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A simulation model evaluating costs of Bovine Viral Diarrhea Virus (BVDV) for a typical U.S. cow-calf producer and benefits of multiple test and cull strategies

by

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A thesis submitted to the graduate faculty

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2007

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ABSTRACT

Increasingly, veterinarian organizations in the United States recommend the control and eradication of Bovine Viral Diarrhea Virus (BVDV). Cow-calf producers comprise 35% of U.S. cattle; however, research on the effects of BVDV in these herds is limited. To gain a better understanding of the pathology of BVDV in cow-calf producers, a stochastic simulation model was developed in C++ to measure epidemiological and financial outcomes. Additional simulations were run to evaluate changes in producer profit for several test and cull strategies. Introducing a PI animal decreased profit by an average of $13,971 over 10 years. When a second generation of PI animals was born, profit decreased an average of $18,738 over 10 years. Of the test and cull methods run, herds with PI animals profited the most by testing newborn calves before the start of breeding each year. When one PI animal was introduced, testing newborn calves each year before breeding increased profit by an average of $8,498 over 10 years. For producers with a low risk of PI introduction, testing retained calves after weaning when motivated by an unusually small number of calves was the least costly strategy and successfully identified 77% of simulations that introduced one PI animal in the herd.

CHAPTER 1. OVERVIEW

In the past 60 years, scientists have begun to understand the pathobiology and complete financial costs associated with bovine viral diarrhea virus (BVDV). The virus was initially understood to cause mortality at low rates, fever, diarrhea, and coughing in beef cattle earning it the inconspicuous name 'bovine viral diarrhea' virus (Moennig et al., 2005a). Today, based on a better understanding of the range of clinical manifestations of infection, BVDV often ranks as one of the most costly diseases affecting the U.S. cattle industry (Weersink et al., 2002). Several European countries (Austria, Denmark, Finland, Germany, Norway, and Sweden) have instituted eradication programs (Moennig et al., 2005a; Moennig et al., 2005b; Houe et al., 2006). Ex-post analyses of eradication programs in Norway and Austria have shown positive results soon after implementation (Walter et al., 2005; Valle et al., 2005). In response, several U.S. organizations including the National Cattle Association, the Academy of Veterinary Consultants, and the American Association of Bovine Practitioners have recommended the eradication of BVDV in the United States. As the U.S. cattle industry contemplates control and eradication options for BVDV, it is important to evaluate alternative policies and consider the cost effectiveness of potential control strategies.

While the U.S. beef industry is often considered a single entity, in reality it contains a number of segments. For the purpose of a national BVDV analysis, three production segments are important: dairy, cow-calf, and feedlot producers. Cow-calf producers in the United States comprise 35% (33.1/95.8 M) of total U.S. cattle inventory (USDA and NASS, 2005). By contrast, cow-calf producers in Europe are few due, in part, to the plentiful rainfall and less available pasture throughout Europe that better support dairy production.

Cow-calf producers earn income primarily by selling six to eight month old calves to feed lots for finishing.

Analysis of potential U.S. eradication programs will focus on production in the three beef segments, as BVDV is not known to have zoonotic potential or to affect consumer consumption patterns. From the consumer's perspective, changes in production and production practices affect only price and quantity of beef products in the market. Of the three beef segments, the effect of BVDV on feedlot production is the best understood and is based on available data (Buhman et al., 2003). Financial costs associated with BVDV in dairy and cow-calf production are less well understood because data on costs and benefits of BVDV are rarely recorded (Chi et al., 2002). Computer models are often employed as the next best alternative to obtain financial data on the effects of BVDV in dairy and cow calf production (Radostits, 2001; Chi et al., 2002). Current literature on beef production modeling was developed to analyze European herds and include several excellent agent-based models (Pasman, 1994; Sorensen, 1995; Innocent et al., 1997; Cherry et al., 1998; Viet et al., 2004; Viet et al., 2006; Ezanno et al., 2007). Unfortunately, cow-calf modeling is less developed because it has not been important for European BVDV analysis (Gunn et al., 2004; Humphry et al., 2005). This paper fills this gap in the literature by comparing modeling results from a BVDV outbreak in a typical cow-calf herd with results from several BVDV control and testing strategies.

The paper is organized as follows. Chapter 2 explains the link between BVDV transmission and producer incentives. The possibility of market failure is discussed in the context of infectious disease literature and specific issues for cow-calf producers. Chapter 3 provides a background to BVDV, previous eradication experience in Europe, current vaccine information, and current BVDV status in the United States. Chapter 4 presents the simulation model in a detailed, transparent fashion. Chapter 5 presents results from introducing one PI carrying animal along with a sensitivity analysis of the transmission parameters. Chapter 6 analyzes three test and cull methods for four levels PI introduction risk and two producer motivation types. Finally, Chapter 7 discusses policy implications of test and cull analysis for individual and public based control and eradication programs. Suggestions are also give for future modeling work.

CHAPTER 2. ECONOMIC ISSUES OF BVDV

In the U.S. beef industry, market-based incentives generally do a good job of organizing scarce resources in an efficient manner. Well-established property rights, low barriers to entry, and producers with little market power allow the competitive market equilibrium to resemble pareto-optimal allocations according to the first fundamental theorem of welfare economics (Mas Collel et al., 1995). Sometimes, however, market failure occurs when producer incentives do not result in socially optimal production. This chapter presents some basic economic issues about the failure of markets to control BVDV infection optimally and possible approaches to BVDV control or eradication. A common theme in infectious disease literature is the failure of markets because producers do not bear all of the costs of infection (Ekboir, 1999; Gersovitz and Hammer, 2003). BVDV results in market failure due to negative externalities associated with intra-herd BVDV transmission. In addition, though BVDV eradication could be beneficial, eradication is unlikely to occur at present because of differences between individual and group incentives to participate in an eradication effort. Both of these problems will be discussed below in turn.

2.1 Market failure in the beef industry

Externalities result when an agent does not bear all the costs or reap all the benefits of his actions. For cow-calf producers, negative externalities result when infection in one producer’s herd increases costs for other producers. Profit-maximizing producers make production decisions based solely on costs and benefits associated with their own herd rather than the effect their decisions have on society. As a result, production decisions made by profit-maximizing producers in competitive markets when an infection is present are suboptimal socially (Gersovitz and Hammer, 2003).

Producers with BVDV infected herds do not bear all of the costs of the disease because between-herd transmission of BVDV does not affect the profit of a producer with a BVDV positive herd. The majority of between-herd BVDV transmission occurs when buyers purchase live animals persistently infected with BVDV (PI). This might occur either because the infected animals are not identified at the time of sale or because of transmission between neighboring herds. PI animals shed BVDV constantly and have the ability to infect the majority of animals in a herd within a few months, yet the infection is often subclinical and therefore undetectable without testing (Evermann and Barrington, 2005). While low cost test options for live animals have recently been developed, testing of animals before purchase is still rare. In addition, the fetus of pregnant animals can be PI even if the mother is not and testing of a fetus is painful and not cost-effective. Therefore, producers are able to sell PI animals at higher prices than buyers would pay if the seller fully disclosed the PI status of live sale animals. Some between-herd BVDV transmission also occurs between neighboring herds because of common fences and the ability of animals to make nose-to-nose contact (Thurmond, 2005). These two effects cause negative externalities to society (other producers in the beef industry).

Figure 2.1 illustrates this problem of externalities for the beef market. Producers are willing to produce beef as long as their marginal benefits (MB) are greater than (or equal to) their marginal costs (MC). However, producers do not experience all of the social costs associated with BVDV infection as an outbreak in one herd can cause an outbreak in another herd (and therefore increase costs). Therefore, the marginal cost curve for producers is lower than society's marginal cost curve (for all possible values $MC^{producer} < MC^{society}$). As a result, producers produce q_1 units of beef rather than the socially optimal production of q_2 units. At this level of production (q_1), the marginal cost to society is p_3. If instead, producers faced the full (social) costs of their actions, they would produce less beef (to produce q_2 units of beef). At this level of production, the price paid in the market would reflect the full cost of production and be the socially optimal price. At levels greater than q_2 units of beef (e.g., the additional units q_1-q_2), the MC for society from producing beef is greater than the MB received by producers (paid by buyers) for units produced. On all units produced greater than q_2, there is a loss to society of the difference between $MC^{society}$ and $MC^{producer}$. Production at q_1 amount of beef, results in a deadweight loss to society as illustrated in Figure 2.1 (Parkin 2005).

Several options exist to motivate producers to produce beef products at socially optimal levels and incur additional costs of disease control. Subsidies could be provided to compensate producers for increased costs of BVDV control, such as increased testing of live sale animals, vaccination of sale animals, or early testing of calves from recently purchased animals. In addition, regulation could be implemented that limits the sale of live animals from herds identified with PI animals.

2.2 Inefficiencies due to lack of market segmentation on BVDV status

At present, technology limits identification of the BVDV status of live sale and no identification system has been established to surmount this problem by certifying BVDV-free herds. Therefore, sellers have incentive not to identify PI animals for sale by either misrepresenting the animal's disease status or simply not testing for PI animals. If identified at market, PI animals would sell for a significant discount and often not be able to be sold (Maday, 2007). Animals from herds guaranteed free of PI animals would sell at a premium. Since no system exists to verify a producer's claim for selling BVDV-free animals, any information on BVDV made available at the market is suspect. This is the problem of the market for lemons (Akerlof, 1970). As a result, offering a higher price for a BVDV free animal may not ensure that a buyer receives BVDV-free animals.

With imperfect market information, sellers of live animals do not have incentive to implement sufficient control measures to be able to verify BVDV-free status of animals for sale. Sellers implement too few control measures for BVDV because they realize buyers will suspect information they provide and therefore only control BVDV to the level that is personally beneficial. At the same time, buyers, who want assurances may implement BVDV control measures that would more efficiently be done by sellers early in an animal's life (for example, repeat vaccination or testing) in order to ensure BVDV-free animals.

Several options exist to remove these inefficiencies from the market, though these options themselves are expensive. Public sector regulation, such as mandated control practices or penalties for selling unidentified animals could be established and enforced. Subsidies could be provided for BVDV testing and vaccinations. Technological innovation may occur that decreases the cost of identifying the BVDV status of animals at market, especially the BVDV status of a pregnant animal's fetus. Finally, an identification scheme could be organized (through the public or private sector) to certify the BVDV-free status of animals from certain producers allowing sellers to charge a higher price for BVDV-free animals.

If a trusted system were established to provide full information in the market, buyers would not implement repeated testing and, if motivated by higher prices, sellers would control for BVDV at a higher level. Allowing buyers to have complete information would increase efficiency in the beef sector, and it would allow BVDV-free herds to be compensated for higher costs of maintaining controls and increased costs of collecting information. Those producers who did not want to invest effort to maintain and verify status would receive a discount to the sale price. However, it is important to note that there would be additional costs of collecting information.

2.3 Eradication of BVDV

Rather than managing BVDV infection levels, producers in the United States could decide to eradicate BVDV. Eradication would require near universal participation since only a few producers are required to perpetuate BVDV. However, this level of group motivation is difficult to obtain in a market system due, in part, to the free-rider problem. As a result, successful eradication campaigns often rest on the shoulders of mandatory public sector regulation.

2.3.1 Free-rider problem

BVDV eradication would require group participation by a significant majority of producers in the beef industry. Previous BVDV eradication campaigns have imposed large costs on producers with PI animals, such as restricting the sale of all live animals and requiring expensive screening tests for all animals in herds suspected to have PI animals (Moennig et al., 2005b). An individual producer, however, knows that selling and screening his animals is unlikely to affect whether BVDV eradication is successful for the larger group of producers as a whole. As a result, an individual producer, acting with self-interest, is inclined to let other producers bear the costs of eradication. An individual producer would be best served if he or she did not participate in a BVDV eradication program, but all other producers did. The value to the individual producer of other options, such as participating with all other producers in a BVDV eradication program, or having no producers participating, would depend on the costs to the producer of participating and the expected gains (or losses) associated with the action of other producers. As a result, individual-based solutions result in no participation in BVDV eradication because the first preference for all producers is not to participate. The basic problem is that of "free-riding". Even though some producers consider eradication personally beneficial, they try to push off costs of eradication in order to benefit from the control actions of others. A common solution is to reduce the number of decision makers by motivating collective actions; for example, producers may be willing to vote for a common tax or mandatory regulation that would require group action designed to eradiate BVDV.

2.3.2 Difficulties with private sector BVDV eradication

Voluntary beef organizations exist throughout the United States that could organize BVDV eradication. However, eradication is only possible if nearly all producers are willing to participate. As a result, voluntary eradication is unlikely to occur because the risk of producer nonparticipation prevents large-scale coordinated action. Private sector initiatives are often more successful when focused on short-range goals, such as agreements between cow-calf producers and feedlots to test calves for BVDV when they are young or the establishment of BVDV-free certification for live-animal sales.

2.3.3 Benefits of Eradication

Considerable debate surrounds the question of whether BVDV eradication in the United States would be beneficial. In the case of Norway, Houe and colleagues (2006) found that eradication involved high up front costs for roughly ten years, followed by lower monitoring costs indefinitely. Financial success of eradication can be measured by the net present value of cost and benefit streams for all beef producers. Analysis of Norway's eradication campaign was very positive showing positive social gains soon after implementation (Valle et al., 2005). However, current eradication campaigns in Germany have resulted in much higher costs due to a increased likelihood of re-infection (Moennig et al., 2005b). While the effects of eradication in the United States are likely to vary, previous research in Europe suggests BVDV eradication in the United States may be beneficial as well.

In addition to financial calculations, eradication of BVDV would increase stability in the beef sector and raise production standards. Producers prefer stable income streams over variable income streams because the vast majority of producers are risk adverse (Mas Collel et al., 1995). A more stable income stream would allow producers to substitute consumption between periods and possibly increase access to credit. In addition, a more stable income stream would decrease investment risk, resulting in an increased willingness to invest in long-term assets.

Eradication of BVDV would increase stability in the beef sector for four reasons. First, it would stabilize producer profits by decreasing costs associated with episodic BVDV outbreaks. Second, while currently no countries impose import controls on BVDV, it may be the case that in the future imports from countries with BVDV would be restricted. Eradicating BVDV would lower future export risk. Third, the use of vaccinations as practiced in the U.S. beef industry tends to increase the mutations of BVDV strains. For this reason, many European countries place bans on live-vaccines and prefer not to vaccinate at all (Houe et al., 2006). A decreased use of BVDV vaccinations would decrease the risk of more virulent strains of BVDV emerging. Fourth, it is possible that the eradication of BVDV could help stabilize the fluctuation in beef prices and quantities of meat sold because region-wide BVDV infection rates vary from year to year (Viltrop et al., 2002).

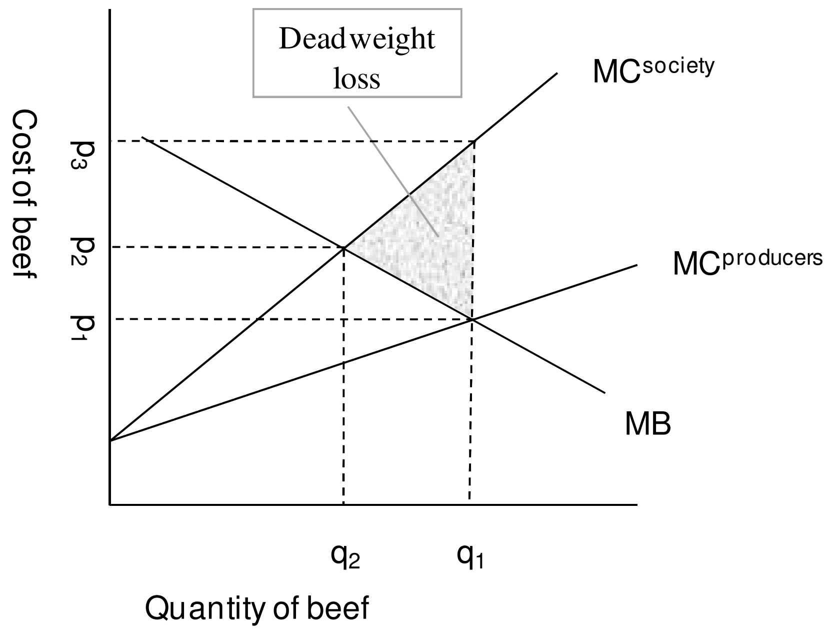
Eradication of BVDV would raise production standards for U.S. producers and increase animal welfare. Low-level infections for the majority of cattle would be reduced and the gaunt lives and painful deaths of PI animals would be eliminated. In addition, the establishment of measures to protect against BVDV would create new disease prevention institutions in the United States. Economies of scale likely exist for disease eradication, and the creation of BVDV monitoring programs would likely decrease costs of controlling or eradication other infectious diseases including Johne’s disease, Enzootic Bovine Leukosis, and Neosporosis.

