A Research Framework for Evaluating the Economic Benefits of Antibiotics in Livestock Production: *Lawsonia Intracellularis* in Canadian Pig Production as an Example

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ABSTRACT

A RESEARCH FRAMEWORK FOR EVALUATING THE ECONOMIC BENEFITS OF ANTIBIOTICS IN LIVESTOCK PRODUCTION: *LAWSONIA INTRACELLULARIS* IN CANADIAN PIG PRODUCTION AS AN EXAMPLE

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Growing concern about antibiotic resistance has increased regulation and market pressure that limits a farmer's ability to use antibiotics and manage their business. Rather than focus specifically on resistance, effective regulation will also consider the value that different antibiotics provide to livestock producers. This study uses a simulation model of a Canadian farrow-to-finish pig farm to demonstrate how the economic benefit of different antibiotics can be measured. This is done by imposing *L. intracellularis* on the model and then evaluating which antibiotics and vaccines are the most profitable for managing the disease. If this were to be done for the most important diseases in each livestock industry, the results could be combined to determine which antibiotics are the most valuable for that sector. This study indicates that prophylactic chlortetracycline is the most profitable option for managing *L. intracellularis* while the two vaccine options are some of the least profitable options.

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CHAPTER 1

INTRODUCTION

1.0 Background Information

Antibiotic resistance is one of the most significant threats facing both human and animal healthcare systems today (Public Health Agency of Canada (PHAC), 2017). Less than a century after discovering penicillin, overuse and misuse of antibiotics has increased the rate at which antibiotic-resistant bacteria develop. This has rendered some antibiotics ineffective. With very few synthetic antibiotics being developed and no effective substitutes currently available, maintaining the efficacy of existing antibiotics is vital for the continued success of all healthcare systems (Davies & Davies, 2010).

It is well known that using antibiotics accelerates antibiotic resistance and that resistant bacteria can spread between humans and animals (Singer et al., 2003). Therefore, given the significant volume of antibiotics being used in livestock, many consider animal antibiotic use as one area that could be improved upon to reduce antibiotic resistance (PHAC, 2017). This perspective has led to a substantial increase in pressure by markets and governments for farmers to reduce the amount of antibiotics that they use. Recently, fast-food giants like McDonalds and A&W have both made commitments to purchase products that are raised using fewer antibiotics. Furthermore, the Canadian government will prohibit farmers from using antibiotics for growth promotion by December of 2018. At that time, they will also require that veterinarians prescribe any of the antibiotics being used for livestock.

There is significant debate as to whether or not livestock antibiotic use impacts human health through antibiotic resistance. Some argue that antibiotics have been given to billions of animals for decades, without there being any compelling evidence to suggest that this has

impacted human health (Cromwell, 2002). Bywater and Casewell (2000) studied the connection between livestock antibiotic use and antibiotic resistance in humans and concluded that only four percent of antibiotic resistance problems in human medicine originate from livestock antibiotic use. Similarly, Schwarz, Kehrenberg and Walsh (2001) reviewed research on antibiotic use and antibiotic resistance. In their study, they found that doctors and farmers are each responsible for the antibiotic resistance problems that their own systems face.

Despite this research, others argue that livestock farmers have used antibiotics in excess. Witte (1998) explains that when we use antibiotics for livestock, we are placing additional selective pressure on all bacteria, even the ones that infect humans. As a result, when farmers use more antibiotics, they are actually helping the resistant bacteria to thrive. This is because the resistant bacteria no longer have to compete against other bacteria, which have been killed off by the antibiotics. As farmers and doctors utilize antibiotics more frequently and for longer periods of time, they create the ideal environment for resistant bacteria to multiply and spread. Food from these animals is still safe but there is concern that the resistant bacteria might spread to humans through the farm workers who come in direct contact with the bacteria (Marshall & Levy, 2011).

Antibiotic resistance should always be the primary consideration for strategies that focus on reducing antibiotic use. However, it is also important to consider the economic benefit that antibiotics provide to farmers. When livestock become sick, there can be a significant decrease in herd health, production and farm profitability. In many cases, antibiotics are the only option available for managing these problems and reducing their availability will impact the ability of farmers to manage their herd and their business. Achieving successful antibiotic regulation will require a comprehensive understanding of how on-farm antibiotic use influences antibiotic

resistance and an understanding of how important antibiotics are for preserving the success of livestock industries. Policy that is too lenient has the potential to impact the efficacy of antibiotics in the future while regulations that are too strict may severely impact the profitability of livestock farms. This thesis is focused on researching how antibiotics impact the profits of livestock farms.

1.1 The Economic Problem

Human health research, media and consumer demand are increasingly driving market changes and regulatory changes related to agriculture and farming. These stakeholders are questioning the need for different tools and management practices that farmers use. Moving forward, the industry will need to be more transparent with the public about what farmers do on their farms. For the past 75 years, farmers have taken certain tools that they use for granted, without taking the proper steps to justify their use. Antibiotics are a good example of one of these tools and increased regulation on antibiotic use may reduce the productivity and economic viability of livestock farming.

For Canada, this risk is highlighted by the experience of Danish pig producers. In the early 2000s, Denmark changed its rules on antibiotic use, requiring that farmers receive a prescription to use antibiotics and banning the use of antibiotic growth promoters. Although initial antibiotic use dropped, pig populations continued to experience clinical disease in different forms. This led to an increase in the volume of antibiotics being used to treat sick pigs (Jensen, 2006). For the next ten years, Danish pig producers were using more antibiotics than before, with many of the antibiotics used being more closely related to those used in human medicine (Jensen & Hayes, 2014; Teillant & Laxminarayan, 2015). Not only did productivity fall on pig farms but the antibiotics being used may also have increased the risk that producers were

putting on human health. In 2010, Denmark introduced an extensive recording and monitoring system for all antibiotics. In that year, antibiotic use fell by more than 12% and since then, antibiotic use has generally continued to fall (Jensen & Hayes, 2014). This example highlights the economic problem that producers face under strict antibiotic regulation and demonstrates that different strategies for reducing antibiotic use can have significantly different outcomes.

1.2 The Economic Research Problem

Reducing antibiotic availability will make it more challenging for farmers to manage herd health and run a profitable business. Currently, there is very little data that quantifies the benefit that antibiotics provide to farmers. Therefore, as the industry transitions to reduced antibiotic use, it is unknown how certain antibiotic regulations will impact the profitability of farms. Research that determines which antibiotics provide the most benefit, which provide the least and which fall somewhere in between will help farmers to better understand this management problem. It will also help them to justify their practices and ensure that their position is considered when rules and regulations are created for antibiotic use on farms.

In order to provide this data, there are two approaches that researchers can take to measure the economic benefit that antibiotics provide to farmers. The first, is to assess one antibiotic and measure the benefit that it directly provides for each disease. The second approach is to focus on one disease and measure the benefit of each antibiotic that can be prescribed to manage it. This second approach makes more sense because researchers tend to have a better understanding of specific livestock diseases rather than specific antibiotics. Furthermore, by focusing on the major diseases, researchers will naturally be focusing on the diseases that are responsible for the majority of the antibiotics being used.

1.3 Purpose

The purpose of this study is to provide an example how the economic benefits of antibiotics can be measured for livestock. This example can then be used as a baseline for a future research program that is designed to estimate the economic benefit of antibiotics in all livestock. The findings from this program can then be used to inform decisions about how to reduce antibiotic use and ultimately reduce antibiotic resistance. Given the author's experience with swine, this research will be measuring the economic benefits of antibiotics and vaccines that can be used for managing one disease on a Canadian farrow-to-finish pig farm.

1.4 Objectives

1. *To develop an understanding of on-farm antibiotic regulation by examining the function and classification of antibiotics, the argument against on-farm antibiotic use, the argument for on-farm antibiotic use, antibiotic use on Canadian pig farms and the alternatives available to antibiotics for managing diseases.*

A thorough review of on-farm antibiotic use will be required in order to understand the current position of the Canadian pig industry. Understanding the complexity of antibiotics and their application is required in order to avoid overgeneralization of this economic analysis.

2. *To develop an understanding of the major diseases that impact swine farming and develop an understanding of the economic models used to evaluate livestock management options.*

Similar to Objective 2, a review of the major bacterial diseases that impact swine farming will be required to choose a suitable disease to be used for this research. Furthermore, reviewing the economic models that are used to evaluate livestock management will ensure that the proper model is selected and being used appropriately in this research.

3. *To develop an empirical baseline simulation model of a Canadian pig farm by collecting typical production values for Canadian pig farms.*

An empirical simulation model will be generated from typical production values on a Canadian pig farm. This will provide a production baseline that can be altered to reflect changes that arise from a disease and from using antibiotics to manage it. This empirical simulation will incorporate relevant price information for Canadian pig farms such as their input costs and their revenue.

4. *To simulate changes in profitability for a Canadian pig farm under one of the major diseases currently affecting Canadian swine farms by imposing this disease on the empirical simulation and observing changes in profitability.*

Prior to investigating antibiotic use, the effect of the disease on farm profitability must be evaluated. The effect of the disease on a swine farm's profitability can be measured by adjusting the farm's production values to reflect an infected herd and observing the effect that this has on profits in the simulation.

5. *To simulate changes in profitability for the infected Canadian pig farm using different antibiotics and vaccines to manage the disease by imposing these products on the empirical simulation and observing changes in profitability.*

The effect of antibiotics on the infected swine farm's profitability can be measured by adjusting the farm's production values to reflect antibiotic management and observing the effect that this has on profits in the simulation.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction to the Chapter

Significant background information is required to build a model that accurately reflects a specific livestock industry. Because this study will be using the Canadian pig industry as an example, most of this section will be focused on pig farming in Canada and the environment that these producers are working within. The chapter describes how antibiotics are classified, highlights both sides of the debate on livestock antibiotic use, describes current antibiotic use on pig farms and highlights some potential alternatives to using antibiotics.

2.1 Introduction to Animal Health, Economics and Antibiotics for Livestock

Research in economics and livestock health has provided veterinarians with significantly improved methods for helping the modern farmer to manage their herds. In addition to keeping animals healthy, veterinarians now have the tools to help farmers make profitable decisions on their livestock farms. However, the benefits of this research extend well beyond the farmer. Research that combines economics and livestock health provides governments and producer groups with information that helps them to do a better job of improving livestock industries. Epidemiological and health research provides veterinarians, farmers and governing agencies with information about the spread, control, and prevention of diseases. Combining this information with business data from farms allows economists to evaluate the costs of these diseases and the impact of different management strategies. This is the type of research that is needed to inform policy and regulation decisions for antibiotic use on livestock farms.

As shown in the previous section, there is significant literature that argues for and against antibiotic use in livestock. However, very few of these sources provide the background

information required to fully understand the debate at hand. Antibiotic use and antibiotic regulation are complicated subjects and doing research that can contribute to this literature requires an understanding of the function of antibiotics, antibiotic resistance, the economics of antibiotics, current antibiotic use and alternatives to antibiotics.

2.2 Function of Antibiotics on Swine Farms

Although antibiotics can be grouped in many ways, this research will focus on two classification methods. The first way that they can be grouped is relative to their importance to human health. The World Health Organization classifies antibiotics as either important (Class 4), highly important (Class 3), critically important (Class 2) or highest priority (Class 1). The second way that antibiotics can be grouped is by their function. On livestock farms, antibiotics serve four important functions in maintaining herd health (Schwarz, Kehrenberg & Walsh, 2001).

The first is the therapeutic function of antibiotics. Similar to antibiotic administration in humans, farmers administer antibiotics to their livestock to treat bacterial diseases. Because there are likely to only be a small number of animals being treated, the antibiotic can be administered by injection. In an ideal scenario, the veterinarian would diagnose the animal and prescribe the appropriate antibiotic and the appropriate dosage for the specific disease. However, specific identification of bacterial diseases generally requires several days because it can only be done through laboratory testing. This means that veterinarians or farmers must rely on their own experience to diagnose an animal or they must opt to prescribe antibiotics that target a wider range of bacteria with the hope that the problem bacteria will be controlled. Researchers of biosensors and nanotechnology are working towards improving on-farm disease identification through these technologies (Neethirajan, 2017).

The second function of antibiotics on swine farms is metaphylaxis. Metaphylaxis is the administration of antibiotics to the entire herd in a proactive manner when one member of the herd becomes sick. Because metaphylaxis requires the targeting of a large population, the antibiotic is often administered through the feed or water that the pigs receive. Metaphylaxis is seen as a precautionary measure that can save the farmer money by eliminating the costs associated with treating the pigs and the costs of raising sick pigs that have poorer performance (Page & Gautier, 2012).

The third function of antibiotics on swine farms is prophylaxis. Similar to metaphylaxis, prophylaxis is a precautionary administration of antibiotics to prevent and reduce the severity of bacterial diseases. However, prophylaxis is different than metaphylaxis in two ways. The first is that it is administered without an infected animal being diagnosed. Instead, prophylactic administration is performed during high stress periods, such as weaning or transportation, when it is more likely for the pig to become sick. Prophylactic administration might also occur if a farmer experienced previous disease problems and now provides antibiotics as a precaution to avoid the problem again. The second difference with prophylaxis is that it can be just as common to administer antibiotics to one animal, several animals or the entire herd.

The fourth function of antibiotics on swine farms is growth promotion. For growth promotion, antibiotics are often administered in very low doses through the pig's feed or water. The mechanism by which antibiotics improve growth in pigs is not exactly known. However, most theories are linked to the impact of antibiotics on the microbiome of the pig's digestive tract (Page and Gautier, 2012). Using antibiotics for growth promotion is the most heavily criticized function of antibiotics on livestock farms because it is believed to be an unnecessary contributor to the development of antibiotic-resistant bacteria.

2.3 Antibiotic-Resistant Bacteria on Swine Farms – Argument to Reduce Use

The Swann Report (1969) was one of the first documents to draw attention to antibiotic use in livestock as a public health concern. This report highlighted that many antibiotics used in human medicine are also used in livestock. Based on this observation, it was recommended that these antibiotics should not be used on farms because this could lead to an increase in the number of bacteria that are resistant to the antibiotics that humans use. Since the publication of this report, extensive research has been performed on antibiotic resistance in livestock and humans.

In 1992, Harold Neu wrote an article titled "The Crisis in Antibiotic Resistance". This piece briefly outlined the how antibiotics work, antibiotic resistance and the different bacteria that are now resistant to previously popular antibiotics. To begin, he describes how antibiotics function in three different ways. Antibiotics can either disrupt the bacteria's cell wall development, disrupt the bacteria's protein synthesis or disrupt the bacteria's ability to replicate its DNA. Bacteria that are resistant to antibiotics can avoid these disruptions by either modifying or destroying the antibiotic, avoiding the antibiotic entirely or altering the target site for the antibiotic on their cell. These resistant bacteria will survive antibiotic treatments and are then able to thrive under the less competitive environment. Non-resistant bacteria can also become resistant through mutations in their own DNA or by exchanging genetic information with resistant bacteria. This transfer can happen when the plasmids or transposons of the resistant bacteria exchange information with non-resistant bacteria cells. Neu identifies *Staphylococci, Streptococcus pneumonia, Streptococcus pyogenes, Enterococci, Haemophilus influenzae, Neisseria* and *Moraxella,* enteric pathogens and hospital bacteria like *E. coli* as bacterial diseases that were once easily controlled by antibiotics, but now face resistance and require increased

dosages or alternative antibiotics to control them. Neu recommends increased hygiene, synthetic antibiotic development and antibiotic control programs as methods for delaying antibiotic resistance. Despite demonstrating significant concern about antibiotic resistance, Neu only mentions the use of antibiotics for livestock as a potential cause of resistance in *Salmonella* species that may be harmful to humans.

More recently, Silbergeld et al. (2008) focused specifically on the connection between food animal production, antibiotic resistance and human health. In their article, they identified four reasons why animal agriculture is a primary driver of antibiotic resistance. The first is that animal agriculture reports the largest consumption of antibiotics in the world. The second is that most of this antibiotic consumption is done through prolonged, low-dose applications. The third is that antibiotics that are clinically important for human health are being used for livestock. The fourth is that humans are exposed to those resistant bacteria by working with the livestock. Specifically, they argue that the use of in-feed antibiotics for growth promotion strongly facilitates antibiotic resistance. This type of antibiotic administration provides low doses of antibiotics over a long period of time. This creates ongoing selective pressure which allows the resistant bacteria to continue to thrive under reduced competition. While confounding factors make it difficult to attribute livestock antibiotic use to human risk, Silbergeld et al. (2008) use anecdotes and logic to argue that antibiotic use on farms poses a significant danger to public health.

Marshall and Levy (2011) also argue that there is significant evidence connecting human health risks to antibiotic use on livestock farms. To them, it is unclear why regulatory action for reduced antibiotic use hasn't been implemented globally. Marshall and Levy specifically focus on antibiotics used in livestock for non-therapeutic use, highlighting that properly administered

therapeutics only presents a small threat to human health because of the short application time and the low number of animals being treated. One of the primary discussion points of this article is that a key driver of resistance is the number of animals being treated. Every time an animal is treated with antibiotics, there is an increased chance of resistant bacteria developing, an increased chance of these bacteria spreading their genes to other bacteria and an increased chance of these bacteria spreading to other animals. All of these incidents increase the number of antibiotic-resistant bacteria that exist and increase the chance of human exposure to these bacteria through food, farm labourers and the environment (Silbergeld et al., 2008). Since the publication of the Swann Report (1969), several countries have opted to ban the use of certain in-feed antibiotics for livestock. These bans have led to a significant reduction in the number of antibiotic-resistant bacteria although some have argued that banning non-therapeutic antibiotics results in a comparable rise in therapeutic use. However, Marshall and Levy's review found that while some farmers faced initial production problems, many found ways to adapt and the new level of treatments being administered were deemed acceptable. Similar to Silbergeld et al. (2008), Marshall and Levy highlight how the prolonged administration of low-dose antibiotics creates an ideal environment for resistant strains of bacteria to thrive. They recommend that data gaps should not hinder a ban on the use of non-therapeutic antibiotics in livestock production.

