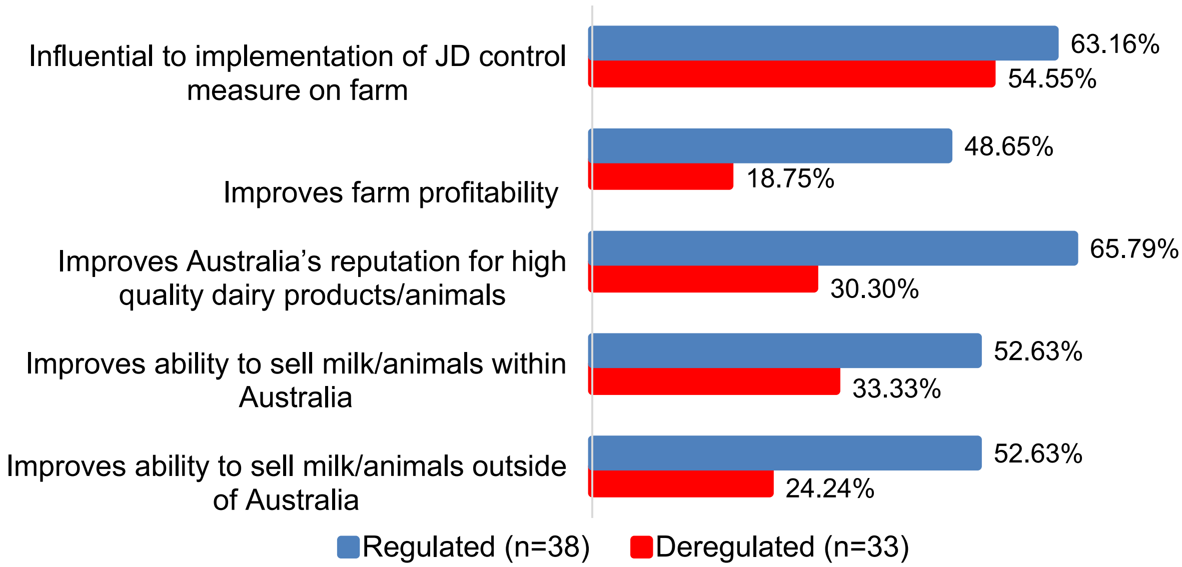

Figure 2.12 Attitudes of Australian dairy farmers toward BJD regulatory control policy

The mean allocation of responsibility for control programs and vaccination to farmers as quantified by participants was 59.7% and 53.3% respectively. Similarly, the mean percentage of costs for control activities that participants were willing to assume were 42.3% and 50.6% for control programs and vaccination respectively.

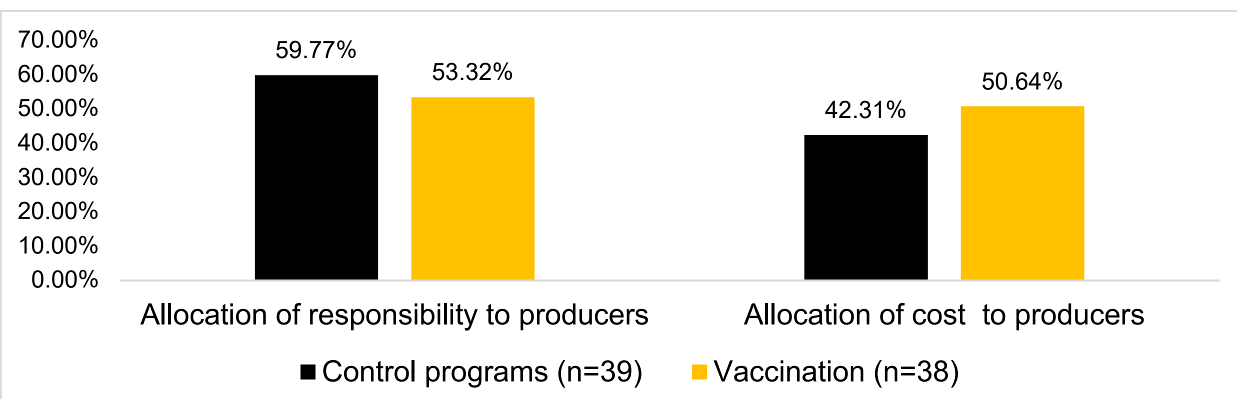

Figure 2.13 Mean allocation of responsibilities and costs for BJD control strategies as quantified by Australian dairy farmers

Roughly one third (32.50%) of dairy farmers perceived BJD as an animal health concern for the beef industry with almost half (47.50%) having the perception that the beef industry strongly influences policy formulation for BJD control. Farmers with the perception that BJD control policy should be uniform and encompass control in both the beef and dairy industries accounted for 87.50% of all participants.

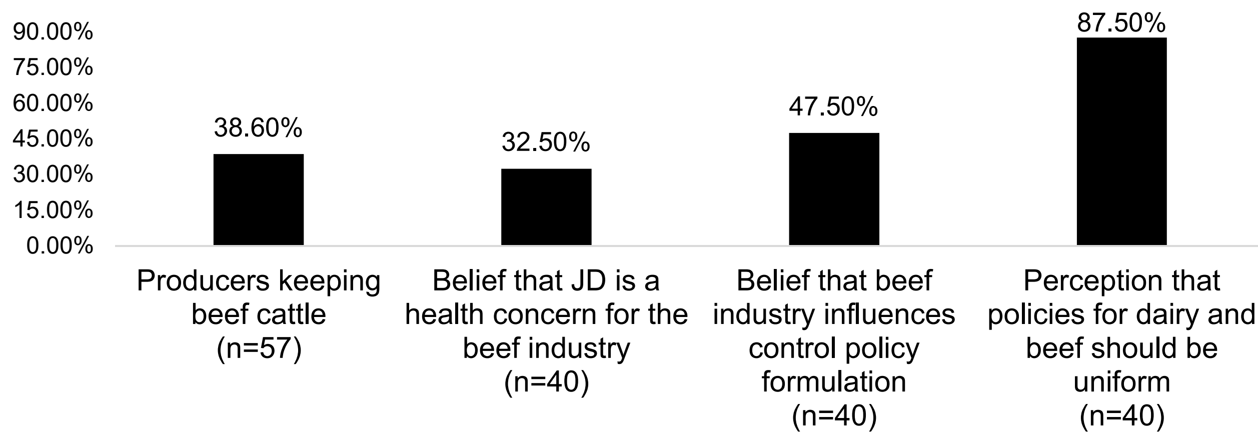

Figure 2.14 **Attitudes of Australian dairy farmers toward BJD and regulatory control in the beef industry**

2.3.2 **Ordinal logistic regression**

Farm location was not identified as an effect modifier or confounder in the BJD control program or vaccination model. Annual production was identified in both models as a confounder on the relationship between self-perceived herd health and level of engagement in BJD control programs and BJD vaccination respectively. After adjustment, the effect of perceived health on each of the dependent variables was reduced and no longer considered a significant explanatory variable. In both models, the presence of beef cattle on-farm was identified as an effect modifier on the relationship between the level of biosecurity and engagement in each of the two BJD control strategies.

The effects of independent variables on dependent variables in the final adjusted models are portrayed by odds ratios in Table 2.6 and Table 2.7. Each odds ratio represents the increase in odds of a higher level of engagement relative to the combined categories below, for a one-unit increase in the explanatory variable. Tests for multicollinearity suggest the explanatory power of variables within the model were largely independent without artificially inflating the variance due to similar effect on the dependent variable. Neither model violated the proportional odds assumption.

Table 2.6 Odds ratios for explanatory variables included in the final adjusted ordinal logistic regression model predicting Australian dairy farmers' level of engagement of s in BJD control programs

Cluster	Variable	Odds Ratio	P>|z|	95% Confidence Interval
Demographics	Age	1.70	0.016**	(1.10 - 2.61)
	Time in industry	0.58	0.010***	(0.38 - 0.88)
	Farmland allocated to cropping	1.04	0.019**	(1.01 - 1.08)
	Number of cows ≥ 1st lactation	1.01	0.372	(0.99 - 1.02)
	Total farm size	0.96	0.011**	(0.93 - 0.99)
	Annual farm milk production	1.35	0.837	(0.08 - 23.27)
	Motivated by profit	1.53	0.802	(0.05 - 42.55)
Animal Health	Self-perceived health of the herd	0.09	0.139	(0.00 - 2.19)
	Farm biosecurity level	312.26	0.037**	(1.41 - 68981.32)
Knowledge, attitudes, and practices	Perception - Control programs are value for money on BJD positive farms	8.48	0.073*	(0.82 - 87.62)
	Perception - Control programs improve farm profitability	2.60	0.476	(0.19 - 36.06)
	Perception - Control programs reduce culling	3.57	0.198	(0.52 - 24.68)
	Livestock trading practices - sells livestock within Australia	0.03	0.029**	(0.00 - 0.71)
Regulatory affairs	Perception - Regulated BJD control influences uptake of control strategies	5.04	0.314	(0.22 - 117.23)

(***p<0.01; **p<0.05; * p<0.1)

Table 2.7 Odds ratios for explanatory variables included in the final adjusted ordinal logistic regression model predicting Australian dairy farmers' level of engagement in BJD vaccination

Cluster	Variable	Odds Ratio	P>|z|	95% Confidence Interval
Demographics	Age	1.19	0.177	(0.92 - 1.54)
	Time in industry	0.90	0.274	(0.74 - 1.09)
	Farmland allocated to cropping	1.01	0.302	(0.99 - 1.02)
	Number of cows ≥ 1st lactation	1.37	0.684	(0.30 - 6.24)
	Annual farm milk production	0.56	0.234	(0.21 - 1.46)
	Motivated by profit	7.95	0.098*	(0.68 - 92.41)
Animal Health	Self-perceived health of the herd	0.44	0.549	(0.03 - 6.48)
	Farm biosecurity level	2.67	0.493	(0.16 - 44.6)
	Number of veterinary emergencies per month	0.39	0.454	(0.03 - 4.51)
Knowledge, attitudes, and practices	Perception - Vaccination improves farm profitability	27.83	0.032**	(1.34 - 579.6)
	Perception - BJD reduces farm profitability	0.03	0.076*	(0.00 - 1.42)

(**p<0.05; * p<0.1)

2.3.2.1 Predicted levels of engagement in BJD control programs

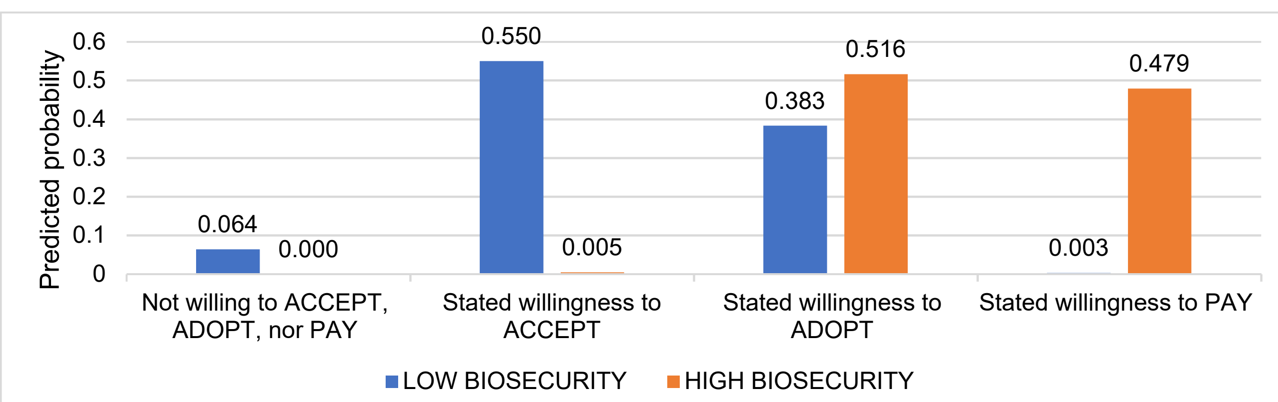

Figure 2.15 Predicted probabilities of Australian dairy farmers' level of engagement in BJD control programs at two different levels of farm biosecurity

By level of farm biosecurity, farmers with the highest probability of a stated willingness to accept the concepts behind BJD control programs (0.55) were those with low farm biosecurity levels whereas the lowest probability occurred at high levels of biosecurity. The highest probability of stated willingness to adopt (0.52) and stated willingness to pay (0.48) for BJD control programs both occurred when farm biosecurity was high.

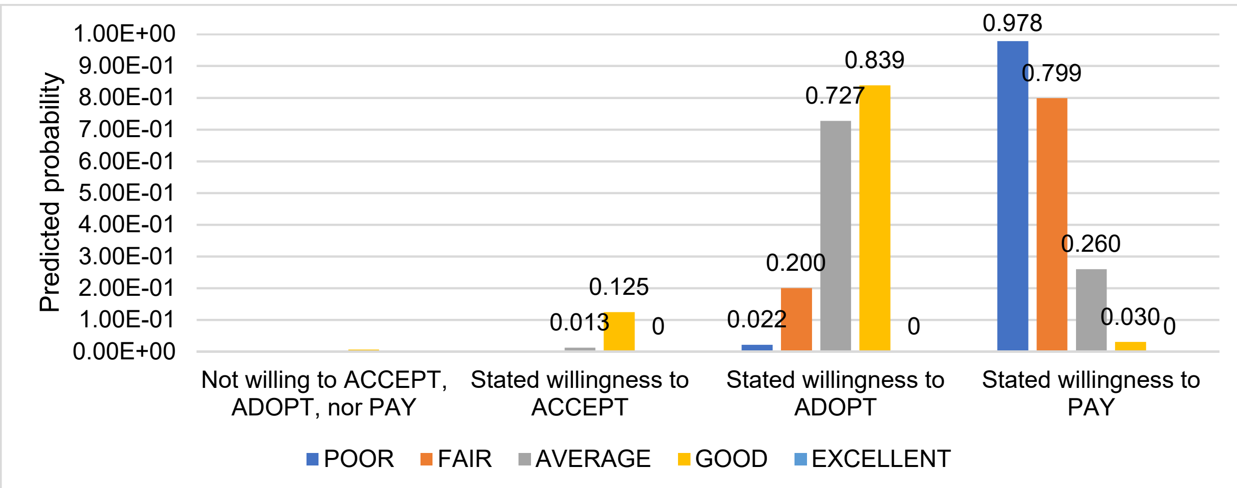

Figure 2.16 Predicted probabilities of Australian dairy farmers' level of engagement in BJD control programs at five different levels of farmers' self-perceived health of herds

By varying levels of farmers' self-perceived health of their herds, the highest probability of acceptance of BJD control program concepts (0.56) occurred when herds were classified as "excellent" whereas the lowest probability was encountered with herds classified as "poor" (0.0001). Farmers had the highest probability of a stated willingness to adopt BJD control programs (0.84) when herd health was classified as "good". The highest probability of a farmer stating willingness to pay for a control program (0.98) occurred when they perceived their herd to be in "poor" health.

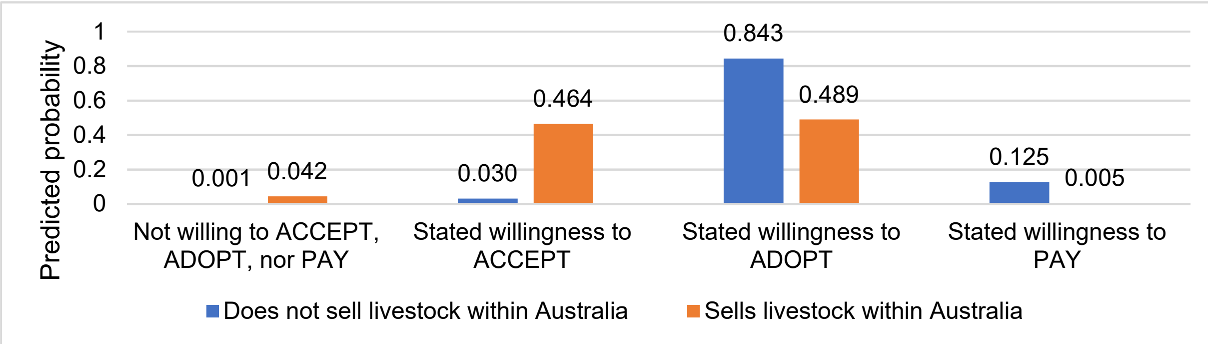

Figure 2.17 Predicted probabilities of Australian dairy farmers' level of engagement in BJD control programs considering two different livestock trading practices in Australia

When looking at different livestock trading practices, farmers selling livestock within Australia had the highest probability of accepting (0.46) the concepts of a BJD control program. However, the probability of farmers' stated willingness to adopt (0.48) and pay (0.005) for such programs was less that of farmers who do not sell animals within Australia. Farmers not selling livestock within Australia had almost double the probability of stating willingness to adopt (0.84) than those who do sell livestock within Australia (0.49).

At different levels of agreement with the statement "control programs are value for money on BJD positive farms", the highest probability of stated willingness to accept BJD control program concepts (0.64) occurred among farmers who disagreed with the statement whereas the lowest probability (0.005) occurred when farmers strongly agreed. Farmers had the highest probability of stated willingness to adopt (0.86) when they agreed with the statement and the lowest probability (0.04) when they strongly disagreed. Farmers strongly agreeing that control programs represent value for money on BJD-positive farms had the highest probability of stated willingness to pay for such programs (0.48) with farmers strongly disagreeing having the lowest probability (0.0002) of stated willingness to pay.