2.4 Summary

It is likely that BVDV in the U.S. beef industry causes market failure from negative externalities associated with the sale of live PI animals. In addition, although eradication of

BVDV may be best from society's perspective based on analysis of costs and benefits of previous eradication programs and the fact that eradication would promote stability in the market, eradication is likely only to occur as a result of public sector involvement. This paper presents an analysis of the cost of BVDV infection in a typical cow-calf producer and measures the cost of live PI animal sales. In this process, an important model is developed that will enable more complete analysis of BVDV eradication in the United States. A main goal of future research in this area will be to measure the costs and benefits of BVDV eradication to identify the most appropriate strategies for U.S. policymakers to pursue.

Figure 2.1 Production of beef by all beef producers



CHAPTER 3. BACKGROUND

This chapter provides background on the nature of the disease, the European experience with control programs, a description of vaccines available for control of BVDV, and available information on BVDV in the United States. First, the chapter presents the body of evidence on BVDV obtained over the past fifty years including BVDV pathology and producer costs. Second, the chapter explains the European approach to BVDV eradication and resulting costs. Third, the chapter presents a brief explanation of available BVDV vaccines. Finally, the chapter presents a summary of U.S. BVDV research. Understanding the evolution of BVDV knowledge and BVDV regulatory efforts is crucial for any attempt to move forward with BVDV control and eradication.

3.1 BVDV background

> "BVDV has proven to be multifaceted in the disease it produces and is arguably the most complicated bovine virus in its pathogenesis" (Deregt, 2005).

3.1.1 Transient BVDV infection

Four different syndromes of the BVDV infection are distinguished: transient BVDV infection, intrauterine infection, persistent infection, and mucosal disease (Liebler-Tenorio, 2005). A number of different subtypes of BVDV can be broadly categorized as either low or high virulence strains. Even this simple classification can be deceiving as effects of a particular BVDV subtype vary over geographical regions and cattle breeds. Low virulence infections generally result in subclinical effects that often go unnoticed by producers. Low virulence subtypes comprise the majority of BVDV infections (70 to 90 percent) (Evermann and Barrington, 2005). High virulence infections (or acute BVDV) are more likely noticed by producers due to symptoms of fever (105 degrees Fahrenheit or greater), diarrhea, anorexia, depression, and occasionally, severe bleeding and lesions (Liebler-Tenorio, 2005). Both low and high virulence strains suppress the immune system of infected animals and can lead to a variety of other diseases including pneumonia and respiratory track diseases. For both levels of virulence, the virus typically takes 5 to 7 days to incubate, is viremic up to an additional 15 days (though typically only a few days), and takes the animal an additional 3 to 14 days to repair direct damage associated with high virulence strains (Evermann and Barrington, 2005). BVDV primarily transmits through direct nose-to-nose contact and shedding in food sources. Less frequently, the virus can infect nearby animals up to 10 meters away by traveling as an aerosol, especially in humid barns (Evermann and Barrington, 2005; Houe et al., 2006).

A special genotype of high virulence, known as type-2 BVDV, affected cattle throughout the Northeast of the United States and Canada in the early 1990s. Type-2 BVDV infection resulted in severe hemorrhagic disease and dramatic calf death. In Quebec, an estimated 25 percent of the veal crop died between 1994 and 1995 as a result of type-2 BVDV infection (Deregt, 2005). Since the widespread outbreak of type-2 BVDV, few cases have been reported possibly due to the introduction of type-2 vaccinations.

3.1.2 Intrauterine infection

In the early 1980s, researchers began to understand the intrauterine effects of BVDV. It was learned that transient BVDV infection in the early, middle, and late stages of pregnancy (0 to 41 days, 42 to 150 days, and 151 days – birth) results in different intrauterine effects. The key finding was that transient BVDV infection of a pregnant animal between days 42 to 150 of pregnancy often persistently infects the fetus with BVDV. [1] At that time, a fetus is immune-incompetent and does not recognize the BVDV virus as foreign. As a result, a fetus becomes PI for the remainder of its life.

3.1.3 Persistent infection

PI animals are the primary reason the virus remains endemic in herds and there is general agreement that any successful control program should target these animals. That is because PI presence over several months results in BVDV transmission to the majority of susceptible animals (Paisley et al., 1996). PI animals suffer from growth retardation and weight loss (Campbell, 2004). They can also suffer from congenital defects (Liebler-Tenorio, 2005). PI animals die at an earlier age than uninfected cattle due, in part, to mucosal disease (Liebler-Tenorio, 2005). While alive, PI animals shed the virus in amounts roughly four times transiently infected animals (Thurmond, 2005). Despite the ill effects PI animals may suffer, a small percentage of PI animals appear clinically normal. As a result, the only accurate way to remove PI animals from a herd is to test animals directly, especially calves as they are more likely to be PI.

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[1] The date range here is flexible. Some research suggests the middle stage to be days 42-125 of pregnancy (McClurkin et al., 1984) while others suggests the middle stage is days 30-150 (Van Oirschot et al., 1999).

3.1.4 Mucosal disease

In addition to the discovery of PI animals, researchers recognized a link between PI status and mucosal disease (MD). Mucosal disease is a nasty event characterized by fever, severe diarrhea, gastrointestinal hemorrhages, erosions, and ulcers. MD affects animals older than 9 months and is inevitably fatal (Liebler-Tenorio, 2005). While studying MD, researchers learned that cytopathic and non-cytopathic biotypes of BVDV exist. Cytopathic strains are more aggressive. They destroy blood cells and are not sustainable in a host for long periods. Non-cytopathic strains, on the other hand, are capable of coexisting with a host indefinitely. After maternal antibodies fade, cytopathic strains can infect PI animals as the result of normal virus transmission, the administration of a live-vaccine (cytopathic strains), or the natural mutation of previously non-cytopathic strains of BVDV (Evermann and Barrington, 2005; Liebler-Tenorio, 2005). The result of cytopathic infection is MD. The immune system of PI animals does not recognize the new cytopathic strain as foreign because it resembles the non-cytopathic strain it inherited during intrauterine transmission. As a result, the cytopathic strain quickly destroys cells throughout PI animals and the infected animal literally bleeds to death within seven to ten days (Liebler-Tenorio, 2005).

3.1.5 Costs of BVDV

A wide variety of economic costs is associated with BVDV. Direct costs include labor, medical and veterinarian expenses. Young animals transiently infected may become dehydrated and require saline solution, antibiotics, a protective environment to rest, and a veterinary visit. Costs associated with PI animals include increased death rates in PI animals, decreased weight of PI animals, increased abortion rate resulting in fewer calves, increased abortion rate resulting in an increased culling rate, and decreased herd size due to unexpected culling of additional animals. In addition, BVDV is an immunosuppressant disease that may result in increased prevalence of other diseases.

Other potential costs include weight loss due to transient infection and milk production loss. Though animals, especially young animals, may lose weight because of transient BVDV infection, studies show that they possess a natural ability through lower metabolism and increased milk consumption, to gain all lost weight back within a month (Virtala et al., 1996; Lathrop et al., 2000). Decreased milk production during transient infection may occur but is not significant for cow-calf analysis.

3.2 European control programs

In the 1990s, researchers established the importance of PI animals in BVDV pathology and recognized the magnitude of associated economic costs. In addition, competitive (blocking) enzyme-linked immunosorbent assays (ELISAs) were developed that were able to detect BVDV antibodies cheaply and rapidly without the need for laboratory work. This advance allowed for inexpensive detection on a large scale (Lindberg and Alenius, 1999; Deregt, 2005; Moennig et al., 2005a; Houe et al., 2006). Armed with this new technology and information, in 1993-94 Denmark, Finland, Norway, and Sweden introduced mandatory, systematic, nation-wide eradication programs. These Scandinavian countries are on their way to BVDV eradication with general agreement on the economic benefit of these control programs (Walter et al., 2005; Houe et al., 2006). In fact, Norway is now BVDV free. A cost benefit analysis of Norway's eradication program reported total net benefit of $6 million dollars in the first five years of eradication and positive results after only the second year of eradication (Valle et al., 2005). While these countries varied dramatically in initial disease prevalence, from less than 1% in Finland up to 50% in Denmark, all countries took roughly 10 years to reach the final phase of eradication (Moennig et al., 2005a).

Eradication or control programs also have been implemented in other parts of Europe including Austria, Britain, France, the Netherlands, Germany, Portugal, and parts of Italy (Moennig et al., 2005a; Houe et al., 2006). In these countries, eradication or control programs are generally in the initial stages, with either voluntary or region-wide programs in place. Many of these nations have faced challenges with reintroduction of the disease in herds that were initially declared BVDV-free. While this may be due to the unsystematic approach taken in controlling the disease, including producers who are not fully informed of correct control practices, it also represents the challenge of controlling BVDV in dense cattle populations where correct biosecurity measures are not always implemented. To aid eradication in certain endemic areas of Germany and Austria, producers with BVDV-free herds have been advised to vaccinate all female cattle before their first pregnancy (Moennig and Greiser-Wilke, 2003). The hope of these programs is that as disease prevalence mitigates, vaccination will no longer be required to maintain BVDV-free herds. However, in the meantime, producers have begun to complain about the high cost associated with dual eradication and vaccination programs (Moennig et al., 2005b).

3.2.1 European eradication approach

Though the details of BVDV eradication have varied from nation to nation, the general approach has been similar (Figure 3.1). The first stage of an eradication program focused on the identification of PI animals. In countries that do not vaccinate against BVDV, this was done through serological tests of bulk milk. In countries that allow vaccination against BVDV, pooled blood serum was tested. Sometimes, sentinel calves were used (Houe, 1995; Pillars and Grooms, 2002). Herds were tested for a length of time (three years in Austria, for example) and if no positive results to BVDV were found, herds were declared BVDV-free. Otherwise, further tests were performed to identify and remove PI animals and, the process of stage 1 testing began anew. The final phase of continual monitoring and certification continues indefinitely. After successful, nationwide eradication, testing of a smaller percent of producers is required to maintain national BVDV eradication.

3.2.2 Costs of eradication

All producers in Scandinavian eradication programs had increased costs due to BVDV testing. Initial screening costs of bulk milk samples for dairy producers and pooled blood serum for cow-calf producers were low ($2 for one bulk milk test and $20 per 8 to 10 animals tested by pooled blood serum analysis). However, costs for producers that tested positive and subsequently identified PI animals were much higher. These producers' costs increased because all animals were tested using individual virus isolation, which costs $20 per test. In addition, all new calves born were tested for several following years and if PI animals were identified, follow-up virus-isolation testing was taken (Houe et al., 2006). All animals identified as PI were sold immediately for slaughter or, in the case of young animals, were euthanized resulting in no revenue. Finally, producers that initially tested positive for PI presence were banned from selling live animal for several years. Instead, all sale animals were sold for slaughter. This distorted producers herd size and significantly decreased revenue (Houe, 2005; Moennig et al., 2005a). In addition, in some areas, herds testing positive initially faced restrictions on the use of common pasture (Lindberg and Alenius, 1999). With the removal of PI animals, BVDV typically cleared herds within a few years. In some regions with high endemic BVDV rates, authorities advised vaccines for herds declared BVDV-free to lower the risk of re-infection (Moennig et al., 2005b).

3.3 BVDV vaccines

BVDV is arguably the most complicated bovine virus in its pathogenesis (Deregt, 2005). While there are currently over 160 vaccines in use in the United States, none has captured the market because current vaccines only protect against certain strains of the disease. Current vaccines do not provide full protection from the disease; neither do they provide full protection against intrauterine disease transmission (Fulton, 2005). Strains protected by particular vaccines vary from vaccine to vaccine and vaccine manufacturers create vaccines based on the needs of particular regions. For example, after the large outbreak of type 2 BVDV in the early 1990s, manufacturers added protection against type 2 BVDV to vaccines and are credited with low type 2 infection rates for the past 10 years (Deregt, 2005).

Few studies exist that quantify vaccine efficacy rates and those that do exist largely focus on the protection vaccines provide against fetal infection (Van Oirschot et al., 1999; Fulton, 2005). The available studies suggest that vaccinated animals provide between 60% to

100% fetal protection. In the United States, producer use of vaccines is widespread, especially in feedlots where purchased animals are often vaccinated on arrival. The BVDV vaccines are typically combined with other vaccines into a single dose and cost between $2.00 and $2.25 per head (Van Oirschot et al., 1999).

Two types of vaccines exist for BVDV: modified live viruses (MLVs) and killed viruses. MLV vaccines are less expensive than killed virus vaccines, because only a small amount of the virus is needed. Once the vaccine is injected in the animal, it self-replicates causing a low-grade infection. MLV vaccines are not recommended for pregnant cattle due to the risk of fetal infection (Thurmond, 2005). MLV vaccines have also been reported to cause severe disease if vaccines are contaminated with non-cytopathic BVDV strains during manufacturing. In addition, MLV vaccines given to PI animals may result in MD, though not always (Fulton, 2005). As a result, many countries ban the use of MLV vaccines, and if no ban exists, guidelines often suggest that cattle receive killed virus vaccines before receiving MLV vaccines.

To manufacture killed virus BVDV vaccines, a large amount of virus is grown and then inactivated. As a result, these vaccines are safer than MLV vaccines. Two doses are generally required for full immunization; however, the length of protection varies with some studies reporting low antibody titers and immune response after only 140 days (Fulton, 2005). Evidence from field studies reports that animals exposed to killed BVDV viruses have significantly lower antibody titers than animals exposed to either MLV vaccines or PI animals suggesting a lower efficacy of killed virus vaccines (Houe et al., 1994). As a result of the higher costs and lower effectiveness of killed virus vaccines, cow-calf producers prefer live-virus vaccines. Dairy producers, on the other hand, tend to use killed virus vaccines frequently due to year-round pregnancy practices and the negative effects live vaccines may have on pregnant animals.

3.4 Prevalence of BVDV in the United States

BVDV infection is endemic in cow-calf populations of the United States; however, quantifying this prevalence is problematic. Many herds in the United States receive vaccines and as a result test positive to serological conversion tests including inexpensive ELISAs. Direct testing is possible through virus isolation, but this costs $20 per test and results are delayed several days for laboratory cultures. The few estimates of BVDV prevalence in U.S. herds that exist tell a story of a small percentage of PI animals that transmit the disease to the majority of animals they contact. A study of herds in Ontario reported that 46 percent of animals in dairy herds were or had recently been infected with BVDV (Weersink et al., 2002). A study of Michigan dairy reported less than 28 percent of herds were infected, though this study surveyed only well-managed herds (Houe, 1995). In a survey of 256 beef herds throughout the United States, PI animals were identified in 3 % to 15 % of herds tested, with 0.13 % to 1.7 % of total animals being PI. Testing rarely reveals isolated PI animals; instead, an average of 3 to 4 PI are identified (Bolin et al., 1985; Houe, 1995; Wittum et al., 2001).