To test the relationship between antibiotic use and antibiotic resistance, Akwar et al. (2008) compared antibiotic use and the presence of antibiotic-resistant *E. coli* on Canadian pig farms. Data for antibiotic use were collected via questionnaires distributed to the thirty-nine Ontario farmers in 1999 and eight British Columbian farmers in 2000. The most common antibiotics used were penicillin (85% of farmers), sulfonamides (57%), tetracyclines (70%) and tylosin (55%). Results from the logistic regression indicated that the use of antibiotics in weaner

pigs is associated with antibiotic resistance in most models but not associated with resistance in finishing pigs. Consistent with Silbergeld et al. (2008) and Marshall and Levy (2011), they found that in-feed medication was more consistently associated with resistance than injected antibiotics. In addition to an increase in *E. coli* resistance to the antibiotics being used, cross-resistance was found for streptomycin after using spectinomycin. Sulfonamide use was also associated with sulfamethoxazole resistance, which is an antibiotic only approved for human use. This study highlights the dangers of cross-resistance and the need for an understanding of how the antibiotics used in livestock production can lead to antibiotic resistance in antibiotics used for humans.

In Canada, most livestock antibiotic monitoring is currently done through the Canadian Integrated Program for Antibiotic Resistance (CIPARS). Deckert et al. (2010) reviewed the 2006-2008 data from this program in an article that studied the relationship between antibiotic use on grow-finish pig farms and the presence of Salmonella and *E. coli* resistant bacteria. Results indicate that for each of the three years 63%, 56% and 62% of Salmonella tested was resistant to at least one antibiotic. In 2006, 13% of Salmonella sampled was resistant to between five and eight antibiotics while 23% of Salmonella samples were resistant to this many antibiotics in 2007 and 2008. In 2006, 84% of feces sampled had *E. coli* that were resistant to at least one antibiotic while 86% of *E. coli* samples were resistant to one antibiotic in 2007 and 2008. Between 12% and 13% of *E. coli* samples were resistant to between five and eight antibiotics for all three years. No Salmonella was resistant to more than 7 antibiotics and no *E. coli* were resistant to more than twelve antibiotics. Less than 1% of bacteria sampled was resistant to the highest priority antibiotics for human health. For each bacterium, the most commonly found resistance was to tetracycline, sulfisoxazole and streptomycin.

The extensive research connecting antibiotic resistance and livestock antibiotic use suggests the need for reduced antibiotic use on livestock farms. However, this type of research rarely mentions the economic and animal welfare benefits that antibiotics provide. The process of developing strategies for reducing antibiotic use must consider the benefits these antibiotics provide to the livestock sector.

2.4 Economics of Antibiotics on Farms – Argument for Antibiotic Use

Despite the evidence provided above, some still argue that antibiotics used in livestock do not present a health risk to humans (Dibner & Richards, 2005). In their review of antibiotic use in veterinary medicine, Schwarz, Kehrenberg and Walsh (2001) argue that livestock industries are being used as scapegoats for resistance problems in human medicine. In general, they argue that antibiotic resistance in humans is caused by human antibiotic use and livestock antibiotic resistance is caused by livestock antibiotic use. Cromwell (2002) shares a similar perspective, arguing that antibiotics have been administered to billions of livestock over the last fifty years without any definitive evidence linking this activity to human health risk. The primary motivation behind supporting antibiotic use on farms is the significant productivity improvements achieved through their application.

In Canada, antibiotics have been used in livestock production for over fifty years with many studies across the world citing significant production and economic benefits to their use for growth promotion, disease prevention and disease treatment. In particular, there has been extensive research on the growth-promoting benefits of low-dose antibiotics being administered in feed. As shown above, this type of antibiotic use has been the primary target of critics given its tendency to facilitate the proliferation of resistant bacteria.

During a time when many European countries were opting to ban or limit the use of growth-promoting antibiotics, an American researcher named Gary Cromwell summarized the results from hundreds of American experiments on the effects of growth-promoting antibiotics in pigs (2002). These experiments were conducted between 1950 and 1985 and results indicated that the use of antibiotics as growth promoters was beneficial for nursery, grower and grow-finish pigs. Average daily weight gain improved by 16.4%, 10.6% and 4.2% for nursery, grower and grow-finish pigs and feed conversion improved by 6.9%, 4.5% and 2.2%, respectively. Using these results and others for sows, Cromwell estimated a net return per pig of $2.99 per marketed hog and $7.12 net return per litter born when using antibiotics for growth promotion.

As a follow-up to studies by Losinger and Williard (1998) and Losinger et al. (1998), Miller et al. (2003) analyzed the economic effects of antibiotics used for growth promotion in the grower/finisher phase of pig production using data from the 1990 and 1995 National Animal Health Monitoring System. Their results found much smaller improvements than those from Cromwell's review, with only a 0.5% improvement in average daily gain, 1.1% improvement in feed conversion and a mortality rate reduced by 0.22 percentage points. In their study, producers using three rations for their finishing pigs saw a $0.59 net benefit from using antibiotic growth promoters while those who used five rations saw a loss. These findings suggest that improved feeding plans may offset the need for growth-promoting antibiotics. A key distinction between Cromwell's review and this study is that Cromwell reviewed experiments whereas Miller et al. used survey data to perform a regression to determine if the use of antibiotic growth promoters was associated with improvements in productivity among farmers.

In addition to providing productivity improvements, Liu et al. (2005) used econometric and financial analysis to argue that using antibiotic growth promoters reduces production risk for

American pork producers and increases net profits. Packers demand uniform hog size from producers and many processors impose financial penalties for hogs outside of a specific weight range. Liu et al. (2005) argue that the increasing number of hogs purchased through contract increases the risk of hogs being outside of this range. This is because contracts specify the number of hogs to be picked up and specify the pickup date. Antibiotic growth promoters reduce this risk by reducing variation in pig weight and increasing the mean shipping weight of market hogs. Using a stochastic budget model, Liu et al. (2005) coincidentally determine that antibiotic growth promoters fed to pigs for sixty-five to seventy days provides an increase in profit of $2.99 per pig. This gain is distributed between a $1.43 gain due to an increase in mean weight and a $1.56 gain from the decrease in variation of live market weights. With costs for antibiotic growth promoters estimated to be around $0.27 per pig in grow/finish barns, the return on investment is quite high for farmers.

In a more recent article, Teillant and Laxminarayan (2015) reviewed the literature on the economics of antibiotic use in U.S. swine production to provide context for regulation and policy decision. They find that despite the benefits consistently being more significant for nursery pigs than for grow/finish pigs, the general research trend is that the benefits of antibiotic growth promoters are less significant than in the past. They also warn that results from animal level research should not be generalized to the population because of the significant variance between the animals and the environments being tested. Teillant and Laxminarayan (2015) speculate that the reduced effectiveness of antibiotics may be caused by improvements in hygiene, nutrition, genetics or because of increasing resistance to the antibiotics being used.

With antibiotic growth promoters being banned by the end of 2018, future research must transition from focusing on growth promotion to therapeutic, metaphylactic and prophylactic

use. While the benefits of therapeutic treatment are rarely debated, metaphylactic and prophylactic antibiotic administration will come under increased scrutiny due to the significant number of animals being treated. Sorting through which of the antibiotics given this way provide the most benefit and which provide the least will help to inform a strategic plan to reduce antibiotic use that doesn't jeopardize the industry's competitiveness.

2.5 Antibiotic Use on Canadian Pig Farms

A major obstacle in studying antibiotic use on Canadian pig farms is that there is no centralized system for recording antibiotic prescriptions in agriculture (Deckert et al., 2010). Despite this challenge, several researchers have attempted to capture antibiotic use across the country by using questionnaires that are distributed to farmers from multiple provinces.

Dunlop et al. (1998a) analyzed data from surveys mailed to farmers across Ontario in 1991. Of the one thousand producers sent this survey, 63% responded. Survey responses indicate that 96.6% of all marketed pigs had been exposed to an antibiotic in their starter ration with tylosin (44.9% of hogs), carbadox (40.6%), furazolidone (39.7%), sulfamethazine (30.6%), tetracycline (29.1%) and penicillin (26.5%) being listed as the most popular antibiotics. By comparison, 47.8% of all marketed pigs had been given an antibiotic in their finisher ration with tylosin (24.9% of hogs), tetracycline (12.7%) and lincomycin (10%) being cited as the most common antibiotics used. Antibiotics were also administered through water (37.3% of market hogs) and 79.5% of operations administered some type of antibiotic through injection. Results from other sections of the survey suggest that many housing and management practices could be improved upon by farmers. Only 19.2% and 14.7% of farmers operated all-in all-out for nursery and finishing respectively. Furthermore, 41% of farmers rarely cleaned feeder pig pens between groups and many did not vaccinate for a number of bacterial diseases.

In addition to studying feeder pigs, Dunlop et al. (1998b) also studied individual and group use of antibiotics on 34 farrow-to-finish farms in Ontario. Data were collected between September and December of 1992 from pig farms that were proximal to Guelph. Of the 34 farms surveyed, 21 used carbadox, 9 used furazolidone, 9 used spectinomycin, 12 used sulfonamides and 10 used tetracyclines strictly in group treatments. Gentamicin (19 farms) was strictly used for individual treatments, 31 farms used penicillin either strictly for individual treatments (13 farms) or for group and individual treatment (18 farms). Tetracyclines were also commonly employed for individual and group treatments (9 farms). Only three farms did not use any broad spectrum in-feed antibiotics in any ration, with many farmers choosing to use multiple.

Outside of Ontario, there have been two studies done on Prairie swine farms. Rajić et al. (2006) surveyed antibiotic use on 90 farms in Alberta, representing 25% of the province's hog production. Data were collected during on-farm interviews between May and September of 2000. Antibiotics being administered in-feed was most common in nursery barns with 96% of farmers including it in the ration >95% of the time. For grower and finisher, 85% and 60% of farmers used antibiotic in their diets >95% of the time. A combination of chlortetracycline/sulfamethazine/penicillin was the most common combination used in nursery rations while tylosin was the most commonly used antibiotic in finishing rations. Penicillin was the antibiotic most commonly administrated either by injection or via water followed by tetracycline. Antibiotics that are important for human health were rarely used on any farms surveyed. One interesting finding was that farmers who did not consult with veterinarians were 2.1 times more likely to not use antibiotics in their feed.

The second study was performed by Rosengren et al. (2008), with data collected from 7 swine farms in Alberta and 13 farms in Saskatchewan in 2004. On-farm records and

questionnaires were used to determine the antibiotic use for the twelve months prior to the visit. Only one producer did not report using antibiotics in feed while 19 added antibiotics to nursery diets, 15 to grow-finish diets and 8 to sow diets. Chlortetracycline, tiamulin, lincomycin and spectinomycin were the most common antibiotics added to suckling and nursery diets while tylosin and lincomycin were common in grow-finish rations. Antibiotics administered through water were used in 10 of the herds with tetracycline, penicillin and amoxicillin being the most common.

As mentioned previously, since 2006, a large part of the reporting related to antibiotic use on Canadian farms has been done by the Canadian Integrated Program for Antibiotic Resistance Surveillance (CIPARS) Farm Program. For hogs, this program focuses specifically on the administration of antibiotics and antibiotic resistance in the grow-finish stage of production. Data are collected from farms in the major pork producing provinces, which include Alberta, Manitoba, Ontario, Quebec and Saskatchewan. In their most recent annual report (2014), CIPARS provided data from 549 questionnaires from 146 farms with 50 of them reporting in each year of the study (2009 and 2014). The most commonly reported antibiotics used on farms were penicillin (mostly done by injection) and then chlortetracycline, lincomycin and tylosin (mostly through feed). Notable findings include an apparent substitution of salinomycin (highest priority) for chlortetracycline (critically important) for in-feed antibiotics in Quebec and an increase in in-feed lincomycin (highly important) use across all provinces. Discouraging results include low levels of vaccinations being used to prevent for bacterial diseases across all provinces. A more positive finding is that management reports indicate significant adoption of all-in all-out management, with 59% of farms reporting this strategy in comparison to the <20% found by Dunlop et al. (1998a) in Ontario.

Despite a 12% decrease from 2006, the 1.5 million kilograms of antibiotics used for animals in 2014 presents a daunting task for researchers looking to reduce antibiotic use on Canadian farms (Government of Canada – CIPARS, 2014). With such an extensive amount of antibiotics being used, it is tempting to follow the European Union and impose a ban on certain uses of antibiotics. Extensive research has been performed on the outcomes of these types of bans (Callesen, 2002; Van der Fels-Klerx et al., 2011; Aarestrup, 2012; Maron et al., 2013) with additional research speculating about the impact of a ban in the U.S. industry (Brorsen et al., 2002; Hayes et al., 2001; Hayes et al., 2002). While it seems that these changes have become manageable for European farmers, speculation from researchers suggests that the results may be less favourable in North America. One alternative to increased regulation is to promote the use of antibiotic alternatives that can maintain or improve upon current production levels on Canadian swine farms.

2.6 Alternatives to Antibiotic Use on Canadian Pig Farms

In his paper that assesses the trade-offs of using antibiotics for animals, Rushton (2015) describes the use of antibiotics as a classic example of a "tragedy of the commons". This title describes a scenario where despite long-term harm, a public good is depleted for the short-term benefit of individuals. Growing concern about the externalities created through animal antibiotic use has led to a recent increase in the amount of research investigating alternatives to antibiotic use. This emergence is particularly evident in Europe, where actions to reduce antibiotic use have been significantly greater than in other parts of the world. In addition to uncovering alternatives that maintain productivity, the challenge remains of proving to farmers that these alternatives actually work and are economically viable (Alarcon et al. 2014).

Two articles published in 2000 provide an excellent review on some of the alternatives available to antibiotics. In the United Kingdom, Close (2000) outlines ten alternatives that may provide similar or improved production performance for pigs in the absence of antibiotic growth promoters. Given that most of the feed efficiency and weight gain benefits of antibiotic growth promoters are believed to be achieved through their effects on the gastrointestinal (GI) tract (Dibner and Richards, 2005), diet acidification is one alternative to antibiotics that impacts this system. Diet acidification reduces pH in the stomach which increases the digestibility of nutrients and promotes the growth of beneficial bacteria. Other alternatives include feed supplements such as oligosaccharides, enzymes, herbs, minerals, probiotics, and non-starch polysaccharides. These supplements have various modes of action but one example for non-digestible oligosaccharides is that they work by binding with bacteria and then carry these bacteria throughout the GI tract and out the pig through it's feces. Zinc oxide and copper sulfate also have antibiotic properties but there is concern about the excretion of these minerals in the environment.

Wierup (2000) discusses preventing bacterial disease as a method for reducing the need for antibiotics. He stresses that antibiotics should be the last line of defense, only to be used when all other methods have failed. Optimizing hygiene, isolating sick animals, and isolating and testing replacement breeding stock for disease are all methods for avoiding diseases in swine herds. Furthermore, pigs will have an easier time fighting off diseases on their own if they are vaccinated, receive proper nutrition and have a healthy immune system. Some specific recommendations include all-in all-out management, age-segregated batch production, segregated early weaning and reducing stress during transportation and mixing.

There has been a significant effort among some European countries to reduce the amount of antibiotics used on pig farms, which has led to a number of studies on antibiotic alternatives. Through a focus group organized by the European Commission in 2013, a group of twenty experts, including farmers, researchers and advisors, were brought in to discuss the issues and existing solutions for reducing antibiotic use (Armstrong et al., 2014). From this group, three areas of focus were identified: general improvements in animal health, alternatives to antibiotics and changing the attitudes of farmers to favour reduced antibiotic use. Options mentioned for animal health improvements included improved external and internal biosecurity, washing hands and changing clothes, age separation of pigs, cleaning and disinfecting between groups and improved management of sick animals that may infect the rest of the herd. Alternatives cited were vaccines, improved tools for disease detection, breeding for resistance to bacterial diseases and using the options mentioned in Close (2000). With respect to farmers' attitudes, the key recommendation was to develop production, antibiotic and financial benchmarking for farmers so they can compare themselves against others. From Denmark's experience, Aarestrup (2012) argues that the AGP ban, comprehensive antibiotic surveillance and preventing veterinarians from profiting on the sale of antibiotics were three necessary steps to reduce the amount of antibiotics being used in pig farming.