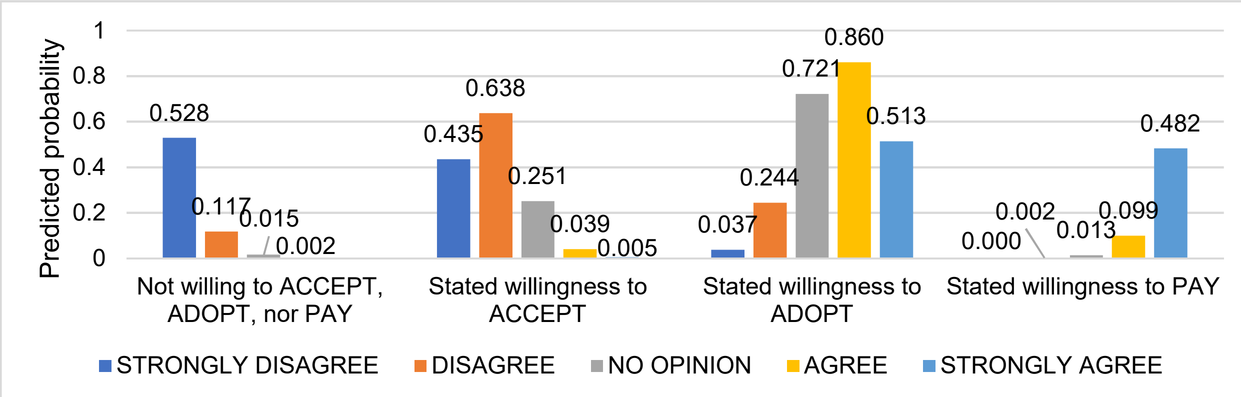

Figure 2.18 Predicted probabilities of Australian dairy farmers' level of engagement in BJD control programs at five different levels of agreement with the statement "Control programs are value for money on BJD positive farms"

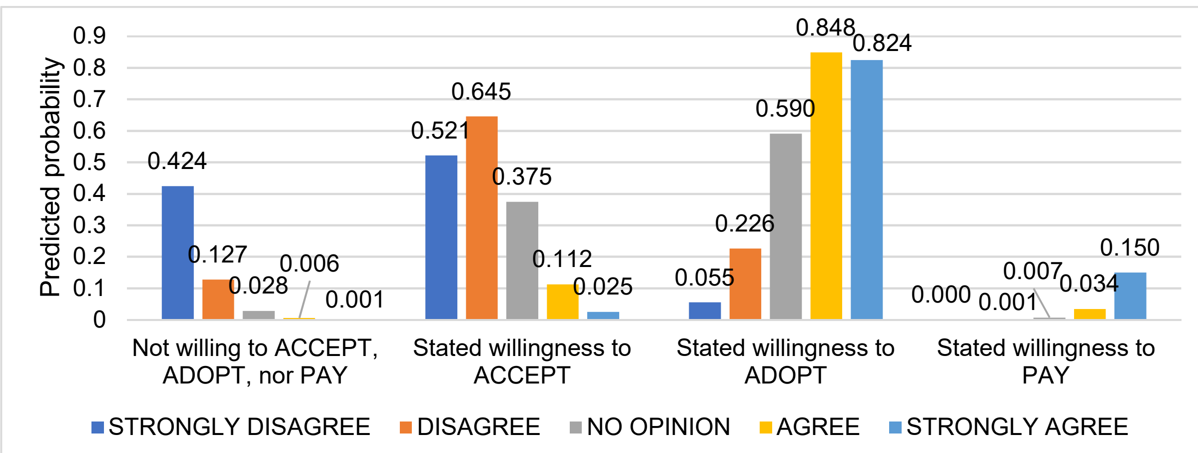

Figure 2.19 Predicted probabilities of Australian dairy farmers' level of engagement in BJD control programs at five different levels of agreement with the statement "Regulatory policy was influential to me implementing control measures for BJD on my farm"

At different levels of agreement with the statement "Regulatory policy was influential to me implementing control measures for BJD on my farm", the highest probability of stated willingness to accept BJD control program concepts (0.65) occurred among farmers who disagreed with the statement whereas the lowest probability (0.005) occurred when farmers strongly agreed. Farmers had the highest probability of stated willingness to adopt (0.85) when they agreed with the statement and the lowest probability (0.05) when they strongly disagreed. Albeit a low probability, those farmers strongly agreeing that regulatory policy influenced their implementation of BJD control measures had the highest probability of stated willingness to pay for such programs (0.15) with farmers strongly disagreeing having the lowest probability (0.0003) of stated willingness to pay.

2.3.2.2 Predicted levels of engagement in BJD vaccination

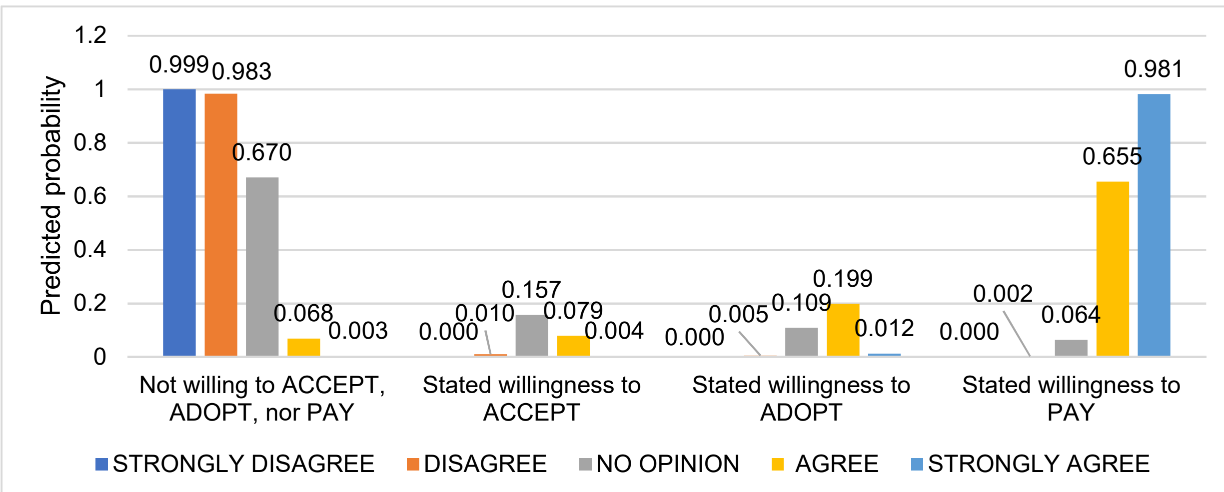

Figure 2.20 **Predicted probabilities of Australian dairy farmers' level of engagement in BJD vaccination at five different levels of agreement with the statement "BJD vaccination improves farm profitability"**

By different levels of agreement with the statement "BJD vaccination improves farm profitability", the highest probability of a farmer accepting the concepts of BJD vaccination (0.16) occurred when they had no opinion on the statement. Farmers had the lowest probability of accepting the concepts behind vaccination (0.0004) when they strongly disagreed. The highest probability of stated willingness to adopt BJD vaccination (0.20) occurred among farmers who agreed that vaccination improves farm profitability whereas the lowest probability occurred again among those who strongly disagreed. Those farmers who strongly agreed with the statement had a 0.98 probability of stating willingness to pay for vaccination compared to those farmers who agreed (0.65), had no opinion (0.06), disagreed (0.002), and strongly disagreed (0.0001).

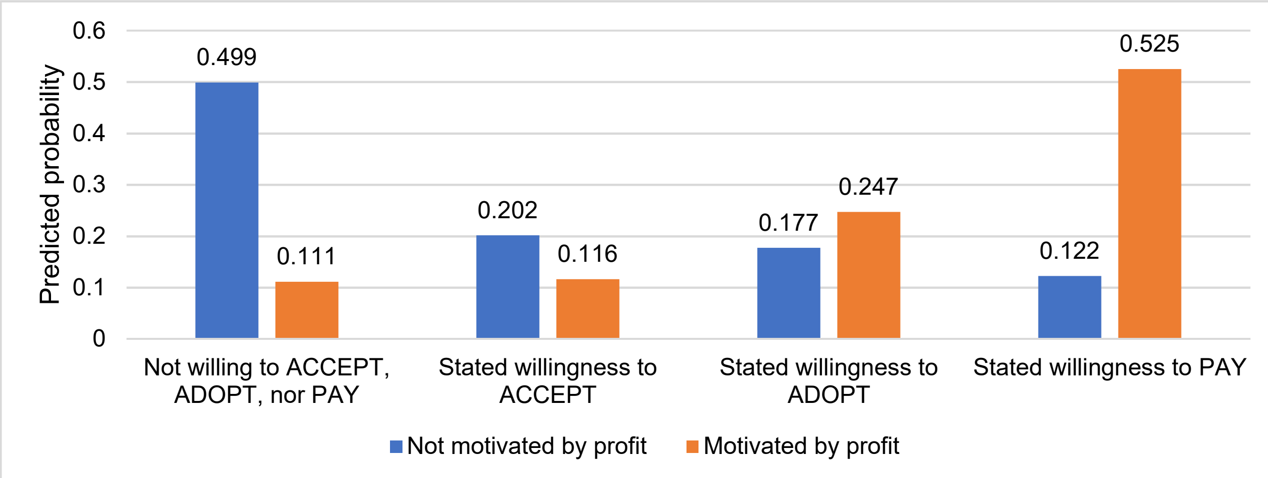

Figure 2.21 Predicted probabilities of Australian dairy farmers' level of engagement in BJD vaccination considering farmers' motivation for being involved in the dairy industry

By varying motivation for being involved in the dairy industry, the highest probability of stated willingness to accept the concepts behind BJD vaccination (0.2) occurred when farmers were motivated by factors other than profit compared to a probability of 0.12 when profit was stated as a primary motivation. However, the highest probability of stated willingness to adopt BJD vaccination (0.25) occurred among farmers who were motivated primarily by profit whereas farmers with other motivation had a 0.18 probability of stated willingness to adopt. Farmers with the highest probability of a stated willingness to pay for BJD vaccination (0.53) were those farmers motivated by profit. Farmers motivated by other factors had a 0.12 probability of stating willingness to pay.

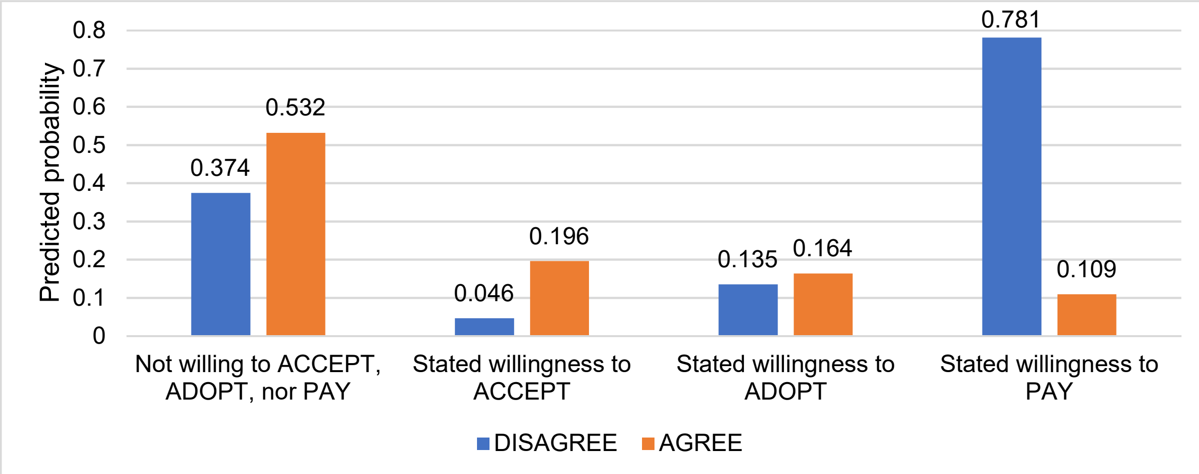

Figure 2.22 Predicted probabilities of Australian dairy farmers' level of engagement in BJD vaccination at two different levels of agreement with the statement "BJD reduces farm profitability"

By different levels of agreement with the statement "BJD reduces farm profitability", the highest probability of stated acceptance of the concepts of BJD vaccination (0.2) occurred among farmers that agreed with the statement whereas those who disagreed had a 0.05 probability of stated acceptance. Stated willingness to adopt BJD vaccination was slightly lower among farmers who disagreed (0.14) than those who agreed with the statement (0.16). The highest probability of stated willingness to pay for BJD vaccination (0.78) occurred among those who agreed that BJD reduces farm profitability compared to those who disagreed (0.11).

2.4 Discussion

This study looked at the factors influencing the uptake of two different BJD control strategies. To the best of my knowledge, this is the first study looking at the role of factors including regulatory affairs and their influence on stated preferences and exercised preferences regarding BJD control strategies.

It is apparent from this analysis that stated levels of engagement in BJD control programs seem to be associated largely with factors concerning the practicality of programs such as the size of farms, amount of land allocated to crops, level of farm biosecurity, and experience in the industry. A possible explanation for this is the availability of existing infrastructure or additional infrastructure and skills required to enable implementation of control program elements such as hygienic calf rearing, colostrum management, availability of replacements for culled animals, and structures in place to minimize the risk posed by introduced animals. An appreciation for outcomes of control programs such as market access and value for money also seem important in determining the stated level of engagement. This is supportive of the fact that farmers as business owners will act in their best interests to improve business efficiency and profitability (Pindyck, 2013).

These results suggest that stated levels of engagement in vaccination are associated with factors concerning profitability. Capital outlay for use of the vaccine is relatively high compared to other commonly used vaccines on dairy farms (clostridial diseases, viral respiratory and reproductive diseases) as the current price of the BJD vaccine in Australia is around $25.00 AUD per dose administered once off to calves from three weeks of age. The government subsidy currently available for farmers in Victoria ($12.50 AUD) potentially allows for easier access to the vaccine. However, barriers to uptake exist such as the initial expense, management of vaccinates, and specific safety training farmers require to use the vaccine (Agriculture Victoria, 2016b). Thus, it is plausible that a good understanding of risks and costs associated with vaccination and belief in the financial advantage that vaccination confers is required prior to consideration of its use as a tool to control BJD.

As per the theoretical models introduced earlier, perceived susceptibility to, and severity of BJD need to be considered when assessing uptake of control strategies. As such, the BJD status of herds was considered for inclusion in both models but was not included in the models best fitting the data of this study. Low strength of association between herd status and attitudes, stated preferences, and exercised preferences however suggest BJD status has less influence than one would expect for diseases with potentially severe consequences. This is supported anecdotally both by qualitative assessment of commentary offered freely by seventeen questionnaire participants and furthermore by submissions to the 2015 review of the national BJD control framework in Australia (AHA, 2015c). Two farmers stated *“BJD is a management disease*”, another two stated “*BJD is not a major problem in cattle*” and “*there are other much more economically debilitating diseases in cattle that are way worse*” respectively with several alluding to the fact that good farm biosecurity provides appropriate reduction of the risk of introduction of BJD into herds.

The influence of regulatory policy on the attitudes, stated preferences, and exercised preferences regarding BJD control activities is seemingly underrepresented however it is included in the model predicting stated level of engagement in control programs. Albeit not statistically significant in the model, it played an important role in obtaining the best fit for the model. The predictions (figure 2.18) suggest that there is reasonable engagement in BJD control programs under a regulated BJD control framework however the willingness to pay for control programs under such a policy environment is very low. The decreased current participation in control programs (figure 2.7) relative to previously may be as a result of government legislation whereby herds tested positive were required to enrol in Test and Cull Programs. Poor diagnostic test characteristics and reduced market access have also been cited as reasons for the decline in previous years (Davis, 2012a; Kennedy, 2000a; Kennedy, 2002; Kennedy, 2011; Shephard, 2014b; Westacott, 2012). This would appear true for three participants who stated the following:

“*The Australian JD system penalized honest farmers who did the right thing regarding JD through increased costs and lower value for cows. A lot of farmers had JD and did not declare it and conducted business as usual without incurring any disadvantage*”

“*We have been penalized for been part of the program i.e. when selling cattle people won’t buy when we say we are in the program to try and control the disease on our farm*”

“*Johnes is a management disease and shouldn't be penalized/rated*”

Participation in vaccination is currently higher than previously but the role of regulatory control in this is difficult to ascertain as the vaccine has only been available in Australia since 2014 (APVMA, 2014).

Noteworthy is the discrepancy between the farmers that have actually participated in BJD control activities and their stated preferences and attitudes especially those within the dissident categories of willingness to accept, adopt and pay. This suggests that farmers may have participated against their free will or perhaps that after initial participation there was the realization that it wasn't worthwhile thus fostering negative sentiments. Comments from participants support this with one farmer stating "*We were one of the first dairy herds to participate in the cattle MAP and it was a waste of time*" and another stating "*We also feel that the level of JD in our herd hasn't changed at all in past 23 years*".

2.4.1 **Bias**

2.4.1.1 Selection bias

The availability of the questionnaire restricted to online channels may have excluded farmers who do not use the internet from participating or those late adopters of technology, including biotechnology. The proportion of farmers using vaccines to control diseases other than BJD accounted for 85.71% of all participants which suggests the majority of farmers are early adopters of technology however this does not account for the low number of participants currently using a BJD vaccine.

About 50% of responses were received directly as a result of dairy veterinarians distributing the questionnaire to their clients. This inadvertently may have selected participants with healthier herds than those who do not routinely use veterinarians but this is unlikely to have influenced the outcome as there is an equal chance these clients require veterinary services owing to poor herd health.