Several activities to control BVDV in the United States have been initiated by the private sector. The majority of veterinarians recommend the use of live and dead vaccines, though a significant percentage of producers have yet to adopt this practice. Herds that suffer from low pregnancy rates are encouraged to test for the presence of a PI animal in their herd. In addition, feedlot producers frequently vaccinate animals entering their feedlots.

At present, support for the eradication of BVDV is building, as exhibited in the position of the Academy of Veterinary Consultants (AVC) in support of eradication. Proposed BVDV eradication schemes in the United States closely mirror models developed by European nations (Figure 3.1). However, eradication in the United States would require a large commitment of resources that is difficult to support without a complete cost-benefit analysis of BVDV eradication.

Figure 3.1 General European eradication strategy

Stage 1	Initial tests to classify herd status
Stage 2	Follow-up tests, culling, and herd restrictions to restrict disease transmission
Stage 3	Continuous monitoring to confirm infection-free status and provision of biosecurity measures such as test certifications for individual animals

CHAPTER 4. COW-CALF MODEL

Since information on cow-calf production is not widely available, a stochastic simulation was developed for this paper and written in C++ to gain an understanding of BDVV transmission in cow-calf production and resulting financial costs. This chapter explains the model in detail to allow understanding and recreation. Model explanation is divided into herd management, BVDV transmission, and financial layers.

4.1 Type of production modeled

A stochastic simulation model was developed that simulated actions of individual agents (discrete-entity). The simulated herd was ideal in the sense that all mature animals were not pregnant and ready to be bred in the spring, producers culled animals on the exact date the model prescribed, and other diseases affected the herd with constant probability. The management structure was based on general industry recommendations of well-managed cow calf operations in the United States (Radostits, 2001). In the basic model, the producer did not purchase new animals. The herd was initially 100% susceptible to BVDV infection.

4.2 Herd management layer

4.2.1 Animal characteristics

An individual animal in the herd belonged to one of five categories: calves, prebreeding heifers, replacement heifers, first-calf heifers, and mature animals. Additionally, an animal was in one of three housing units according to dietary needs. Figure 4.1 illustrates how an individual animal category and housing unit changes over its lifetime.

4.2.2 Yearly production cycle

Three management activities occurred yearly (365 days in a year): breeding for 63 days beginning on May 5 (day 1 of the year), pregnancy checking on September 7 (day 123 of the year), and weaning on October 12 (day 160 of the year) (Radostits, 2001). Natural breeding was modeled with bull exposure occurring for 63 days (Radostits, 2001). The gestation period for all pregnancies was 282 days (Radostits, 2001).

Selection of the number of animals retained at weaning maintained on average 140 healthy first calf heifers and mature animals at the start of breeding each year (Table 4.1). Two constants were used in this equation. The first constant (equation 1.2) provided the number of calves needed on day 160 to expect one calf one year later on day 365 and the second constant (equation 1.3) provided the expected number of remaining stock one year later on day 365 given one animal on day 160. Equation 1.3 did not include animals with high parity (parity 7 or higher) as part of the healthy stock since the producer knew these animals would not remain in the herd 18 months later. The retention rule did not change when BVDV was introduced in the model because subclinical BVDV infection resulted in the expectation of future disease-free herd.

After the number of retained animals was determined, a weight based rule was used to select female calves. Ideally, calves with weight in the lowest and highest 10% were not retained and usually this was possible. When more calves were needed to reach the ideal number of retained calves, these boundaries were slowly relaxed until the desired number of calves were selected. The calves that were of too low and too high weight were automatically culled. Afterwards, one calf at a time was randomly selected and culled until the ideal number of retained calves remained.

4.2.3 Management and event decisions in the model

In an uninfected herd, possible exit events were pregnancy, gestation loss, classification as unthrifty, culling and death (Table 4.2). Death events for calves were modeled by selecting a random variable between zero and one at birth for calves. Calves died before the age of 15 days if this value was less than 0.063 and before weaning if this value was less than 0.07 (Radostits, 2001). To determine the exact day of calf death, a second random variable between zero and one was selected, multiplied against the maximum number of days the calf could survive (either 15 or the number of days from birth to weaning) and then rounded down to the nearest integer. On this future date, the calf died immediately. Death for animals over the age of one was similarly modeled. At the start of the year (May 5), a random variable between zero and one was selected. If it was less than 0.02, a second random variable was selected, multiplied by 365, and rounded down to the nearest integer. When the date equaled this selected date, the animal over the age of one died immediately. Therefore, the cumulative probability of death for calves and animals over the age of one without competing causes of exit was 7% and 2% respectively.

Pregnancy was modeled in a similar fashion. A conception success rate of 60 percent was assumed for each of three 21-day estrus cycles (day 1 to 21, 21 to 42, and 42 to 63) resulting in cumulative success rates of 60% by date 21, 84% by date 42, and 93.6% by date 63 (Radostits, 2001). At the start of breeding, a random variable was selected between zero and one for all animals more than one year old. If this variable was between 0 and < 0.6, 0.6 and < 0.84, or 0.84 and < 0.936 the animal became pregnant in the 1st, 2nd or 3rd 21 days of the simulation respectively. To determine the precise conception date within the selected estrus cycle, another random variable between zero and one was selected, multiplied by 21, and rounded down to the nearest integer. When the date equaled this selected date, the animal became pregnant.

Possible culling decisions for animals over the age of one were gestational loss, classification as unthrifty, unsuccessful conception, calf death, and old age. Animals with these characteristics were scheduled for culling at pregnancy checking if they did not have calves at foot or when calves were weaned if they did have calves at foot (Radostits, 2001). Gestational loss was modeled on day 200 of the year since the particular day of pregnancy loss was unimportant. Animals with gestational loss were culled at pregnancy checking regardless of pregnancy status. Classification as unthrifty was determined when calves were weaned. As a result, unthrifty animals remained in the herd for up to one year to give birth and wean a calf. All animals with calves that died before weaning were culled. Finally, animals that did not exit prior to parity nine (age eleven) were culled due to their age. When an animal was assigned to exit the model for multiple reasons, the event that occurred first was recorded as the exit reason, except in the case of death or old age. Death was always recorded as the exit decision and old age was only recorded if no other exit decision existed.

4.3 BVDV transmission layer

The viral transmission model was based on previously published work (Innocent et al., 1997; Viet et al., 2004; Ezanno et al., 2007). Animals were in one of five mutually exclusive disease categories for BVDV infection: protected by maternal antibodies (M), susceptible to infection (S), transiently infected (TI), recovered and immune (R) and persistently infected (PI).

4.3.1 Horizontal transmission

Table 4.3 summarizes information on horizontal transmission of the virus. PI animals are not included, as they remained PI for life. PI animals shed the virus considerably more than TI animals, as reflected in the default values of the transmission coefficients $\beta_1 = 0.5$ and $\beta_2 = 0.03$ and the inability of TI animals to transmit the disease between housing units (Moerman et al., 1994; Lindberg, 2003). In addition, BVDV transmission primarily occurred within housing units (Thurmond, 2005). Finally, the default values of the transmission coefficients between housing units were set equal ($\beta_{la} = \beta_a$ for all $a \neq l$), assuming identical transmission risk between housing units.

If a dam was immune to BVDV, her calves were born with disease status M; otherwise, calves were born with disease status S. For calves in disease status M, a random variable between zero and one was selected when the calf was born and compared with a triangular distribution to determine when the calf transitioned to disease status S (Table 4.3).[2] For animals in disease status S, transition to disease status TI was determined by comparing a daily selected a random variable between zero and one with the animal's corresponding housing unit's $\lambda(l)$. The transmission rate $\lambda(l)$ was recalculated whenever an animal was born, an animal exited the herd, or an animal's disease status changed in order to ensure heterogeneity of contact in disease transmission. If the random variable was less than the

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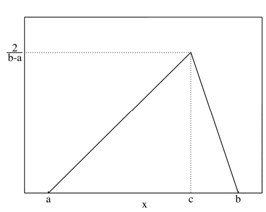


[2] A triangular distribution has a continuous probability distribution with a lower limit a, mode c, and upper limit b. A probability density function is shown for illustration.

transmission rate, another random variable between zero and one was selected and compared against 0.33, 0.66, and 1 to determine if the incubation period was 5, 6, or 7 days long. After the incubation period elapsed, the animal transitioned to disease status TI and began to shed the BVDV virus (Evermann and Barrington, 2005). For animals in disease status TI, a random variable was selected daily and compared against 0.2. If the random variable was less than 0.2, the animal transitioned to disease status R and remained in this category until exit from the herd. TI infection was assumed not to affect death, weight gain, or culling decisions of affected animals.

4.3.2 Vertical transmission

Table 4.4 summarizes information on vertical transmission of the virus. When an animal was assigned to become pregnant, if she was in disease status TI or had transitioned to disease status R within four days, she had a 50% chance of not becoming pregnant. If pregnancy did not occur, the animal was reassigned a random pregnancy variable and was given a 60 percent likelihood of successful pregnancy every subsequent 21 days (Grahn et al., 1984; Kafi et al., 1997; Viet et al., 2004).

When a pregnant animal transitioned to disease status TI, reproductive dysfunctions occurred (Table 4.4). For these animals, a random variable was selected between zero and one and compared against a cumulative distribution based on the stage of pregnancy of the animal (Table 4.4). Effects were stored in dummy variables until birth, when they were assigned to newborn calves. The result of embryonic death, fetal death or abortion for dams less than 42 days pregnant was immediate embryonic death. However, if the dam was more than 42 days pregnant, a delay of between 30 and 90 days was simulated before abortion occurred. In this case, a random variable between zero and one was multiplied by 60, added to 30, and rounding down to the nearest integer (Kendrick, 1971; Done et al., 1980; Viet et al., 2004). If an animal gave birth before having an abortion, the abortion did not occur.

4.3.3 Effects of persistent infection[3]

50% of PI animals died each year due to PI status (Duffell and Harkness, 1985; Innocent et al., 1997; Cherry et al., 1998; Viet et al., 2004; Ezanno et al., 2007). At the beginning of a PI animal's life, a random variable between zero and one was drawn and never updated. For PI animals, this variable was compared daily against a power distribution using the standard C++ library math.h with parameters 0.0019 and the age of the animal. This was equivalent to a half-life of one year. In addition to a higher death rate, PI animals also have lower weight gain. A weight difference of 43 kg (94.6 lbs) was assigned to all PI animals at weaning (Campbell, 2004). PI animals that survived to be bred, always gave birth to PI calves. During a PI animal's pregnancy, an additional 50% chance of gestational loss was modeled based on the best guess of the author to account for increased potential for early abortion.

4.4 Financial layer

The financial layer calculated costs and revenue to determine the cost associated with BVDV infection. To that end, only costs that varied with BVDV prevalence were measured:

[3] Several alternative approaches for PI effects are part of the current literature. Young PI calves may have a lower death rate than older PI animals due to antibodies in the colostorol provided by its mother (Innocent et al., 1997; Ezanno et al., 2007). In addition, TI infection may have different intrauterine effects on pregnant animals and a higher chance of PI creation between day 1 and 42 of the pregnancy (Innocent et al., 1997). Further analysis of less ideal cow-calf structures, including overlapping birthing/breeding would also be of interest.

veterinarian visits and medication costs, labor costs, and feed costs. All financial calculations were discount in order to determine the net present value of future returns. A rate of 5.47% was used from Moody's AAA rating in May 2007 (Moody's Investors Services, 2007)

4.4.1 Veterinary / medical and labor costs

Routine medical and veterinarian costs were $12.30 per year and labor costs were $12.25 per year for all animals in the herd based on 2006 Food and Agricultural Policy Research Institute (FAPRI) average prices for beef producers in the United States (FAPRI Staff, 2007). Costs for most animals experiencing TI infection were negligible; however, calves that remained sick at least two days (roughly 60% of calves experiencing TI infection) incurred additional treatment costs of $19.01 in 2002 Canadian dollars ($13.57 in 2006 U.S. dollars) due to increased use of saline solution and the possibility of veterinarian visits (Gow et al., 2005).[4] After the first year of record, future vet and medical costs were inflated using CPI estimates (FAPRI Staff, 2007).

4.4.2 Feed costs

Baseline feed costs for summer (April 15 to Nov. 1) and winter (Nov. 1 to April 15) were estimated using commercial beef cattle ration formulation software (Dahlke, 2003). Price per day for animals and detailed rations are described in Table 4.5 and 4.6 respectively. All feed components, including pasture, were assumed to be variable costs. After the first

[4] 2002 Canadian dollars were converted to 2006 U.S. dollars using average 2002 exchange rates and the U.S. consumer price index.

year of record, the price of each feed component was updated using future predicted prices (Table 4.7).

4.4.3 Revenue

In order to calculate revenue, animal weight was first determined. Animal weight varied between 75 and 1,400 pounds and grew in a non-stochastic fashion. At birth, an animal had a base weight of 75 to 83 lbs depending on the age of its dam (Table 4.8). Between birth and either age 190 or weaning (whichever was happened first), calves gained weight based on normal growth rates (Table 4.9) and on the age of their dam (Table 4.8) (Rumph and Van Vleck, 2004). Afterwards, animals gained weight at summer and winter rates (Table 4.9). The benefits provided by an animal's mother continued until it reached the maximum weight of 1,400 pounds.

Using an animal's weight, the current month and the current year, sale price and revenue was calculated using data from St Joseph feedlot in Oklahoma City provided by Dr. John Lawrence at Iowa State (Table 4.10). Future prices were calculated by multiplying an index of St. Joseph's prices by projected future slaughter and feeder prices (FAPRI Staff, 2007). Revenue was then calculated by multiplying price by an animal's weight. This calculation was performed when an animal was sold and yearly at breeding when the value of the herd was estimated.

4.5 Computer simulation

The model was coded in C++ using Visual Basic development tools and will run on any machine that has a C++ compiler. Characteristics and costs for individual animals were updated daily and output data were saved in multiple formats. Formats included data on changes in individual animal characteristics, daily herd summary data, and yearly herd-level summary information. Analysis in this paper refers only to yearly herd level data; however, agent specific information is available on request. All data were saved in csv format and analyzed using Excel. Multiple warning lines were written in the code providing protection against inappropriate program actions. In addition, the program was checked systematically to verify correct operation by a second programmer.