More recently, Postma et al. (2015) asked swine experts across Europe to rate nineteen alternatives to antibiotics based on perceived effectiveness, feasibility and return on investment (scale of 0 to 10). Based on perceived effectiveness, the top five alternatives to antibiotics were improved internal biosecurity, improved external biosecurity, improved climate/environmental conditions, high health/disease eradication, and increased vaccination. Rated on feasibility, the top five were increased vaccination, the use of anti-inflammatory products, improved water

quality, improved feed quality, and the use of zinc/metals. Alternatives with the greatest perceived return on investment were internal biosecurity, the use of zinc/metals, having diagnostics plans, improved feed quality and improved climate/environmental conditions. Given the data from the 2014 Annual CIPARS Report, some of these recommendations appear directly relevant to Canadian swine farmers. It is interesting to note that veterinarians showed a preference for improving internal biosecurity, feed, vaccination, zinc/metals use and climate/environmental conditions while researchers favoured the increased use of a diagnostic tools and having a disease action plan. These preferences may speak to the experiences of these individuals and may provide guidance on the roles that each member should play in organizing programs to reduce antibiotic use.

In addition to these recommendations, there have been two recent field studies done in Flanders, Belgium where farmers attempted to reduce antibiotic use on their farms. Both of these studies involved three visits to farms by researchers, eight months apart, with the first visit being an evaluation, the second to provide recommendations and the third being a follow-up evaluation. Postma et al. (2016) found that between the second and third visit, there were significant improvements on farms. According to the Biocheck.UGent^{TM} risk-based scoring system, external biosecurity increased by an average of 2.4 points while internal biosecurity increased by 7 points. On these farms there was a 52% decrease in antibiotics use for fattening pigs and 32% decrease in breeding swine. Furthermore, the number of weaned pigs per sow increased by 1.1 pigs per year, average daily gain increased by 5.9 grams per day and average mortality fell from 3.2% to 2.6%. In a similar study, Rojo-Gimeno et al. (2016) also visited farms but chose to use a control group and incorporate economic data into their work. Treatment and control farms were matched and evaluated using propensity score matching and difference-

in-difference techniques. Recommendations on biosecurity, general management, vaccination and antibiotic use were provided to the treatment group. The difference-in-difference technical parameters and cost of interventions, inputs and outputs were used to create eleven virtual farrow-to-finish pig farms. These virtual farms were modified to a Monte Carlo stochastic model, which accounted for volatility in prices and treatment effects. Results that included volatility found a €39.21 net increase in enterprise profit per sow per year while the deterministic model presented an increase of €107.47 per sow per year under reduced antibiotic use.

While Rojo-Gimeno et al. (2016) provide an excellent economic model for evaluating antibiotic alternatives, there has been very little research of this type in North America. As attention to antibiotic resistance drifts west, effective economic modeling will be a key contribution to evaluating methods for profitably reducing the use of antibiotics on Canadian livestock farms. For the most part, these alternatives remain unproven and antibiotics continue to be relied upon as the sole means for responding to diseases.

2.7 Summary

Performing research that can contribute to the literature on antibiotic use and pig farming requires significant consideration of the information featured in this chapter. Table 1 provides a summary of this information and highlights the specific points that are relevant for this research.

CHAPTER 3

MAJOR BACTERIAL DISEASES AFFECTING PIG FARMS

3.0 Introduction to the Chapter

The following chapter outlines the pathogenic bacteria affecting swine health and pig farming in Canada. While there are many pathogenic bacteria in pigs, this review will focus on four diseases that the author believes to have the largest production and economic impact on the Canadian swine industry. This decision was based on personal experience, professional opinion and the survey results of a U.S. study on pig farmers producing more than 150,000 pigs per year (Holtkamp, Rotto & Garcia, 2007). The information from this review will be used to determine which bacterial disease will be used in this research to provide an example of how the model can be used to measure the economic benefits of antibiotics. The first section in this chapter provides background information on bacterial diseases. The following sections discuss the four diseases studied in greater detail, focusing on the way they impact pig health and the medication available for treating them. The final section outlines which disease was chosen and provides justification for this decision.

3.1 Introduction to Bacterial Diseases

In order to understand this review, the following introduction will provide some background information on bacterial diseases. Bacteria are single-celled organisms that occur naturally in pigs and all living animals. While most of our attention is drawn to harmful or pathogenic bacteria types, the vast majority either have no impact (commensal) or have a positive impact on the organism that they live in. Because this research is related to antibiotic use, this review will focus on the pathogenic bacteria that antibiotics target. When discussing bacteria in terms of antibiotics, antibiotic resistance and human health, there are several

characteristics of bacteria that are important to understand. The first is that most bacteria have a plethora of variations or serotypes that exist. These different variations are often what makes the bacteria pathogenic to certain animals and not others. The second characteristic of bacteria are that they are either gram-positive or gram-negative. While many differences exist between the two, the most important distinction for our purpose is that gram-negative bacteria do not have a cell wall and gram-positive bacteria do. Many antibiotics act by influencing the cell wall of bacteria, so gram-negative bacteria are naturally resistant to this type of antibiotic. The third characteristic of bacteria is whether they are an aerobe or anaerobe. Generally, an aerobe requires oxygen to survive while an anaerobe does not. There are varying oxygen requirements in each category, but this characteristic helps farmers to think about the requirements of the bacteria that are living inside and outside of the pigs on their farm. The fourth characteristic of bacteria is whether or not the bacteria that are pathogenic in pigs are also pathogenic in humans (zoonotic). This characteristic is important because zoonotic antibiotic-resistant bacteria in animals may present an immediate threat to humans. These four characteristics play a significant role in the onset, treatment and resistance of bacteria and will be referred to in this review.

While harmful bacteria exist within every animal, for the most part, signs and illness rarely emerge. This is because of the animal's immune system, which is incredibly effective at identifying pathogenic species and handling them very subtly. There are two primary reasons that a major bacterial outbreak might occur on pig farms. The first reason is when a new pathogenic bacterium is introduced to a herd, the pig's immune system is not prepared to fight the disease (existing antibodies etc.). Administering vaccinations (harmless doses of the disease) to the pig before a natural exposure will help them to be more prepared to fight the disease. The second reason that an infectious outbreak might occur would be when the immune system of a

pig is overwhelmed and is unable to handle the bacterial load that is present. Stress, malnutrition, barn design and other illnesses are all examples of why a pig's immune system may no longer be able to handle the disease that it can usually fight off. The mechanism of outbreaks is important to know so that farmers can improve the preventive measures that they take in lieu of having to treat the diseases when they occur.

Prevention is the ideal means of handling diseases but oftentimes treatment and control are required. For bacterial diseases, antibiotics are the most common treatment method with a few effective antibiotic alternatives currently available. Antibiotics and their alternatives are designed to supplement the immune system by targeting pathogenic bacteria and killing them. One downside of these products is that they are unable to differentiate bacteria as effectively as the immune system. As a result, they often kill the pathogenic bacteria and also the non-pathogenic bacteria, which are not the intended target. Therefore, it is not only the resistant pathogenic bacteria that survive but also the resistant non-pathogenic bacteria. These are the bacteria that the pig was already able to control without antibiotics. If these non-pathogenic bacteria were to become a problem in the future, it is more likely that they will be resistant to the antibiotics available to treat them. Furthermore, these bacteria are now able to multiply, thrive and then share their resistance traits with other serotypes and other pathogenic bacteria in an environment with reduced competition.

As previously described, many bacteria are naturally resistant to antibiotics because of their different characteristics. However, resistance can also occur due to mutations in the bacteria that prevent the antibiotic from harming them. The populations of these mutated bacteria are often low under normal conditions, but when an antibiotic kills the other bacteria, they no longer have to compete and can rapidly grow their numbers. As a result, one single mutated bacteria cell

that is resistant to the antibiotics can quickly multiply and then become a major threat to the pig and the entire herd. However, the resistance problem is not limited to the spread of mutated bacterial cells within a herd. Resistant bacteria are also able to share their resistant genes with other bacteria in various capacities. Some can share within the same serotype, some within the same bacteria and others can share their traits with other bacteria types. There are also examples of cross-resistance, where the administration of one antibiotic can lead to resistance to a different antibiotic. The diverse and complicated nature of antibiotic resistance warrants significant attention as we transition to reduced antibiotic use and reduced effectiveness of the antibiotics currently available. This is true for both human and veterinary medicine which should converge to a "one-health" approach when tacking antibiotic resistance (Seitz, Valentin-Weignand & Willenborg, 2016). Below is a review of bacterial diseases affecting swine farms and a discussion relating to the impact of their management on human health.

3.2 *Streptococcus suis*

3.2.1 Introduction to *Streptococcus suis*

Streptococcus suis (*S. suis*) is a gram-positive, facultative aerobe bacterium (Laber et al., 2002). There are thirty-five known serotypes of *S. suis,* with serotypes 1-9 and 14 being the most frequent in pigs (Hughes et al., 2009). However, *S. suis* type 2 is considered the most pathogenic serotype for humans and for swine and will be the focus of this section.

3.2.2 Health Impact of *Streptococcus suis* on Swine Farms

S. suis colonize in the tonsils of swine and is often found in healthy pigs that show no sign of disease. These pigs are known as carriers and can make up 100% of the population of a healthy herd (Amass, Wu & Clark, 1996). Carrier pigs can generally handle the disease and

remain unaffected by *S. suis* unless their immune system becomes compromised through disruptions like stress or disease. This stress can be caused by several things including weaning, mixing or moving pigs. Herds that do not have *S. suis* can become infected when a carrier of the disease is introduced. This new disease is generally first recognized by *S. suis* symptoms showing up in recently weaned pigs. However, the illness can also first appear in pigs up to four months of age (Laber et al., 2002). Symptoms often include fever, laziness and lack of eating, with severe cases including septicemia, meningitis and arthritis (Byra et al., 2011).

3.2.3 Economic and Production Impact of *Streptococcus suis* on Swine Farms

In their survey of American farmers producing more than 150,000 pigs per year, Holtkamp, Rotto and Garcia (2007) asked farmers to list and rank the diseases that had the highest production impact on their sow barn, nursery barn and finishing barn. The results for *S. suis* were:

- Sow barn: Fourth most cited with an average rank of 7.
- Nursery barn: Fourth most cited with an average rank of 4.
- Finishing barn: Tenth most cited with an average rank of 9.

Generally, farms experience problems with *S. suis* in the nursery barns as piglets no longer have immunity from their mother (passive immunity) and they are stressed from switching to solid feed, being moved and being mixed with other litters. When infected, morbidity (animals showing clinical symptoms from *S. suis*) in a herd is generally around 5% but it can reach up to 50% in herds with poor hygiene and existing disease problems (Seitz et al., 2016). A Canadian study found that mortality between weaning and four weeks post-weaning can reach 14% in herds infected with *S. suis* (Byra et al., 2011). This is high compared to the typical mortality rate

of 3% in a healthy Canadian nursery barn. Varela et al. (2013) highlight six ways that *S. suis* diseases impact production:

1. *S. suis* leads to neonatal septicemia which causes healthy looking newborns to die within 12-24 hours of birth (Sandford et al., 1988).
2. *S. suis* is often paired with Porcine Reproductive and Respiratory Syndrome virus (PRRSv) and contributes to Porcine Respiratory Disease Complex (PRDC) (Gottschalk, Segura & Xu, 2007).
3. *S. suis* causes post-weaning meningitis or septicemia that, when left untreated, can cause mortality up to 20% (Laber et al., 2002; Varela et al., 2013).
4. Septicemia from *S. suis* causes arthritis which leads to unusable tissue that must be cut away from the carcass. In a farrow-to-finish operation with 300 sows, if 50% of hogs need to be trimmed then losses can exceed $20,000 per year (Keenliside et al., 2006).
5. *S. suis* can cause a decrease in farrowing rate. Although rare, there is a reported case where farrowing rates dropped from 85% to 70% over a three-month period (Sanford et al., 1988).
6. *S. suis* leads to sick animals which increases costs associated with increased labour from managing the sick animals (Keenliside et al., 2006).

The challenges created by *S. suis* highlight the importance of preventing an outbreak and controlling the disease on swine farms.

3.2.4 Prevention and Control of *Streptococcus suis* on Swine Farms

Despite the significant damage caused by *S. suis*, Varela et. al (2013) highlight that there are no currently effective control measures for the disease. Attempts to eliminate the carrier state in pigs through antibiotics or age segregation have been unsuccessful and vaccines have shown

varying success (Amass, Wu & Clark, 1996; Laber et al., 2002, Lun et al., 2007). Nevertheless, there are still things farmers can do to mitigate the risks of an *S. suis* disease and their actions should depend on the *S. suis* status of their herd.

For herds currently not infected with *S. suis*, efforts should be directed towards keeping the bacteria out. There are several ways that *S. suis* can enter a farm including humans, pests and replacement breeding stock (Laber et al., 2002). Transmission from humans can easily be reduced by strong biosecurity practices. These practices include reducing the number of visitors to your barn, in particular from other farms, having barn specific clothes and washing your hands before entering the facility. Transmission by pests is less common but can be avoided through bird screens, rodent traps and fly control. The most likely cause for disease is through the introduction of new breeding stock (Hughes et al., 2009). Therefore, any new animal to be introduced to your herd should be kept in an isolation barn for around six weeks. This won't eliminate the carrier state, but it will give the animal time to stop shedding the pathogen and reduce its impact on the rest of the herd. Outside of the pig, *S. suis* is easily killed by washing barns with a simple bleach solution and this practice should be incorporated into the cleaning regiment of barns worried about a *S. suis* disease (Lun et al., 2007)

For farms with a high prevalence of carrier pigs, emphasis should be placed on reducing stress so that the bacteria don't become pathogenic. Disease, moving animals, mixing age groups, poor ventilation and overcrowding can all increase animal stress and the level of *S. suis* morbidity in herds. It is especially important to avoid concurrent disease with *S. suis* as typical *S. suis* treatments are not sufficient to treat the disease when it is paired with other diseases like PRRSv (Seitz, Valentin-Weignand & Willenborg, 2016). To reduce stress, animals should be moved in smaller groups and all pigs should have sufficient space and ventilation to keep dry,

safe and comfortable. Prophylactic administration of dissolved penicillin has been suggested for nursery pigs, however there is a history of some resistance. Furthermore, Amass, Wu and Clark (1996) noted increased lethargy in pigs given penicillin for *S. suis* in the nursery stage (Laber et al., 2002; Varela et al., 2013).

3.2.5 Treatment of *Streptococcus suis* on Swine Farms

Treatment of *S. suis* is done via the administration of antibiotics to pigs. The Canadian Edition of the Compendium of Veterinary Products includes five antibiotics that list either *S. suis* or *Streptococcus* species as a target bacterium. Amoxicillin and penicillin are both provided as water-soluble options for treating *S. suis* while ceftiofur is available as an injection. More generally, lincomycin, penicillin and a trimethoprim-sulfadoxine mix are available for treatment of all *Streptococcus* species via injection. However, it should be noted that the Compendium does not include "off-label" use of antibiotics that get prescribed by veterinarians.

Canadian research from a herd with a history of *S. suis* disease found that piglets treated with penicillin G via water in the nursery stage performed much better than untreated piglets (Byra et al., 2011). Treated pigs only saw a mortality of 7% in comparison to the 14% seen in the control group. Furthermore, the probability of control pigs having a positive *S. suis* swab was 1.6x higher than for pigs given penicillin. Treatment of *S. suis* is most commonly done in the nursery barn as piglets are colonized with *S. suis* at birth, lose lactogenic immunity and face extensive stress at weaning. This stress and loss of immunity provides the perfect environment for *S. suis* to become pathogenic in vulnerable pigs.

3.2.6 Antibiotic Resistance in *Streptococcus suis*

With six antibiotics being labelled for *Streptococcus* therapy, veterinarians and farmers have several tools at their disposal for treatment. However, the efficacy of these antibiotics can be limited by several factors, including bacteria being resistant to them. Resistance to Penicillin, the most commonly prescribed treatment for *S. suis*, has typically been low. In Canada, resistance to penicillin was only found in 0-3% of *S. suis* samples collected (Cantin et al., 1992) but antibiotic resistance does vary across different parts of the world. Between 7% and 67% of *S. suis* samples in Canada were resistant to sulphonamides and there are no Canadian data on resistance to amoxicillin, ceftiofur, lincomycin or trimethoprim. Research from the United States showed that 14-14.5% of *S. suis* samples were resistant to penicillin, 1-23.1% resistant to cephalosporins (ceftiofur), 86.8% resistant to lincomycin and 46.7-57.8% resistant to sulphonamides. For an international summary of *S. suis* antibiotic resistance, please refer to Varela et al. (2013). In the absence of data on amoxicillin and relatively low resistance to penicillin and ceftiofur in North America, these seem like the most appropriate methods for treating *S. suis* in Canadian pig herds.

3.2.7 Connecting *Streptococcus suis* in Swine Farming to Human Health

As Canadian swine farmers attempt to reduce antibiotic use, *S. suis* requires attention because it is a zoonotic bacterium. This means that in addition to infecting swine, *S. suis* can also infect humans, with human diseases commonly arising from contact with swine or swine products (Hughes et al., 2009). The first reported human case was in Denmark in 1968 but it wasn't until 2005 when *S. suis* caught global attention. With more than 200 *S. suis* incidences occurring, China experienced the largest human *S. suis* disease occurrence ever recorded

(Gottschalk, Segura & Xu, 2007). As of 2007, there were only two reported cases in Canada, but globally reported *S. suis* diagnoses have increased dramatically. With only 409 cases reported in 2007 to over 700 reported by 2009, *S. suis* control and treatment in swine and humans will become increasingly important (Hughes et al., 2009).