The estimated herd-level prevalence of BJD among participants' farms (19.23%) is not statistically significantly different from prior estimates of between herd prevalence (14%) as determined by Kennedy, 2010.

Geographically, the bulk of participant farms were situated in the state of Victoria (52.46%) which reflects the current location of the majority of dairy farmers in Australia (67.86%) (Dairy Australia, 2018). This also mirrors the areas where anecdotally farmers have experienced more issues with BJD and BJD control programs. The proportion of participants from South Australia (26.23%) was significantly higher than the actual proportion (4.24%) of dairy farms owing to the researcher having worked in the area thus receiving higher participation rates than other states (Dairy Australia, 2018). Although the estimated prevalence of BJD in South Australia is reportedly lower than Victoria, the farming environment and predominant animal husbandry systems are similar (Rogers, 2012). The overrepresentation from South Australia is thus unlikely to invalidate these results. There were no responses recorded from farmers in Western Australia. Unfortunate as this may be, the number of farmers located in Western Australia accounts for only 2.65% of all dairy farms in Australia and is known to have a very low prevalence of BJD (Government of Western Australia, 2016). Thus, the lack of representation from WA is unlikely to invalidate these results.

2.4.1.2 Misclassification bias

Levels of engagement in BJD control programs and vaccination was established by asking participants' level of agreement with the statements "The principles behind JD control are valid", "I am willing to adopt this to control JD", "Producers should pay for this to control JD" to represent "Stated willingness to accept", "Stated willingness to adopt", and "Stated willingness to pay" respectively. Responses were recorded on a 5-point Likert scale (strongly disagree – strongly agree) and subsequently dichotomized such that those agreeing and strongly agreeing were represented by the affirmative groups of stated willingness to accept, adopt and pay respectively and all other responses representing the dissenting. This classified those farmers choosing the "no opinion" for any of the aforementioned statements as being dissenting which may have artificially inflated these categories. However, given that all responses were voluntary where farmers could advance the questionnaire without having to answer these questions, those farmers responding to the statements effectively ranked their choice thereby allowing for dichotomization without imposing inaccurate perceptions.

All questionnaires were answered completely anonymously and thus there is no reason that participants may have felt coerced into answering certain questions in a particular way due to social pressure (false negatives) as previous reports would suggest is true (AHA, 2015c). Thus, the classification of herd BJD status and levels of engagement resultingly is likely a reflection on the true situation owing to high sensitivity and specificity.

2.4.1.3 Effect modification and confounding

Potential effect modifiers and confounders were identified *a priori* and controlled for during analysis using regression modelling techniques. Owing to the small sample size, models including the interaction terms were unable to be tested for meeting the proportional odds assumption as there were missing values in the matrix. Stratification by levels of the effect modifier produced insufficient observations for the models to run. Thus, final models and predictions were run with the models adjusted for and including confounding variables only. There remains the possibility of residual confounding due to unidentified or unspecified variables that may be influencing the results. However, tests for multicollinearity were conducted on each model revealing no evidence for artificially inflated variance due to the similar influence of explanatory variables on the dependent variable.

2.4.1.4 Chance

There is the possibility of both Type 1 and Type 2 statistical errors owing to the small sample size and use of liberal p-values. The large confidence intervals of odds ratio estimates, many which traverse the null value (1.00), suggest lower precision of estimates which could be improved by larger sample size.

2.4.2 **Generalizability**

Selection bias and misclassification bias were deemed of negligible effect on estimates obtained during analysis. Effect modification and confounding were dealt with by controlling for variables likely to change the association between the independent and dependent variables. There remains however the possibility of residual confounding whereby unspecified or unidentified variables may be influencing estimates.

This sample differs from the population of Australian dairy farmers when looking at a few key aspects (Table 2.3). The farmers in this sample have farms that are statistically significantly larger than the mean dairy farm size in Australia ($p<0.05$). Participant herds have a significantly higher annual production per cow than the national average and a lower percentage of farms maintain closed herds ($p<0.001$). Cows with higher production in the sample may imply the general health status of herds is higher than the average across Australia, thus supportive of the potential selection bias mentioned earlier due to questionnaire distribution via dairy veterinarians. One would thus assume the BJD prevalence among participant herds is lower than the population however it is slightly higher although not statistically significant ($p>0.1$). Although participants had spent significantly more time being dairy farmers than the mean time all Australian dairy farmers had spent in the industry ($p<0.001$), it is likely they are ideally poised to have perspective on the different management approaches to BJD control policy and programs in Australia over the years. Moreover, the mean herd size, breed composition, and estimated BJD herd prevalence are not significantly different from the national population and thus offers a sample that is largely representative of Australian dairy farms thereby allowing generalization to the population of Australian dairy farms.

2.4.3 **Strengths and limitations**

2.4.3.1 Strengths

As this sample may be deemed an adequate representation of Australian dairy farms it allows for generalization as to the factors influencing the uptake of BJD control strategies within Australia. Furthermore, the results are supported by a basic qualitative assessment of comments made by participants at the end of the questionnaire which are consistent with reports previously seen (AHA, 2015c).

2.4.3.2 Limitations

The small sample size and increased likelihood of findings due to chance potentially make extrapolation of results ambitious. The cross-sectional nature of this data prevents any inference of causality. This is especially limiting concerning the comparison of the current deregulated and former regulated BJD control policy environment and how this may be related to current and previous participation in BJD control activities. Furthermore, the study design does not allow for the determination of risk. The concept of "willingness to pay" for BJD control activities was not quantified by asking participants a specific amount they would be willing to pay. This precludes making informed estimates as to costs dairy farmers may be willing to incur to pursue different BJD control strategies in their herds. Given the differences in BJD prior prevalence estimates across states, it would have been valuable to identify state-specific differences however this is thwarted by the small sample size and lack of ability to further stratify.

2.4.4 **Knowledge to action**

One could cautiously extrapolate results from this study to other countries with similar dairy production systems, similar BJD prevalence and challenge, and where control by regulatory policy is in place or has been proposed. Many BJD control efforts around the globe have objectives of reducing the public health risk posed by BJD however the zoonotic potential of BJD was of concern to only a small percentage of participants (9.62%). The statistical models in this study allow for characterization of farms and farmers with a higher likelihood of stated willingness to engage in BJD control activities however they can only suppose the factors that would convince farmers to take the next step of actual participation.

It would seem from risk factor studies, commentary from participants, and existing literature that the presence of BJD in a herd can be managed to a level where it is of negligible concern. The knowledge gap, however, remains as to what factors contribute to bridging the gap between stated preferences and exercised preferences. It is evident that regulatory affairs play some role in determining the stated level of engagement, especially where farmers are not willing to pay for BJD control activities should it be enforced by regulation. This opens the question as to the distribution of costs and responsibilities for BJD control among stakeholders and therein potentially lies the explanation for the discrepancy between what farmers say they are willing to do about BJD control and what they actually end up implementing.

2.5 **Conclusion**

Given Australia's history and evolution of control programs, the changes in a regulatory control policy, and the availability of a vaccine, these results allow some insight into what drives farmers' decisions around BJD control. It is evident that participation in BJD control programs is multifactorial and does not solely depend on favorable attitudes and farmers being convinced by the virtues of controlling the disease. The immediate financial considerations, particularly for use of BJD vaccination as part of an overall control approach to BJD is noteworthy as are the market access considerations concerning false positive reactions to bovine tuberculosis testing. Control programs and vaccination have been deemed feasible on Australian dairies (Shephard, 2016) but producers need to be empowered to make decisions that best suit their business objectives without being clouded by regulations unsupportive of reducing the risk BJD to the industry.

Further research is required to investigate these issues more thoroughly; ideally with a larger sample size of farmers that would provide adequate power to assess some of the more intricate relationships between stated preferences and exercised preferences. The role of the beef industry and how this influences policy formulation also needs further investigation and warrants a separate study to capture the knowledge, attitudes, and practices whether the disconnect between stated and exercised preferences is of the same nature as in the dairy industry.

Chapter 3 Variations in the profitability of dairy farms by different levels of engagement in BJD control

3.1 Introduction

BJD causes losses for dairy farmers in the form of increased culling, increased replacement animals, reduced milk yield, control costs, and regulatory costs. Numerous studies have investigated the economic impact of BJD on dairy herds with most revealing a decrease in milk production associated with herds testing positive for MAP. However, there are some conflicting findings (Garcia, 2015). A systematic review of milk production losses due to BJD suggests the detection of the MAP organism in cows is associated with a 5.9% decrease (McAloon, 2016).

Among Canadian dairy herds, the average loss in herds with a prevalence of 12.7% is approximately CAD$50 per cow per year with additional culling representing 46% of losses (Tiwari et al., 2008). Dairy farms in Alberta, Canada participating in the AJDI modelled over a 10-year period revealed a net benefit of CAD$74 per cow. Although this benefit was reduced to CAD$27 if farmers had to pay for associated costs (testing, veterinary fees), participation was found to be cost-effective for the average dairy farm over the long term (Wolf et al., 2014). Simulation of the effect of BJD on typical dairy farms in Victoria, Australia exercising no control strategies revealed a profit loss of AUD$44.84 per cow. Participation in BJD control programs and vaccination has been deemed economically feasible for typical Victorian dairy farms with vaccination identified as the most cost-effective over the long term (Shephard, 2016).

As per the conceptual and theoretical models introduced in chapter two, the microeconomic theory assumes dairy farms as business firms aim to optimize profitability in the short and long term (Pindyck, 2013). In economic terms, profit is the difference between total revenue and total costs. Control options exist to decrease the costs of BJD to dairy farms. Decisions based on a profit optimization framework can help ensure their viability. The objective of this chapter is to determine differences in profitability between dairy farms by varying levels of engagement in BJD. The hypothesis being tested here is that Australian dairy farmers engaging in BJD control activities are more profitable than those who are not engaged.

3.2 Materials and Methods

3.2.1 Participant selection and data stratification

A spreadsheet model was created using Microsoft Excel 2019 and the @Risk add-in to calculate farm profit. Data obtained using the methodology described in Chapter 2 was processed to include only observations from farmers in Victoria. Remaining observations were then stratified by categories of a binary variable representing farmers' level of engagement in BJD control strategies. This process was repeated for thirteen selected variables (Table 3.1) such that individual categories of variables each represented a reduced independent dataset. Further, to examine differences within levels of engagement in BJD control activities, those variables with roughly equal numbers of observations in each stratum were then sub-stratified. "Stated willingness to adopt BJD control programs" and "Stated willingness to adopt BJD vaccination" were further stratified by farmers' experience to elicit any differences in engagement due to the length of time in the dairy industry.

Within each of the 26 reduced datasets, outliers for herd size and annual production per cow were identified using the quartile method (Chapter 2.2.5). Observations with erroneously large values for annual milk production per cow (physiologically not plausible) were replaced with an imputed observation equal to the reported 2017/2018 mean for Victorian dairies (Dairy Australia, 2018). Outliers and imputed observations were included in the calculation of means and standard deviations of herd size and annual milk production per cow within each reduced dataset. For the purposes of simulation, standard deviations for herd size were then adjusted to 10% of the mean herd-size.

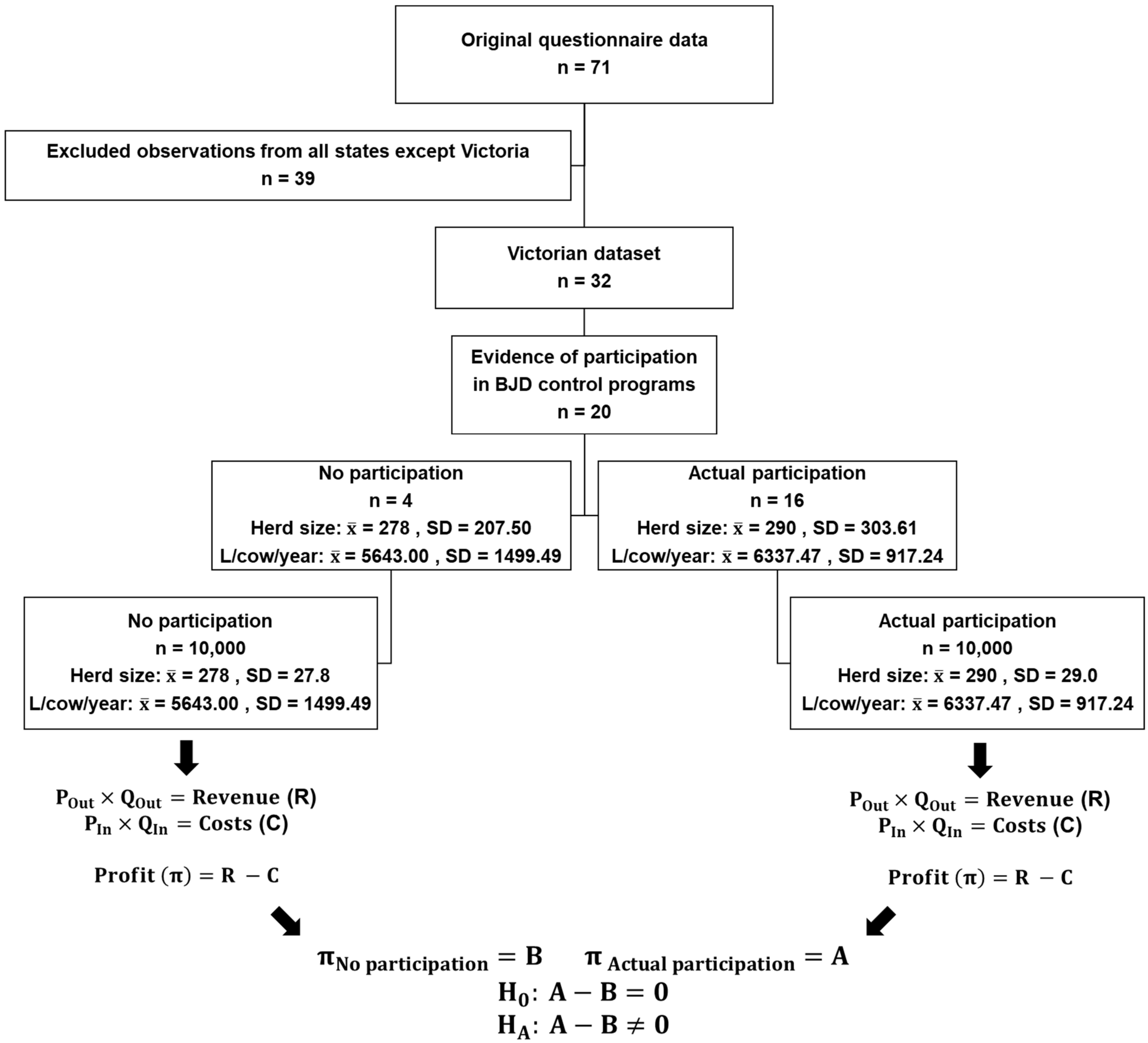

Figure 3.1 Flow chart demonstrating participant selection and sequence followed to estimating farm profitability

Table 3.1 Mean (+/- SD) herd-size and annual milk production per cow by select characteristics and different levels of engagement in BJD control activities of Australian dairy farmers

Category			Herd size (cows ≥1st lactation)		Annual milk production/cow (L)	
	n	(%)	Mean	Standard deviation	Mean	Standard deviation
Biosecurity						
Low biosecurity	24	85.71	305.75	246.73	6306.17	1028.73
High biosecurity	4	14.29	220.50	216.89	6518.69	550.22
BJD Herd Status						
Negative	18	69.23	267.22	153.13	6194.56	1145.05
Positive	8	30.77	351.25	396.33	6513.91	498.68
Motivation for Dairy Farming						
Not profit motivated	11	61.11	276.36	166.40	6045.09	1192.61
Profit motivated	7	38.89	178.57	125.92	6221.09	506.73
Level of Engagement in BJD Control Programs						
Unfavorable attitude	13	61.90	289.62	323.96	6265.72	1045.97
Favorable attitude	8	38.10	294.38	192.44	6073.65	1042.83
Not willing to accept	6	28.57	194.17	129.94	6197.56	938.07
Stated willingness to accept	15	71.43	330.33	311.09	6190.55	1086.40
Not willing to adopt	9	42.86	240.56	155.57	6105.52	1193.89
Stated willingness to adopt	12	57.14	329.58	341.70	6257.83	924.49
Not willing to pay	14	70.00	322.14	315.51	6277.48	1155.82
Stated willingness to pay	6	30.00	185.00	141.42	5959.81	785.85
No participation	4	20.00	278.00	207.50	5643.00	1499.49
Actual participation	16	80.00	289.88	303.61	6337.47	917.24
Level of Engagement in BJD Vaccination						
Unfavorable attitude	13	68.42	211.15	150.90	6174.88	1042.17
Favorable attitude	6	31.58	295.83	169.89	5965.95	1105.43
Not willing to accept	10	52.63	252.80	143.55	6125.45	1178.40
Stated willingness to accept	9	47.37	221.33	179.18	6090.52	923.25
Not willing to adopt	9	47.37	271.11	139.32	6242.92	1186.15
Stated willingness to adopt	10	52.63	208.00	174.12	5988.29	928.54
Not willing to pay	9	52.94	244.44	134.45	6451.26	1102.25
Stated willingness to pay	8	47.06	208.13	177.02	5644.54	972.53
No participation	12	66.67	206.08	143.38	5921.90	1266.06
Actual participation	6	33.33	279.50	190.21	6489.06	283.71

3.2.2 **Simulation**

The profit model in this study followed the format used in the Dairy Farm Monitor Project (DFMP) for Victoria from 2012 to 2018. The DFMP report provides aggregated farm-level data concerning costs and revenues of dairy production for 75 dairy farms across the three key Victorian dairy areas of Murray region, south-western Victoria, and Gippsland. Categories of cost and revenue referenced to milk production are presented in Table 3.3 (DFMP, 2018).