Table 4.1 Retention formula for calves at weaning[†]

$$\text{Retained} = \text{E[Calves]}(140 - \text{E[Stock]} \times \text{Herd}) \qquad \text{Equation 1}$$

Calves: animals less than one year old not weaned from their mothers

Stock: all replacements, first calf heifers and mature animals

Herd: all first calf heifers and mature animals

$$\text{E[Calves]}_{t,...,(t+570)} = [1/(1-\text{Death}_{t,...,(t+205)})][1/(1-\text{Gest.Loss})][1/(1-\text{CalfLoss}^{90\%})][1/(1-\text{Death}_{(t+205),...,(t+327)})]$$
$$[1/(1-\text{CalfLoss}^{10\%})][1/(1-\text{NotPregnant})][1/(1-\text{Death}_{(t+327),...,(t+365)})][1/(1-\text{Unthrifty})] = 1.221 \qquad \text{Equation 2}$$

$$\text{E[Stock]}_{t,...,(t+570)} = [(1-\text{Death}_{t,...,(t+205)})(1-\text{Gest.Loss})(1-\text{CalfLoss}^{90\%})]^2(1-\text{CalfLoss}^{10\%})$$
$$(1-\text{Death}_{(t+205),...,(t+327)})(1-\text{NotPregnant})(1-\text{Death}_{(t+327),...,(t+365)})(1-\text{Unthrifty}) = 0.7367 \qquad \text{Equation 3}$$

Where:

$\text{Death}_{(t+327)...(t+365)} = 0.002027$ $\quad$ $\text{Gest.Loss} = 0.02$ $\quad$ $\text{CalfLoss}^{90\%} = 90\% \times 0.07 = 0.063$

$\text{Death}_{(t+205)...(t+327)} = 0.006740$ $\quad$ $\text{NotPregnant} = 0.064$ $\quad$ $\text{CalfLoss}^{10\%} = 10\% \times 0.07 = 0.007$

$\text{Death}_{t...(t+205)} = 0.011233$ $\quad$ $\text{Unthrifty} = 0.03$ $\quad$ $t = \text{time}$

E[] = expected future number of animals

[†] Retention formula only valid when measuring at weaning (the remainder of t / 365 equals 160)

Table 4.2 Possible exit reasons for all animals

Affected Categories[†]	Exit	Description	Probability
C (age 1-15 days)	Death		(6.3 / 15)% per day for 15 days[‡]
C (age 16 days-N_i)	Death		(0.7 / (N_i-15))% per day for N_i-15 days where N_i is the number of days animal i was a calf [‡]
C	Cull	Weaning (male)	100%
C	Cull	Weaning (female)	number needed to replenish herd: Retained = E[calves]*(140 - E[stock]*totalStock)
P, R, F, M	Death		2%
P, R, F, M	Cull	Gestational loss after pregnancy check	2%
P, R, F, M	Cull	Calf loss	7% [‡]
P, R, F, M	Cull	Unthrifty[*]	3%
P, R, F, M	Cull	Unsuccessful conception	6.4%[**]
M	Cull	High parity	deterministic, if parity equals 9 (avg. 3.9% of herd annually)

[†] C: Calves; P: Pre-breeding Heifers; R:Replacements; F:First Calf Heifers; M:Mature Cows

[‡] These probabilities are the same (total calf deaths = total mothers culled due to calf loss)

[*] Culled due to bad teeth, bad eyes or other physical defects

[**] A conception success rate of 60 percent was assumed for each of three estrus cycles resulting in a 93.6 percent successful conception rate (Radostits, 2001).

Table 4.3 Default horizontal BVDV transmission rates for all animals

Transition[†]	Distribution	Parameters	Source
M-S	Triangular	min = 60 max = 120 mode = 90	(Thurmond, 2005)
S-TI	$\lambda(l) = S \times \left[\beta_1 \frac{PI_t^l}{N_t^l} + \beta_2 \frac{TI_t^l}{N_t^l} + \sum_{\alpha \in (other\ subgroups)} \beta_{la} \frac{PI_t^a}{N_t^l N_t^a} \right]^{\ddagger}$	β_1=0.5 β_2=0.03 β_{la}= β_a= 0.1	(Radostits and Littlejohns, 1988; Moerman et al., 1993; Viet et al., 2004)
TI-R	1/5		(McGowan et al., 1993)

[†] M: protected by maternal antibodies; S: susceptible; TI: transiently infected; R: recovered (immune)

[‡]λ(l) is the transmission rate. l is a specific housing unit. a is a specific housing unit where $a \neq l$. S is an indicator for season equal to 1 in the winter and ½ in the summer. PI_t^l the number of PI animals in housing unit l at the time t. N_t^l the total number of animals in housing unit l at the time t. TI_t^l the number of TI animals in housing unit l at the time t; β_1 and β_2 are the transmission coefficients with housing unit l and β_{la} ($a \neq l$) is the transmission coefficient between pens

Table 4.4 Default vertical BVDV transmission probabilities for pregnant animals experiencing a transient infection

	Outcome					Source
Stage of pregnancy (days)	Embryonic death or fetal death or abortion	Calf protected by maternal antibodies	Calf persistently infected	Immune calf	Calf with congenital defect	
0-41	0.2	0.2	0	0	0	(Carlsson et al., 1989; McGowan et al., 1993)
42-150	0.2	0.025	0.7	0.025	0.05	(Done et al., 1980; McClurkin et al., 1984)
151-282	0	0	0	1	0	(Kendrick, 1971; Moerman et al., 1993)

Source: (Viet et al., 2004) Appendix D p.232

Table 4.5 Per day feed costs for all animals in U.S. dollars calculated using 2006 costs

	Calves	Pre-breeding Heifers	Replacements	First Calf Heifers	Mature Cows
Summer	0.227	0.407	0.476	0.518	0.554
Winter	0.000	0.798	1.052	1.098	1.138

Source: (Dahlke, 2003)

Table 4.6 Per pound average daily ration components for all animals[†]

	Pasture	Corn silage	Grass leg 2nd	CRP hay	Corn (dry)	Distiller grain	Grower mineral
Calves (s)[‡]	10	0	0	0	0	0	0.1
Calves (w)	0	12	4.8	0	1.2	0.6	0.1
Pre-breeding heifers (s)	150	0	0	0	0	0	0.12
Pre-breeding heifers (w)	0	20	8	0	2	1	0.12
Replacement heifers (s)	170	0	0	0	0	0	0.19
Replacement heifers (w)[*]	0	25.5	0	17	1.4	0	0.19
First calf heifers (s)	186	0	0	0	0	0	0.196
First calf heifers (w)[**]	0	27.9	0	18.6	0.66	0	0.196
Mature cows (s)	200	0	0	0	0	0	0.2
Mature cows (w)	0	30	0	20	0	0	0.2

[†] Five percent of provided food was assumed to be wasted or trampled.

[‡] (w) = Nov. 1st to April 15th (s) = April 15th to Nov. 1st

[*] Heifers consumed 85% of the amount mature animals consumed

** First calf heifers consumed 93% of the amount mature animals consumed.

Table 4.7 Beginning feed cost and inflation index for each component of feed ration component

Ration component	Initial model price	Index used to inflate prices
Pasture	$.0025 lb of grass[†]	FAPRI pasture projections
Corn silage	$28 per ton	FAPRI U.S. hay prices
Grass leg 2nd	$79.68 per ton[‡]	FAPRI U.S. hay prices
CRP hay	$66.40 per ton[*]	FAPRI U.S. hay prices
Feeder steer price	$117.59 dollars per cwt.	FAPRI 600-650 # Oklahoma City feeder steers prices
Slaughter cow price	$47.73 dollars per cwt.	FAPRI utility cows, Sioux Falls prices
Dry corn	$3.16 per bushel	FAPRI U.S. corn prices
Distiller grain	$107.47 per ton	FAPRI U.S. distillers, brewers grains prices Lawrenceburg, IN
Grower mineral	$13.50 per 50 lbs	FAPRI National PPI projections

Source: (FAPRI Staff, 2007)

[†]Pasture price was determined as follows. Four tons of dry matter can be obtained from an acre of land per year. Grass is roughly 80% water, giving us 40,000 lbs of grass per acre. Due to grazing, half of this grass is trampled or wasted leaving 20,000 lbs for consumption. Rent per acre was approximately $50. As a result, price per pound of pasture was $.0025/lb. This price could be higher if costs of fencing and lost weight due to animal movement were considered. This price could also be lower, even close to zero, if government subsidies, tax incentives and cost of bailing hay were included. Given the scope of this project, only a rough estimate of pasture cost was required.

[‡]20% increase from CRP hay prices.

[*] 60% of the FAPRI national CRP hay averages were used for 2006 Midwest costs.

Table 4.8 Additional weight added at birth and weaning with adjustment for dam age[†]

Age	Parity	Birth	Weaning	
		All cattle	Steers	Heifers
2	1	0	0	5.94
3	2	2.86	20.02	23.98
4	3	5.94	39.82	41.8
5-10	4-8	7.92	59.84	59.84
11+	9	4.84	39.82	41.8

Source: (Rumph and Van Vleck, 2004)

[†] While heifers benefit more from the age of their dam, overall weight effects cause steers to weigh more than heifers.

Table 4.9 Animal weights in pounds based on age of animal

Category	Start age (days)	End age (days)	Start weight (lbs)	End weight (lbs)	Average daily gain (lbs)
Calf - steer	0	130	75	350	2.12
Calf - heifer	0	130	75	345	2.08
Calf - steer	131	190	350	500	2.25
Calf - heifer	131	190	345	475	2.17
Prebreeding heifer	191	355	475	825	2.12
	356	555	825	1200	1.88
First calf heifer	556	720	1200	1175	-0.15
	721	920	1175	1250	0.38
2 to 3 years old	921	1085	1250	1225	-0.15
	1086	1285	1225	1300	0.38
3 to 4 years old	1286	1450	1300	1275	-0.15
	1451	1650	1275	1350	0.38
4 to 5 years old	1651	1815	1350	1325	-0.15
	1816	2015	1325	1375	0.25
5 to 6 years old	2016	2180	1375	1350	-0.15
	2181	2380	1350	1400	0.25
6 years old and greater	2381	2545	1400	1375	-0.15
	2546	2745	1375	1400	0.13

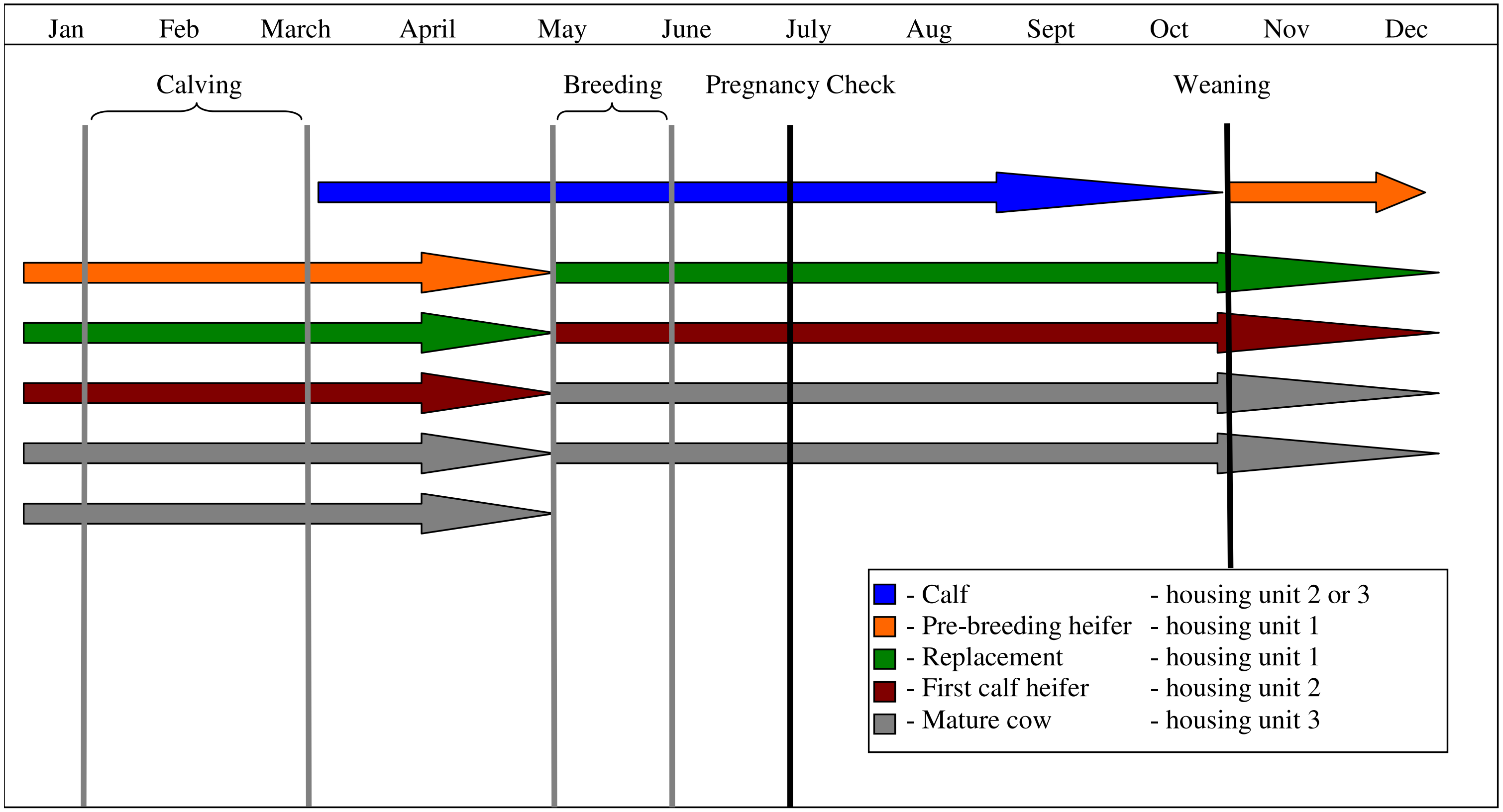
Table 4.10 Baseline sale prices per hundredweight for live calves based on weight and month[†]

	Steers (calves)				Heifers (calves)				Slaughter
	< 400	400-500	500-600	600-700	< 400	400-500	500-600	600-700	800-1200
May	146.96	136.56	128.41	120.04	119.06	114.22	110.41	105.14	49.05
June	150.50	149.00	134.07	121.76	146.54	129.14	124.51	114.00	49.31
July	140.00	142.78	136.63	125.74	130.19	124.85	124.95	115.42	49.28
August	155.00	140.02	131.56	126.14	135.50	126.27	122.67	121.17	49.50
September	159.79	142.37	136.36	130.63	140.80	132.45	122.43	120.57	51.25
October	147.14	131.71	123.14	117.48	127.57	118.41	110.79	108.15	49.55
November	145.72	123.25	110.00	101.88	113.23	110.68	99.22	97.03	43.16
December	132.70	118.55	111.33	106.17	114.38	101.89	96.83	99.02	43.16
January	136.35	123.35	113.02	100.76	119.52	105.30	98.12	94.07	48.13
February	138.00	125.23	113.79	103.43	124.04	108.85	100.38	93.16	48.13
March	142.64	133.14	125.15	114.55	127.42	119.82	112.70	104.25	48.13
April	147.28	135.14	130.84	122.18	123.24	117.25	111.39	108.46	49.73

Source: St Joseph feedlot, Missouri 2006

[†] In the model, slaughter animals were older than one year old

Figure 4.1 Flow diagram illustrating how an individual animal's category and housing unit change over time in the cow-calf model



† Regardless of age, animals scheduled for culling are housed in unit

CHAPTER 5. RESULTS

This chapter presents financial costs and benefits when one PI carrying animal is introduced to the simulation. First, initial conditions and types of simulations performed are provided. Second, results are given for simulations introducing 1 PI animal. These results are divided into epidemiological and financial results. Finally, a sensitivity analysis is performed of the key transmission rate.

5.1 Simulations performed

5.1.1 Initial conditions

154 calves, 0 pre-breeding heifers, 40 replacements, 32 first calf heifers, and 133 mature cows were created on the first day of the simulation (May 5). Animal age was assigned randomly according to initial classification of potential age. Of the mature cows, 22.5%, 15.8%, 15.0%, 7.5%, 16.7%, 10.0%, 8.3%, and 4.2% had parity 2, 3, 4, 5, 6, 7, 8, and 9 respectively. Calves were randomly assigned to 93.6% of first calf heifers and 93.6% of mature cows. Bulls were not modeled. The herd structure was based on a client herd of Dr. Terry Engelken.

5.1.2 Data collection

The model ran for three years before herd statistics were gathered in order to insure that initial conditions played a minimal role. During that time, no epidemiological or financial information was collected. Three years and 280 days into the model, a pregnant first calf heifer was introduced to the herd. This first calf heifer was previously TI, and though recovered, had a PI fetus. She was in excellent health and gave birth successfully under all simulations. To avoid an increase in profit associated with introducing another animal in the herd, the new animal simply replaced an existing first calf heifer in the herd and gave birth as previously scheduled.

From the third year of simulation onwards (the first year of record), a variety of statistics were recorded. Epidemiological data were collected on the number of PI calves at weaning, the last day a PI animal was present in the herd, the percent of animals pregnant at pregnancy checking, and the percent of animals susceptible to BVDV infection. Financial data were collected on profit, revenue, and costs with summarized results reported in this paper and detailed information available on request.