Prudent antibiotic treatment of *S. suis* in pigs is required to protect the antibiotics used for treating humans. As mentioned previously, Seitz, Valentin-Weignand and Willenborg (2016) suggest a "one-health" approach to public and veterinary medicine as their interconnectedness becomes increasingly clear. Like pigs, penicillin is often used for treating human *S. suis* diseases and while instances of resistance are low, there is still the possibility of resistant bacteria infecting humans. Potential for resistance, production impact and zoonosis are what make *S. suis* relevant in the discussion about antibiotic use on Canadian pig farms.

3.3 *Escherichia coli*

3.3.1 Introduction to *Escherichia coli*

Escherichia coli (*E. coli*) is a gram-negative, facultative anaerobic bacterium (Laber et al., 2002). With over 50,000 known serotypes, *E. coli* is identified by the type of O, H, K or F antigens present on the bacteria (Ørskov & Ørskov, 1992). These antigens are toxic and, depending on which ones are present, can prompt a response from the pig's immune system. The F antigens (fimbrial antigens) are particularly significant because the fimbriae are what allow the *E. coli* to attach to the pig's cells. More than 90% of *E. coli* that are pathogenic to swine can be characterized by a small family of fimbriae with either the F4 or F18 antigen being most commonly associated with diarrhea (Moon & Bunn, 1993; Amezcua et al., 2002; Fairbrother, Nadeau and Gyles, 2005). This section will focus specifically on diseases of *E. coli* with the F4 or the F18 antigen.

3.3.2 Health Impact of *Escherichia coli* on Swine Farms

E. coli colonize the length of the jejunum and the ileum of pigs (Moon & Bunn, 1993). Diarrhea is the primary symptom of *E. coli* as the bacteria stimulate the secretion of water and electrolytes from the small intestine's epithelial cells (1993). These fluids exit the body in the form of diarrhea which leads to dehydration and possibly death. *E. coli* diseases in swine are most commonly spread through fecal-oral contact in barns and morbidity (experiencing symptoms) is often seen in neonatal piglets or recently weaned pigs (Laber et al., 2002). Neonatal diarrhea is caused by *E. coli* with F4 antigens and post weaning diarrhea is caused by *E. coli* with either F4 or F18 antigens. Neonatal diarrhea appears as early as eight hours after birth and this timing helps to differentiate *E. coli* from other causes of neonatal diarrhea, such as Porcine Epidemic Diarrhea virus (PEDv) and Transmissible Gastroenteritis (TGE) which tend to cause diarrhea later in life. *E. coli* with F18 antigens won't cause diarrhea in neonatal pigs because the F18 fimbriae are not fully developed until the pig is about 20 days of age (Fairbrother, Nadeau & Gyles, 2005).

3.3.3 Economic and Production Impact of *Escherichia coli* on Swine Farms

When American farmers were asked to list and rank the production impact of diseases on their farm (Holtkamp, Rotto & Garcia, 2007), the results for *E. coli* were:

- Sow barn: Tenth most cited with an average rank of 8.
- Nursery barn: Fifth most cited with an average rank of 5.
- Finishing barn: Twenty-first most cited with an average rank of 16.

Generally, *E. coli* diseases occur in either neonatal or recently weaned pigs. Newborns are susceptible to disease because they have yet to develop physical strength and immunity from

their mother's milk and colostrum. While neonatal *E. coli* can cause severe diarrhea and death, it is often well controlled on Canadian farms. By comparison, post-weaning *E. coli* is more difficult to control and is likely to surface due to the stress of switching to solid feed, loss of lactogenic immunity, transportation and mixing. Post-weaning diarrhea severely impacts production which leads to economic losses from increased mortality, increased morbidity, decreased growth rate and an increased cost of medication (Fairbrother, Nadeau & Gyles, 2005). This production impact was studied by Ontario researchers who found that infected piglets grew at a rate of 414 grams per day while control herds grew at a rate of 452 grams per day (Amezcua et al., 2002). Furthermore, infected farms saw mortality reach an average of 7.7% while mortality on control farms was only 1.8%.

3.3.4 Prevention and Control of *Escherichia coli* on Swine Farms

E. coli diseases are incredibly common in Canadian swine herds, with effective control measures available to farmers. Neonatal *E. coli* diseases can be controlled by giving a vaccine to pregnant sows or gilts during gestation (Moon & Bunn, 1993). For gilts, this vaccine should be given at two separate occasions for maximum antibody production. Then, in each successive parity, one dose should be provided to sows as antibody production will fall over time without the presence of an *E. coli* threat in their system.

Although manageable, post-weaning diarrhea from *E. coli* is much harder to control than neonatal diseases. Like *S. suis*, the immune system of nursery pigs is compromised from the stress of weaning, mixing and moving. The result can be sporadic with severe diarrhea being caused by *E. coli.* In this case, attempts to reduce stress should always be the priority of farmers, but certain preventive and control measures are also available. Fairbrother, Nadeau and Gyles (2005) suggest a nursery diet with less protein, less soybean and higher in fibre. Vaccination is

an option, but there are challenges. For live vaccines, their effectiveness is either complicated by passive immunity in the sow barn or antibiotics in nursery rations. Furthermore, injected vaccines have a difficult time providing mucosal immunity at the site where *E. coli* diseases occur (Fairbrother, Nadeau & Gyles, 2005). Oral administration of a live vaccine is an alternative to injected vaccines and appears to be effective for both the F4 and F18 type of *E. coli* that cause post-weaning diarrhea (Fairbrother, Nadeau & Gyles, 2005).

One promising alternative to vaccines, are the prophylactic administration of bacteriophages. Jamalludeen et al. (2007) investigated this option and found that while many bacteriophage isolates were successful at lysing pathogenic *E. coli* strains, there is concern that using these bacteriophages will select for resistant *E. coli* strains, in a manner similar to the development of antibiotic resistance. This concern makes licensing the product difficult and is limiting the potential of bacteriophages as a viable option for treating or preventing *E. coli* diseases.

Breeding pigs that are resistant to *E. coli* is another potential venue for controlling diseases, as some pigs lack the receptors for F4 and F18 adhesions in the epithelial lining of their intestine (Laber et al. 2002). The allele for the F4 receptor is on chromosome 13 while the allele for the F18 receptor is on chromosome 6. These traits can easily be identified in pigs through a simple polymerase chain reaction (PCR) test and breeding stock could be selected accordingly. However, there are concerns that breeding for *E. coli* resistance may select for other undesired traits (Fairbrother, Nadeau & Gyles, 2005).

While common, prophylactic antibiotic use is rarely effective for preventing *E. coli* diseases due to problems with antibiotic resistance. Farmers with herds that aren’t infected with

E. coli should adhere to the biosecurity guidelines provided in previous section and place a strong emphasis on cleaning barns and farrowing rooms between new groups of pigs.

3.3.5 Treatment of *Escherichia coli* on Swine Farms

The treatment of *E. coli* diseases is done by administering antibiotics. Seven antibiotics have been listed by the Canadian Edition of the Compendium of Veterinary Products for the treatment of *E. coli* or colibacillosis (any disease or disease caused by *E. coli*). Apramycin, neomycin, neomycin-oxytetracycline, neomycin-tetracycline and spectinomycin are water-soluble options, while gentamicin and trimethoprim-sulfadoxine are available as an injection. apramycin and neomycin are labelled for use in drinking water, which suggests that they are to be used for treating weaner pigs in the nursery barn. neomycin-oxytetracyline and neomycin-Tetracycline can either be squirted in the mouths of neonates with a syringe or they can be dissolved into the drinking water of the nursery barn. Spectinomycin is listed specifically for oral administration in piglets up to four weeks of age and can be given with a syringe. Gentamicin should only be injected into piglets that are 1-3 days of age and trimethoprim-sulfadoxine injections can be administered at any age. The treatments listed above do not include "off-label" use of antibiotics, which can be prescribed by veterinarians.

Research in Ontario (Amezcua et al., 2002) found that the drugs listed above are commonly used among farmers for treating *E. coli* diseases. Water-soluble antibiotics were used by 19 of the 26 farms being studied and of those 19, 73.1% used apramycin (14/19), 15.7% used neomycin (3/19) and 5.2% used neomycin-oxytetracycline (1/19). Furthermore, 7 of the 19 farmers used two types of water-soluble antibiotics rather than just one. In this case, 71.4% chose neomycin (5/7) as their second antibiotic and 28.5% chose neomycin-oxytetracycline (2/7). Despite the use of these drugs among farmers, over time their application has led to resistance

problems. Therefore, identifying the unique serotype of *E. coli* on each farm will avoid misuse of antibiotics and lead to more effective treatment programs. Amezcua et al. (2002) highlight colistin as a possible alternative to the drugs currently being used. However, colistin is a high-priority drug for human medicine and is not listed for veterinary use in Canada (World Health Organization, 2016). Alternatives to antibiotic treatment include zinc oxide supplementation, diet or water acidification and prebiotic supplements (2002).

3.3.6 Antibiotic Resistance in *Escherichia coli*

In Canada, there are seven antibiotics listed for the treatment of diarrhea in pigs caused by *E. coli*. However, *E. coli* resistance to antibiotics is a common problem in Canada and across the world. Research from Ontario found *E. coli* that were resistant to different types of antibiotics, with many being resistant to multiple antibiotics (Dunlop et al., 1998a). Of the antibiotics listed above, Dunlop et al. (1998a) tested *E. coli* for resistance to gentamicin, spectinomycin and tetracycline. When fed antibiotics, pigs of all ages had *E. coli* resistant to tetracycline while sows and weaner pigs showed some evidence of *E. coli* that were resistant to spectinomycin. There was minimal evidence to suggest that in-feed antibiotic use has an impact on developing gentamicin-resistant *E. coli*.

A more recent Ontario study tested pigs that were positive with *E. coli* for resistance to gentamicin, neomycin, spectinomycin, tetracycline and apramycin (Amezcua et al., 2002). Of the samples collected, close to 100% of isolates were resistant to spectinomycin and close to 100% were resistant to tetracycline. More than 55% were resistant to neomycin, 23.5% were resistant to apramycin and 20% were resistant to gentamicin. Given that apramycin and neomycin are the most commonly used antibiotics for treating *E. coli*, it is important to recognize that they are both from the aminoglycoside class of antibiotics, alongside gentamicin. Aminoglycosides can

easily develop cross resistance with one another and this characteristic is important to consider when developing multi-drug treatment programs.

In a third Canadian study, logistic regression was used to determine if there was a connection between antibiotic use and antibiotic resistance on farrow-to-finish swine farms in Ontario and British Columbia (Akwar et al., 2008). Among others, resistance to apramycin, neomycin, spectinomycin, tetracycline and cotrimoxazole (trimethoprim and sulfamethoxazole) was tested for. Of the 47 farms studied, 10% of *E. coli* samples were resistant to neomycin, 55% were resistant to spectinomycin, 81.3% were resistant to tetracycline and 5.5% were resistant to trimethoprim-sulfamethoxazole. Medicating piglets with injected penicillin was associated with *E. coli* resistance to neomycin and adding tiamulin to weaner rations was associated with *E. coli* resistance to tetracycline.

Identifying behaviours that lead to antibiotic resistance is equally important as identifying the presence of resistant bacteria. Research from Denmark demonstrated that a voluntary ban on cephalosporin in Danish pig production significantly reduced cephalosporin-resistant *E. coli* from hogs at processing plants (Agersø & Aarestrup, 2012). Similarly, in a literature review on *E. coli* and antibiotic-resistance, ten of the eleven studies on reducing antibiotic use found that reducing antibiotic use does reduce the number of antibiotic-resistant *E. coli* found in pigs (Burrow et al., 2014). In the same review, twenty-two of the twenty-five studies done on the relationship between antibiotic use and antibiotic resistance, found that pigs being treated with antibiotics were more likely to harbour resistant *E. coli* than pigs that weren't being treated. While some of this *E. coli* was not pathogenic, resistance still presents a health concern given that resistance genes can easily be transferred to different *E. coli* and other gram-negative bacteria that may be harmful to swine and humans.

3.3.7 Connecting *Escherichia coli* in Swine Farming to Human Health

Despite naturally occurring in healthy humans, pathogenic strains of *E. coli* are opportunistic and emerge in vulnerable populations (Dunlop et al., 1998a). Pathogenic serotypes in swine are generally not harmful to humans but commensal and pathogenic *E. coli* in swine can serve as a reservoir for antibiotic-resistant genes. These genes can be passed to other *E. coli* serotypes and to other gram-negative bacterium that are harmful to humans.

It could be argued that creating resistant *E. coli* is a greater threat to public health than the zoonosis of *E. coli* from swine sources. This is because aminoglycosides are the most commonly used antibiotics for group treatments of *E. coli* in swine herds. Not only are aminoglycosides listed as critically important for human health by the World Health Organization, they easily share antibiotic-resistant genes with other aminoglycosides (Jensen et al., 2006). This was demonstrated by Danish researchers who showed that the increased use of apramycin on Danish pig farms increased the number of *E. coli* that were resistant to gentamicin (Jensen et al., 2006). Gentamicin is used in human medicine to treat severe bacterial diseases in hospitals and the increased use of aminoglycosides in livestock production threatens the efficacy of this drug.

In addition to the antibiotics that are labelled for the treatment of *E. coli*, Moodley and Guardabassi (2009) demonstrate how the prophylactic or growth promoting use of broad spectrum antibiotics leads to antibiotic-resistant bacteria. In Danish farms, where ceftiofur was used prophylactically in the early 2000s, *E. coli* collected from pigs, farm personnel and manure were found to be resistant to cephalosporins. Extended-spectrum cephalosporins are listed as one of the highest priority antibiotics in human medicine (World Health Organization, 2016), and any behaviour that facilitates cephalosporin-resistant bacteria should be avoided. Therefore, it is

important for livestock producers to reduce the use of antibiotics labelled for *E. coli* and the use of broad spectrum antibiotics given to pigs to protect antibiotics for human medicine.

3.4 *Mycoplasma hyopneumoniae*

3.4.1 Introduction to *Mycoplasma hyopneumoniae*

Mycoplasma hyopneumoniae (*M. hyopneumoniae)* is a gram-negative, facultative anaerobe bacterium and is the causative agent of enzootic pneumonia in pigs (Laber et al., 2002; Erlandson et al., 2002). Very little information is provided in the literature about *M. hyopneumoniae* serotyping but strain 232 is commonly used in the United States for vaccination programs and it has had its genome sequenced in 2004 (Minion et al., 2004). This section is written about *M. hyopneumoniae* generally and is not about one specific serotype or strain.

3.4.2 Health Impact of *Mycoplasma hyopneumoniae* on Swine Farms

M. hyopneumoniae colonize the respiratory tract of pigs and can be found on the mucosal surface of the trachea (windpipe), bronchi (air branches) and bronchioles (smaller air branches) (Laber et al., 2002). These bacteria damage the pig's mucous clearing system by killing the cilia of epithelial cells and by filling the alveoli with unwanted cell debris (Simionatto et al., 2013). As a result, the primary symptom of a *M. hyopneumoniae* disease is a dry, non-productive cough that will generally appear in the finishing barn, 7-14 days after the original disease (Thacker, 2004). Because *M. hyopneumoniae* colonize in the respiratory tract, the disease is spread by coughing and the sharing of mucous. This location also makes diseases hard to treat and allows the bacteria to avoid the pig's immune system (Thacker, 2004). Another challenge to treating *M. hyopneumoniae* is that it lacks classical virulence factors and researchers are unsure of how they elicit toxic effects (Maes et al., 2011). One known characteristic of *M. hyopneumoniae* is that

they are able to modify the pig's immune system, rendering the pig more susceptible to other diseases and viruses (Maes et al., 2008). These diseases are varied, but *M. hyopneumoniae* is most generally recognized for its role in facilitating Porcine Respiratory Disease Complex (PRDC) (Erlander et al., 2002). The resulting illness causes more severe symptoms and a much higher mortality than a non-concurrent *M. hyopneumoniae* disease.

3.4.3 Economic and Production Impact of *Mycoplasma hyopneumoniae* on Swine Farms

When American farmers were asked to list and rank the production impact of diseases on their farm (Holtkamp, Rotto & Garcia, 2007), the results for *M. hyopneumoniae* were:

- Sow barn: Seventh most cited with an average rank of 7.
- Nursery barn: Seventh most cited with an average rank of 7.
- Finishing barn: First most cited with an average rank of 4.

Most of the harm caused by *M. hyopneumoniae* is seen in finishing pigs and young breeding stock between the ages of three to six months (Laber et al., 2002). With an estimated 38%-100% of herds being infected worldwide, this disease has a significant impact on the industry (Simionatto et al., 2013) A 1989 literature review found a 2.8% to 44.1% decrease in the average daily weight gain of finishing pigs infected with *M. hyopneumoniae* (Straw, Tuovinen & Bigras-Poulin, 1989). More recently, European researchers found that uncomplicated *M. hyopneumoniae* diseases decreased finisher growth rate by about 60 grams per day (Rautiainen et al., 2000). In the United States, the average daily weight gain of finishing pigs fell when they were seropositive for Swine Influenza (-18g/d), Porcine Respiratory and Reproductive Syndrome virus (PRRSv) (-40g/day) and *M. hyopneumoniae* (-38g/day) compared to seronegative pigs (Regula et al., 2000). For finishing pigs that typically average growth of about 800g/day, this

results in a 2%, 5% and 4.8% reduction. This decrease in average daily weight gain paired with poorer feed efficiency, uneven growth and additional treatment significantly increase costs for farmers (Maes et al., 2011). Haden et al. (2012) estimated the cost of an uncomplicated *M. hyopneumoniae* disease to be around $0.63 USD per head in a grow-finish barn. However, respiratory diseases in pig barns are often complicated, with *M. hyopneumoniae* diseases often being paired with PRRSv, Porcine Circovirus type 2 (PCV2), Influenza A and other diseases (Holst, Yeske & Pieters, 2015). Pairing *M. hyopneumoniae* with these other diseases can dramatically increase a farmer's costs to around $10 USD per pig (Haden et al., 2012). For farmers working on thin margins, these diseases can quickly turn a profitable operation into one that is operating at a loss.