Reference values presented in dollars per kilogram of milk solids ($/kgMS) as per the DFMP report were converted to dollars per litre of milk ($/L) using a conversion factor calculated for each year. Conversion factors were calculated by taking the average quotient of Victorian farmgate milk prices represented by $/kgMS and $/L (Dairy Australia, 2018[b]). Means (±SD) of reference values for cost and revenue categories were derived using the values from DFMP reports 2012 – 2018.

Table 3.2 Average farmgate milk prices received by dairy farmers in Victoria, Australia during the period 2012 - 2018

Units	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Average
Dollars per kilogram of milk solids ($/kgMS)	5.05	6.81	6.24	5.68	5.04	5.87	5.76
Dollars per litre ($/L)	0.38	0.51	0.47	0.43	0.38	0.44	0.43
Quotient (L/kgMS)	13.36	13.35	13.25	13.27	13.26	13.28	13.30

(Adapted from Dairy Australia, 2018)

Herd size and annual milk production per cow were defined as inputs in @RISK and their means and standard deviations used to simulate total farm milk production for 10,000 Victorian dairy farms within each stratum. The minimum herd size generated by the simulation model was constrained to 60 cows as this was deemed to represent the minimum feasible number of lactating cows in a commercial dairy enterprise in Australia.

Similarly, each of the references for cost and revenue categories was defined as an input for the model and multiplied by total farm milk production to estimate the costs and revenues for each of the 10,000 farms.

Table 3.3 Mean reference values used to calculate total revenue and total costs relative to milk production on dairy farms in Victoria, Australia (2012 - 2018)

Category	$/kgMS of milk sold		$/Litre of milk sold	
	Mean	SD	Mean	SD
Revenue				
Milk sales (net)	5.668	0.698	0.426	0.052
Livestock trading profit	0.493	0.103	0.037	0.008
Other farm revenue	0.082	0.022	0.006	0.002
Costs				
Herd costs	0.287	0.014	0.022	0.001
Shed costs	0.208	0.013	0.016	0.001
Total feed costs	2.812	0.278	0.211	0.021
Employed labor	0.492	0.044	0.037	0.003
Repairs and Maintenance	0.325	0.014	0.024	0.001
Imputed owner/operator and family labor	0.803	0.079	0.060	0.006
Depreciation	0.223	0.021	0.017	0.002
All other overheads	0.262	0.016	0.020	0.001

(Adapted from DFMP 2012 – 2018)
Livestock trading profit = changes in number and value of livestock; Other farm revenue = dividends, interest, rent; Herd costs = artificial insemination, herd milk recording, animal health, calf rearing; Shed costs = Milking infra-structure and equipment; Total feed costs = grown, purchased, water + feed inventory change

Correlations between input variables in the model were defined prior to simulation and calculated using data obtained from all Australian states in the questionnaire. Pearson correlation coefficients were calculated in Stata 15.0 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC) and are represented below in Table 3.4.

Table 3.4 Matrix of correlations between input variables included in the @RISK model simulating profit of dairy farms in Victoria, Australia

	Herd size	Herd costs	Annual production per cow
Herd size	1.0000	0.1706	-0.0749
Herd costs	0.1706	1.0000	0.1414
Annual production per cow	-0.0749	0.1414	1.0000

Adhering to these simulation model specifications, revenue from milk sales was calculated as the product of annual production per cow, herd size, and the reference value for Victorian farmgate milk price (net after subtraction of compulsory levies and charges). Likewise, revenue from changes in the number and value of livestock, dividends, interest, rent, interest payments received, and rental of farm dwellings was calculated as the product of the reference value for the category of revenue and total annual farm milk production. Total revenue was calculated as the sum of all categories of revenue.

Similarly, variable costs were calculated and included costs incurred due to artificial insemination (AI), herd milk recording, animal health, calf rearing, milking equipment, and all feed costs. Overhead costs included both imputed and employed labor, repairs and maintenance, depreciation, and all other cash costs to the business. Total costs were calculated as the sum of variable and overhead costs.

Farm profit was calculated as the difference between total revenue and total costs as per definitions above. Farm profit is also referred to as Earnings Before Interest and Tax (EBIT) in the DFMP as this is income prior to payment of lease and interest costs. Values for farm profit were then divided by herd size to generate a value for "profit per cow" as the economic unit for comparison with all values in Australian dollars.

Values of profit per cow simulated for farms within the strata of each variable were plotted as independent distributions on the same axes. The left tails of distributions were truncated such that farms with negative profit per cow are not shown but are still included in the calculation of the mean profit per cow for the stratum. Two-sided, heteroscedastic t-tests were conducted to determine any statistically significant differences in mean profit per cow between strata.

3.3 **Results**

Table 3.5 Select characteristics of dairy farmers in Victoria, Australia included in a profit simulation model compared with the population of all dairy farmers in Victoria Australia

Variable	Sample (Victoria, Australia)	Population (Victoria, Australia)	p-value
Mean Time in Dairy Industry (years)	30.06	20.00 [3]	0.0171*
Mean Total Farm Size (Ha)	223.00	246.00 [3]	0.2756
Mean Herd size (cows ≥ 1st lactation)	286.33	258.95 [1]	0.2637
Mean Annual Milk Production/cow (L)	6331.10	6072.00 [1]	0.1003
Percentage Holstein/Friesian in Herd (%)	53.33	77.00 [2]	0.0081**
Closed Herds (%)	14.29	45.00 [1]	0.0000***
Introduced cattle assessed for BJD (%)	70.83	77.00 [2]	0.2609
JD Herd Prevalence (%)	30.77	28.57 [4]	0.8136
Annual profit per cow	395.17	380.01 [5]	0.0035**

(***p<0.001; **p<0.01; *p<0.05)
([1] Dairy Australia, 2018; [2] Condron, 2016; [3] Cockfield, 2016; [4] Jubb, 2004; [5] Simulated based on industry reference data)

Study participants from Victoria had spent a significantly longer time in the industry (30.06 years) compared to the overall population of dairy farmers in Victoria having spent only 20.00 years (p<0.05). The composition of herds in the study sample (53.33% Holstein/Friesian) differed significantly from the population with sample herds having 77.00% Holstein/Friesian cattle (p<0.01). The study sample had a significantly lower proportion of closed herds (14.29%) than the population figure of 45.00% (p<0.001). There were no statistically significant differences in variables contributing to the calculation of farm profitability (herd size, annual milk production per cow). However, the profit per cow in sampled herds ($395.17) differed significantly from the $380.01 per cow in the population (p<0.01).

Table 3.6 Differences in profit per cow on dairy farms in Victoria, Australia by levels of engagement in BJD control activities and farm characteristics

Variable	Mean profit ($/cow)	Difference in annual profit per cow between each stratum and sample means ($/cow)	p-value	Difference in annual profit per cow between strata means ($/cow)	p-value
Biosecurity					
Low biosecurity	393.09	-2.08	0.6924	14.75	0.0053****
High biosecurity	407.83	12.67	0.0172		
BJD Herd Status					
Negative	387.40	-7.77	0.1390	19.82	0.0002****
Positive	407.22	12.05	0.0231		
Motivation for Dairy Farming					
Not profit motivated	377.55	-17.62	0.0007	11.20	0.0267**
Profit motivated	388.75	-6.42	0.2146		
Level of Engagement in BJD Control Programs					
Unfavorable attitude	392.18	-2.99	0.5699	-12.40	0.0160**
Favorable attitude	379.77	-15.39	0.0030		
Not willing to accept	387.81	-7.35	0.1584	-0.54	0.9157
Stated willingness to accept	387.27	-7.90	0.1301		
Not willing to adopt	381.49	-13.68	0.0087	9.57	0.0637*
Stated willingness to adopt	391.06	-4.10	0.4337		
Not willing to pay	392.31	-2.86	0.5881	-20.22	0.0001****
Stated willingness to pay	372.09	-23.08	0.0000		
No participation	352.57	-42.60	0.0000	43.80	0.0000****
Actual participation	396.37	1.20	0.8196		

(****p<0.001; ***p<0.01; **p<0.05; * p<0.1)

Farms with a high level of biosecurity showed $14.75 more profit per cow than those farms with a lower level (p<0.01). Herds likely positive for BJD were $19.82 more profitable per cow than those likely negative (p<0.001). Similarly, dairy farmers stating profit as a primary motivation for being involved in the dairy industry had cows $11.20 more profitable than cows in the herds of farmers motivated by other factors (p<0.05). Farmers with favorable attitudes toward BJD control programs were $12.40 per cow less profitable than farmers with unfavorable attitudes (p<0.05). Similarly, farmers with favorable attitudes toward BJD vaccination were $13.27 per cow less profitable than those with a favorable attitude (p<0.01).

Table 3.6 Differences in profit per cow on dairy farms in Victoria, Australia by levels of engagement in BJD control activities and farm characteristics (continued)

Variable	Mean profit ($/cow)	Difference in annual profit per cow between each stratum and sample means ($/cow)	p-value	Difference in annual profit per cow between strata means ($/cow)	p-value
Level of Engagement in BJD Vaccination					
Unfavorable attitude	386.08	-9.08	0.0822	-13.27	0.0093***
Favorable attitude	372.82	-22.35	0.0000		
Not willing to accept	382.40	-12.77	0.0146	-1.40	0.7846
Stated willingness to accept	381.00	-14.16	0.0062		
Not willing to adopt	390.12	-5.05	0.3383	-15.89	0.0019***
Stated willingness to adopt	374.24	-20.93	0.0000		
Not willing to pay	403.02	7.85	0.1417	-49.41	0.0000****
Stated willingness to pay	353.61	-41.56	0.0000		
No participation	369.89	-25.28	0.0000	35.84	0.0000****
Actual participation	405.73	10.56	0.0456		

(****p<0.001; ***p<0.01; **p<0.05; * p<0.1)

Categories of both the variables willingness to accept BJD control programs and willingness to accept BJD vaccination revealed no significant differences in profitability per cow. Farmers with stated willingness to adopt BJD control programs were $9.57 per cow more profitable (p<0.1) than those not willing to adopt. This differs from farmers with stated willingness to adopt BJD vaccination being $15.89 per cow less profitable than those not willing to adopt (p<0.01). Sub-stratification of willingness to adopt by farmers' experience revealed very similar outcomes to the original strata. Noteworthy, among farmers with less experience the difference in profit per cow between those willing to adopt BJD control programs and those not willing becomes insignificant. Conversely, among less experienced farmers the reduced profit per cow among adopters of BJD vaccination relative to non-adopters becomes more significant (p<0.001) than observed in the original strata (p<0.01). Similarly, this is observed among those farmers with more experience.

Farmers with stated willingness to pay for BJD control programs and those with stated willingness to pay for BJD vaccination were respectively \$20.22 and \$49.41 per cow less profitable than farmers not willing to pay (p<0.0001).

Significant differences exist between farms with evidence of participation in BJD control activities and those that did not participate (p<0.0001). Participants in control programs were \$43.80/cow more profitable and participants in vaccination were \$35.84 than non-participants.

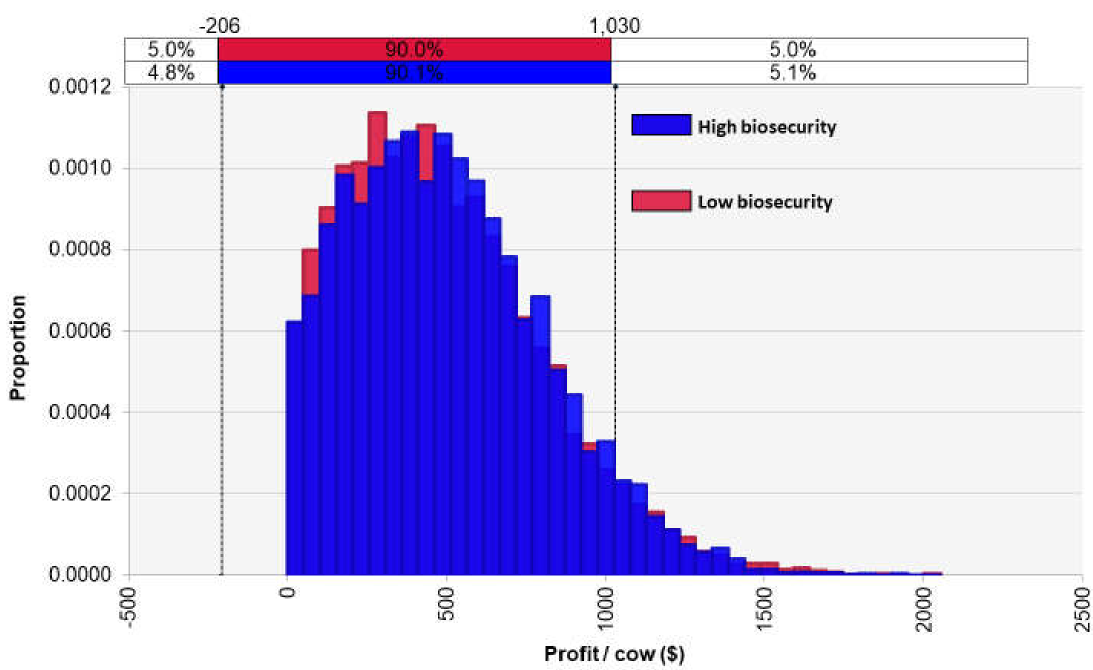

Figure 3.2 **Distribution of annual profit per cow on dairy farms in Victoria, Australia by levels of biosecurity**

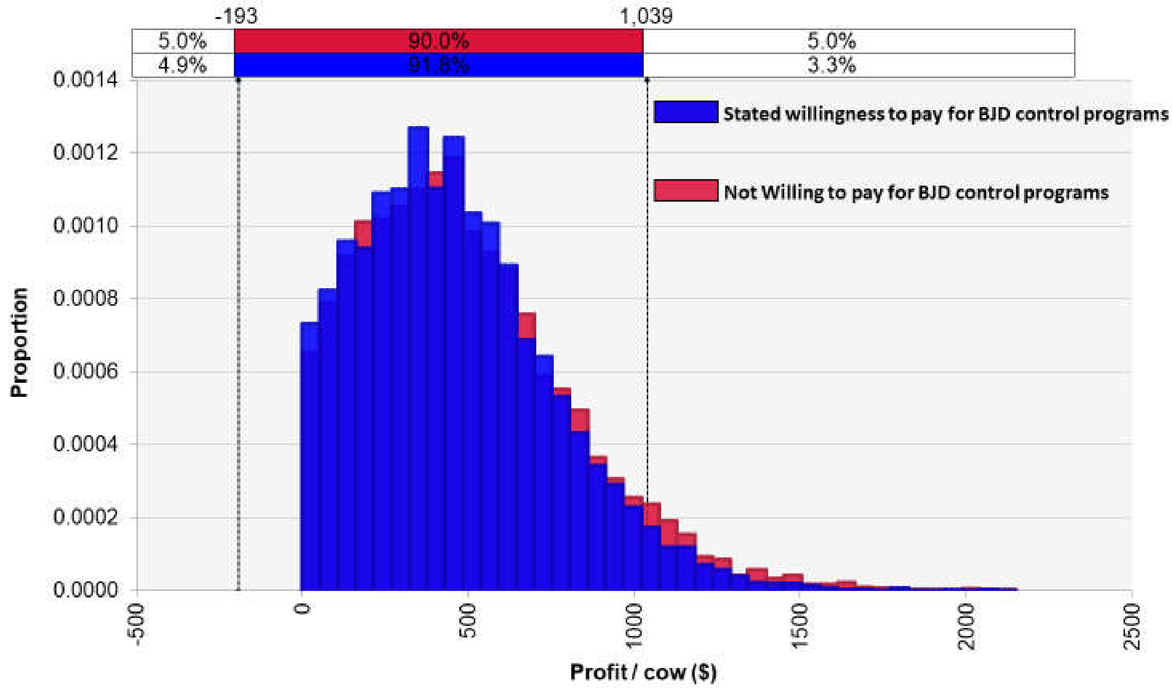

Figure 3.3 Distribution of annual profit per cow on dairy farms in Victoria, Australia by farmers' willingness to pay for BJD control programs