Initially, 1,000 simulations of a BVDV-free herd were compared against 1,000 simulations introducing one PI animal to costs of introducing a PI carrying animal and costs of the birth of a second generation of PI animals. Next, 1,000 simulations of a BVDV free herd were compared against 1,000 simulations of four different BVDV transmission rates in order to analyze the sensitivity of the transmission rate. While verification with real-world data was not performed, this model rests on previously verified models, suggesting results are similar to real world events (Viet et al., 2004; Ezanno et al., 2007).

5.2 Results

5.2.1 Epidemiological results

To gain a general understanding of the way BVDV affects the herd, 100 simulations introducing a PI animal were run and then ranked according to the severity of the BVDV outbreak. The average number of PI animals in the herd determined the severity of an outbreak. The number of susceptible animals (S), PI animals (PI), and animals carrying a PI fetus (carrying PI) are reported for the 33rd, 66th, and 100th most severe outbreak of these simulations (Figure 5.1). The top three graphs in Figure 5.1 show the percent of susceptible animals in the herd over the ten-year simulation. Initially, 100% of animals were susceptible, and after the birth of a PI calf, the percent of susceptible animals dropped to zero over the next year. Afterwards, the percent of susceptible animals varied cyclically throughout the year. Cyclical variability was caused by the birth and weaning of calves, which were more likely to be susceptible to BVDV than older dams. Animals immune to BVDV remained in the herd long after PI animals exited.

The middle set of graphs in Figure 5.1 depict the number of PI animals in the herd. A considerable number of PI animals were born in all three scenarios. To keep this in perspective, for 26 percent of scenarios (a level lower than shown here), the presence of a PI calf did not create a second generation of PI calves and cleared the herd in the first year of record. The middle PI graphs show gaps when all PI animals exited the herd but several months later new PI animals were born, continuing the outbreak. This is a classic sign of a BVDV outbreak and can lead to misdiagnosis in the field. The lower three graphs of Figure 5.1 depict the number of animals carrying a PI fetus. In this study, as with previous research, the number of pregnant animals carrying PI fetuses is small after the first year of outbreak (Viet et al., 2004). This suggests that the birth of a third generation of PI calves is unlikely.

PI animals can persist in a herd for many years (Figure 5.2). 3.0% of simulated herds did not clear the disease after ten years. On the other hand, 26% of herds cleared BVDV within the first six months due to low disease transmission and high PI calf death rates. Dramatic reductions occurred yearly at weaning when the majority of calves and roughly 20% of mature animals were sold. PI calves faced an even lower likelihood of retention because the weight based retention rule discriminated against PI animals by automatically selling ten percent of the lowest weight animals. The lower weight cutoff was, on average, 515 pounds resulting in the automatic culling of 60% of PI animals (Figure 5.3). As a result, measured annually just before calves were weaned, 67% of PI animals in the herd after the first year of record were calves.

5.2.2 Financial results

1,000 simulations of a BVDV-free herd were compared against 1,000 simulations introducing a PI carrying animal to determine the difference attributable to the introduction of a PI carrying animal (Table 5.1 and Figure 5.4). Financial results report on the differences between two simulations since data obtained from a single simulation has little interpretable meaning. This is because no effort was made to account for producer costs that did not vary with BVDV infection. Nor were government payments or tax effects considered. However, the difference between herds with no PI animals and herds introducing one PI carrying animal (with otherwise identical initial conditions), presented the full effect of introducing a PI carrying animal to the herd.

Producer outcomes were bimodal: either a substantial BVDV outbreak occurred or introducing a PI carrying animals had little financial impact. This main cost of introducing a PI carrying animal occurred when a second generation of PI animals was born (Table 5.1 and Figure 5.4). 26% of simulations did not create a second generation of PI animals and resulted in lost profit of $459 over 10 years in net present value terms. This loss includes the possibility of the PI calf dying before weaning and TI infection costs for some calves. In addition, of simulations without a second generation of PI animals, 44.7% resulted in profit higher than the average profit level of a BVDV-free herd. When a second generation of PI animals was born, lost profit increased to an average of $18,738 per herd over 10 years in 2006 net present value terms. Nominally, this translated to roughly $2,200 per year. Only 3.8% of simulations with second generation PI animals had profit greater than average profit of a BVDV-free herd. Using a t-test, data were statistically significant at the 99% level (Table 5.1).

Financial losses due to the introduction of a PI carrying animal have several explanations. First, 23% of producer losses were due to direct treatment costs of calves transiently infected with BVDV. Second, lower conception rates and higher abortion rates decreased the number of calves born leading to a decrease in revenue (Figure 5.5). On average, 29.5 fewer calves were born when a PI carrying animal was introduced to the model. Third, the birth of PI animals resulted in increased death rates and lower revenue. Roughly $5,000 loss can be directly attributable to PI animal deaths and resulting loss of calves.[5] Decreased conception rates and increased abortion rates resulted in higher than expected culling rates for animals over the age of one. As a result, low-value breeding stock was sold and high-value calves were retained. In addition, herd size decreased because the producer's retention rule at weaning did not consider BVDV effects and because the producer did not purchase outside animals to maintain herd size (Figure 5.5). The smaller number of potential mothers magnified the effects of a decrease in the conception rate.

[5] Average PI related deaths over 10 years are 5.7, 1.1, 1.5, and 1.4 calves, prebreeding heifers, animals over the age of one, and animals over the age of one that would have given birth to a calf respectively. Discounting these values for the year of occurrence and multiplying potential lost calves from animals over the age of one by 0.85 to account for calf exit, we get $4,931 or approximately $5,000 attributable to PI related deaths in 2006 adjusted dollars.

With the introduction of a PI carrying animal, average costs decreased for all years while decreases in average revenue principally occurred between years 2 and 5 (Figure 5.6). With fewer animals in the herd, average feed, labor, and veterinarian/medical costs decreased. Even after accounting for treatment cost increases, the average result of introducing a PI animal was a decrease in costs. Revenue decreases were concentrated in years following a large number of PI calf births (years 2-5). During these years, PI calves died and fewer animals over the age of one were retained due to lower conception rates and higher abortion rates. These cyclical patterns of lower calf sales may be part of the reason U.S. cattle prices are not stable.

When considering costs of PI purchase for producers, it is also important to consider risk. The introduction of a PI carrying animal increased variability in producer profit from $10,307 to $12,894 over ten years. Risk adverse producers dislike increased volatility and would be willing to pay to limit volatility. Further analysis of BVDV risk preferences for beef producers would be interesting to consider in future work.

5.3 Sensitivity analysis

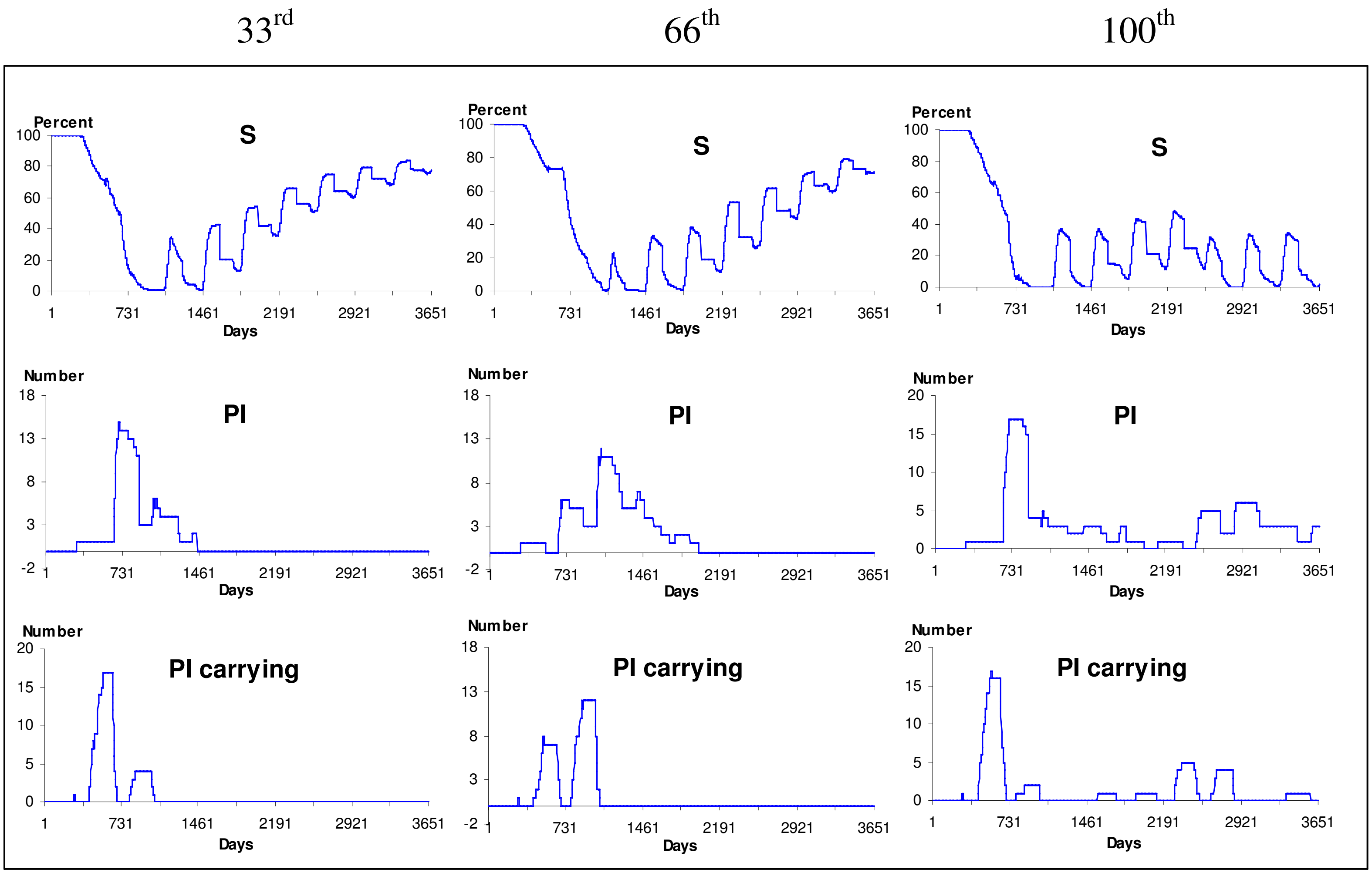
A sensitivity analysis of the BVDV transmission rate was performed because coefficient values were derived from scarce published data. Simulated PI transmission rates were low, normal, high, and very high (β_1 values of 0.1, 0.5, 1.5, and 2.5 respectively) following previous work (Viet et al., 2004). Significant differences arose in BVDV prevalence rates (Figure 5.7); however, profit was similar across the simulated transmission rates (Figure 5.8). As the transmission rate increased, BVDV infection was transmitted through the herd more quickly causing initial large outbreaks and costs but also reducing later outbreaks and costs since the herd quickly developed immunity to BVDV. Lower transmission rates had lower costs per year attributable to BVDV, but because of increased persistence of PI animals, aggregate costs were slightly higher than simulations with higher transmission rates. Under low BVDV transmission, a significant portion of herds retained PI animals after 10 years (39.3%). Final profit differences after 10 years were -15,829, -$14,557, -14,076, and -14,639 for low, normal, high, and very high transmission rates respectively.

Table 5.1 Changes in financial measures caused by the introduction of a PI carrying animal in net present value adjusted 2006 U.S. dollars

		Number of simulations	Profit	Revenue	Feed costs	Labor costs	Treatment costs	Veterinarian and medical costs
Second generation of PI animals born	Average	744	-18,596	-21,429	-5,125	-1,077	4,229	-1,082
	Standard deviation		(504)	(671)	(165)	(29)	(27)	(29)
No additional PI animals born	Average	256	-459	-118	99	-16	210	-16
	Standard deviation		(773)	(1016)	(245)	(43)	(11)	(44)
All simulations introducing a PI carrying animal	Average	1,000	-13,971	-15,995	-3,793	-807	3,204	-810
	Standard deviation		(532)	(689)	(169)	(31)	(59)	(31)

†All values statistically significant at the 95% level

Figure 5.1 The number of susceptible (S), persistently infected (PI), and PI carrying animals after introducing one PI carrying animal†



†Of 100 simulations, the 33rd, 66th, and 100th most severe outbreaks are shown.

Figure 5.2 Final persistence date of born PI animals for 1,000 simulations when one PI carrying animal was introduced

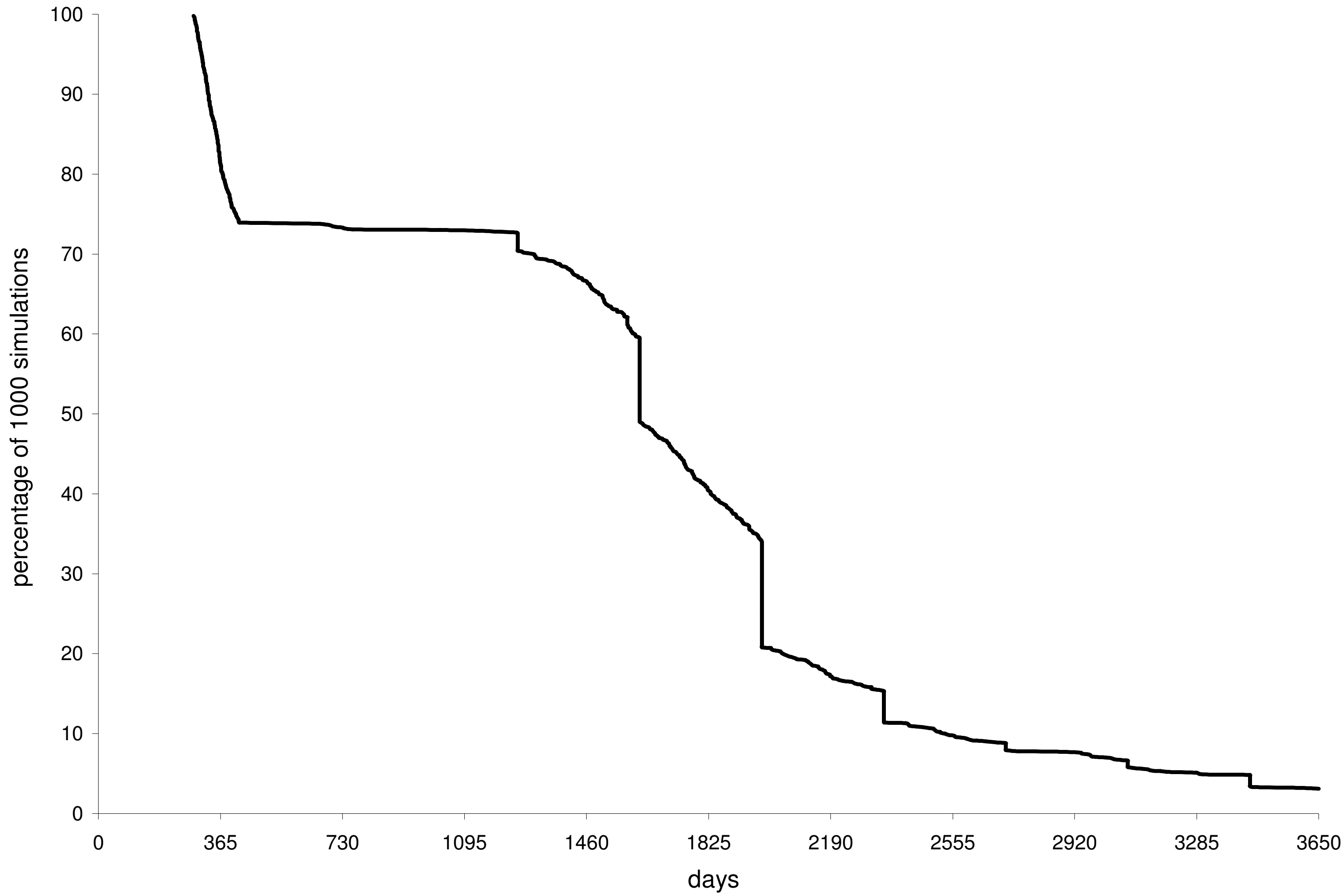


Figure 5.3 Distribution of weights for persistently infected and healthy female calves at weaning for 10 years of 100 simulations