3.4.4 Prevention and Control of *Mycoplasma hyopneumoniae* on Swine Farms

Due to growing farm sizes and increased treatment costs, many farmers choose to prevent or eliminate *M. hyopneumoniae* from their herd. In lieu of total eradication, many farmers opt to vaccinate herds as an economical means of preventing a disease outbreak. Simionatto et al. (2013) estimate that over 85% of herds in the U.S. are vaccinated for *M. hyopneumoniae* and it is widely considered the most cost-effective control measure available. Injected vaccines are the most common, with many farms opting to vaccinate sows prior to gestation and vaccinate piglets sometime around weaning (Maes et al., 2008; Pieters & Sibila, 2017; Maes et al., 2011). Vaccination of naive gilts is particularly important in endemically infected herds. This allows them to build an immune response to the disease before being introduced to the rest of the breeding herd. If left unvaccinated, susceptible gilts can become infected with *M. hyopneumoniae* and will shed the pathogen. This additional disease load will greatly increase the chance of an outbreak in the breeding and growing herd (Nathues et al., 2016).

For piglets, optimal administration of the *M. hyopneumoniae* vaccination is challenging for reasons similar to the administration of the *E. coli* vaccine. Effectiveness is compromised by lactogenic immunity, organization of barn labour and the stress of being weaned. According to researchers, there doesn't appear to be a "one size fits all" timing for *M. hyopneumoniae* vaccination. However, Maes et al. (2011) found that vaccinating three days before weaning showed slightly better results that vaccinating at weaning. Pieters and Sibila (2017) hypothesize that this may be because generating a strong immune response from a vaccine is a significant challenge for young animals which may be amplified when paired with the stress of weaning. While vaccination does not prevent the colonization of *M. hyopneumoniae* in herds, Maes et al. (2008) reported that vaccine use resulted in a 2-8% increase in average daily weight gain, 2-5% improvement in feed conversion and the potential for reduced mortality compared to non-vaccinated pigs.

Similar to other bacterial diseases, Holst, Yeske & Peters (2015) highlight the importance of optimizing management and housing conditions when dealing with *M. hyopneumoniae*. They offer several recommendations including:

1. All-in all-out management where barns are cleaned between different groups
2. Reduce mixing or sorting of pigs
3. Wean pigs early and keep gilts separate from sows during gestation and farrowing
4. Buy replacement breeding stock from herds that are *M. hyopneumoniae* negative and keep them isolated from the rest of the herd for >30 days
5. Lower stocking densities and increase biosecurity to avoid concurrent diseases

In a study done on reducing within herd transmission of *M. hyopneumoniae*, appropriate gilt acclimatisation, early weaning, and all-in all-out management were the most for reducing

transmission (Nathues et al., 2016). More specifically, acclimatizing gilts was the most important factor for transmission in the sow barn and finishing barn whereas suckling length was the most important factor for within herd transmission in the nursery barn. In this study, vaccination did not play a role in transmission of the disease. However, the model only tested for rate of disease transmission and did not test for the severity or length of the disease. Tiamulin is listed in the Canadian Compendium of Veterinary Products for use in preventing *M. hyopneumoniae* and there is little evidence that a resistance issue exists.

3.4.5 Treatment of *Mycoplasma hyopneumoniae* on Swine Farms

Despite being different than other bacteria, *M. hyopneumoniae* is still treated by administering antibiotics. The Canadian Edition of the Compendium of Veterinary Products lists four antibiotics that can be used to treat *Mycoplasma* diseases in pigs. For *M. hyopneumoniae,* lincomycin and tiamulin can be given in feed, tilmicosin can be given in feed and water and tulathromycin can be given via an injection. More generally, a lincomycin injection is available that can be used to treat all *Mycoplasma* diseases. The list of treatments above does not include the "off-label" prescription of antibiotics by veterinarians.

While many other bacteria have begun to develop resistance to these antibiotics, Maes et al. (2008) suggest that, to date, the antibiotics available are still highly effective at treating *M. hyopneumoniae.* However, despite the effectiveness of treatment options, the literature on *M. hyopneumoniae* seems to focus on using these antibiotics as a tool in eliminating the disease rather than simply treating it. By using these antibiotics, farmers can avoid a full depopulation and repopulation of the herd and still eliminate e disease. The original version of this strategy is called the Swiss Method and was used to eradicate *M. hyopneumoniae* in Switzerland in the 1990s. Since then, other countries have added different medication, vaccination and closure

protocols to help improve disease eradication while having a smaller effect on production (Holst, Yeske, & Pieters, 2015). Depending on the strategy used, *M. hyopneumoniae* is successfully removed in 58-81% of herds and pigs stay seronegative for between 37 to 49 months after eradication. Given these findings, in a 2500 head sow herd, the estimated cost of the program would be $15.90 USD per sow with benefits of $1.19 USD per growing pig. At 25 pigs per sow per year, it would take 4.5 months for the farmer to get their investment back and an additional 26.5 months of improved production would be provided. A more detailed summary of *M. hyopneumoniae* eradication plans and their effectiveness can be found in Holst, Yeske and Pieters (2015).

3.4.6 Antibiotic Resistance in *Mycoplasma hyopneumoniae*

Canadian pig farmers and veterinarians have four listed antibiotics at their disposal for treating *M. hyopneumoniae*. Despite the smaller number of treatment options available, reported antibiotic resistance in *M. hyopneumoniae* is far less common than in other bacteria. Resistance to tetracyclines, lincosamides, macrolides and fluoroquinoles have been reported (Inamoto et al., 1994; Vicca et al., 2004) but Maes, Pasmans and Haesebrouck (2011) suggest that this resistance does limit our current ability to treat *M. hyopneumoniae* diseases. Despite these findings, prudent use of antibiotics in treating *M. hyopneumoniae* will be essential to avoiding problems with resistance in the future.

3.4.7 Connecting *Mycoplasma hyopneumoniae* in Swine Farming to Human Health

Fortunately, *M. hyopneumoniae* is a host specific pathogen that doesn't infect humans (Simionatto et al., 2013). Given that there is no risk of human disease and little evidence of

antibiotic resistance in *M. hyopneumoniae*, this disease and its treatment present very little risk to humans.

3.5 *Lawsonia intracellularis*

3.5.1 Introduction to *Lawsonia intracellularis*

Lawsonia intracellularis (*L. intracellularis*) is a gram-negative, obligately intracellular bacterium that is the causative agent of Proliferative Enteropathy (PE) in pigs (McOrist et al., 1995). *L. intracellularis* is an intracellular bacterium which means that it will enter the host cell it is attacking rather than just attacking the outside. As a result, *L. intracellularis* does not grow in an aerobe or anaerobic culture which makes it difficult to study. Genomic and protein analysis have determined that there is only one strain of *L. intracellularis* that infects swine and no variant strains have been documented (Kroll, Roof & McOrist, 2004). These findings have been supported by field studies where pigs from thousands of kilometers away were still infected by the same strain of *L. intracellularis* (McOrist and Smits, 2007).

3.5.2 Health Impact of *Lawsonia intracellularis* on Swine Farms

L. intracellularis colonize the epithelial cells of the small intestine in swine (Boutrup et al., 2010). Diseases cause a thickening of the gut wall which can reduce the ability of the pig to digest food and absorb nutrients (Laber et al., 2002). McOrist and Smits (2007) describe diseases as acute, subclinical or chronic depending on the severity of symptoms. Other names for the varying severity of *L. intracellular* diseases include porcine intestinal adenomatosis (chronic), necrotic enteritis (chronic with secondary diseases), regional ileitis (recovering stage of necrotic enteritis) and proliferative haemorrhagic enteropathy (acute) (Jacobson, Fellström & Jensen-Waern, 2010). Bae et al. (2013) highlight the subclinical form as being the most common, with

many producers not realizing there is a disease unless they look at their barn's productivity metrics. The chronic form is common among pigs that are 4-20 weeks old and acute diseases are often seen in pigs that are over 4 months old (McOrist & Smits, 2007; Jacobson, Fellström & Jensen-Waern, 2010). Chronic symptoms include reduced performance, soft brown faeces and a rough hair coat (Jacobson, Fellström & Jensen-Waern, 2010). In acute cases there is sudden death paired with black, tarry faeces and a significant reduction in performance (McOrist & Smits, 2007). Diseases are spread through fecal-oral contact and infected pigs will generally shed the bacteria for 2-6 weeks after the original disease (Stege et al., 2004). Most of the herd will become seropositive after the first disease and will remain seropositive until they are processed (Stege et al., 2004).

3.5.3 Economic and Production Impact of *Lawsonia intracellularis* on Swine Farms

When American farmers were asked to list and rank the production impact of diseases on their farm (Holtkamp, Rotto & Garcia, 2007), the results for L. *intracellularis* were:

- Sow barn: Fifth most cited with an average rank of 6.
- Nursery barn: Twentieth most cited with an average rank of 8.
- Finishing barn: Fifth most cited with an average rank of 5.

Similar to *M. hyopneumoniae*, problems with *L. intracellularis* are often observed in finishing pigs and young breeding stock. Regionally, it has been estimated that between 15-100% of herds are infected and disease rates within herds often range between 8% and 67% (Laber et al., 2002, Jacobson, Fellström & Jensen-Waern, 2010). The costs of *L. intracellularis* to the entire industry has been estimated at $100 million in the U.S. (Kroll, Roof &, McOrist, 2004) and £4 million in the U.K. (McOrist et al., 2000b). Using a simulation, Australian research found that chronic

diseases resulted in 12% of pigs' suffering a 23% decrease in average daily weight gain over a two-week period (weeks 8 to 10) (Holyoake, Mullan & Cutler, 1996). The resulting cost was estimated at $0.80 CAD per pig sold. For acute cases of *L. intracellularis*, 4% of pigs suffered from a 35% decline in average daily weight gain while 8% suffered at 23% decline in weight gain. The severity of acute *L. intracellularis* also increased mortality and veterinary costs such that the estimated cost of the disease increased to $7.57 CAD per pig sold. Stege et al. (2004) estimated that *L. intracellularis* increased the cost of weaner production per pig by $1.50 – $3.00 USD, Bae et al. (2013) estimated the cost to be between €0.50 and €1.00 and Jacobson, Fellström & Jensen-Waern (2010) estimated that farmers lose $1.53 USD per pig when it is infected with *L. intracellularis*. Prevention, control and treatment of this disease should be a priority among famers.

3.5.4 Prevention and Control of *Lawsonia intracellularis* on Swine Farms

L. intracellularis can be effectively controlled using an attenuated live vaccine that is extensively used in the hog industry (Kroll, Roof & McOrist, 2004; McOrist & Smits, 2007). An attenuated live vaccine is a vaccine that is made up of live pathogenic bacteria but has reduced virulence. For *L. intracellularis*, the vaccine stimulates an immune response in the pig by infecting a limited portion of its gut. However, unlike a natural disease, these bacteria are unable to replicate and won't reach populations that can cause harm to the pig (Jacobson, Fellström & Jensen-Waern, 2010).

In an Australian study performed in 2003, this type of vaccine was administered either via a drench or drinking water to three-week-old pigs (Kroll, Roof & McOrist, 2004). Oral administration is preferred to injection at weaning because it is less stressful. Three weeks later, these piglets were infected with *L. intracellularis* through exposure to a virulent isolate of the

bacteria. Although this artificial disease may not replicate a natural farm disease, the timing of this disease is consistent with the onset of the disease described in previous studies. Weight, seroconversion and fecal consistency were measured from the time of disease to twelve weeks of age. Vaccinated and negative control pigs showed comparable average daily weight gain and this weight gain was significantly higher than the positive control pigs for final three weeks of the study (730g/day and 740g/day vs. 660g/day). There were also fewer lesions and less shedding in pigs that were given the vaccine.

In addition to vaccines, options for preventing and controlling the disease include using a course feed ration, feeding a restricted diet, reducing the unnecessary mixing of pigs and using an all-in-all-out pig flow with cleaning and disinfecting between groups (Jensen, 2006). *L. intracellularis* can live in extracellular conditions for 1-2 weeks but is easily killed with disinfectants like ammonia and iodine (Stege et al., 2004). Slatted flooring and disinfecting reduce fecal-oral transmission of the disease but fail to control for transmission by rodents. Therefore, in addition to standard biosecurity measures, rodent control should be a priority for biosecurity programs designed to address *L. intracellularis* (Laber et al., 2002). Tylosin and chlortetracycline are listed in the Canadian Compendium of Veterinary Products for the prevention of *L. intracellularis* and there is very little evidence of any meaningful antibiotic resistance in this bacterium.

3.5.5 Treatment of *Lawsonia intracellularis* on Swine Farms

L. intracellularis in pigs is treated by administering antibiotics. The Canadian Compendium of Veterinary Products lists four antibiotics for treating *L. intracellularis*, including lincomycin, tiamulin, tylosin and tylvalosin. Lincomycin and tiamulin are all provided to pigs via feed while tylosin and tylvalosin can be administered via feed or water. This list does

not include “off-label” use of antibiotics that can be prescribed by veterinarians for *L. intracellularis* treatment.

Initially, the drugs listed seem unlikely to be effective against *L. intracellularis* given that most of their activity is against gram-positive bacteria. Furthermore, when cultivated in a lab (in vitro), many of these antibiotics actually require high to moderate concentration levels to be effective against *L. intracellularis* (McOrist, 2000). However, due to the intracellular nature of *L. intracellularis* diseases, these drugs appear to be able to do a better job of targeting this disease in natural setting (in vivo) rather than in vitro.

In his personal review of Denmark’s transition to reduced antibiotic use, Jensen (2010) highlights the importance of *L. intracellularis* for farmers transitioning to reduced antibiotic use. Historically, *L. intracellularis* had not been a major problem for Danish pig producers. This changed in the year 2000 when antibiotic growth promoters were banned and there was a significant increase in diarrhea caused by *L. intracellularis* emerging on farms. This ban led to a significant increase in the amount of antibiotics that were being used for treating diseases, in particular gastrointestinal diseases like *L. intracellularis*.

Laber et al. (2002) highlight that penicillin, erythromycin, difloxacin, virginiamycin and chlortetracycline were the most effective against *L. intracellularis* in a lab setting. A recent study from Denmark (Larsen et al., 2016) found that providing oxytetracyline via water for five days after weaning was effective at improving average weight gain and reducing fecal shedding. A water-soluble lincomycin-spectinomycin powder was also shown to be effective at improving average daily weight gains, reducing fecal shedding and improving fecal consistency (McOrist et al., 2000a). Research specific to pork producing regions will help to establish best practices for treating *L. intracellularis* in Ontario.

3.5.6 Antibiotic Resistance in *Lawsonia intracellularis*

Of the four antibiotics listed for *L. intracellularis* treatment, several have a history of resistance problems with different bacterial diseases. However, there is currently very little research to suggest that *L. intracellularis* is resistant to any of them. Part of this may be due to a lack of research, strained by the challenge of cultivating *L. intracellularis* in a lab setting (Jacobson, Fellström & Jensen-Waern, 2010). However, McOrist (2000b) highlights several potential characteristics of *L. intracellularis* that may make it less likely to develop resistance to antibiotics than other bacteria:

1. *L. intracellularis* might be incapable of acquiring new genes, like resistance genes
2. Antibiotic resistance might reduce the viability of *L. intracellularis*
3. The altered metabolism of *L. intracellularis* might reduce its ability to utilize resistance genes

L. intracellularis is a relatively new bacterial discovery and continued surveillance will be essential as Canadian farmers transition to reduced antibiotic use. This is especially true for *L. intracellularis* given the experience of Denmark, where low-dose antibiotics were effectively controlling the disease until they were banned.

3.5.7 Connecting *Lawsonia intracellularis* in Swine Farming to Human Health

The full extent of *L. intracellularis* hosts has yet to be clearly established (Smith & Lawson, 2001). The bacteria have been shown to infect several warm-blooded animals although it has never been confirmed in humans (Jacobson, Fellström & Jensen-Waern, 2010). Public health research has considered whether *L. intracellularis* is connected to Crohn's Disease or Ulcerative Colitis because of the similarities in symptoms. However, it was found that neither were connected to this bacterium (Michalski et al., 2006). Other than general concerns about

resistance to macrolides from Tylosin use, there doesn't appear to be any human threat created through zoonosis or treatment of the disease.