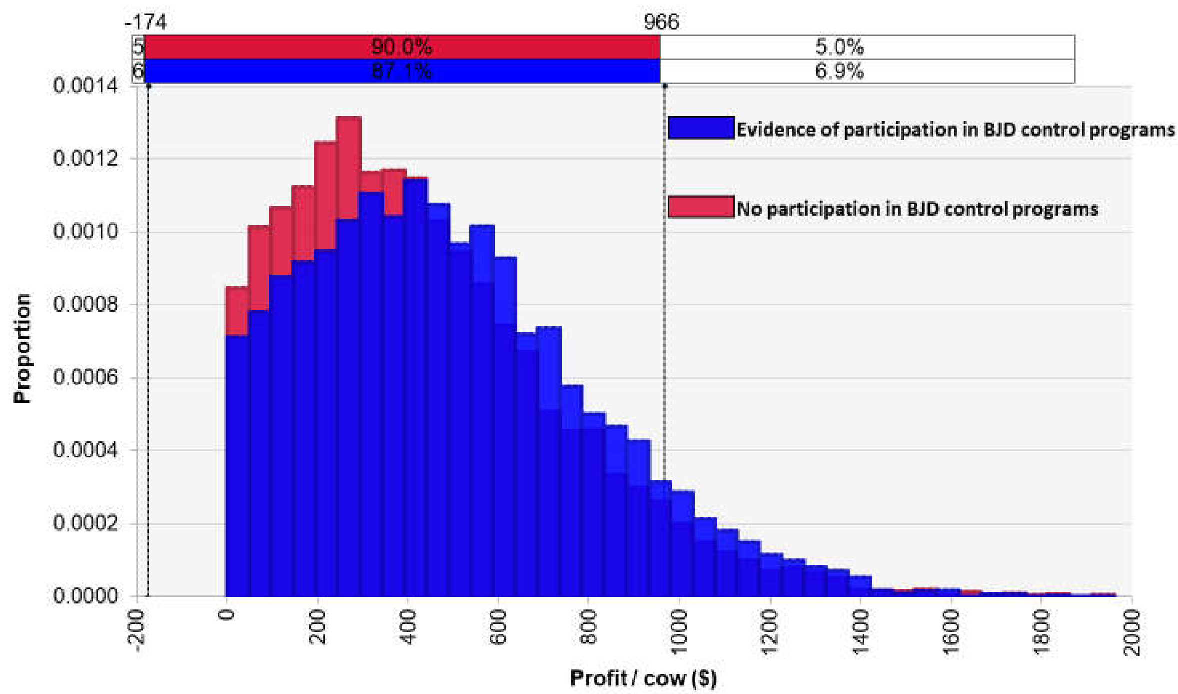

Figure 3.4 Distribution of annual profit per cow on dairy farms in Victoria, Australia by participation in BJD control programs

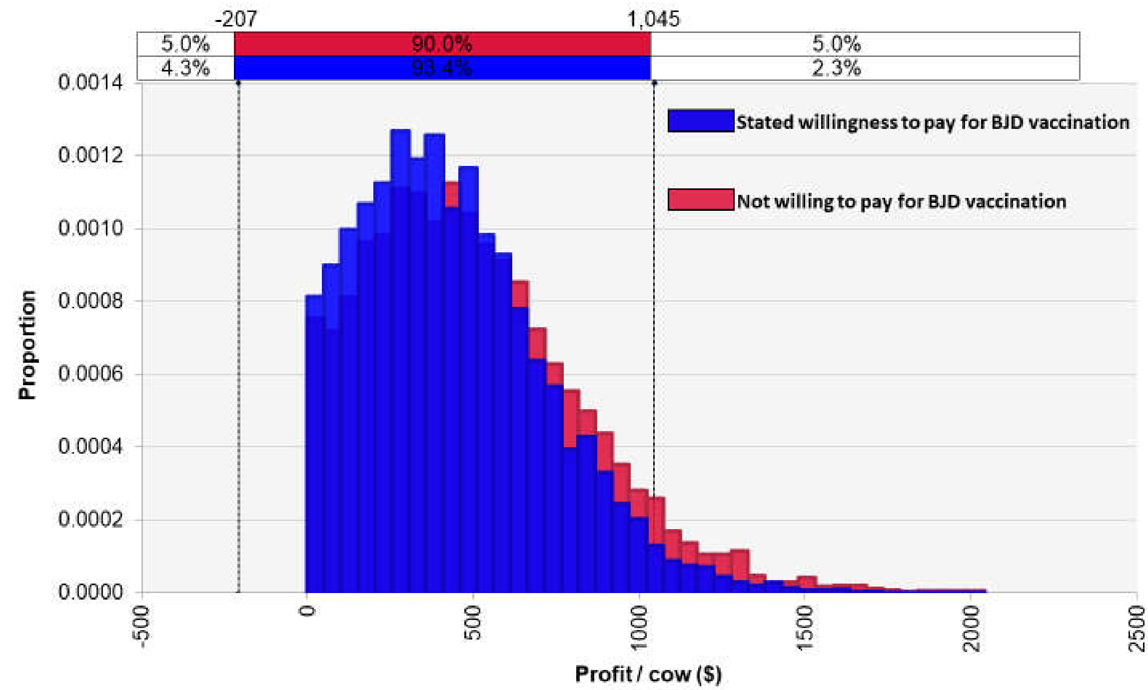

Figure 3.5 Distribution of annual profit per cow on dairy farms in Victoria, Australia by farmers' willingness to pay for BJD vaccination

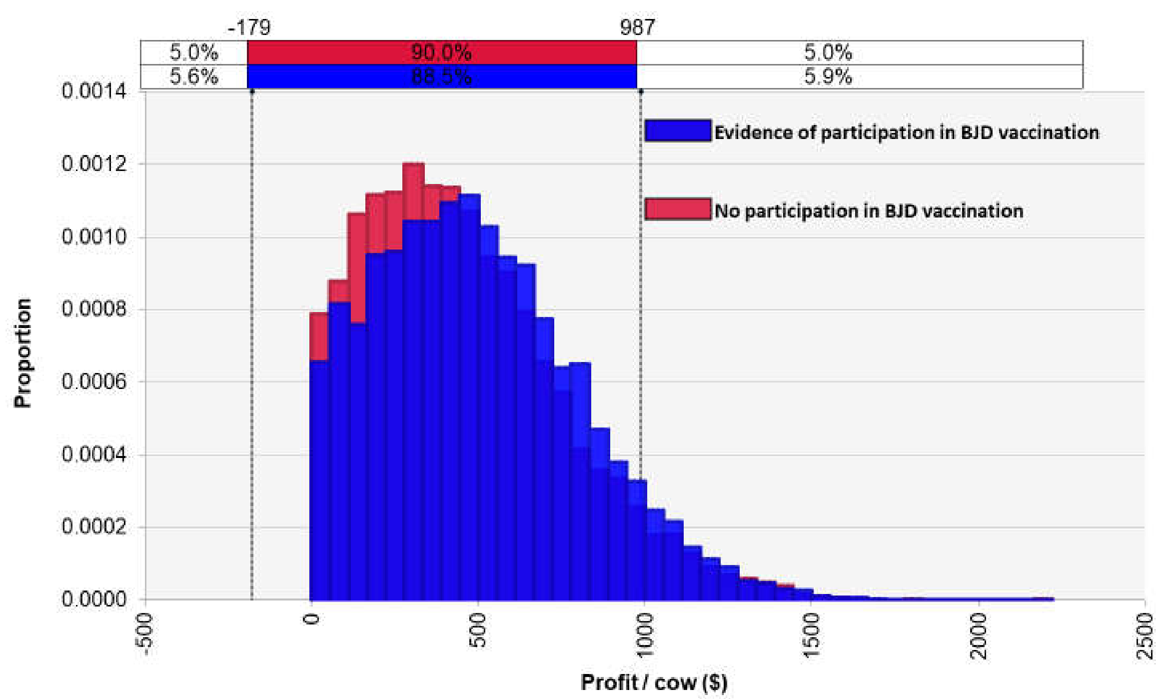

Figure 3.6 Distribution of annual profit per cow on dairy farms in Victoria, Australia by participation in BJD vaccination

Table 3.7 Differences in profit per cow on dairy farms in Victoria, Australia by willingness to adopt BJD control activities and sub-stratification by length of time farmers have spent in the dairy industry

Level of Experience	Level of Engagement	Mean profit ($/cow)	Difference in annual profit between stratum and sample means ($/cow)	p-value	Difference in annual profit between strata means ($/cow)	p-value
	BJD Control Programs					
≤20 years	Not willing to adopt	360.85	-34.32	0.0000	4.84	0.3374
	Stated willingness to adopt	365.69	-29.48	0.0000		
>20 years	Not willing to adopt	398.63	0.46	0.5120	10.44	0.0473**
	Stated willingness to adopt	409.07	13.90	0.0084		
	BJD Vaccination					
≤20 years	Not willing to adopt	362.18	-32.98	0.0000	-17.37	0.0004***
	Stated willingness to adopt	344.81	-50.36	0.0000		
>20 years	Not willing to adopt	413.60	18.44	0.0006	-18.84	0.0004***
	Stated willingness to adopt	394.76	-0.41	0.9378		

(***p<0.001; **p<0.01)

3.4 Discussion

Various studies investigating the economic impact of BJD have used simulation models to assist better decision making for producers and consultants (Collins, 1992; Dorshorst, 2006; Shephard, 2016; Smith, 2017). Aspects of these results support the hypothesis that farmers engaged in BJD control activities are more profitable than those not engaged. However, it is evident that profitability varies significantly by different levels of engagement.

Foremost, in support of the conceptual and theoretical models, it is evident that farmers motivated by profit are more profitable than farmers with other motivation for being in the dairy industry ($p<0.05$). Farmers motivated by profit achieve a profit per cow similar to the sample mean. However, a reduction of $17.62 profit per cow relative to the sample mean is seen among farmers not motivated by profit ($p<0.001$).

Farmers with evidence of participation in BJD control programs have a profit per cow of \$396.37 compared to non-participants with a mean of \$352.57. Although the difference in profit is a significant \$43.80 per cow more for participants than non-participants ($p<0.0001$), this does not translate into significantly more profit relative to the sample mean. This is potentially a result of farmers previously choosing to vaccinate against BJD most likely being part of a control program to establish herd status. Profitability among non-participants however, was reduced by \$42.60 relative to the sample mean ($p<0.0001$). This may also be explained that this group of farmers have never been engaged in any form of BJD control.

Similarly, farmers participating in BJD vaccination were \$35.84 more profitable than those who had never used the vaccine ($p<0.0001$). In contrast to BJD control programs, herds using a BJD vaccine were seen to be significantly more profitable per cow with an additional \$10.56 relative to the sample mean ($p<0.05$). For non-participants, there is a reduction of \$25.28 profit per cow relative to the sample mean ($p<0.0001$). Albeit significant, the difference is not as large as that observed among BJD control program participants and non-participants.

Figures 2 – 6 show extensive overlaying of the profitability distributions representing levels of engagement in BJD control activities. At higher levels of profit (+3-4 SDs from the mean), the overlay between distributions is reduced as there are fewer farmers within this range. The truncated left tails preclude any judgement on losses due to engagement in BJD control. However, truncation represents a more realistic scenario as farmers making a significant loss are unlikely to remain in the industry.

The economic benefits of participation in BJD control programs in this study are consistent with previous findings in Victorian dairy farms by Shephard *et al*. (2016) and also with findings in Canadian dairies by Wolf *et al*. (2014). In addition, the simulation model used by Shephard et al. (2016) suggests vaccination is a cost-effective means of BJD control.

Most notable is the profit reduction relative to the sample mean for farmers willing to pay for BJD control programs and vaccination. This seems counter-intuitive as one would assume that farmers willing to pay for activities would most likely have used the vaccine and seen the aforementioned benefits. However, this could also be due to farmers stating willingness to pay for BJD control due to being severely impacted economically by the disease and seeing value in active participation in forms of control not previously used.

Numerous results suggest higher profit among farmers not engaged in BJD control activities. This anomaly may be explained by frustration farmers are known to experience with BJD control programs and vaccination (AHA, 2015c). It is plausible that farmers with unfavorable attitudes previously voluntarily or involuntarily participated in BJD control activities such as test-and cull and experienced negative outcomes.

As previously described, the risk reduction approach taken as part of BJD control activities confers protection against several other diseases impacting animal health (Barkema, 2018; Dairy Australia, 2008[a]). Despite any potential unintended consequences due to participation, mitigation measures such as removal of infected animals and improved biosecurity are likely to have been exercised with perpetual benefits. In support of the explanation for the anomalous findings above, farmers with higher levels of biosecurity are more profitable than those with low levels ($p<0.01$).

Selection bias

Table 3.5 illustrates significant differences between the study sample and the overall population. Despite similar herd sizes and annual milk production per cow, the higher profit per cow in the study sample compared to the population seem anomalous and invite a closer look at the simulation model. Thus, the simulated values for profit per cow within each stratum (Table 3.6) are possibly an overestimation of the profitability of these population sub-groups.

Participants in the study had spent a significantly longer time in the dairy industry than the average Victorian dairy farmer ($p<0.05$). This suggests that participants are likely to be better dairy farmers and thus demonstrate higher profits per cow. Similarly, due to more experience in the industry participants are likely to have experienced the many changes in approach to BJD control in Australia over the past 20 years. Many farmers have expressed frustration with BJD control policies and programs over the years which potentially explains why some farmers have participated in BJD control activities yet do not accept the principles behind them (AHA, 2015c).

Another significant difference is the increased number of herds in the study sample with cross-bred and Jersey cows as the predominant breed relative to the overall population where Holstein/Friesian herds predominate ($p<0.01$). Inadvertent selection of herds with smaller framed animals having fewer nutritional requirements for maintenance and subsequently improved production efficiency may have biased profit estimates upwards. In addition, the composition of milk from different breeds varies significantly and as such influence the price farmers are paid for their milk. Offsetting this potential bias was attempted by using the average price of milk in Victoria from 2012 - 2018 converted to dollars per kilogram ($/L) rather than dollars per kilogram of milk solids ($/kgMS). Differences in breed predisposition to MAP have been reported where Channel Island breeds are more susceptible to infection (McAloon, 2019; Sorge, 2011). However, the herd-prevalence of BJD in the sample compared to the population is not significantly different.

Chance

Stratification of observations reduces effective sample size, even more so when sub-strata are further defined. The resulting small numbers of observations used to calculate means and standard deviations make calculations more prone to error. Mean herd sizes across all strata varied from farms with 179 – 330 cows having had one lactation or more, with standard deviations frequently larger than the mean. Adjustment of standard deviations based on judgement and experience helped reduce excessively unrealistic variation in simulated herds. A large number of iterations (10,000 farms) subsequently increased the power of the model and allows for cautious conclusions to be drawn. Furthermore, correlations among variables were included to ensure covariation was captured adequately.

Generalizability

This study only included herds from Victoria, Australia and thus caution needs to be exercised when extrapolating these results to other states in Australia. Differences in regulatory policy, control programs, vaccine registration, BJD prevalence, and milk pricing structures exist from state to state which has the potential to significantly influence farmers' engagement in control activities and farm profitability. However, as a model for BJD control, this study serves the Australian dairy industry appropriately as 67.86% of all dairy farms are in Victoria (Dairy Australia, 2018), which also has a historically higher prevalence of BJD.

The study is appropriately designed to generalize to countries with similar production systems, regulatory environments, and market conditions. Extrapolation to Canada, for example, would be unreasonable owing to the supply management system governing milk prices as opposed to a free market in Australia. Milk prices received by Canadian dairy farmers are among the highest globally and have been approximately 33% higher than Australia over the past 10 years (Dairy Australia, 2018). It would be interesting to compare the profitability of dairy farms in Australia prior to the deregulation of milk production with current performance to allow for more informed comparison with supply-managed markets.

The practice of housing cattle because of the harsher climate in Canada changes MAP infection and spread on dairy farms by comparison with the warmer, primarily pasture-based systems in Australia. Pasture as the main source of feed in Australia also presents a very different cost structure compared to predominantly processed feed being used in Canadian systems. Other differences in costs may be experienced due to the challenge from other diseases which differ according to husbandry practices and climatic conditions.

Major differences in costs and revenue structures pose an obvious barrier to generalization. However, significant variations in profit per cow by levels of engagement in BJD control warrants further investigation under different market and disease conditions.

Strengths

To the best of my knowledge, this is the first study looking at the differences in dairy cow performance across farmers with different levels of engagement in BJD control activities in addition to differences due to actual participation. This study is based on actual participant data capturing preferences and behavior of farmers in their approach to BJD control. The assumptions from multiple sequential DFMP reports used to capture the cost and revenue structure offers a realistic framework on which to base simulation inputs (Shephard, 2016). Correlation of input variables based on observed data offers further complexity to the factors influencing farm profit.

The use of simulation modelling to rapidly explore various scenarios affecting farm profitability allows insight into the economic implications of various control methods. The ability to explore scenarios using many iterations provides for a more robust statistical analysis with higher levels of significance compared to smaller samples of collected data.

As one of the few countries globally with a registered vaccine available for BJD, since 2016 Victorian dairy farms positive for BJD have had access to a government subsidy of $12.50 per dose for use of the vaccine (Agriculture Victoria, 2016b). This provides an ideal platform whereby additional control options are available to producers relative to countries still considering registration of the vaccine and formulation of supporting policy.

Limitations

Only observations from dairy farms in Victoria, Australia were included in this study making generalization to other states and countries difficult. The small number of stratified observations used to generate the inputs for the simulation model reduces the power of within-stratum estimates. Thus, despite the large sample sizes generated by simulation, there remains the possibility of type 1 errors disguised by an artificially increased sample size.

This study effectively describes differences in farm profitability due to milk production and reports profit synonymous with Earnings Before Interest and Tax (EBIT). However, it does not account for differences in interest and lease costs across farms. A sensitivity analysis would be required to identify variables most influential to the outcomes of the model.

Reference values for the cost and revenue structure employed by DFMP is calculated based on 75 model farms and is not necessarily representative of the entire state of Victoria. Noteworthy is the mean herd size of 352 for the 2017/2018 DFMP compared to the population mean of 259 cows, a figure not different from the sample mean of 286 ($P>0.2$). The DFMP describes fixed costs as a percentage of production which implies that fixed costs vary proportionately to herd size which is not necessarily accurate.