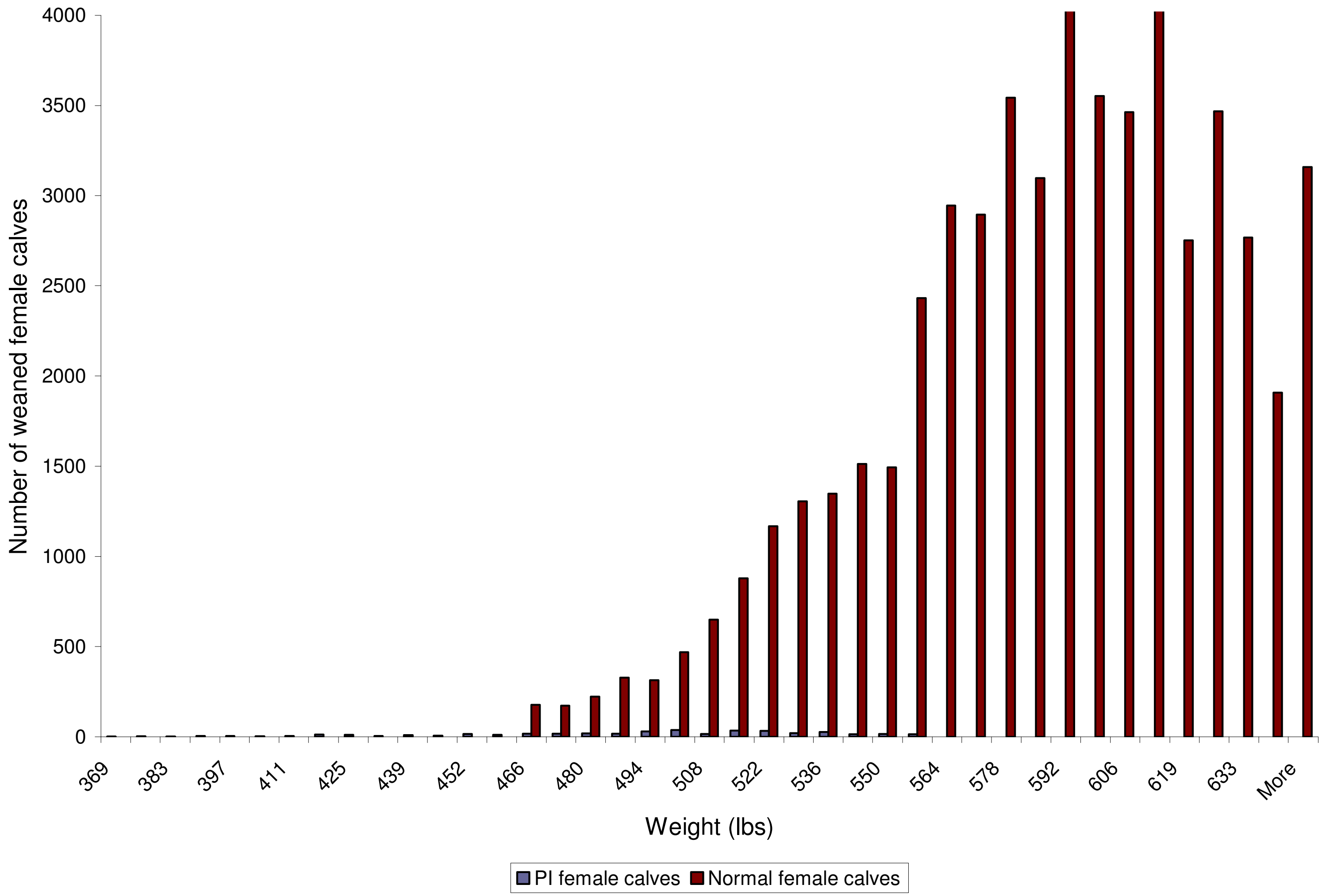
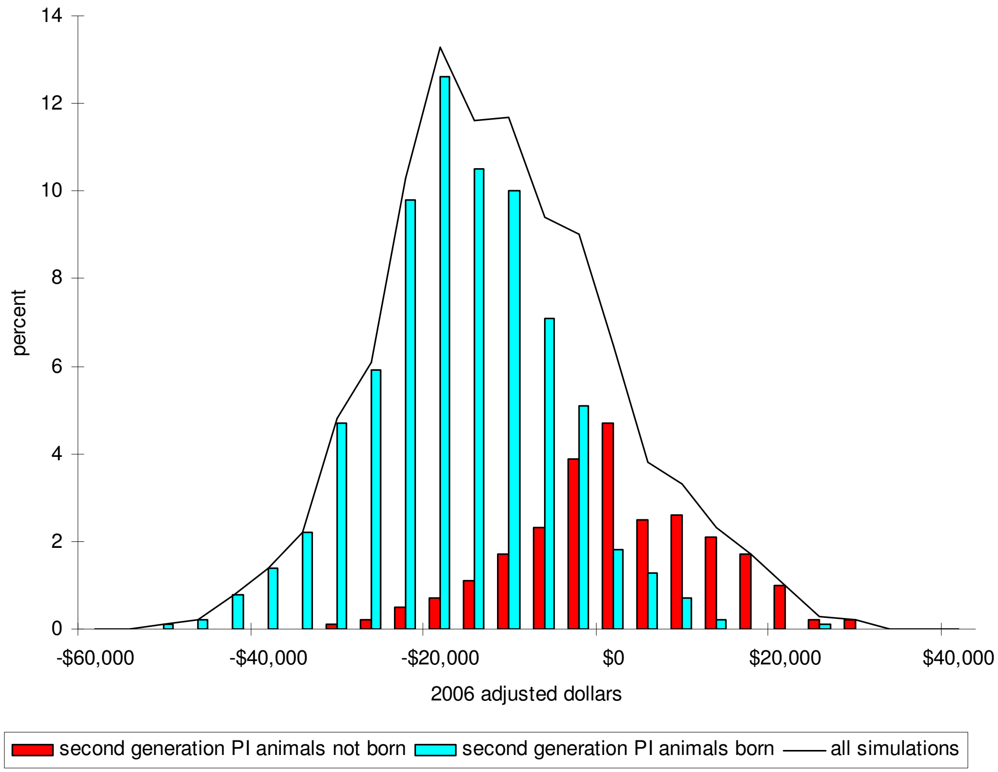


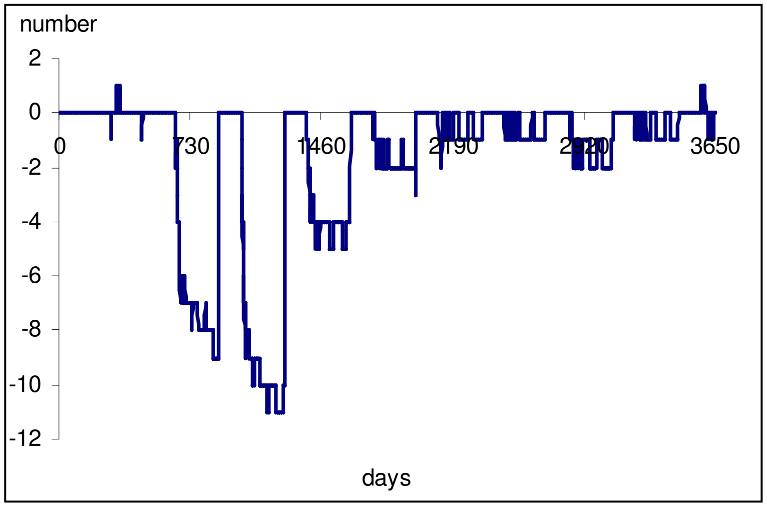
Figure 5.4 Change in profit from the introduction of one PI carrying animal over 10 years [†]



[†]Average profit for a BVDV-free herd over 10 years in 2006 adjusted dollars was subtracted from profit based on 1,000 unique simulations introducing a PI carrying animal. These results were further subdivided between simulations creating (aqua) and not creating (red) a second generation of PI animals.

Figure 5.5 Change in herd size and number of calves caused by the introduction of one PI carrying animal over 10 years

Animals over the age of one year



Calves

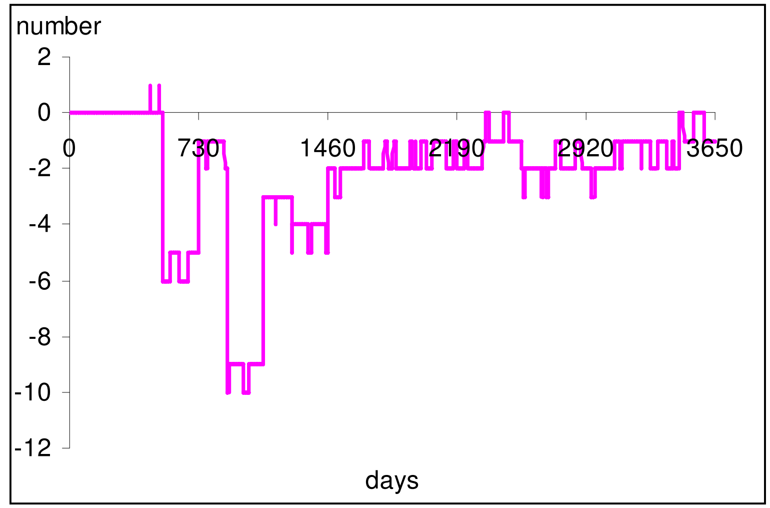


Figure 5.6 Changes in revenue and total measured costs over time caused by the introduction of one PI carrying animal in 2006 net present value adjusted U.S. dollars

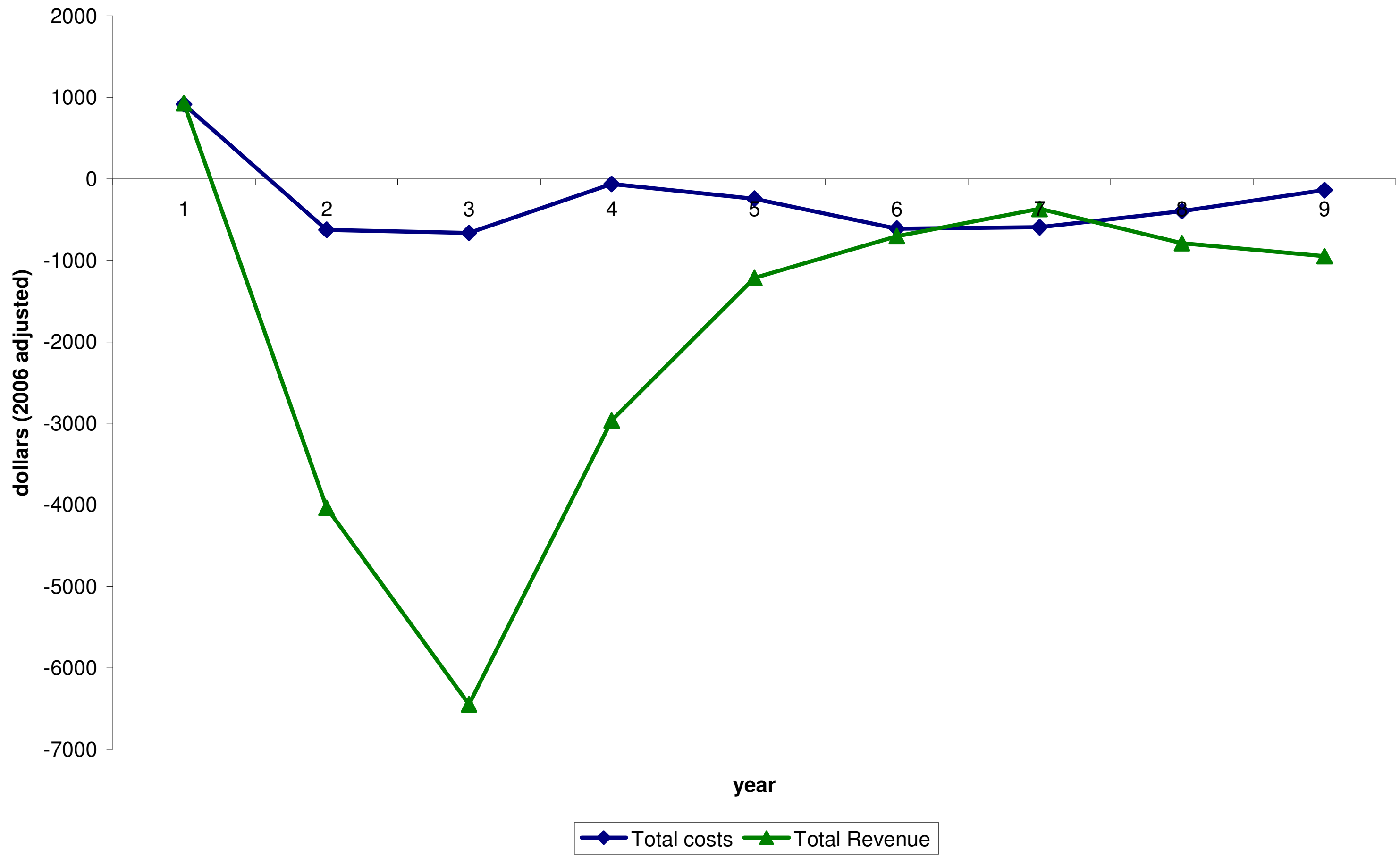


Figure 5.7 PI persistence for various PI transmission coefficients (β_1 values) after the introduction of one PI carrying animal on day 280