3.6. Summary

The impact of bacterial diseases on swine farming is significant and complex. Each bacterium is unique in the way that it affects pigs and, in the way that it needs to be managed. Given the information provided in this review, the remainder of this research will be focusing on *Lawsonia intracellularis* (*L.* i*ntracellularis)*. *L. intracellularis* is a good candidate for this research for several reasons. The first is that *L. intracellularis* was one of the biggest issues that producers in Denmark faced following the ban on AGPs and the requirement to have a prescription for antibiotics. Therefore, when the same rules are applied in Canada, the information provided in this study will be immediately relevant for producers. Furthermore, *L. intracellularis* is often endemic, so there is no progression of the disease throughout the herd. This means that the model used for this research can be static as it does not require a time component and does not require complex epidemiological inputs to be relatively representative of an infected herd. The following section reviews the economic models that are used to research livestock management. This information will be used to make a decision about which model will is best suited to measure the economic benefit that antibiotics provide for managing a *L. Intracellularis* disease.

CHAPTER 4

REVIEW OF EMPIRICAL MODELS

4.0 Introduction to the Chapter

The following chapter will discuss the different types of economic models that are used for studying livestock management. This begins with an introduction to economic models in livestock research and then follows with specific information on partial budget analyses, cost-benefit analyses, decision analyses, dynamic programming and system simulation. This section concludes by stating the model that will be used for this research and providing justification for this decision.

4.1 Introduction to the Economic Models used for Studying Livestock Health

Economic models are increasingly being used to evaluate farm practices. Within this type of research, there are several modeling techniques that have been used to analyze the economics of livestock diseases and the strategies that farmers use to control them. Each technique provides unique benefits and limitations depending on the approach of the researcher or the type of questions they are trying to answer. Bennett (1999) outlines how this wide range of modeling techniques presents several limitations for policy makers who are looking to use this information to make decisions. One of these limitations is that with so many different models, it can be difficult compare results across different studies. The following section will explore some of these modeling techniques and provide examples of how they have been used to study the economics of livestock health. Based on this information, a model will be selected to study the economic benefits of the antibiotics and vaccines available for managing a *L. intracellularis* disease on a Canadian pig farm.

4.2 Partial Budget Analysis

The partial budget is one of the most common modeling techniques used for analyzing the impact of a disease on a farm. Partial budget analyses work by comparing the performance of an economic system at baseline to the economic system once it has had some kind of a shock applied to it. In livestock research, this shock might be a new feed supplement, the use of a new vaccine or the introduction of a disease to the herd. While partial budget analyses tend to focus on the financial impact of these shocks, the initial analysis is often done on the livestock's performance. These changes in performance then provide the information needed to do a financial analysis. When partial budget analyses are used for estimating the impact of a shock, they will also often include a sensitivity analysis around the expected outcome. This means that a wide range of outcomes are analyzed and each one is assigned a likelihood of occurring. Boehlje and Eidman (1984) outline the four pieces of a partial budget analysis: Additional revenue due to the change, reduced costs as a result of the change, returns lost because of the change and the additional costs of implementing the change. In addition to its use in research, partial budgeting is a helpful tool for veterinarians and farmers to use when making decisions on their farms.

An example of a partial budget analysis applied to livestock health can be found in research performed by Alarcon et al. (2013a). Their paper included a partial budget analysis that outlined the cost of post weaning multi-systemic wasting syndrome and porcine circovirus type-2 in pigs on farrow-to-finish farms. They concluded that there was no additional revenue from the diseases, some cost savings from fewer inputs due to increased mortality, revenue forgone from mortality, and additional cost for feed and other accommodations required for sick pigs. With respect to livestock health economics, the partial budget analysis is primarily used for a farm-level analyses similar to the one described above.

4.3 Cost-Benefit Analysis

A cost-benefit analysis is a process by which alternative decisions or outcomes are evaluated. As the name implies, researchers performing a cost-benefit analysis will try to identify and measure all of costs and benefits associated with a particular choice. While many costs and benefits are not naturally quantified in monetary terms, it can be helpful, although very challenging, to try and describe all of the factors using their dollar value for ease of comparison. Unlike the partial budget analysis which is often utilized at the farm level, the cost-benefit analysis can be used to evaluate different livestock health decisions made at the farm, in the industry and at the national level. Bennett (1992) characterizes cost-benefit analyses as analyses whose outcomes include the net present value, internal rate of return and cost-benefit ratios of a decision. The net present value highlights that costs and benefits in the future carry less weight than those in the present. A cost-benefit analysis can be helpful when trying to include the value of externalities in an assessment such as the impact of livestock antibiotic use on human health.

An example of a cost-benefit analysis in livestock health can be found in Berentsen et al.'s (1992) analysis of preventive and control strategies for foot-and-mouth disease (FMD) in Dutch cattle and swine herds. This model paid special attention to export bans that could result from a disease outbreak. The authors concluded that in the optimistic and expected outbreak situation, a yearly vaccination program was not profitable. However, under more pessimistic expectations about an outbreak, the yearly vaccination was more profitable than not vaccinating which would lead to importers cutting off market access for producers. Due to researchers' valuations for different costs and benefits, this type of analysis has been criticized for its subjectivity and variation. However, Bennett (1992) suggests that this type of analysis remains

useful as long as the authors provide clear and justified methods for their evaluations and are consistent throughout their work.

4.4 Decision Analysis

Decision analysis is a more general framework by which complex decisions can be broken down into a more manageable format. This analysis generally consists of one of the following four techniques: mathematical equations, payoff matrices, process diagrams or decisions trees, although decision trees are most commonly used (Ngategize et al., 1986). A decision tree is a graphical representation spanning from left to right that looks similar to a flow chart. Moving from left to right, a decision is made and represented by a decision node. To the right are the possible outcomes of that decision, each with an assigned probability of occurrence. These outcomes are broken down into the factors that the decision maker will use to help make their decision. For livestock health, a decision might be to vaccinate your herd. Vaccination can lead to no disease, some disease and a complete outbreak with all outcomes carrying a different probability of occurrence. Based on each outcome, factors like costs and revenues can be calculated and compared to the potential outcomes of other decisions. Unlike partial budget or cost-benefit analyses which are specific tools, a decision analysis is more often used as a framework for economic researchers, which then incorporates these tools afterwards.

4.5 Dynamic Programming

Dijkhuizen et al. (1991) describe dynamic programming as a mathematic means to evaluate a process of decisions. Using the decision tree framework, this process begins at the most desired final outcome and works its way backward through a chain of outcomes and decisions to the decision makers current state. Dynamic programming can identify the most

desired path to reach this outcome based on the parameters outlined by the researcher. Dijkhuizen's paper highlights two examples of economic research that has been performed using dynamic programming (Van Arendonk, 1985; Huirne et al., 1988). In these two papers, the authors use dynamic programming to make decisions about whether or not to cull dairy cattle (1985) and swine (1988). Despite historically being used for farm-level decisions, this programming may be an effective means for making national level decisions about the spread of livestock diseases and its effect on the public. For this analysis, the outcomes and factors included should be generated with a cost-benefit analysis that incorporates animal welfare, consumer welfare and national economic loss.

4.6 System Simulation

System simulation is a popular method for modeling shocks to livestock health. In practice, a researcher creates a simulation that attempts to replicate real life. This simulation is generally developed using parameters drawn from the real-life system that the simulation is trying to imitate. For example, in Weng et al.'s (2016) research on porcine epidemic diarrhea, a simulated pig farm was constructed using the average production numbers provided on the provincial government's agricultural website. System simulations are particularly helpful for research in livestock health because it allows the researcher to estimate the effects of a disease without needing to actually infect the herd. In the research by Alarcon et al. (2013a) mentioned previously, a production simulation was built based on the industry's benchmarks for production metrics. The impact of the disease was imposed on this model according to the results of a previous study that analyzed the impact of the disease on a herd's production (Wieland et al., 2012). The same can be done for evaluating alternative treatment and prevention strategies. In the second part of Alarcon et al.'s research (2013b), different strategies to control the disease

were assessed using a production simulation based on average production values for the industry and the impact of treatments were simulated based on information from a number of sources including journals and consultation with industry representatives. For research in livestock health, a production simulation is generally constructed and then shocked with different diseases and intervention strategies. The economic analysis is then performed using the production values generated by the simulation. However, it is possible to incorporate financial data directly into the simulation so that outputs of the simulation include financial information about the shock imposed. An example of this can be found in Marsh et al.'s (1987) Dairy ORACLE model which is used to compare four different decision rules for culling dairy cows.

There are a number of different characterizations of simulation models. One is that they can either be dynamic or static. A static simulation shows a one-time picture of what would happen should a shock occur to a system. For example, a static stimulation can show the cost of a disease to a farmer at one particular point in the progress of the disease through a producer's barn. What are more useful for research in livestock health are dynamic simulations. These simulations provide researchers with a well-suited format for modeling the epidemiology of a disease as it progresses through a herd. Farmers use a wide range of intervention strategies that depend on things like the age of the animal and the progression of the disease. These dynamic simulations provide more opportunity to explore the wide range of disease intervention strategies and then monitor their affect on the herd over time. In this way, they are far more realistic than the simple static model. Another characterization of a simulation model is how it incorporates uncertainty into its calculations. There are three approaches to incorporating uncertainty into a simulation model. The first is to not incorporate uncertainty at all and base the model off of expected values. The second is to perform a sensitivity analysis with the simulation. A sensitivity

analysis involves running the simulation under three to five possible outcomes. Because the progress of diseases is difficult to predict, many researchers will run their simulation under a worst-case scenario, a poor scenario, the expected scenario, a good scenario and the best-case scenario. This type of research allows farmers and veterinarians to use the model to make decisions about farm management based on their risk preferences. Berensten et al. (1992) performed a sensitivity analysis in their analysis of vaccination programs by running a simulation under the most optimistic situation, the most likely situation and the most pessimistic situation. Similarly, Bennett et al. (1999) described rates of disease incidence, treatment and prevention as low and high to evaluate the spread of outcomes from a number of different diseases and their control strategies. Sensitivity analyses are popular within this type of research because they are relatively simple to perform using a simulation and provide more useful information to the livestock producers who benefit from this type of work. The third approach is using a stochastic simulation which is different in that it incorporates risk and uncertainty directly into the simulation. A researcher can then run the simulation repeatedly in an attempt to show how all of the random variables interact with one another. The repeated simulations create a sample that is used to make generalizations about the population. Dijkhuizen et al. (1987) built a stochastic simulation model that imitates day to day production on a dairy farm to help farmers make management decisions.

4.7 Summary

For this research, a deterministic static simulation model is the most appropriate method for measuring the performance of a farrow-to-finish swine herd at baseline, with a disease and with a disease being managed by antibiotics. A static model is appropriate given the reasons outlined in Chapter 3 and it will be deterministic because there is insufficient data to justify the

distributions needed for a stochastic model's production parameters. However, there are sufficient clinical studies that can be used to justify the assumptions required for a deterministic simulation model and the results of this simulation can then be used to perform a partial budget analysis for the different antibiotics and vaccines available for managing a *L. intracellularis* disease. The results of the partial budget analysis will indicate which antibiotics provide the most amount of benefit, which provide the least and which fall somewhere in between. These are the data needed by livestock industries to inform decisions about reducing antibiotic use and antibiotic resistance.

CHAPTER 5

SIMULATION DESCRIPTIONS

5.0 Introduction to the Chapter

The following chapter will describe the groups of simulations that were run in order to perform the necessary partial budget analyses for this research. These simulations built in Excel ® and are broken down in Figure 1. Here we can see that there is one baseline scenario, three disease scenarios and thirty-six disease management scenarios. By comparing these scenarios against one another, the damage caused by the disease and the benefit provided by the medication can be measured. The chapter begins by describing the operations of a typical farrow-to-finish pig farm. This is used as the basis for building the baseline simulation, from which all of the other simulated scenarios are generated. The next section describes the disease scenarios and provides justification for the production assumptions in each scenario. The final section describes the medications available for managing *L. intracellularis* and the cited impact that these medications have on herds infected with *L. intracellularis*. Information from this chapter provides the production information needed to generate data on the economic benefits that each antibiotic and vaccine provide.

5.1 Farrow-to-Finish Description

5.1.1 The Sow Barn

The sow barn is the first stage of production in a pig operation. The sow barns house the farmers' breeding animals and it is where these animals are kept for breeding, pregnancy, birthing and nursing. Running a sow barn is the most complicated production stage in pig farming and requires the most amount of management and labour.

Female pigs will start breeding once they reach sexual maturity, at around six months of age. These young females (gilts) are often bought in by the farmer and come from herds with superior breeding genetics. Unlike the pigs that a commercial producer will raise, these pigs are designed to have large, robust litters rather than be good growers themselves. After a few weeks of becoming acclimatized to the new barn, these gilts will join a breeding group of older sows and replace the sows in that group, that the farmer no longer wants to keep. The farmer will then breed this group several times over a period of 2-3 days.

After breeding, each pig is typically kept in an individual stall for the next three to five weeks. Keeping these pigs in stalls improves the individual monitoring of pigs and makes it easier for the farmer to see if the sows come back into heat (indicating that they were not successfully bred). After this time, the successfully bred pigs will be moved into a group pen where they will stay until they are ready to have their piglets (113-117 days after breeding). The pigs that were not successfully bred are either removed from the herd or moved into the next breeding group to try again.

About a week before the mother pigs are ready to have their piglets, they are moved into farrowing crates. These specially designed crates allow a mother pig to safely raise her piglets while giving the piglets access to extra heat and supplemental feed (creep feed). Three weeks after birth, the piglets are weaned from their mothers and mixed with the other piglets to be moved into the nursery barn. After weaning, the sow returns to the breeding barn and will often be bred within three to five days of weaning. The older sows are replaced with new gilts and the process begins all over again.

5.1.2 The Nursery Barn

The nursery barn is the second stage of production in a pig operation. This is the barn where the piglets are moved to after they have been weaned from their mothers. A nursery barn is often at a different site than the sow barn and the nursery pigs are moved using a truck and trailer. Piglets enter the nursery barn at three weeks of age and will stay there for eight weeks. In the nursery barn, the litters from the sows are mixed together and piglets are moved to a solid feed diet. Moving to the nursery barn is a challenging time for piglets as they are switching to solid feed and being weaned, moved, mixed and vaccinated all at the same time. To help with this, nursery barns are typically smaller and use mechanical heating and ventilation to provide a warm, dry environment. This well-controlled housing and prophylactic medication help the piglets to thrive during a time when they are most susceptible to illness.

5.1.3 The Finishing Barn

The finishing barn is the final stage of pig production, where pigs are moved to after they have left the nursery barn. Finishing barns are bigger, have cement flooring and are better able to handle the much larger pigs. Pigs enter the finishing barn at eleven weeks of age and will stay there for roughly sixteen weeks. Similar to in the nursery barn, the transportation and moving of pigs is challenging for them and may make them more susceptible to illness. If medication is used in the finishing barn, it is often within the first few weeks of arrival. Figure 2. outlines the typical animal flow in a farrow to finish operation.

5.2 Description of the Baseline Model

The following section will outline the assumptions used to simulate the production stages described above for farrow-to-finish operation with 1000 sows. Based on the author's

experience, this is the typical size for a producer that has a farrow-to-finish operation. In the sow barn, mature female pigs are housed to raise their piglets. Assuming 21 days for weaning, a 5-day weaning to breeding interval, 2 days of breeding and a 115-day gestation length, a sow can produce 2.55 litters per year. For a 1000 head sow-herd that batch-farrows weekly, this results in 20 groups of sows with 50 sows per group. Assuming the farmer sells his sows as culls after the sixth parity and there is 0.8% sow herd mortality, the replacement rate for sows is 17.5% per parity or 44.62% annually.

Therefore, in each group, 41 of the females are sows and 9 of the females are gilts. If sows wean 11.31 piglets and gilts wean 9.35 piglets per breeding, then annually, this combines to 27.96 pigs/sow/year. Assuming an 85% farrowing rate, this amounts to approximately 24,239 pigs per year being shipped to the nursery barn or 466 pigs per week. Pigs are then kept in the nursery for 8 weeks and, with typical mortality around 3%, there are approximately 452 pigs being shipped from the nursery to the finishing barn per week for a loss of about 14 pigs per group. Provided there is 2% mortality in the finishing barn over a 16-week period, this amounts to 443 pigs being shipped per week to the processing plant or about 23,042 pigs per year. Table 2 provides the references for these assumptions and the calculations made to determine the pig flow described above.

5.3 Disease Model

The baseline simulation described in Table 2 reflects a typical, healthy herd that is not impacted by a severe disease like *L. intracellularis.* The following section will describe how this baseline simulation is impacted by a *L. intracellularis* with regards to changes in animal growth and productivity. In order to perform some sensitivity analysis around a *L. intracellularis* disease, three disease scenarios were created to be imposed on the simulation. These three

scenarios reflect the three different levels of *L. intracellularis* severity commonly described in the literature (McOrist & Smits, 2007; Jacobson, Fellström & Jensen-Waern, 2010). The assumptions made about these scenarios were generated from previous clinical studies that showed the impact of a *L. intracellularis* disease on fattening pigs.

For fattening pigs, symptoms from a *L. intracellularis* disease generally appear at about 8-10 weeks of age but may show up anywhere between 6-20 weeks of age (Stege et al., 2004; McOrist and Gebhart, 2012). Herd mortality increases slightly with *L. intracellularis* diseases, ranging anywhere from a 1-5% (Winkelman, 1996). The major damage caused by *L. intracellularis* comes from its impact on pig growth. Because *L. intracellularis* colonize the epithelial cells of the small intestine, diseases cause a thickening of the gut wall which can reduce the ability of the pig to digest food and absorb nutrients (Boutrup et al., 2010; Laber et al., 2002). Citing work form Gogolewski et al. (1991) McOrist et al. (1996) and McOrist et al. (1997), McOrist and Gebhart (2012) report that weight gains are reduced by 6-20% in infected pigs and feed conversion generally becomes 6-25% poorer on average in the entire herd.