The simulation model only explores differences in profit by levels of a single variable at a time and does not account for other influencing factors such as BJD prevalence within herds, costs due to control activities, other diseases, herd structure, or other herd management practices in place.

The BJD vaccine subsidy currently available which covers approximately 50% of the vaccine costs also poses a study limitation as farmers are not responsible for the full costs associated with participation. The subsidy is available until 31 December 2019 and its cessation is likely to reflect as decreased use of the vaccine. The cross-sectional nature of these data prevents any inference of causality or determination of risk as the performance of herds before and after engagement in BJD control cannot be determined. Studies of comparative statics need to be conducted to investigate the effect of such shocks and changes to the outcome of the model.

Knowledge to action

From an industry perspective, reduced losses due to BJD and improved market access are very tangible benefits of control programs (Caldow, 2005; Citer, 2007; Hoogendam, 2009; Kennedy, 2000; McKenna, 2006; Rogers, 2012). Control programs have a positive impact on producer awareness of BJD and potential impacts on the dairy industry (Citer, 2007; Citer, 2009). However, to garner support from farmers and justify expenses incurred by control programs, the benefits of programs need to be realized, especially in commercial dairy herds where benefits are less tangible than for stud breeders (Brett, 1995; Garcia, 2015; McAloon, 2017). Aside from costs due to regulatory conditions, cost-benefit analyses suggest that infected Australian dairy herds engaging in BJD control can be financially justified where clinical disease is significantly reduced at a cost of less than AUD$50/cow/year (Shephard, 2014a). Various studies have shown economic benefit to dairy farmers controlling BJD, however, this benefit is mostly seen over the longer term (Cho, 2013; Rasmussen, 2018; Shephard, 2016).

Despite the inability of current vaccines to completely prevent infection, the decreased shedding of MAP and reduction of clinical BJD cases makes vaccination in endemic herds a useful tool to reduce environmental contamination and minimize production losses (Bastida, 2011; Caldow, 2005). Provided vaccination is cost-effective over the long term and complements existing BJD and TB control frameworks, acceptance as a tool to control BJD could be enhanced. This would be most beneficial on high prevalence farms provided farmers do not forego other best management practices in lieu of a misplaced reliance solely on vaccination (Brett, 1995; Garcia, 2015; Groenendaal, 2014; McKenna, 2006a; Shephard, 2016).

3.5 **Conclusion**

The benefits of partaking in BJD control activities have been highlighted with participants in BJD control programs standing to gain an additional $43.80/cow/year compared to non-participants. The $35.84/cow/year that farmers using a BJD vaccine stand to gain is substantial compared to non-users, especially since this represents $10.56/cow/year over and above the average producer in the industry. However, it is evident that there is a barrier between farmers intentions to participate and actual participation in BJD control activities.

These significant profitability differences realized by farms using different approaches to BJD control offer a starting point from which to explore questions of how much farmers would be willing to pay for BJD control activities, why they are willing to pay, and the likelihood of acting. Communication of the benefits of participation needs to be better communicated to bridge this gap between farmers intentions and their actions (Wolf, 2014a).

Chapter 4 Synthesis, Policy options, and Recommendations

4.1 Synopsis of key findings

The benefit of increased farm profitability among farmers participating in BJD control activities has been described in Chapter 3. Despite the economic benefits, findings from Chapter 2 reveal the complexity of factors influencing the level of engagement in control activities. As described in Chapter 1, the underrepresentation of literature on the role of vaccination and regulatory policy in BJD control warrants further investigation. Regulatory policy and the availability of a vaccine in Australia represent two key differences in the approach to BJD control relative to Canada. These two factors are closely linked as registration of a vaccine requires a policy environment supportive of its use as a control strategy.

One of the principal reasons for agricultural sectors requiring governance through policy is a market failure. Market failure implies the allocation of goods and services are not efficient to the extent that one or more agents suffer significant losses in welfare. Furthermore, a policy is a framework of rules and standards to guide stakeholder behaviour. The concept of policy as a safety net is that certain instruments such as regulations to quarantine BJD infected farms or price floors are incorporated to protect producers from market shocks. Ideally, such instruments are not invoked on a normal basis and are no longer necessary once the market has adjusted to shocks (Hall, 2019).

Using Australia as a model to explore the role of policy and vaccination has its merits as it represents a country with a history of regulatory control policy, evolving control programs, and availability of a vaccine for BJD control. However, the formulation of policy is relative to industry characteristics and market dynamics and as such may not be applicable in other settings. Table 4.1 outlines some differences in characteristics between the Australian and Canadian dairy industries.

Table 4.1 Dairy industry characteristics in Australia and Canada (2016)

Characteristic	**Australia**	**Canada**
Number of dairy cows (million cows)	1.66 [a]	0.96 [f]
Number of dairy farms	6,102.00 [a]	11,280.00 [f]
Volume of milk produced annually (billion L)	9.54 [a]	8.47 [b]
Average herd size (cows ≥ 1st lactation)	273 [e]	85 [e]
Average annual milk production per farm (million L)	1.56 [e]	0.75 [e]
Average annual milk production per cow (L)	5,736.02 [e]	8,831.20 [e]
Average farmgate milk price (CAD$/L)	0.44 [a]	0.78 [c]
Predominant production system	Pasture-based	Free-stall / Tie-stall barns
Supply management system	No	Yes
Exported dairy products	Cheese, whole milk powder, skim milk powder, infant formula, butter, butter oil, whey products, liquid milk [a]	Skim milk powder, cheese, whey products, yoghurt [b]
Main destinations for exported dairy products	China, Japan [a]	USA, Egypt, Philippines [b]
Genetics and live dairy cattle exports	Yes [a]	Yes [b]
Main destinations for exported genetics and dairy cattle	China, Pakistan, Indonesia [d]	USA, Republic of Korea, Columbia, Netherlands, Brazil Australia, Japan, Germany [b]

All figures pertain to the 2016 calendar year
([a] Dairy Australia, 2016; [b] AAFC, 2016; [c] PLQ, 2016; [d] Livecorp, 2017; [e] Derived; [f] CDC, 2016)

Key differences include the greater number of farms, smaller average herd sizes, and annual production per cow 54% greater in the Canadian dairy industry relative to Australia. Housing systems employed in Canada compared to the predominantly pasture-based systems in Australia highlight differences in husbandry and feeding practices. The farmgate milk price in Canada under a supply-managed system is 44.0% greater compared Australian prices under the free-market and represents one of the most significant differences (Dairy Australia, 2018).

Under supply management, a primary driver for dairy production in Canada is meeting domestic consumption. Although Canada remains a net importer of dairy products, from 2016 to 2017 there was a 10.0% decrease in imports and a 69.5% increase in exports. Canada also has an export market for reputable dairy genetics in the form of live cattle, embryos, and semen (AAFC, 2016). As a net exporter, Australia exports 69.9% of domestic dairy products which places it as the fourth largest exporter of dairy products after New Zealand, the European Union, and the United States (Dairy Australia, 2018). Australia also exports genetics, primarily in the form of dairy heifers to China (68.2%), Pakistan (12.8%), and Indonesia (4.6%) (Livecorp, 2017). Many trade partners receiving dairy produce and genetics from Australia require strict criteria for BJD testing to be met prior to shipping (AgForce, 2012).

Objectives of the former regulatory approach driven by the government in Australia included reducing the impact of clinical BJD and maintaining access to international markets through regulatory control imposed on farms tested positive for BJD. Failure of the regulatory approach to contain the spread of BJD in endemic areas prompted the move to risk-based trading in the higher prevalence dairy areas initially with later application to the whole of Australia under the current BJD framework. This has alleviated political debate associated with BJD control and helped facilitate trade especially within higher prevalence areas and has allowed other objectives to be achieved over time (Citer, 2009; Citer, 2012; Geraghty, 2014; Kennedy, 2005; Kennedy, 2012).

Despite producer frustrations toward the Australian regulatory approach (AHA, 2015c), findings in Chapter 2 show fewer farmers have favorable attitudes toward the current deregulated approach (21.2%) compared to a regulated approach (42.1%). However, finding that survey participants feel producers should take on the majority of responsibility for both BJD control programs (59.8%) and vaccination (53.3%) suggests producers want to be the ones driving BJD control. Similarly, it was felt that producers should bear much of the costs for BJD vaccination (50.6%). In contrast, it is of interest that participants felt that producers should bear less than half the costs (42.3%) associated with BJD control programs. Thus, despite producers wanting to be in charge of how BJD is controlled, relatively more financial input is expected from other stakeholders.

The industry-driven approach to BJD control during the former Canadian Johne's Disease Initiative had similar objectives to those of Australian control programs. However, differences include the stakeholders in charge of driving and funding BJD control, certain dairy industry characteristics, and industry performance at the time. Table 4.2 compares and contrasts industry performance relative to investment in BJD control in Australia and Canada. The notable difference in net trade of dairy products is due to the significant amount of processed dairy products exported from Australia which places is as the 4th largest exporter of dairy in the world (Dairy Australia, 2018).

Table 4.2 Economic indicators, value of dairy industry outputs, and BJD control program expenditure in Australia and Canada (2016)

Economic indicator	Australia	Canada
GDP (trillion $)	1.73 $_{a}$	2.02 $_{a}$
Value Added from Agriculture, Forestry and Fishing (billion $)	47.83 $_{a}$	32.80 $_{a}$
Market Value of Milk Production (billion $)	4.22 $_{b}$	6.61 $_{b}$
Net trade of dairy products (milk equivalent) (billion $)	1.25 $_{c}$	-0.40 $_{c}$
Annual expenditure on BJD control programs (million $)	1.67 $_{d}$	0.83 $_{e}$
Source of funding for BJD control	Industry levies $_{d}$	Public = 52% $_{e}$ Industry = 48% $_{e}$

All figures pertain to 2016 represented in Canadian dollars using the average exchange rate (World Bank, 2016) ([a] FAO, 2019; [b] Derived: Product of average farmgate milk price and total volume of milk produced in 2016; [c] FAO, 2018; [d] Kennedy, 2010; [e] Barker, 2013)

Table 4.3 outlines expenditure on BJD control in Australia and Canada relative to dairy farms and cattle as the economic units. Values for expenditure in Australia do not include additional funding from government or compensation paid out to farmers with properties under quarantine. Despite recipients of compensation primarily being beef farmers, it is estimated that total costs of the National Johne's Disease Management Plan up until 2015 were in excess of $80 million (AHA 2015c).

Dairy cows in Canada contribute 2.7[2] times more to the market value of milk production and GDP than dairy cows in Australia. However, for every dollar of milk production value, investment in BJD control in Australia is 3.3[3] times greater the investment in Canada. Furthermore, milk production from dairy cows in Canada contributes 20.1% to the aggregate agricultural sector compared to 8.6% in Australia yet BJD control expenditure per cow is 15.2%[4] less in Canada.

Table 4.3 Derived economic indices showing the relative contribution to investment in BJD control in Australia and Canada (2016)

Index	Australia	Canada
Contribution of Agriculture, Forestry, and Fishing to GDP (%)	2.77	1.62
Contribution of milk production to GDP (%)	0.24	0.33
Contribution of milk production to agriculture, forestry, and fishing (%) [5]	8.56	20.14
Contribution of dairy product exports to market value of milk production (%)	69.88	3.56
Contribution per farm to market value of milk production ($)	691,465.60	585,691.49
Control program expenditure per farm ($/farm)	274.45	73.14
Contribution per cow to market value of milk production ($)	2,537.18	6,888.33
Control program expenditure per cow ($/cow)	1.01	0.87
BJD control investment ratio	0.0004	0.0001

2 Contribution per cow to market value of milk production ($):$6888.33 (Canada) ÷ $2,537.18 (Australia)= 2.71

3 BJD control investment ratio = Control program expenditure ÷ Contribution to market value of milk production)

4 Control program expenditure per cow ($/cow): Australia = $1.0[1] ; Canada = $0.87; $\frac{\$1.01 - \$0.87}{\$0.87} \times \frac{100}{1} = 15.19\%$

5 Contribution of milk production to agriculture, forestry, and fishing (%) = Market Value of Milk Production (billion $) ÷ Value Added from Agriculture, Forestry and Fishing (billion $) x $\frac{100}{1}$

4.2 BJD Control Policy Formulation

This section outlines a sequential process for the formulation of policy options to control BJD. Starting with the identification of stakeholders impacted by BJD, a statement of their position regarding BJD control is then established followed by the factors impacted by BJD. Subsequently, identification of the market failure pertaining to engagement in BJD control is necessary for the ultimate proposition of different policy options in Canada with associated implications (Table 4.4).

Option One refers to a policy environment synonymous with the current approach (*status quo*) in Canada. This is characterised by a framework for BJD risk assessment as part of the biosecurity module of proAction. Hereby, the onus is on producers and veterinarians to take action as deemed necessary to mitigate BJD risk including management of stock movement and calf hygiene.

Option Two differs from Option One by the addition of a vaccine available for producers to use as a voluntary BJD control tool.

Option Three builds on this by including voluntary herd testing and herd status system with compensation for testing and BJD-positive animals culled. Under this policy environment, regulatory control is imposed on farms with BJD-positive herds. This represents a policy environment similar to the former regulated approach to BJD control in Australia.

Finally, Option Four introduces mandatory herd testing and status program for producers compared to the voluntary program in Option Three.

4.2.1 Problems posed by bovine Johne’s disease

As described in chapter 1, BJD causes economic losses for dairy farms in the form of early culling, decreased milk production, mortality, and reduced fertility (McAloon, 2016; Tiwari, 2008). Trade restrictions imposed on producers with positive herds may contribute to economic loss at the farm level and also limits access to some international markets. Should the link between MAP and human health concerns become more widespread or causality become conclusive, countries with dairy industries showing a pro-active role in BJD management will have a competitive advantage globally (Wolf, 2014a).

4.2.1.1 Stakeholder: Consumers

Position: Steady supply of safe affordable dairy products.

Factors impacted:
- Potential human health risks (zoonosis)
- Vulnerability to inconsistent milk production

4.2.1.2 Stakeholder: Industry

Position: Keep healthy, productive animals that maintain or increase farm profitability.

Factors impacted:
- Health, reproduction, productivity of animals
- Production efficiency, risk to farm profitability, trade barriers
- Psychological and social effects
- Steady supply of milk for processors

4.2.1.3 Stakeholder: Government

Position: Maintain export markets and increase public confidence in the ability to control disease.

Factors impacted:
- Program costs, infrastructure for regulatory control measures
- Public confidence in government services
- Quality assurance provision for livestock exports

4.2.2 **Identification of the market failure**

The current market climate in Australia and Canada does not encourage producer participation in BJD control programs or vaccination. External factors such as weather events, the conglomeration of dairy processors, commodity pricing, policy environment, and attitudes toward industry influence allocation of resources accordingly. Disruptions to market equilibrium and inadequate incentives for participation further lowers the priority of BJD control.

The supply management system in the Canadian dairy industry offers producers reasonable protection from fluctuations in the price received for milk. Assuming constant prices for inputs such as feed, labor, fuel, and other services there is no great incentive to invest in BJD control as it may take as long as ten years before tangible benefits are realised (Rasmussen, 2019). Furthermore, under the assumption of increased uncertainty and varying input prices, engagement in BJD control may become even less palatable in perspective of more important concerns. Thus, it is necessary to have a policy environment supportive of producers' engagement in BJD control.