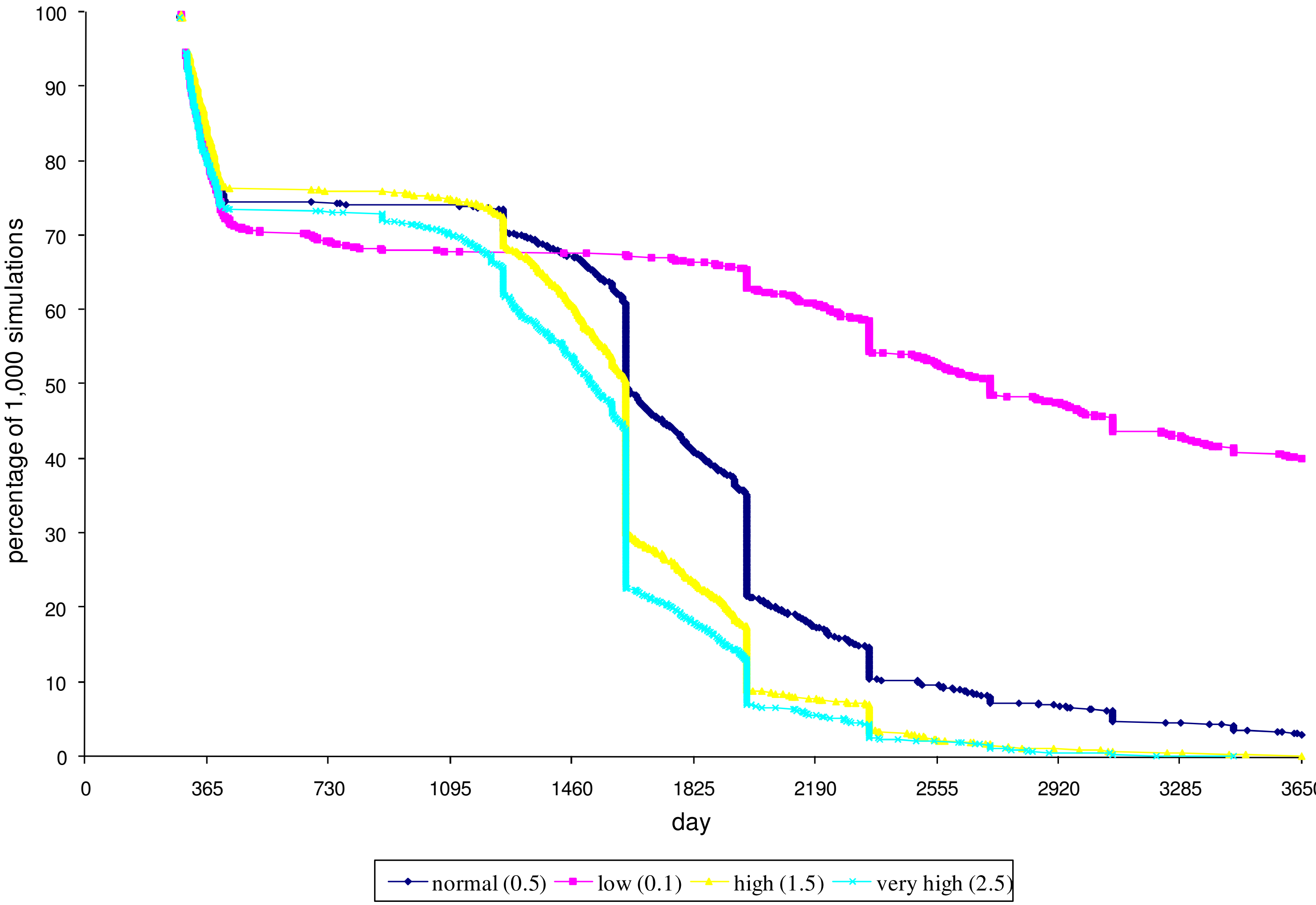
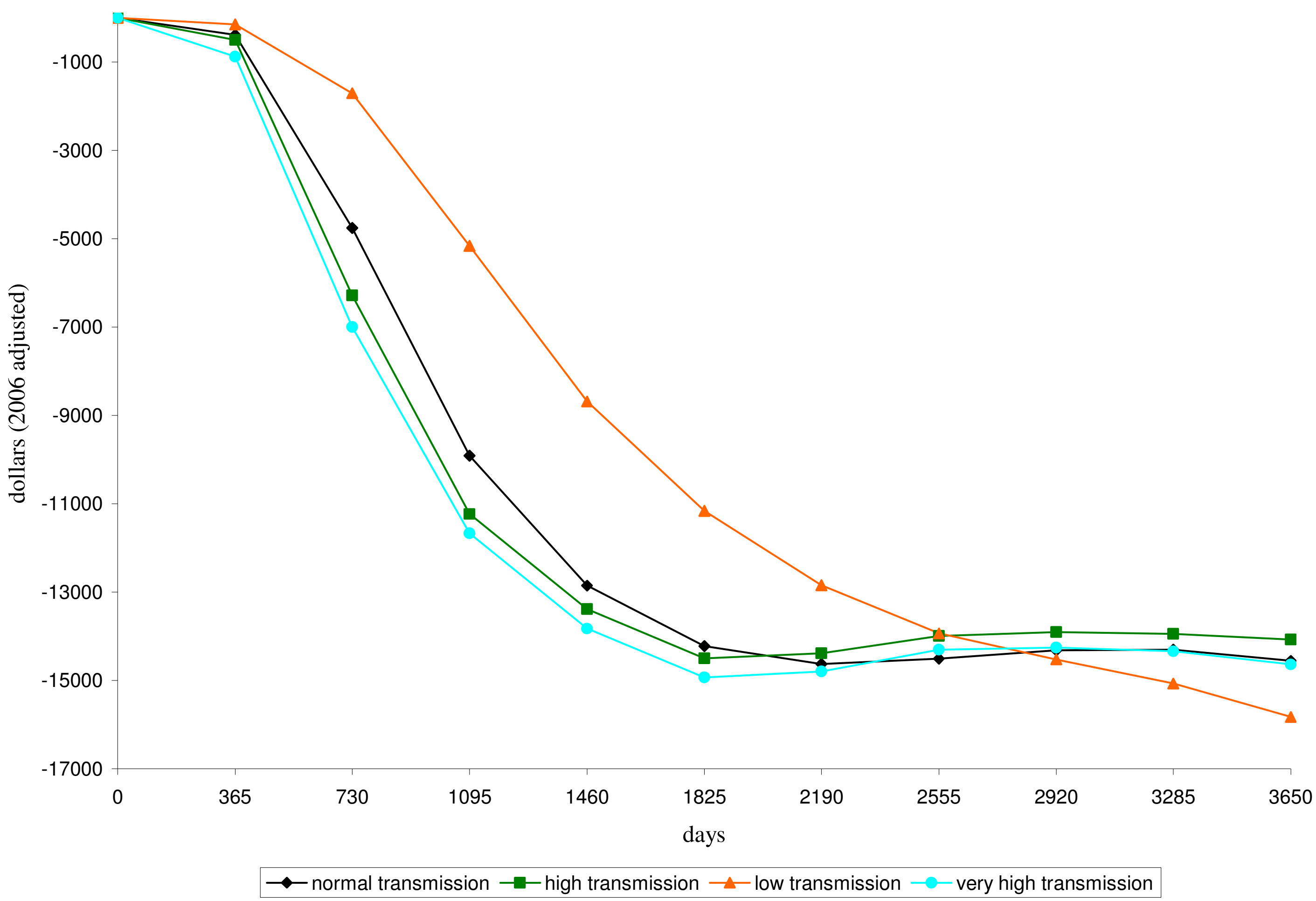


Figure 5.8 Aggregate change in profit over time after introduction of one PI carrying animal in net present value adjusted 2006 U.S. dollars



CHAPTER 6. ANALYSIS OF VARIOUS TEST AND CULL METHODS

In practice, producers do not often test for the presence of PI animals in their herds. Producers that do test for BVDV either test yearly regardless of herd characteristics or only test when motivated by an indicator of PI presence. This chapter presents financial costs and benefits for three common testing approaches at four levels PI carrying animal introduction. First, model parameters are motivated and explained for all test and cull simulations. Second, epidemiological results are introduced. Finally, financial benefits of testing strategies are presented.

6.1 Materials and methods

6.1.1 Producer motivation types

Two motivation methods were simulated for all test and cull methods. The first motivation method was unmotivated testing defined as yearly testing regardless of indicators of PI presence. Yearly testing started in the first year of record before a PI carrying animal was introduced. The second motivation method was motivated testing defined as testing only if a producer is motivated by an indicator of PI presence in his herd. A typical measurement used by veterinarians is low pregnancy rates. Average pregnancy rates of a BVDV-free simulations measured at pregnancy checking compared with animals alive at pregnancy checking was 93.6% with a standard deviation of 1.9%. When one PI carrying animal was introduced, average pregnancy rates measured at pregnancy checking compared with animals alive at pregnancy checking dropped to 90.9% with a standard deviation of 2.1%. It is difficult to argue that a producer would notice a drop in pregnancy rate any higher than 85%;

however, only 9.9% of simulations introducing a PI carrying animal resulted in a pregnancy rate of 85% or lower at pregnancy checking. In response, our model used a better indicator of PI presence in the herd so that more than a few outlying data points were considered.

The number of calves at foot just before cows began breeding was chosen as the motivator for BVDV testing because it captured all of the effect of PI presence on the herd and allowed for testing before breeding allowed the possibility of another wave of intrauterine effects. The number of calves at foot when cows were bred decreased when PI animals were present due to lower conception rates caused by TI infections, higher abortion rates caused by TI infection, increased calf death caused by higher PI calf death rates, and decreased herd size caused by increased deaths and culling. The average number of calves at breeding in a BVDV-free herd was 147 with a standard deviation of 6.35. When a PI animal was present, this dropped to an average of 140 with a standard deviation of 7.59. Therefore, although average pregnancy rates at breeding dropped only 2.7% (number of pregnant cows at pregnancy checking / number of cows bred at the start of breeding), the average number of calves at weaning dropped 5.0%. Though still imprecise, counting calves at the start of breeding was a more robust measure than measuring the pregnancy rate at pregnancy checking. The selected motivation rate was three standard deviations below a BVDV-free herd (less than 129 calves just before breeding). If a producer had fewer than 129 calves, he was motivated to test according to his test and cull strategy. The selected motivation rate rarely occurred for producers with healthy herds (< 0.2% over 10 years) but occurred often for simulations introducing one PI animal (26.7% over 10 years).

6.1.2 Risk of PI introduction

Risk of PI carrying animal introduction was 0, 1, 3, or 5 animals following the example of previous literature (Viet et al., 2004; Ezanno et al., 2007). At the lowest risk level, no PI carrying animals were introduced and testing for PI animals simply increased costs to the producer. At the second-lowest risk level, one PI carrying animal was introduced during the first year of record. At the second-highest risk level, one PI carrying animal was introduced during the first, fourth and seventh years of record. At the highest risk level, one PI carrying animal was introduced during the first, third, fifth, seventh and ninth years of record.

6.1.3 Testing methods

Three testing strategies were examined: testing all calves just before breeding (date 362), testing all retained calves after weaning (date 161), or a combination of these approaches where a producer tested all retained calves after weaning and, if a PI calf was discovered, follow up testing was performed just before breeding began. If a calf was tested just before breeding, it was never retested at weaning.

Animals were tested individually by immunohistochemical staining of skin biopsies. Ear notch tissue samples were collected, sent to a laboratory and results were received three days later. For model simplicity, costs of testing were assigned the date results were received (either day 161 or 362). Test effectiveness was high, with a 1% likelihood of PI calves testing negative and a 0% likelihood of uninfected calves testing positive (Njaa et al., 2000). Animals with TI infections also tested positive with a 20% likelihood and a 0% chance of false positives for uninfected animals. If a calf tested positive, its mother was also tested. If an animal tested positive, it was removed from the herd. Identified PI calves were euthanized for zero revenue, while PI animals over the age of one were immediately sold at the prevailing slaughter price.

Direct costs from testing included labor costs, tests and laboratory fees. Costs for the test and laboratory fees were estimated to be $3 in 2006 U.S. dollars per animal tested. Labor costs were estimated as one minute per calf tested for both testing at weaning and at breeding. Testing of mothers after receiving results of PI calves took an estimated 60 minutes per animal due to the difficulty of locating individual mothers. Per hour labor costs were taken from 2006 Bureau of Labor and Statistics (BLS) estimates for average hourly wage of farm-workers (BLS category 45-2093) equal to $9.92 per hour (BLS Staff, 2007). All testing costs were inflated after the first year of record using a 2007-2015 estimate of the CPI index (FAPRI Staff, 2007).

6.1.4 Simulation specifications

Two producer motivation types, four risk levels and three testing strategies were evaluated for a total of 21 combinations. For yearly testing, data reported was obtained by comparing 1,000 simulations testing and culling for PI animals yearly with 1,000 simulations doing nothing at the same PI introduction risk level. For motivated testing, data reported was obtained by comparing 1,000 simulations when the number of calves dropped below 129 on date 362 and motivated testing occurred with 1,000 simulations when the number of calves dropped below 129 on date 362 and no testing took place at the same PI introduction risk level. If the number of calves just before weaning dropped below 129 in any year it was included in motivated testing results. No results were reported for motivated testing for herds introducing zero PI animals because the number of calves was rarely below 129 on date 362 (0.1% of simulations). Comparing results between simulations with otherwise similar initial conditions ensured the only difference between results was the decision to test and cull for PI animals.

6.1.5 Testing assumptions

The well-managed structure of the herd allowed for simplification. First, animals older than one were not tested because herds were initially BVDV-free and only a small likelihood existed that PI animals matured past the age of one before death, culling, or testing and subsequent culling. Second, testing calves before the start of breeding implied the testing of all calves that year. A perfect break between calving and breeding existed, so that no calves were born during the period of breeding. As a result, testing and culling just before breeding nearly always broke the link between the presence of PI calves and the creation of another generation of PI calves through intrauterine effects. Future research may focus on herds with mixed calving/breeding cycles.

6.2 Results

6.2.1 Epidemiological results

PI animal persistence rates were lower when using test and cull methods than otherwise. For the risk level introducing one PI carrying animal, average PI persistence was 4.28 years (1564 days) when no testing method was employed. This dropped to 3.98 years (1454 days) for an average of all motivated testing methods and to 2.39 years (873 days) for an average of all yearly testing methods. Yearly testing was effective at reducing PI persistence rates (Figure 6.1). For all testing methods, testing calves yearly at breeding was by far the most effective strategy with 99.8% of simulations clearing the introduced PI calf before it was able to cause intrauterine effects. This was a result of the clear separation between birthing and breeding. Surprisingly, always testing at weaning was not effective. In fact, always testing at weaning resulted in a slightly increased persistence rate of PI animals after 10 years similar to the low transmission rate shown in Figure 5.7.

Motivated test and cull methods were effective at reducing PI persistence in the worst 20% of BVDV outbreaks (Figure 6.2). In the other 80% of outbreaks, the producer was not motivated to test and cull. Motivated testing at weaning, however, did not decrease PI persistence rates and may actually have increased them. The most effective strategy was to testing at weaning with possible follow-up at breeding. One reason testing at weaning resulted in low PI persistence rates was that testing at weaning was effective at identifying herds with PI animals. While testing revealed PI animals, it also revealed some calves experiencing transient BVDV infection. In fact, testing at weaning identified 5.6 transiently infected calves for every identified PI calf in simulations introducing 1 PI carrying animal. As a result, producers were able to identify PI presence in their herds 77% of the time by testing at weaning and the use of this information to remove PI animals at breeding was very useful.

6.2.2 Financial results

For producers testing yearly for BVDV, the only testing strategy to yield positive profits was testing at breeding (Table 6.1). However, yearly testing at breeding was also the most expensive yearly testing strategy when no PI animals were introduced ($3,651 in 2006 adjusted dollars for 10 years). Testing retained calves at weaning was effective at identifying herds with PI animals 77% of the time and was the least expensive yearly approach when no PI animals were introduced ($1,141 in 2006 adjusted dollars for 10 years). $1,141 is equivalent to increased costs of $0.18 per hundredweight for all calves sold at weaning in 2006 adjusted dollars.[6]

Motivated testing had the advantage of no cost when zero PI animals were introduced to the simulation (Table 6.2). In addition, when only one PI carrying animal was introduced, testing of any kind resulted in positive profits. Using a one-tail significance test, significance levels were 95.0%, 89.6%, and 95.5% for testing at breeding, at weaning, and at weaning with possible follow-up at breeding respectively. As more PI animals were introduced, benefits from delayed testing decreased and resulted in negative or ambiguous effects on profit.

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[6] Intervention costs were approximately $3.20 per retained calf each year. All retained calves were tested (an average of 45 calves) for the three initial years and in subsequent years only 10 calves were tested. Assuming an infinite horizon problem with a discount rate of 1.057, total testing costs were $880. The price of calves increased three years after testing, and remained higher indefinitely for each calf sold at weaning (an average of 66 calves were sold each year). Each calf weighed 500 lbs when sold. Therefore, total cost increased an average of $0.18 per hundredweight for each calf sold. Mandatory testing for all calves at weaning indefinitely raises total costs to $0.52 per hundredweight for each calf sold.