Given this information, three disease scenarios were created with clinical signs beginning to appear at 10 weeks of age. The first scenario is the lowest estimate from the citations above and is described as a best-case scenario. Here, mortality increases to 4% in the nursery barn, average daily gain falls by 6% and an additional 6% more feed is required for the same amount of weight gain. In the best-case scenario these symptoms persist for two weeks if no intervention strategy is taken. The second scenario is the middle of the estimates from the citations above and is described as the expected scenario. In this scenario mortality increases to 6% in the nursery, average daily gain falls by 13% and an additional 15% more feed is required for the same amount of weight gain. The symptoms in the expected-scenario persist for five weeks in the

disease model. The final scenario is highest estimate from the citations above and is described as the worst-case scenario. Here, mortality in the nursery reaches 8%, average daily gain falls by 20% and an additional 25% more feed is required for the same amount of weight gain. In the worst-case scenario symptoms continue for 9 weeks, provided there is no intervention by the farmer. A comparison of the three disease scenarios and the baseline scenario can be found in Table 3.

5.4 Methods for Managing *Lawsonia intracellularis*

Using the Canadian Edition of the Compendium of Veterinary Products, twelve options are described for managing *L. intracellularis*. These options consist of two vaccines and five antibiotics. However, several antibiotics can be administered using different routes, in different combinations and with different concentrations. These variations allow for the ten antibiotic management options from the five antibiotics listed. Vaccines and antibiotics are the only proven methods for managing a *L. intracellularis* disease and their use can have a significant impact on the production performance of an infected herd.

The twelve management options, their doses and the associated cost are listed in Table 4. Four of these options are prophylactic management options and can be used pre-emptively to reduce the severity of symptoms if a pig were to become introduced to *L. intracellularis*. Two of these options are antibiotics, chlortetracycline and tylsoin, and two are vaccines, Enterisol Ileitis and Porcilis Ileitis. Chlortetracycline and tylosin are provided in the feed of nursery pigs. For chlortetracycline, it is suggested that it is put in the feed of pigs for the two weeks prior to an expected outbreak. If tylosin is used, then it is to be put in the feed for three weeks prior to the expected outbreak. However, due to the significant health challenges that recently weaned pigs face, antibiotics like chlortetracycline and tylosin tend to be given to pigs as soon as they enter

the nursery. In an attempt to simulate true farm scenarios, this model assumes that the chlortetracycline or tylosin are given as soon as the pigs enter the nursery barn.

Enterisol Ileitis and Porcilis Ileitis are the vaccines available for managing *L. intracellularis* in pig herds. Enterisol Ileitis is a live vaccine that can be administered via injection right at weaning. Enterisol Ileitis has been available to producers for more than ten years while Porcilis Ileitis is a newer option. Unlike Enterisol Ileitis, Porcilis Ileitis is a bacterin and can be given as a drench right at weaning or via drinking water in the nursery. The authors chose to only include Porcilis Ileitis as a drench for this model. While there is debate as to when it is best to provide vaccines to piglets, the convenience of vaccinating when piglets are being handled at weaning often dictates when they are provided.

The remaining management options for *L. intracellularis* are antibiotics to be used for metaphylaxis and are given to the entire herd once clinical signs appear. Four of these options are variations of administering tylosin, either in feed or water or a combination of both. Tiamulin can be provided as a feed additive, lincomycin can be provided as a feed additive and tylvalosin can be administered via feed or water. Given that these medications are given after symptoms appear, this model assumes that each of these options start to be administered one week after symptoms appear (eleven weeks of age). Therefore, treatment for the entire herd begins in the last week in the nursery barn and may continue into the finishing barn. While each of these antibiotics could be given to individual animals as treatment, on a farm it is incredibly challenging to identify all of the animals that are infected with *L. intracellularis*. Therefore, this approach to managing *L. intracellularis* is rarely used and will not be simulated in this model.

5.5 Disease Management Model

Given that there are three levels of disease and twelve disease management options, there are 36 scenarios that are run under the disease management model. Using previous literature, this model assumes that each of the twelve management options provide unique production benefits to pigs infected with *L. intracellularis*. The production benefits from these management options are listed in Table 5 and show the improvements in average daily gain, decrease in feed efficiency and a decrease in mortality that come from using them. In the model, these management options can improve the production performance of a sick pig up to the performance of a pig from the baseline scenario.

Because studies on *L. intracellularis* and *L. intracellularis* management strategies do not come from a coordinated research program, the data cited in Table 5 does not come from studies that use perfectly consistent methods. However, because this research is primarily intended to provide an example, the cited references and their associated assumptions are sufficient for the purpose of this research.

Sources from Table 5 that include an Asterix at end of their citation come from research that uses clinical trials. In these trials, the treatment group is given a vaccine/antibiotic while the control group is not. Then, both groups are inoculated with *L. intracellularis* and their production performance is measured over a set period of time. Because all pigs are inoculated with *L. intracellularis*, the results of these studies are assumed to show the benefits of vaccines/antibiotics for managing a worst-case disease. These data were then used to make assumptions about the impact of the vaccine/antibiotic for managing an expected *L. intracellularis* disease (25% less beneficial) and a best-case *L. intracellularis* disease (50% less beneficial). If citations do not have an Asterix, then this research involved naturally infecting the

pigs with *L. intracellularis* rather than inoculating them. In this case, data from these studies were assumed to show the benefits of the vaccine/antibiotic for managing an expected disease scenario. These data were then used to make assumptions about the worst-case disease scenario (33% more beneficial) and the best-case disease scenario (33% less beneficial). For any missing data, assumptions were made by comparing between management strategies to fill in the gaps. These are the assumptions for this research, but the model can be adjusted to fit any desired assumption about production performance, disease impact or the efficacy of disease management strategies.

5.6 Summary

At baseline, the simulated farrow-to-finish operation will be shipping 443 pigs per week that are approximately 300lbs and are given a 110 index. When each of the three disease scenarios are imposed on this baseline scenario, the number of pigs shipped per week decreases, the weight of these pigs decreases, and the amount of feed required per unit of weight gain increases. Imposing any of the twelve management options reduces mortality and improves average weight gain and feed efficiency. For preventive options, these improvements occur right from when the disease is imposed on the model. For the treatment options, these improvements occur one week after symptoms appear. Despite each of these options providing production improvements to the farmer, the cost of these medications must be weighed against the benefit that they provide in order to determine which options are the most profitable for managing a *L. intracellularis* disease.

CHAPTER 6

RESULTS OF THE EMPIRICAL MODEL

6.0 Introduction to the Chapter

The following chapter provides an overview of the simulations results. The first section describes the profitability of the baseline simulation and provides justification for the financial assumptions that were made in order to arrive at the calculated values. The next section describes the impact of the unmanaged *L. intracellularis* disease on the profits of the farm at all three disease severity levels. The final section provides the calculated profit per pig under each of the twelve disease management strategies for all three disease severity levels. These management options are then ranked based on the simulated farm profits in the model. The contents of this chapter demonstrate how a simulation model and partial budget analysis can be used to quantify the economic benefit that different antibiotics provide for managing a disease.

6.1 Baseline Model

For a farrow-to-finish pig farm, the profitability of the operation is measured by subtracting the cost of raising pigs from the revenue received for selling them. The following section outlines these costs in the sow barn, nursery barn and finishing barn and shows how the revenue for the farm is calculated in the baseline model. This model is the author's best attempt at simulating a typical Canadian farrow-to-finish farm under normal conditions. The description for this model is summarized in Table 6 and includes all of the references that were used to generate assumptions for this simulation. For a summary of the assumptions made about pig growth and feed efficiency see Table 38.

In the baseline model, sows are assumed to eat two rations, a lactation feed and a dry feed. For 21 days of lactation, sows are assumed to eat 6.37 kilograms of feed at a cost of

$0.32/kg or $315.40/tonne. For the remaining 122 days, sows are assumed to eat, on average, 2.55 kilograms of dry feed per day at a cost of $0.26/kg or $263.71/tonne. The total cost to feed one sow for the year is $316.22 or $13.72 per marketed pig. This model assumes all gilts are bought in and the net cost for replacing cull sows is $70. The cost for gilts to replace sows that died is $130 plus the estimated value of a market pig. At baseline, this cost is estimated to be about $2.01 per marketed pig. In the sow barn, other variable costs are $18.07 per marketed pig and fixed costs are $7.23 per marketed pig.

Nursery piglets are assumed to only eat one ration for the 8-week period at a cost of $348.24/tonne. Over the 8 weeks, pigs are assumed to eat 40.91 kg of feed for a cost of $16.19 per marketed pig. In the nursery barn, other variable costs are $6.50 per marketed pig and fixed costs are $3.74 per marketed pig.

In the finishing barn, pigs are assumed to eat two rations, the grower ration ($290.43/tonne) for the first 7 weeks and a finisher ration ($264.29/tonne) for the final 9 weeks. Over the 16 weeks in the finishing barn, pigs are assumed to eat a total of 285.96 kg of feed for a cost of $85.42 per pig shipped. In the finishing barn, other variable costs are $14.19 per marketed pig and fixed costs are $12.18 per marketed pig.

To calculate revenue per marketed pig, the hog index is assumed to be 110.00, the market price per hundred-weight is $153.74 and dressed weight is 80% of live weight. Since 2014, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) has assumed a 110.00 index in their published Swine Enterprise Budget. Given the relatively normal distribution of monthly Ontario hog prices since January of 2000 and no obvious trend over time (Figure 3, Figure 4), the average monthly price since January 2000 was used for this model. Using the model's animal growth assumptions, at baseline, pigs reach 135.87 kilograms during their 27

weeks of growth and the estimated revenue per marketed pig is $183.83. With costs at $178.83 per pig the total profit is $4.99 per pig, $2,213.28 per week and $115,090.39 per year.

6.2 Disease Model

The following section provides the results of the disease model. This model shows how *L. intracellularis* impacts the profitability of the farm by reducing the herd's the average daily gain, decreasing the feed efficiency and increasing barn mortality (Winkelman, 1996; Holyoake, Collins & Mullan, 2010). By reducing the average daily gain, *L. intracellularis* increases the average amount of time that it takes for a pig to reach market weight. Due to space limitations in a farrow-to-finish operation, shipping schedules must generally be followed in order to make room for the next group of pigs that are coming into the barn. Therefore, by reducing average daily gain, a *L. intracellularis* disease reduces a farmer's revenue because they are shipping pigs that are lighter and less desirable for the processor.

While lower average daily gains reduce revenue, decreased feed efficiency and increased mortality increase the farmer's cost of production. *L. intracellularis* reduces the feed efficiency of growing pigs which means that more feed and more cost is needed per unit of weight gain. Increased mortality in growing pigs also increases the farmer's costs. For pigs that die, farmers no longer see a return on the feed, medication and labour that were invested in that animal. Additionally, the fixed costs for the farm must now be spread across fewer pigs, thus increasing the total cost to raise each pig.

Average daily gain, feed efficiency and mortality are impacted in all three of the disease scenarios. A financial summary of the farm under these three disease scenarios can be found in Table 7. In the best-case scenario, the pig's average daily gain and feed efficiency both fall by 6% for weeks 10 and 11. Paired with an increase to 4% mortality in the nursery barn, this

reduced performance leads to a 0.55-kilogram decrease in shipping weight, five fewer pigs being shipped per week and an increase in fixed cost by $0.24 per pig. With revenue per pig decreasing to $183.08 and cost per pig increasing to $179.27, the profit per pig falls from $4.99 in the baseline scenario to $3.81 in the best-case scenario. As a result, total annual profits fall from $115,090.39 to $86,869.01 per year under the best-case disease scenario.

In the expected scenario, average daily gain falls 13% and feed efficiency falls 15% for a five-week period. Total nursery mortality increases from 3% to 6% and, as a result, approximately fourteen fewer pigs are being shipped per week when compared to the baseline scenario. For pigs that are shipped, their average weight decreases by 3.10 kilograms and the fixed cost per pig increases by $0.74. These lighter pigs only bring in $179.64 per animal and the cost per pig increases to $180.24. This means that the profit per pig falls from $4.99 in the baseline scenario to $-0.60 in the expected scenario and total annual profits fall from $115,090.39 to $-13,452.49 per year.

In the worst-case scenario, total nursery mortality increases from 3% to 8%. Additionally, average daily gain falls 20% and feed efficiency becomes 25% less efficient in comparison to the baseline model for weeks 10-18. This mortality leads to approximately 24 fewer pigs being shipped per week and the pigs that are shipped are 9.72 kilograms lighter. With fixed costs increasing by $1.26 per pig, the total cost per pig increases to $181.21 while the revenue falls to $170.68 per pig. Therefore, the profit per pig falls from $4.99 in the baseline scenario to $-10.53 in the worst-case scenario and total annual profits fall from $115,090.39 to $-230,209.99 per year.

6.3 Disease Management Model

The farm profits when using each of the antibiotic and vaccine management strategies can be found in Table 8 through Table 10. Table 8 highlights the financial impact of these management strategies when used under the best-case scenario for *L. intracellularis*, while Table 9 summarizes the results for the expected *L. intracellularis* scenario and Table 10 reflects the worst-case scenario for *L. intracellularis*.

In the best-case *L. intracellularis* scenario, chlortetracycline is the most profitable disease management option of the twelve listed. At a cost of $0.25 per pig, this prophylactic medication reduces the clinical symptoms of *L. intracellularis*. When compared to no management, administering chlortetracycline increases the net profit per pig by $0.92 and increases annual farm profits from $86,869.01 to $109,022.52. This is only a $6,067.88 fall in annual profits from the healthy, baseline scenario. Of the twelve management options, seven of them are actually less profitable than not intervening in the best-case disease scenario. However, in order of profitability, administering tiamulin, prophylactic tylosin, lincomycin or in-feed tylosin for treatment (110 ppm for three weeks) are all still more profitable than not intervening at all. Porcilis Ileitis is the least profitable management option, coming at a cost of $1.38 per pig and a net return per pig of $-0.58. If the producer administers Porcilis Ileitis instead of not intervening, it results in $12,490.80 less profit per year for the farm. Therefore, with chlortetracycline providing a $22,153.51 increase in annual profits and Porcilis Ileitis providing a -$12,490.80 loss in annual profits, there is a spread of $34,644.30 in annual farm profitability between the different options for managing a best-case *L. intracellularis* disease scenario.

In the expected *L. intracellularis* scenario, using any of the twelve management options is more profitable for the farm than doing nothing. Again, chlortetracycline is the most profitable

disease management option available. When compared to no intervention, administering chlortetracycline increases the net profit per pig by $4.90 and increases annual farm profits from $-13,452.49 to $98,320.31. This is a net benefit of $111,772.80 in profit and is only $16,770.09 less than the annual farm profits under the healthy, baseline scenario. Similar to the best-case scenario, Porcilis Ileitis is the least profitable management option. However, in the expected disease scenario it keeps the farm profitable at a net return of $0.46 per pig shipped. This amounts to annual farm profits of $10,486.11 and a $23,938.60 improvement from annual farm profits of $-13,4452.49 with no intervention. Under the expected scenario, the range in annual profitability for different management options is $87,834.20, with chlortetracycline ($98,320.31) being the highest and Porcilis Ileitis ($10,486.11) being the lowest. One notable change in the rank of management options from the best-case scenario to the expected disease scenario is the administering of Tylvalosin in water. Under the best-case scenario, Tylvalosin in water is the 9th ranked management option in terms of profitability and in the expected scenario it is ranked 5th. This is because administering Tylvalosin in water is expensive but under the more severe disease scenario, the significant productivity improvements can now be realized.

In the worst-case scenario, without any intervention, the farmer loses $10.53 per pig or $230,209.99 per year. Employing any of the disease management options is more profitable than doing nothing, with chlortetracycline being the most profitable ($89,687.78) and Porcilis Ileitis being the least profitable ($-140,327.04). Of the twelve management options, seven of them will keep the farm profitable under the worst-case disease scenario while five of them result in an annual net loss in income. In addition to Porcilis Ileitis, these products include Enterisol Ileitis ($-91,945.60), Tylvalosin in feed ($-45,321.86), Tylosin in feed at 110 ppm and 44 ppm ($-34,138.45) and Tylosin in feed at 110 ppm ($-25,439.43). With profits being $89,687.78 with

chlortetracycline and $-140,327.04 for Porcilis Ileitis, the spread between management options is quite significant under the worst-case disease scenario at $230,014.82 per year.

6.4 Disease Management Model – Sensitivity Analysis

A sensitivity analysis was performed on the efficacy of each of the twelve management options in all three of the disease scenarios. This analysis compared the rankings of each management option when their efficacy in managing mortality, average daily gain and feed efficiency were either increased or decreased by 10%.

The first analysis is summarized in Tables 11-16. These tables show the financial impact of *L. intracellularis* on a farm if their management options become 10% more effective or 10% less effective at managing mortality. For both the 10% increase and 10% decrease, there isn't a significant change in the ranking of management options when compared to the original disease management model. When 10% more effective, chlortetracycline remains the most profitable and tylosin becomes the second most profitable management option in all three disease scenarios. When 10% less effective, chlortetracycline remains the most profitable with tylosin being the third most profitable. Both vaccines remain as some of the least profitable management options.