4.2.3 **Policy options for BJD control in Canada**

Currently, there is no national program or policy in Canada directed specifically at BJD control. It is evident that a regulatory approach to BJD control can be effective but the impacts on certain factors and stakeholders need to be carefully considered to minimize unintended consequences. Selected options for potential policy environments and the potential factors impacted are outlined in Table 4.4. The following assumptions are made to standardize vaccine characteristics and nature of regulatory control:

<u>BJD vaccine assumptions</u>: (As per Silirum® currently registered in Australia)

- Vaccine has little protective value; mainly reduces shedding
- Vaccine invokes false-positive TB test and false-positive BJD test
- Producer pays for the vaccine (no subsidy)
- BJD vaccine is contracted by public health research institute to government

<u>Regulatory control assumptions:</u>

- Farmers can still sell milk
- Animal movement restrictions and containment imposed on positive dairy farms
- All animals require testing
- BJD-positive animals culled

Table 4.4 BJD Control Policy Options in Canada: Factors and Stakeholders Impacted

Policy option	Impact	Stakeholders		
		Consumers	**Industry**	**Government**
One *Status quo*	+	Minimal risk of market interruption	Freedom to manage BJD as necessary Voluntary control costs are cheaper than blanket mandatory industry control	Reduced funding required for animal disease control
	-	Increased risk of MAP entering the food chain Vulnerable to inconsistent milk production	Reduced engagement in BJD control Increased BJD prevalence Increased costs for reactive disease control	Export markets may close if freedom from BJD becomes a mandatory requirement
Two Vaccine available	+	Milk price stability due to lower farm input costs Reduced risk of MAP entering the food chain	Freedom to manage BJD as necessary Additional BJD control options available Reduced shedding of MAP + reduced prevalence in vaccinated herds Reduced BJD prevalence Increased profitability for farms using the vaccine	Increased public confidence in disease control Decreases government funds to control BJD
	-	Vulnerable to inconsistent milk production Risk of MAP entering the food chain remains	Reduced engagement in BJD control Increased BJD prevalence Increased costs for reactive disease control Risk of regulatory control imposed due to false positive TB tests	Cost of vaccine registration and manufacture Cost of the regulatory framework required to manage false positives Risk to export markets if assurances for BJD freedom become a requirement Risk to export markets if due to false positive TB test reactions

Policy option	Impact	Stakeholders		
		Consumers	Industry	Government
Three Vaccine available <u>Voluntary</u> herd testing with herd status system Participants receive compensation for testing and for culled animals Regulatory control imposed on BJD positive farms	+	Reduced risk of MAP entering the food chain	Freedom to manage BJD as necessary BJD testing costs covered Additional BJD control options available Reduced shedding of MAP + reduced prevalence in vaccinated herds Standardized herd status across provinces Increased profitability for farms using the vaccine Increased profitability for farms pursuing a herd status Improved market access	Government-industry partnership model for disease control Increased public confidence
	-	Welfare concerns for culled cattle Increased cost (++) of dairy products (additional government costs passed on) Possibility of farmers concealing sick cows to avoid testing thereby posing a risk of MAP entering the food chain	Upfront cost of testing and herd accreditation Risk of regulatory control imposed due to positive BJD tests Trade barriers for positive farms Poor participation due to the threat of regulatory penalty Increased BJD prevalence Risk of regulatory control imposed due to false positive BJD tests Risk of regulatory control imposed due to false positive TB tests Social and psychological impact of regulatory control	Cost of the regulatory framework required to enforce movement restrictions Cost of vaccine registration and manufacture Cost of the regulatory framework required to manage false positives Risk to export markets due to false positive TB and BJD test reactions Costs associated with testing and compensation

Policy option	Impact	Stakeholders		
		Consumers	Industry	Government
Four Vaccine available Mandatory herd testing with herd status system Participants receive compensation for testing and for culled animals Regulatory control imposed on BJD positive farms	+	Reduced risk of MAP entering the food chain	Additional BJD control options available Reduced shedding of MAP + reduced prevalence in vaccinated herds Reduced BJD herd-level prevalence BJD testing costs covered Improved herd health across Canada Standardized herd status across provinces Increased profitability for farms pursuing a herd status Improved market access Increased profitability for farms using the vaccine Fewer trade barriers for all producers	Improved disease surveillance Elimination of BJD possible Increased public confidence Reduced longer-term costs of BJD control
	-	Welfare concerns for culled cattle Increased cost (+++) of dairy products (additional government costs passed on)	Reduced freedom to manage BJD according to individual needs Risk of regulatory control imposed due to positive BJD tests Risk of regulatory control imposed due to false-positive BJD tests Risk of regulatory control imposed due to false positive TB tests Social and psychological impact of regulatory control Exercised BJD control preferences not in line with stated preferences	Cost of testing and risk assessments Cost of the regulatory framework required to enforce movement restrictions Cost of vaccine registration and manufacture Cost of the regulatory framework required to manage false positives Risk to export markets due to false positive TB and BJD test reactions Self-imposed restricted access to international markets

4.3 Policy implications and application to Canada

The policy options outlined in Table 4.4 represent scenarios of potential approaches to BJD control in Canada that bear elements resembling current and prior policy environments in Canada and Australia. However, these represent only a few of many potential policy options worth exploring for future approaches to BJD control in Canada. Each option has advantages and disadvantages for one or more stakeholder groups with implications over the short and longer term.

4.3.1 Policy Option One: *Status quo*

Control efforts specifically targeting BJD are lacking. In the short term, all stakeholders benefit from this approach to a degree. proAction offers a solid framework to control multiple important diseases such as bovine viral diarrhoea (BVD), enzootic bovine leukosis (EBL), various mastitis pathogens, and BJD (CFIA, 2013). However, decreased participation in provincial programs of the CJDI was observed as funding diminished (Atkins, 2019). As there is currently no funding for BJD control activities, further reduction in active BJD management increases the risk of a rising prevalence over the longer term. This subsequently reduces the ability of producers to provide assurances of low BJD risk in their herds. Furthermore, this increases the risk of MAP entering the food chain. Demands by trade partners for assurances of MAP freedom in dairy products and genetics would thus pose a threat to the value of dairy exports.

4.3.2 Policy Option Two: Registration and availability of a BJD vaccine

The addition of a vaccine to the current approach in Canada provides another effective option to control BJD (Shephard, 2016). This offers additional benefit in the form of more flexibility for producers wishing to actively control BJD. However, false-positive test results for TB in cattle vaccinated against BJD raises concern. Although Canada is officially free of bovine TB, recent incursions in beef herds and the presence of infected bison in northern Alberta and several other locations emphasize necessary vigilance (CFIA, 2016; Nishi, 2016). A BJD vaccine causing TB false-positives thus creates a need for increased government regulatory resources and supporting policy to manage this. Moreover, should public registration of a vaccine be pursued, this would incur additional government costs and regulatory infrastructure for manufacturing and distribution.

4.3.3 **Policy Option Three: Voluntary herd status program, compensation, regulatory control**

Option three allows for a scenario with potential benefits to all stakeholders in the short term. Findings from Chapter 2 suggest more producers favor a regulated approach to BJD control as opposed to a deregulated approach to BJD control. Fair government financial support for producers willing to accept and adopt BJD control activities further encourages participation. This may create a favorable environment for exercised preferences to be synonymous with stated preferences for BJD risk mitigation.

However, this option also potentially allows for a scenario with several unintended consequences. Proactive farmers participating in testing and herd status programs may inadvertently have regulatory control imposed upon their farm with subsequent animal movement restrictions. Upon removal of regulatory control, breeder farms with low BJD herd status may suffer further reputational damage and financial consequences from reduced stock sales. Adequate compensation of producers for regulatory losses incurs significant cost. Furthermore, high herd-level prevalence would result in many farms requiring compensation potentially resulting in some farms receiving only partial compensation. The threat of regulatory control thus may discourage participation as direct losses from BJD are estimated to be less than indirect losses from regulatory control (AHA, 2015b).

4.3.4 **Policy Option Four: Mandatory herd status program, compensation, regulatory control**

Relative to option three, the addition of mandatory BJD control on dairy farms offers a scenario largely beneficial to all stakeholders in the long term. Participation of all producers through mandatory control measures increases the likelihood of successful BJD elimination from Canada. Survey participants had spent more time in the dairy industry compared to the population average with more participants favoring a regulated approach compared with a deregulated approach to BJD control. This suggests that over time producers have seen the benefit of regulatory measures. Canadian producers have recognized BJD as an industry problem rather than a problem of individual farms (Sorge, 2010a). Thus, it is plausible that producers may support an approach that benefits the overall industry. The current supply management system in Canada offers an existing framework to support enforcement of BJD control policy consistently across all provinces. Furthermore, over time it is likely that more stakeholders will recognize the benefits of controlling BJD at the farm and industry level. When this point is reached, the safety net of policy ought to be no longer required especially if the elimination of BJD is achieved.

In the short term, however, a top-down approach removes producers' freedom to allocate resources for disease control at will. Poor management of regulatory control measures and inadequate compensation is thus likely to decrease public confidence. Producers deeming BJD as a low priority may object to time, energy, and funding spent on BJD control rather than other economically important diseases such as BVD, mastitis, and lameness. The increased costs in the short term are considerably higher and raise questions regarding suitable funding sources.

4.4 Recommendations and conclusions

Although the factors impacted by selected policy options have been highlighted herein, the magnitude of impact has not been quantified. In-depth policy analysis is warranted to quantify these impacts, particularly the cost and responsibility implications for stakeholders.

4.4.1 BJD vaccination in Canada

Use of a vaccine to control BJD on dairy farms has shown to be beneficial (Chapter 3). Thus, access to a vaccine would be a valuable tool for producers wishing to control BJD. However, currently available vaccines mainly reduce shedding of MAP and do not confer adequate protective immunity. Thus, use of the vaccine should not be solely relied upon for control, rather, should be complementary to other evidence-based mitigation strategies such as best practice biosecurity and hygienic calf rearing (Chapter 2). Specifically, vaccination on farms with a high cow-level prevalence of BJD would be useful in reducing shedding and subsequent infection of naïve animals.

Despite the advantages of having a vaccine available to control BJD, there remains the risk of interference with bovine TB control. Introduction of new vaccine conferring protective immunity and reduction of false-positive TB and BJD test reactions would be desirable. Should the development of a vaccine with such credentials not be plausible, differential diagnostics to distinguish vaccinated from infected animals would be a useful tool. In addition, animal health regulatory policy needs to allow for producers to use vaccines where applicable without unduly restricting market access.

Considering the inadequate protective immunity and interference of current vaccines with TB control registration, use of the current vaccine poses risks to both government and industry. It is thus recommended that registration of any BJD biotechnology vaccine should take place on condition of sufficient evidence of protective immunity in addition to reduced MAP shedding and the ability to differentiate infected from vaccinated animals.

4.4.2 **BJD control policy in Canada**

The benefits and drawbacks of different BJD control scenarios over the short and long term vary considerably. To improve voluntary producer participation, control programs need to have tangible short-term benefits and minimal barriers to engagement. However, longer-term benefits also need to be forthcoming to maintain engagement. It is evident that a top-down approach to BJD control can contribute to producer frustrations and reduced confidence in the delivery of government services (AHA, 2015c). Although seemingly restrictive and less desirable, findings of this study suggest producers do see the benefit of regulated control over the long term.

Conversely, with sufficient incentive, a participatory approach may be more desirable to foster engagement in the short-term and long-term but benefits need to be clearly communicated (Garcia, 2015; Roche, 2014). A policy framework supportive of a participatory approach may reveal benefits of participation and bridge the gap between stated preferences and exercised preferences for BJD control. Ideally, a scenario may evolve whereby voluntary participation in BJD control remains high and policy is no longer necessary for enforcement.

4.4.3 **Conclusion**

Control programs, whether market-driven or supported by government policy need to consider whether the effects on producers, consumers, and government are supportive of BJD control or may have unintended consequences. Thus, the major challenge to successful BJD control is to ensure the relevance of control policy in helping producers realise more profitable enterprises through engagement in BJD control activities. This is particularly crucial to the success of a vaccine such that upon registration it can fit into existing frameworks of control within Canada.

Chapter 5 Conclusion

5.1 Summarizing discussion

Review of the literature revealed a lack of clarity as to the role of regulatory policy in determining the uptake of BJD control activities. More specifically, factors influencing the use of vaccines to control BJD and the role of vaccination in BJD control programs under different policy scenarios have not been previously described. As such, the objectives of this thesis were to better understand factors influencing dairy producers' participation in different BJD control activities, assessment of the financial benefits of participation, and application of learnings to BJD control policy in Canada and other countries.

Chapter 2 aimed to characterize producers with evidence of participation in BJD control activities, namely control programs and vaccination. Attempts to use binary logistic regression modelling to explore factors associated with "actual participation" as the independent variable revealed the disconnect between stated preferences and exercised preferences and alluded to complex relationships requiring alternative modelling techniques. Subsequently, "level of engagement in BJD control activities" was defined as an ordinal independent variable representing producers' sequential progression over stages of their stated preferences. Namely, these stages were stated willingness to accept, stated willingness to adopt, and stated willingness to pay for BJD control activities.

This is contrary to the depiction in the Farmer Technology Acceptance Model (Figure 2.2). These results ultimately suggest external factors have a direct influence on actual participation in BJD control activities as opposed to prerequisite intermediary steps. Regulatory policy is possibly one external variable influencing producers to actively participate in control activities despite not willing to accept the principles behind them. Conversely, it may also explain why some producers are willing to accept and adopt control programs but are not willing to pay or participate owing to previous threats of regulatory penalty for revealing an infected farm. This disparity between producers' stated preferences and their exercised preferences precluded the use of "actual participation" in BJD control activities as the ultimate level of engagement in the ordinal independent variable during analysis.

Producers engaging in BJD control programs were characterised by factors concerning producers' attitudes and the practicality of programs. As such, those with higher levels of engagement were older farmers that had not been in the industry for a long period, had a favorable attitude to using control programs on BJD-positive farms, and did not sell livestock within Australia. Farms with higher levels of engagement were smaller with high biosecurity and more land allocated to cropping. The demographic profiles and characteristics of Australian dairy farmers participating in control programs have not been described in the literature. These study findings do not contradict previously described characteristics of participants in other countries although there are some additional features not previously described. Participants of the former CJDI had larger herds, more knowledge about the CJDI, better production figures and management practices, and used a veterinarian more often compared with non-participants (Kelton, 2011a; Ritter, 2015). Farmers' attitudes and importance relative to engagement in disease control has previously been described in Canadian dairy farms by Sorge *et al*. (2010). Roche (2014) and Ritter *et al*. (2016) described similar findings for the provincial BJD control programs in Ontario and Alberta respectively.

The stated level of engagement in BJD vaccination seemed to be influenced more by factors concerning profitability. As such, those producers with a higher level of engagement stated "profit" as a primary motivation for being involved in the dairy industry and believed BJD vaccination to increase farm profitability. This characterization is supported by results from Chapter 3. Characterization of BJD vaccine users has not been published before.

Chapter 3 investigated the profitability of farms by different levels of engagement in BJD control activities. This was achieved using a simulation model based on observations from

Victorian dairy farmers in the collected dataset and application of cost and revenue data from ongoing industry research to determine profit. Most notably, farms actively participating in control programs and vaccination were more profitable than non-participants. The financial benefits of participation in BJD control programs have previously been described in Australia by Shephard *et al.* (2016) and Canada by Wolf *et al.* (2014). The revealed benefits of vaccination are consistent with findings by Shephard *et al.* (2016) where it was found to be cost-effective for dairy farms in Victoria, Australia. Despite reservations expressed by producers regarding BJD control activities, this demonstrates that participation is beneficial.

5.2 Implications

Conferring benefits of BJD control beyond a limited number of farms requires actual participation from more producers for the industry to benefit as a whole. As noted in the review by Garcia *et al.* (2015), better communication and awareness of these benefits is a necessary precursor to active participation. Consistent with this sentiment, changes to the BJD control approach in Australia lacked the desired positive impact because the tangible benefits of the changes were not disseminated among relevant stakeholders (AHA, 2018b). It is likely this contributed to the current deregulated approach ranking less favorable than the former regulated approach, as noted in Chapter 2.

BJD control policy options described in Chapter 4 explore the stakeholders and factors impacted under each scenario in Canada. The need for a policy environment supportive of active participation to help achieve this objective is evident. This is of particular importance as the value added from agriculture to GDP in Canada would suffer significant losses should the market value of milk production decrease substantially from disease impact or other shocks.

It is important to note the policy options presented in this thesis represent only a few of many possibilities. Furthermore, all disease control policy options have caveats; support for farmers from the market being crucial to achieving policy objectives successfully.

5.3 Outlook and Recommendations

As noted in Australia and Ireland, collaborative efforts between government and industry show promise as a model for approaching BJD control. However, farmers and the dairy industry as a whole need to realize the benefits of a more active approach to successfully achieve control objectives. The *status quo* for BJD control in Canada allows producers to allocate disease control resources as per individual needs. Producers opting to control BJD may realize financial benefits (Chapter 3) at the farm level. However, a more active BJD control campaign would not necessarily be well received by all producers, particularly if there is no immediate need or benefit. Furthermore, if accompanied by stringent regulations and other deterrents to uptake, control efforts are less likely to succeed.

The lack of a comprehensive BJD-specific control framework may be viewed as a vulnerability for the Canadian dairy industry and related markets. Supply management in Canada remains a contentious issue within the dairy industry and with trade partners. Although abolishing supply management is unlikely in the near future, it would significantly change industry and market dynamics. A free market scenario would likely increase competition among producers and processors alike, thereby affecting profit margins. Under these circumstances, the industry would become more open to import and export trade of dairy products. Additionally, should the link between MAP and human health become more concrete or Canada's trade partners demand products with low risk of BJD, this vulnerability would be exposed.

Chapter 4 outlines the potential hazards of vaccinating cattle in Canada with current BJD vaccines and interference with ongoing TB testing and surveillance. In order to protect the markets dependent on a declaration of BTB freedom, vaccination is not a feasible option until improved products are available. However, ongoing communication to all stakeholders regarding individual and industry benefits of BJD control is recommended to improve awareness of BJD and pathways to manage it. Thus, upon registration of an appropriate vaccine in Canada barriers to its usage will be minimized whereby individual producers and the industry can remain profitable and globally competitive.

5.4 Study Limitations

An obvious limitation of the study is the small sample size used to characterize producers engaging in BJD control activities. In addition, potential selection bias may have skewed these results. However, a comparison of the sample frame to the population of Australian dairy farmers suggests the results in Chapter 2 are generalizable within Australia. Generalization to other countries with similar production systems and market dynamics is possible but local factors need to be carefully considered.

Although the Dairy Farm Monitor Project represents a practical method to calculate farm profit in Chapter 3, an obvious limitation is the calculation of fixed costs directly relative to milk output. However, this approach has been validated in studies conducted by Shephard *et al.* (2016) to calculate farm profit relative to different BJD control activities.

Exploration of policy options in Chapter 4 excludes a quantitative assessment of the impact each policy option has on stakeholders and various factors. Although outside the scope of this thesis, quantitative estimates of impacts are imperative for policymakers and decision-makers to implement policy based on evidence.

Despite these limitations, this research contributes unique insight into the factors influencing producers' decisions on BJD control, specifically how control programs and vaccination can fit into existing regulatory and non-regulatory control frameworks.

5.5 Future directions

Although this study has addressed some important gaps in the literature, questions have been raised that require further investigation.