Table 6.1 Changes in profit when unmotivated test and cull methods are employed over 10 years in net present value 2006 U.S. dollars

Number of PI animals introduced	Producer type		Test and Cull strategies: Just before breeding	Test and Cull strategies: After weaning	Test and Cull strategies: After weaning with follow up at breeding if necessary
0	Unmotivated	Average[†]	-3,651[‡]	-1,141[‡]	-1,141[‡]
		Standard deviation[*]	(460)	(465)	(465)
1	Unmotivated	Average	8,498[‡]	-1,239[‡]	-758
		Standard deviation	(509)	(586)	(578)
3	Unmotivated	Average	12,528[‡]	-1,754[‡]	-3,982[‡]
		Standard deviation	(466)	(499)	(514)
5	Unmotivated	Average	12,040[‡]	-2,262[‡]	-5,084[‡]
		Standard deviation	(471)	(496)	(510)

[†]The difference between a producer doing nothing and a producer employing the above test and cull strategy

[‡]Results statistically significant at the 95% level

[*] $\sigma = \sqrt{\frac{\sigma^2_{\text{do nothing}}}{1000} + \frac{\sigma^2_{\text{test and cull}}}{1000}}$ Assumes that profits and the difference between profits were normally distributed.

Table 6.2 Changes in profit when motivated test and cull methods (number of calves < 129) are employed over 10 years in net present value 2006 U.S. dollars †

Number of PI animals introduced	Producer type		Test and Cull strategies: Just before breeding	After weaning	After weaning with follow up at breeding if necessary
1	Motivated	Average‡	731*	558	755*
		Standard deviation**	(445)	(444)	(445)
3	Motivated	Average	-1,613*	-165	-775*
		Standard deviation	(471)	(461)	(463)
5	Motivated	Average	-1,980*	-261	-779*
		Standard deviation	(462)	(457)	(466)

† Results were restricted to the subset of simulations experiencing fewer than 129 calves at the start of breeding during any one of the 10 years of record.

‡ The difference between a producer doing nothing and a producer employing the above test and cull strategy

* Results statistically significant at the 95% level

** $\sigma = \sqrt{\frac{\sigma^2_{\text{do nothing}}}{1000} + \frac{\sigma^2_{\text{test and cull}}}{1000}}$ Assumes that profits and the difference between profits were normally distributed.

Figure 6.1 PI animal persistence for unmotivated test and cull strategies after the introduction of one PI carrying animal on day 280

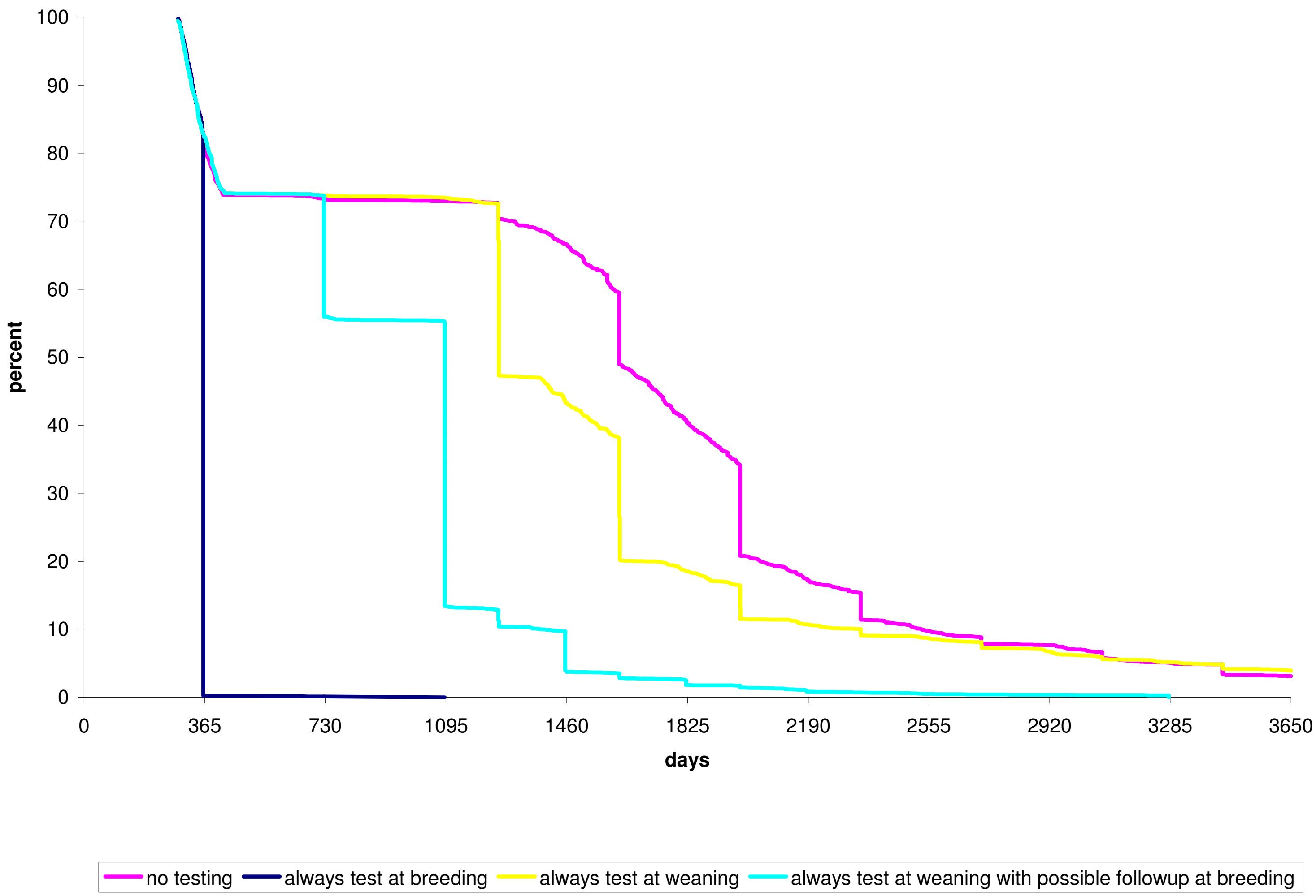
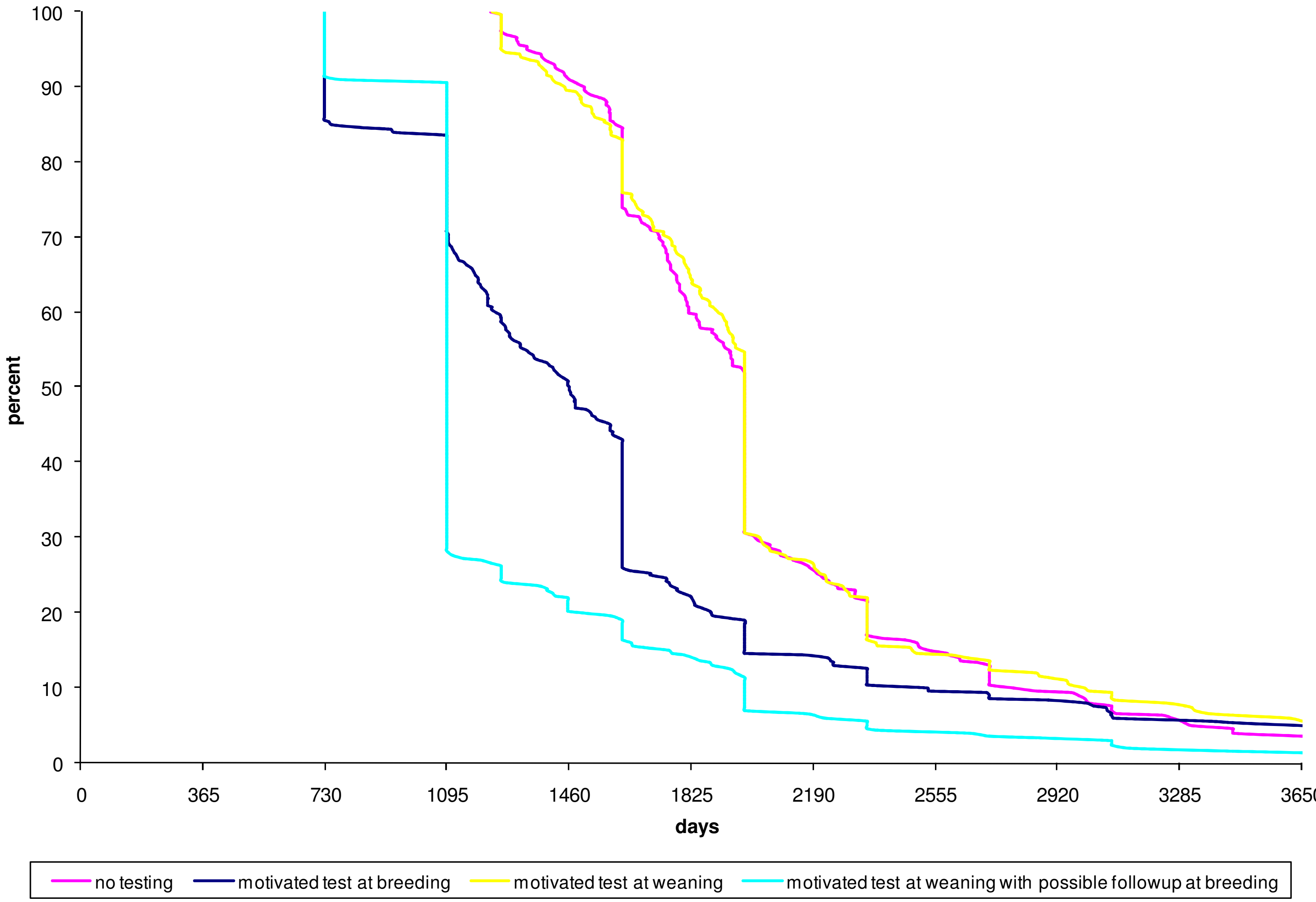


Figure 6.2 PI animal persistence after the introduction of one PI carrying animal for motivated test and cull strategies (< 129 calves) †



†Results show the subset of simulations experiencing fewer than 129 calves at breeding during the 10 years of record.

CHAPTER 7. DISCUSSION AND POLICY IMPLICATIONS

7.1 Individual producer BVDV testing

On average, producers with yearly breeding and low mixing between birthing and breeding benefit from yearly testing of all calves just before breeding if they experience high likelihoods of PI introduction. A risk-neutral producer with a susceptible herd should be willing to test yearly at weaning if he has a 43% chance ($3,651 / $8,498) or higher of introducing a PI animal in the next 10 years (see Table 6.1). Producers facing lower likelihood of PI introduction benefit, on average, from a motivated testing strategy based on a low number of calves just before breeding. For these producers with low PI introduction risk, testing at breeding or testing at weaning with possible follow-up at breeding brought roughly equal benefits. Actual producer results are bound to vary from herd to herd, and would be highly influenced by the degree of overlap between calving and breeding cycles.

In practice, the majority of cow-calf producers do not test for BVDV. This may be the result of producers employing a motivational test and cull approach and rarely needing to test. It could also be the case that other technologies are better at lowering costs from BVDV, such as vaccinations or biosecurity measures for newly purchased animals. Low-cost tests for PI animals are also a new technology and may take time before they are widely adopted. Further research on vaccination cost-effectiveness should be considered.

Yearly testing at breeding results in much higher profit than any motivated testing strategy whenever a PI animal is introduced. This is because motivational testing requires an outbreak of second-generation of PI animals before it is identifiable. Since the creation of a third generation of PI animals is unlikely (Figure 5.2), motivated testing often just increases costs by euthanizing PI calves. The costs for society, however, may be much different because PI animals sold at market cause large negative externalities. Public sector involvement in promoting BVDV testing would be a useful way to mitigate the sale of PI animals.

7.2 Public sector BVDV testing

Much debate surrounds BVDV eradication in the United States. In theory, the negative externalities associated with PI animal sales and insufficient BVDV control practices result in market failure. Previous eradication programs in Europe suggest successful eradication of BVDV can be done in a cost-effective fashion. Before policymakers act, though, a thorough cost-benefit analysis should be performed to determine the benefits of BVDV eradication. If an eradication program is established, several suggestions can be drawn from this research. First, when the goal of testing is to lower PI persistence rates, testing at breeding should be employed. Second, when the goal of testing is to only to identify herds with PI animals, regular testing of retained calves at weaning has a lower cost and is just as effective at identifying herds with PI animals. Third, profit-maximizing producers experiencing higher risk of PI purchase should be more willing to participate in testing schemes for BVDV eradication while producers with less risk of PI purchase will be more hesitant (Table 6.1).

One market-based approach would be to establish a voluntary herd-identification system. While BVDV testing of all retained calves at weaning is not profitable, over ten years it only costs a producer $1,141 in 2006 adjusted dollars. If purchasers of live cattle were willing to pay more for animals from certified BVDV-free herds, it may be possible to motivate producers to voluntarily test for BVDV. An estimate of the needed difference in price is $0.18 per hundredweight in 2006 adjusted dollars. If calves from herds declared BVDV-free command a price of more than $0.18 per hundredweight in 2006 adjusted dollars, voluntary testing for PI animals could be motivated and would result in increased net social benefit. Depending on the percent of animals requiring testing and the number of years certification testing would be required, this value could be significantly lower.

7.3 *BVDV eradication*

Eradication of BVDV has proven possible and cost effective in parts of Europe. In response, several U.S. veterinarian organizations have recommended the control and eradication of BVDV in the United States. The endemic presence of BVDV results in market failure, largely as a result of a lack of BVDV information when live animals are purchased. Eradication of BVDV has the possibility of bringing positive net benefits, however, it is unlikely to occur without public sector involvement. The free-rider problem ensures that individuals do not act in their collective interest and coordination problems plague any voluntary private sector initiative.

The introduction of a voluntary herd identification system may be an essential first step for any eradication program as a way to alleviate regulatory problems associated with the inevitable light touch mandatory U.S. regulatory infrastructure would demand. That is because U.S. regulatory agencies face problems of compliance and enforcement beyond that of European nations due to the much larger U.S. cattle industry and its distribution in relatively unpopulated, unregulated states. In addition, U.S. regulators face coordination difficulties between state and national agencies and across large geographical distances.

Initial results from European BVDV voluntary herd identification systems in areas with dense cattle populations (parts of Germany and France) suggest that voluntary identification systems may impose high costs for some participants and that subsidies may be necessary for large-scale producer enrollment. Data from chapter 6 on BVDV testing should be useful for policymakers when deciding whether to provide subsidies for voluntary herd identification and, if so, at what level.

At present, the cost and benefits of eradication of BVDV in the United States are widely unknown. Analogies can be drawn from several European nations' experiences to suggest that positive net benefits may exist, however overwhelming evidence does not exist and experts in the U.S. are only beginning to suggest eradication. Trends in research suggest that U.S. analysis is beginning and may provide some answers in the next few years. If this paper can stress one thing, it is that a national cost-benefit analysis of BVDV eradication strategies in the United States is highly recommended before any form of public sector intervention is considered. Though BVDV eradication could bring positive net benefits, current understanding of BVDV eradication in the United States is limited.

7.4 Further research

Results from this analysis and further adaption of this cow-calf model will be useful in future U.S. BVDV analysis. There is still much to learn about the interconnected pathology of BVDV between the dairy, cow-calf, and feedlot sectors. Different types of cow-calf producers could be modeled, such as mixed breeding cycles, twice a year breeding, and changes in yearly production parameters (Table 4.2). Different PI introduction risk levels could be modeled such as shared fences (multi-producer model) and ungulate wildlife transmission. Finally, additional biosecurity practices could be modeled including testing of all calves within days of being born in mixed breeding cycles, quarantining newly purchased animals, and vaccinations of various effectiveness. The next step for this model would be a multiple farm adaption to gain an understanding of the natural pattern of BVDV transmission between producers and the three segments of the beef industry.

In addition, analysis of BVDV eradication in the United States should consider producer willingness to participate in various steps of a possible eradication campaign. Regulators in the United States are stretched thin, and any successful eradication campaign will rely on individuals and local cattle organizations to help coordinate action.

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