Given the nature of currently available BJD vaccines, it would be of value to repeat this study after the introduction of a new vaccine with better efficacy in preventing infection, reducing

BJD prevalence, and not having the gravely complicating feature of interference with BTB testing. Under this scenario it would also be of value to have suitable discriminatory tests to differentiate between BTB infections and BJD vaccinates. This would help ascertain whether any aversion to vaccination is due to a lack of willingness to accept the principles behind vaccination or relates specifically to the product available. Additionally, probing the reasons behind producers' lack of willingness to accept, adopt, and pay for BJD control activities would offer further insight into this matter. Establishing how much producers would be willing to pay for both control programs and vaccination would also complement this data.

It would be of value to perform longitudinal studies to assess changes in producers' knowledge, attitudes, and practices before and after the implementation of BJD control strategies. The addition of a time component could potentially offer more robust estimates as to the factors likely to improve uptake of control activities in future and what factors pose a risk to attrition of BJD control participants.

The role of the beef industry in BJD control was addressed briefly in Chapter 1. Although less affected by clinical BJD, beef producers were most affected by regulatory measures imposed under the previous policy environment in Australia. Owing to the low prevalence of BJD in the Australian beef industry, it is unlikely that many farmers would be using the current BJD vaccine. However, it would be of great value to repeat this study capturing the knowledge, attitudes, and practices of beef producers to compare and contrast with findings in the dairy industry. Furthermore, capturing similar information from Australian sheep producers would be useful as vaccination has been well established as a credible means of BJD control in the sheep industry for many years (Windsor, 2013; Windsor, 2014).

Finally, a comprehensive survey needs to be conducted to capture consumers' thoughts and attitudes toward public health concerns regarding dairy products. This would offer a valuable understanding as to current market perceptions and demands and how this may influence producer behaviour in controlling BJD.

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Appendix A: Questionnaire distributed to Australian dairy farmers capturing knowledge, attitudes, and practices regarding BJD control

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Australian dairy farmers' attitudes toward JD control

Dear Australian Dairy Farmers,

Johne's disease (JD) is a debilitating wasting disease affecting cattle and other ruminant species, well known to dairy farmers in Australia and Canada. Australia has had a comprehensive control policy which has undergone significant revisions over time. Although Canada has voluntary JD programs offering advice for controlling JD, it does not have a formal testing and certification policy and support program. Learning what did and did not work for Australia would be valuable to Canadian dairy farmers, policy formulators, and JD researchers including developers of JD vaccines and differentiation tests.

The main research question of this study pertains to the benefits and drawbacks of Australian JD control policy, as perceived by Australian dairy farmers. The objectives are to (a) understand perceived catalysts and barriers to JD control in Australia, (b) understand the role of a vaccine in a control strategy in Australia, and (c) apply the learnings from Australian JD control programs to JD control in Canada. The study has been approved by the ethics review board at the University of Calgary.

This study will ask you to answer a series of questions regarding your dairy farm characteristics, animal health and biosecurity, attitudes and perceptions of the benefits and drawbacks of the Australian JD control program, and some basic demographics. All responses are anonymous and will be aggregated; no individual responses will be identifiable. The questionnaire should take 20 minutes or less to complete.

Results of our study are expected in 6 months of completion of this questionnaire and will be made available through popular dairy press in Australia and in Canada. Scientific publications will also be available in the academic literature. Your contribution to our knowledge of JD control policy will benefit dairy farmers in all countries where JD is present, as well as dairy policy formulators and dairy consumers.

We very much appreciate your willingness to consider participation in our study.

Sincerely,

David C. Hall, DVM, PhD (AgrEcon)
Assoc. Professor, Animal health economics and policy
Dept. Ecosystem and Public Health, Faculty of Veterinary Medicine,
University of Calgary, Calgary, Alberta, Canada

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Australian dairy farmers' attitudes toward JD control

Preliminary Information

This research questionnaire is being conducted to understand the on-farm, industry, and government factors that influence control of Johne's disease.

Your participation is greatly appreciated and will be handled with the strictest confidence and anonymity.

Please select the best answer or fill in your answer in the space provided.

Please do not put your name or address anywhere on this questionnaire.

* 1. Before or during 2016 did you have any dairy cattle on your farm?

◯ Yes

◯ No

* 2. Are you currently farming with dairy cattle?

◯ Yes

◯ No

* 3. During 2019 will you have dairy cattle on your farm?

◯ Yes

◯ No

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Australian dairy farmers' attitudes toward JD control

General Information

1. What is your role on the dairy farm?

- Owner/Co-Owner
- Worker
- Manager
- Other
- Share Farmer

2. In which State/Territory is most of your dairy operation located?

3. How many total hectares does your dairy farming operation cover?

4. How many hectares are allocated to produce crops for sale or on-farm cattle feeding?

5. What is the current number of cows (1st lactation and older) in your herd?

6. What is the main breed of cows in your milking herd?

7. What type of cow housing system is used on the dairy farm?

- Pasture-based
- Free-stall

8. What is your dairy farm's total annual milk production? ***million litres/year***

9. What calving system do you use in the herd?

- Seasonal
- Year-round
- Split calving
- Batch calving

10. How many beef cattle do you keep on your farm (excluding dairy cattle reared for beef)?

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Australian dairy farmers' attitudes toward JD control

Animal Health

1. What is your average Bulk Milk Cell Count (BMCC) over the last year?

2. What are your top 3 animal health concerns on this farm? (Select up to 3 that apply)

- ☐ Infertility
- ☐ Mastitis
- ☐ Johne's Disease
- ☐ Metabolic diseases (milk fever/hypocalcaemia, ketosis, LDA, RDA, fatty liver etc.)
- ☐ Lameness
- ☐ Other (please specify e.g. External parasites, Internal parasites, Bovine Viral Diarrhoea/Pestivirus, Calf diseases – diarrhoea/pneumonia etc.)

3. Relative to the average herd in your state/territory, how would you categorize the overall health of your herd?

- ○ Poor
- ○ Good
- ○ Fair
- ○ Excellent
- ○ Average

4. What is the average body condition score of your cows at calving (Dairy Australia 1-8 scale)?

5. Do you receive routine veterinary visits for herd health consulting, pregnancy testing, pre-mating checks, hoof trimming, calf health etc.? (routine visit = at least one visit every three months)

- ○ Yes
- ○ No

6. How many times per month (on average throughout the year) do you receive unscheduled veterinary visits? (e.g. dystocia, sick cows etc.) *visits/month*

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Australian dairy farmers' attitudes toward JD control

Biosecurity

1. Have you brought in bulls, heifers, or cows from outside sources in the last 2 years?

- Yes
- No

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Australian dairy farmers' attitudes toward JD control

Biosecurity

1. When bringing in bulls, heifers, or cows from outside sources do you routinely request vendor declarations or animal health declarations?

- ◯ Yes
- ◯ No

2. Do you sell breeding bulls, heifers, or cows to buyers *within* Australia (other than for slaughter)?

- ◯ Yes
- ◯ No

3. Do you sell breeding bulls, heifers, or cows to buyers *outside* of Australia (other than for slaughter)?

- ◯ Yes
- ◯ No

4. Does your farm have a biosecurity plan in place overseen by a veterinarian?

- ◯ Yes
- ◯ No

5. Do you currently use vaccines to control any diseases on the farm?

- ◯ Yes
- ◯ No

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Australian dairy farmers' attitudes toward JD control

Biosecurity

1. What are the 3 most important attributes you consider when choosing a vaccine? (Select 3 that apply)

- ☐ Cost
- ☐ Prevents spread of disease
- ☐ Ease of administration
- ☐ Safety for animals receiving vaccine
- ☐ Prevents infection
- ☐ Other (please specify - e.g. Provides a return on investment, Safety for person administering vaccine, Improves the health of my herd, Once off dosing, Protects against multiple diseases, etc.)

2. Who/what do you consider your 3 most important sources of information and guidance for disease control in your dairy herd? (Select 3 that apply)

- ☐ Feed/Drug company representative
- ☐ Internet
- ☐ Government/Primary Industries
- ☐ Veterinarian
- ☐ Industry associations
- ☐ Other (please specify - e.g. Family member, Stock agent, Milk processing company, Neighbour, Peers, Textbooks, etc.)

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Australian dairy farmers' attitudes toward JD control

Johne's Disease – Testing and Potential Impact

1. Has your dairy herd ever had a clinical case of JD (confirmed by a veterinarian)?

- ◯ Yes
- ◯ No
- ◯ Don't know
- ◯ Prefer not to answer

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Australian dairy farmers' attitudes toward JD control

Johne's Disease – Testing and Potential Impact

1. How many clinical cases of JD (confirmed by a veterinarian) have occurred in the past 24 months?

2. Have any routine tests for JD conducted (on animals or the yard/environment/) in the last 2 years resulted in a JD-positive result?

- Yes
- No
- Not tested
- Prefer not to answer

3. Considering the potential negative impacts that JD can have on cattle, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
JD increases culling					
JD reduces profitability					
JD in dairy cattle poses an infectious disease risk to the Australian public					
JD in dairy cattle poses a trading risk to the Australian dairy industry					

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Australian dairy farmers' attitudes toward JD control

Johne's Disease – Management and Control

In the following questions, JD control program refers to formal programs targeting control of JD such as the former CattleMAP, TCP, and DairyManaJD. It also refers to the elements of control programs such as hygienic calf rearing (JDCAP, 3-step-calf plan), the Dairy Score system, and any tools advocated by the New BJD Framework rolled out in 2016.

In the following questions, JD vaccine refers to any pharmaceutical product/biotechnology compound used to invoke an immunologic response to prevent JD infection in healthy animals or reduce clinical signs and shedding of MAP organisms in infected animals.

(Mobile users: it may be easier to provide your responses in the JD Vaccine column if your device is in landscape orientation)

1. Regarding each strategy used to control JD, please select the most appropriate option:

	JD Control Program	JD Vaccine
Currently used on my farm		
Have used on my farm in the past		
Used by neighbouring dairy farms		

2. Regarding each strategy used to control JD, to what extent do you agree with the following statements?

	JD Control Program	JD Vaccine
The principles behind JD control are valid		
I am willing to adopt this to control JD		
Producers should pay for this to control JD		
Represents value for money in a JD-positive farm		
Represents value for money in a JD-negative farm		
Should be mandatory for all producers to implement		

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Australian dairy farmers' attitudes toward JD control

Johne's Disease – Impact of Control Activities

(Mobile users: it may be easier to provide your responses in the JD Vaccine column if your device is in landscape orientation)

1. Considering the ability of JD control strategies to mitigate any negative impacts of JD, to what extent do you agree with the following statements?

	JD Control Program	JD Vaccine
Reduces culling		
Improves farm profitability		
Improves ability to trade cattle within Australia		
Improves the ability to trade cattle outside Australia		
Improve Australia's reputation for high quality dairy products/animals		

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Australian dairy farmers' attitudes toward JD control

Johne's Disease – Policy and Regulatory Control

Policy and regulatory control refer to JD in Australia being a notifiable disease and any regulatory components of control such as farm quarantine, animal movement restrictions, etc.

Aside from some state-specific differences, consider the impacts of the *previous* predominantly government-driven/regulatory approach to Johne's Disease control in Australia and the *current* industry-driven/producer-centric approach (New BJD Framework), please answer the following questions.

(Mobile users: it may be easier to provide your responses in the JD Vaccine column if your device is in landscape orientation)

1. Regarding policy governing JD control, to what extent do you agree with the following statements?

	Regulated approach to JD Control (previous)	Deregulated approach to JD Control (current)
Influential to me implementing control measures for JD on my farm		
Improves ability to sell milk/animals within Australia		
Improves ability to sell milk/animals outside of Australia		
Improves Australia's reputation for high quality dairy products/animals		
Improves farm profitability		

2. Considering the influence of the beef industry on government JD control policy formulation, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
JD is a problem in the Australian beef industry	○	○	○	○	○
The beef industry in Australia strongly influences regulations around control of JD	○	○	○	○	○
JD control policy should be a comprehensive framework covering both beef and dairy industries	○	○	○	○	○

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Australian dairy farmers' attitudes toward JD control

Johne's Disease Control - Distribution of Responsibility

For the following questions, consider the stakeholders that should bear the responsibility for various JD control activities in Australia.

Note that "industry" refers to transporters, processors, manufacturers, and retailers.

1. Responsibility for JD control

	JD Control Program	**JD Vaccine**
Should the responsibility for this control activity be evenly distributed between Producers, Industry, Consumers, State Government, and Federal Government?		

2. What percentage of the responsibility for *JD control programs* should be allocated to producers?

0% Responsibility 100%

3. What percentage of the responsibility for *JD vaccines* should be allocated to producers?

0% Responsibility 100%

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Australian dairy farmers' attitudes toward JD control

Johne's Disease Control - Distribution of Costs

For the following questions, consider the stakeholders that should bear the costs for various Johne's Disease control activities in Australia.

Note that "industry" refers to transporters, processors, manufacturers, and retailers.

1. Costs for JD control

	JD Control Program	JD Vaccine
Should the costs for this control activity be evenly distributed between Producers, Industry, Consumers, State Government, and Federal Government?		

2. What percentage of the costs for *JD control programs* should be allocated to producers?

0% Costs 100%

3. What percentage of the costs for *JD vaccines* should be allocated to producers?

0% Costs 100%

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Australian dairy farmers' attitudes toward JD control

Farmer Characteristics

1. What is your age?

0 Age in years 100

2. What is your gender?

- Female
- Male
- Other
- Prefer not to say

3. What is your highest level of education?

4. How many years have you been dairy farming?

5. What are the top 3 factors that motivate you to be a dairy farmer? (Select 3 that apply)

- Business management interests
- Lifestyle
- Family legacy
- Profit
- It's a job
- Other (please specify)

6. What percentage of your household income is derived from dairy farming?

0% 100%

7. Do you have any other comments, questions, or concerns?

Appendix B: Johne's Disease Requirements of countries importing livestock commodities from Australia (Source: AgForce 2012)

Importing Country	Commodity	Requirement
Argentina	Cattle - Semen	90-day freedom
Brazil	Cattle - Breeder	60-day freedom
Brunei	Cattle - Slaughter	Clinical freedom from major infectious diseases
Canada	Cattle - Breeder	Test freedom
Chile	Cattle - Breeder	90-day freedom
	Cattle - Embryos	Clinical freedom
	Cattle - Semen	Test freedom
China	Cattle - Breeder	1-year freedom, plus test freedom
Colombia	Cattle - Semen	60-day freedom
Costa Rica	Cattle - Semen	Clinical freedom
Cuba	Cattle - Semen	Centre freedom
Czech Republic	Cattle - Semen	5-year freedom
East Timor	Cattle - Breeder	Clinical freedom
Ecuador	Cattle - Semen	Clinical freedom
Indonesia	Cattle - Breeder	Test freedom
	Cattle - Feeder	5-year freedom
Iraq	Cattle - Semen	Clinical freedom
Israel	Cattle - Feeder	3-year freedom
	Cattle - Semen	3-year freedom
Japan	Cattle - Breeder	Test freedom
	Cattle - Feeder	5-year freedom
	Cattle - Semen	6-month freedom
Kazakhstan	Cattle - Breeder	3-year freedom
Korea	Cattle - Embryos	Test freedom
	Cattle - Semen	5-year freedom
Libya	Cattle - Breeder	1-year freedom
Malaysia	Cattle - Breeder	3-year freedom, plus test freedom
	Cattle - Feeder	2-year freedom
	Cattle - Slaughter	2-year freedom
Mauritius	Cattle - Slaughter	3-year freedom
Norfolk Island	Cattle - Breeder	Test freedom
Oman	Cattle - Breeder	2-year freedom
Pakistan	Cattle - Embryos	Clinical freedom
	Cattle - Breeder	Test freedom
	Cattle - Semen	Clinical freedom
Paraguay	Cattle - Semen	60-day freedom
Philippines	Cattle - Breeder	5-year freedom
	Cattle - Embryos	6-month freedom
	Cattle - Feeder	1-year freedom
	Cattle - Semen	5-year freedom
Qatar	Cattle - Breeder	Clinical freedom

Russian Federation	Cattle - Breeder	3-year freedom, plus test freedom
	Cattle - Embryos	3-year freedom
	Cattle - Feeder	3-year freedom
	Cattle - Semen	3-year freedom
Sabah	Cattle - Breeder	6-month freedom
	Cattle - Feeder	Clinical freedom
	Cattle - Slaughter	Clinical freedom
Sarawak	Cattle - Breeder	Clinical freedom
	Cattle - Slaughter	Test freedom
Singapore	Cattle - Breeder	Clinical freedom
	Cattle - Breeder	Freedom one month before export
Solomon Islands	Cattle - Breeder	Clinical freedom
Sri Lanka	Cattle - Breeder	Test freedom
Sudan	Cattle - Breeder	Clinical freedom
Taiwan	Cattle - Embryos	1-year freedom
	Cattle - Breeder	1-year freedom
	Cattle - Semen	1-year freedom
Thailand	Cattle - Embryos	Test freedom
	Cattle - Semen	1-year freedom
Turkey	Cattle - Breeder	5-year freedom
	Cattle - Feeder	Test freedom (not required from a JD-free state)
	Cattle - Slaughter	Property not in quarantine
UAE	Cattle - Breeder	Clinical freedom
	Cattle - Semen	Clinical freedom
Uruguay	Cattle - Embryos	2-year freedom
	Cattle - Semen	Test freedom
USA	Cattle - Breeder	5-year freedom
Vanuatu	Cattle - Embryos	3-year freedom
	Cattle - Semen	3-year freedom
Vietnam	Cattle - Feeder	Clinical freedom
	Cattle - Semen	Centre freedom