The second analysis focuses on average daily gain and compares the disease management options to one another if they are 10% more effective or 10% less effective at handling reduced average daily gain caused by *L. intracellularis.* The results of this analysis can be found in Tables 17-22, which summarize the farm's profits for all three disease levels, for all twelve management options, under both the 10% increase and 10% decrease in efficacy in managing average daily gain. Similar to the sensitivity analysis around mortality, there was very little change in rankings when a 10% increase and 10% decrease in efficacy was imposed on the

model. For the 10% improvement, in the best-case and expected disease scenario, the order was chlortetracycline, tiamulin and then prophylactic tylosin. In the worst-case scenario tylvalosin was substituted for tiamulin as the second most profitable management option. For the 10% reduction in efficacy, the only change was that for the expected scenario, prophylactic tylosin was the second most profitable option while tiamulin was the third most profitable.

The final analysis used a similar approach to the first two but focused on feed efficiency rather than mortality or average daily gain. When the efficacy of the management option increased by 10%, the ranking for the three most profitable options was the same as the original management option model for the best-case and expected scenario (chlortetracycline, tiamulin, prophylactic tylosin). However, in the worst-case scenario, tiamulin becomes the second most profitable option, tylvalosin the third most and prophylactic tylosin the fourth most profitable management option, after chlortetracycline. When the efficacy of management options falls by 10%, chlortetracycline and prophylactic tylosin are the first and second most profitable options in the best-case and expected disease scenario with tiamulin being third most profitable in the best-case scenario and tylvalosin being the third most profitable option in the expected scenario. In the worst-case scenario there was a significant change in the rankings as variations of administering tylosin become the three most profitable methods for managing *L. intracellularis*. Prophylactic tylosin is the most profitable while a water/feed combination is the second most profitable and providing tylosin solely in water is the third most profitable management option.

In general, the results of this sensitivity analysis suggest that the results of this model are robust. The rankings of management options do not change significantly when their efficacy is either increased or decreased by 10% for each of the three productivity variables tested. Prophylactic antibiotics remain as two of the most profitable options while tiamulin and

tylvalosin are the more profitable metaphylactic options. Furthermore, the vaccines remain as two of the least profitable options in each of the scenarios run.

6.5 Summary

In the baseline scenario, a farrow-to-finish farmer with 1000 sows earns $4.99 per marketed pig, $2,213.28 weekly and $115,090.30 in annual net profits. These profits are impacted by *L. intracellularis*. In the best-case disease scenario, the farmer earns $3.81 per marketed pig, in the expected disease scenario they lose $0.60 per pig and in the worst-case disease scenario they lose $10.53 per marketed pig. In the expected and worst-case disease scenario, all twelve of the management options listed are more profitable than doing nothing. For all three disease scenarios, chlortetracycline is the most profitable option and Porcilis Ileitis is the least profitable option. When using chlortetracycline, in the best-case disease scenario, the farmer earns $4.73 per marketed pig, in the expected disease scenario they earn $4.30 per pig and in the worst-case disease scenario they earn $3.93 per marketed pig. When using Porcilis Ileitis, in the best-case disease scenario, the farmer earns $3.23 per marketed pig, in the expected disease scenario they earn $0.46 per pig and in the worst-case disease scenario they lose $6.15 per marketed pig. The results of these simulations indicate that medications can provide significant improvements in profitability when facing *L. intracellularis* and that there is a significant difference between the profitability of different management options.

CHAPTER 7

DISCUSSION AND CONCLUSION

7.0 Introduction to the Chapter

Chapter 7 begins by discussing the significant outcomes of the research. The following section identifies some of the ways that this research can inform policy and help livestock industries transition to reduced antibiotic use. Then, a sensitivity analysis is performed for the two prophylactic antibiotics to see how the profits of the farm change when these antibiotics are 5%, 10% or 20% less effective at managing *L. intracellularis*. After testing the robustness of these management options, the limitations of the study are highlighted, and potential applications of the model are discussed. This section will conclude by providing suggestions for future research and a summary of the thesis.

7.1 Discussion of the Results

These simulations show the economic benefits of different antibiotics for managing *L. intracellularis.* The forty scenarios simulated demonstrate that small changes in growth rate, feed efficiency and mortality can have a significant impact on the financial success of a farm and these productivity parameters are significantly impacted by disease. For most of the 36 management scenarios simulated, it was more profitable to intervene rather than do nothing when facing a *L. intracellularis* disease. This was certainly true for the more severe disease scenarios, as the substantial productivity improvements warranted the added cost of the medication. However, for each of the three disease scenarios there was a significant difference in profitability between the most beneficial and least beneficial options. This suggests that if prophylactic medications, like chlortetracycline and tylosin, become limited under new regulation, producers who are forced to use less desirable options may be giving up thousands of dollars in profits.

In all three of the disease scenarios, prophylactic medication of in-feed chlortetracycline was the most profitable option and prophylactic in-feed tylosin was the third most profitable option for managing *L. intracellularis*. Part of this can be explained by fact that these medications are provided to the pigs at much younger age. Medicating younger piglets is much cheaper than medicating older pigs because the younger piglets are smaller and require less medication. Furthermore, when medication is provided prophylactically, it is able to act on the disease as soon as it appears. This contrasts with the treatment scenario, where a farmer or veterinarian must first notice the symptoms before the pigs are medicated. This means that there is a period of time where the disease is able exist, multiply and impact the pigs before they finally receive the medication they need. In the best-case and expected disease scenario, the second most profitable management option was tiamulin. In the worst-case scenario, the second most profitable management option was tylvalosin in water. Despite being provided to older pigs, tiamulin is very affordable and provides modest improvements in productivity. This makes it a good candidate for managing less severe *L. intracellularis* incidences. Tylvalosin in water is much more expensive but provides significant improvements in average daily gain, feed efficiency and mortality. Therefore, in the worst-case disease scenario the increased cost is justified to mitigate the more severe symptoms.

7.2 Implications for Industry and Policy

With Canada's livestock industries transitioning to reduced antibiotic use, it is likely that farmers will be required to reduce or eliminate prophylactic antibiotic administration in favour of using antibiotics metaphylactically or for individual treatment. This prevention versus treatment argument is significant with respect to reducing antibiotic use as this model shows that there are significant financial benefits to managing diseases prophylactically. Furthermore, prophylactic

antibiotic administration is likely to improve animal welfare as the livestock's symptoms are either avoided entirely or managed more quickly. However, increased antibiotic use as a result of prophylactic administration is seen as a significant contributor to antibiotic resistance for reasons explained previously in this thesis. Therefore, it is expected that for policy, the risks of resistance and threat to human health will outweigh the financial and welfare benefits that prophylactic antibiotics provide to farmers and their livestock.

In addition to the way that antibiotics are used, the type of antibiotic used is an important consideration for human health risk. As previously stated, the World Health Organization groups antibiotics into four classes depending on their relative importance to human health. Class 4 is the least important and Class 1 is the most important. The results of this study suggest that chlortetracycline is the most profitable option for managing *L. intracellularis* in all three disease scenarios. Chlortetracycline is a Class 3 antibiotic and is therefore less important to human health than a Class 2 antibiotic or Class 1 antibiotic, like tylosin. Tiamulin, the second most profitable option for the best-case and expected disease scenarios, is a pleuromutilin and Class 4 antibiotic. Tylvalosin is the second most profitable management option for the worst-case scenario but is a macrolide and a Class 1 antibiotic. Therefore, if prophylactic antibiotic administration were allowed, it would be best to manage *L. intracellularis* prophylactically with chlortetracycline. In addition to being the most profitable option, chlortetracycline is only a Class 3 antibiotic and presents a low risk to human health. If symptoms appeared after using chlortetracycline, they would likely be less severe and the farmer could handle them by administering tiamulin. Similar to chlortetracycline, tiamulin is a cost-effective strategy and as a Class 4 antibiotic, it is the least important for human health. Taking this approach would leave tylvalosin, one of the most important antibiotics (Class 1), for emergency situations when *L.*

intracellularis symptoms became very severe. Based on profitability, if prophylactic antibiotics become banned, Tiamulin is the only management option that the farmer can use to avoid a severe *L. intracellularis* incidence. Therefore, this policy would increase the chance of the farmer having to use a Class 1 antibiotic, like Tylvalosin, which is more important to human health. This simple analysis highlights how the economic data provided in this research can be paired with information about human health risk to evaluate different antibiotics and the way that they are used.

Quantifying the benefit that different antibiotics provide to livestock farmers is essential for creating a strategic plan to reduce antibiotic use. Antibiotic resistance should still be the primary consideration in this plan, but producer buy-in is an important part of shifting the industry to a framework of using less antibiotics. Showing farmers the financial return that different antibiotics provide will help to create this buy-in, especially if this information is used to develop the regulations that govern antibiotic use. Producer buy-in is far more sustainable than strict regulations which would face constant push back. Furthermore, strict regulations would likely add significant administration and monitoring costs to different stakeholders along the value chain. Performing more studies, on more livestock, for more diseases will provide industry stakeholders and policy makers with a much better understanding of the economic value that antibiotics provide. This information, alongside information about antibiotic resistance, can then be used to inform farmers about which antibiotics they can and should be using.

7.3 Sensitivity Analysis focusing on the Prophylactic Use of Chlortetracycline and Tylosin

Given that the results of this study identify prophylactic chlortetracycline and tylosin as two of the more profitable options for managing *L. intracellularis*, a sensitivity analysis was performed on the efficacy of these drugs for managing this disease. A sensitivity analysis that

focused specifically on these two management options was done for several reasons. The first is that with the expected push to reduce prophylactic antibiotics, it is important to ensure that the model's rankings are robust and that these prophylactic antibiotics remain as two of the most profitable options even if their efficacy is reduced. The second reason is that the studies that were used to provide data for these management options were performed over fifteen years ago. General improvements in the industry like management, biosecurity and genetics may mean that these antibiotics are now less beneficial then they were at the time of the research. This consideration is even more important for prophylactic antibiotics, whose production benefits may also come from managing other diseases or growth promotion instead of just from managing the intended *L. intracellularis* target.

The sensitivity analysis compared the profitability of the other ten management options to the profitability of prophylactic chlortetracycline and prophylactic tylosin when these antibiotics were 5%, 10% and 20% less effective than in the original model. The results of this analysis are summarized in Tables 29-37. When 5% less effective, there was very little change from the original disease management model in terms of ranking. For the best-case and expected scenarios, chlortetracycline and prophylactic tylosin remained as the first and third most profitable options while tiamulin was the second most profitable. In the worst-case scenario tylvalosin became the most profitable management option with chlortetracycline being second most profitable and tylosin being third most profitable. When chlortetracycline and tylosin were 10% less effective, they were still the top three most profitable options, alongside tiamulin for the best-case and expected scenario. However, in the worst-case scenario, chlortetracycline became the eighth most profitable option, while tylvalosin was the most profitable and prophylactic tylosin the second most profitable. This downward trend for chlortetracycline

continued in the final analysis, where the prophylactic antibiotics were 20% less effective. In the best-case scenario, there was not a significant difference in rankings when compared to the original model. However, in the expected and worst-case scenario, chlortetracycline was the ninth and eleventh most profitable option while tylosin remained as the second and then third most profitable option. Chlortetracycline becomes far less profitable because, even with a 20% reduction in efficacy for average daily gain, it is still able to keep the pig's average daily gains around the same level as when it is healthy. Therefore, with average daily gain being maintained and feed efficiency dropping significantly, the pig eats a lot more feed and costs the farmer a lot more money per unit of weight gain. In the worst-case scenario of the original management model, the farmer is still making $3.93 per pig when using chlortetracycline. In the reduced efficacy model, when the farmer uses chlortetracycline in the worst-case scenario they are losing $2.92 per pig. This is a change in $6.01 of profit per pig and highlights the need for there to be accurate data filling these models if they are going to be used for policy decisions.

7.4 Limitations of the Study and Future Research

To our knowledge this is the first study that takes a holistic approach to estimating the economic benefit of each antibiotic and each vaccine labelled for managing a specific disease in pigs. By simulating the impact of these management strategies for different disease severity levels, it can be seen which intervention strategies provide the most amount of benefit and which provide the least amount of benefit for producers who are facing this illness. Despite this research providing specific numbers and rankings for each of the management options, the results of this model are restricted to the assumptions used by the authors. For the model to produce more valid results, a clinical study should be conducted with the intent of providing the

values for these assumptions. This necessity is highlighted in the sensitivity analysis provided in section 7.3.

While the model in this study used herd-level averages to measure the production impact of *L. intracellularis*, it can be easily modified to include multiple sub-groups within the herd. This would more accurately reflect a true disease scenario, where some pigs are infected, some are not and some have more severe symptoms than others. Given that the purpose of this study was to provide an example for future research, the intricacies of these types of disease scenarios were too complicated and required too many unjustifiable assumptions for this research. For veterinarians or farmers that know their specific herd scenario, this type of detailed simulation may be more useful and could be used as decision making tool for different disease management options. It could also be used as a tool to help determine the minimum price required by farmers who raise livestock for markets like "raised without antibiotics" (RWA). Based on this model, we can see from Tables 8-10 that for a RWA farmer to make the same as a conventional farmer they would need $0.92 per pig in the best-case scenario, $2.96 per pig in the expected scenario and $8.01 per pig in the worst-case scenario. Although this is only for one disease, it provides a reference that producers and buyers could work off of.

Another way that this model could be adjusted is to change it so that it reflects a different business structure, rather than farrow-to-finish. Although farrow-to-finish operations still exists, the majority of the hogs in Canada are now produced under a different management system. This alternative system is sometimes called a "loop" and will involve different farmers raising the pigs for each stage of their life. By working in collaboration, these farmers are each able to specialize in either sow production, nursery production or finishing production. Although slightly more complicated, this coordinated production allows farmers to raise pigs that are

healthier and cost less to produce. Regardless of the agreements within the loop, farmers focusing on one area of production have different incentives than a farmer who manages a farrow to finish operation. Incentives and business structures are an important consideration for those looking to reduce antibiotic use and may be another area of focus for research that uses the model from this thesis.

Irrespective of the assumptions made or the potential applications of this model, this research provides a framework that other researchers can use to perform a coordinated evaluation of the economic value that antibiotics provide to the swine industry and other livestock industries. If this type of study were repeated for other diseases and other livestock, a fairly representative assessment could be made as to which antibiotics provide the most amount of benefit and which provide the least amount of benefit to each of the livestock industries. Then, through work with public health officials and other experts in antibiotic resistance, a strategic plan could be made for reducing antibiotic use. This plan would value the importance of antibiotics in maintaining the financial viability of farms while considering the significant risk that the use of some antibiotic presents to human and animal healthcare systems.

7.5 Conclusion

Antibiotics play a significant role in helping farms to remain profitable in the presence of a disease or illness. As livestock industries transition to reduced antibiotic use, models like the one presented in this research can be used to inform strategic plans for reducing antibiotic use that consider both the benefits and the risks of antibiotic use. Diseases cost farmers money and antibiotics help to reduce these costs. The simulated annual profits of a baseline farrow-to-finish operation with 1000 sows was $115,090.39. In the best-case disease scenario, annual profits were $86,869.01, in the expected scenario, profits were $-13,452.49 and in the worst-case

scenario, profits were $-230,209.99. While vaccines are emerging as viable alternatives to antibiotics, this model suggest that their cost relative to antibiotics presents a barrier for adoption in some scenarios. Employing prophylactic chlortetracycline in the feed of nursery pigs for their first two weeks in the barn was the most profitable management option in each of the three scenarios, with an annual profit of $109,022.52 in the best case-scenario, $98,320.31 in the expected scenario and $89,687.78 in the worst-case scenario. The Porcilis Ileitis vaccine was the least profitable management strategy and resulted in annual profits of $74,378.22 in the best-case scenario, $10,486.11 in the expected scenario and $-140,327.04 in the worst-case scenario. Despite vaccines being the least profitable management strategy in this model, in practice, many producers see them as a low-cost, risk mitigation strategy that is increasingly being used in barns for *L. intracellularis*. Policy focusing on reducing antibiotic use should look to make alternatives like vaccines more viable. In the meantime, the use of antibiotics that provide the least amount of benefit to farmers and present the greatest risk for resistance should be reduced more quickly. For the antibiotics that provide more benefit and contribute less to resistance, their use can be reduced more slowly as new information and disease management strategies emerge.

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APPENDIX

Tables

Table 1: Summary of Information on Antibiotics and Antibiotic Resistance in Pig Farming

Section Number	Key Points
2.2 Antibiotics on Swine Farms	• **Four Groups of Antibiotics:** 1. Important 2. Highly Important 3. Critically Important 4. Highest Priority • **Four Functions of Antibiotics:** 1. Therapy/Treatment 2. Metaphylaxis 3. Prophylaxis 4. Growth Promotion
2.3 Antibiotic-Resistant Bacteria	**The Basics of Antibiotics, Bacteria and Antibiotic Resistance** • Antibiotics work by disrupting the bacteria's: o Cell Wall o Protein Synthesis o Ability to Replicate its DNA • Resistant bacteria avoid antibiotics by: o Modifying or destroying the antibiotic o Avoiding the antibiotic o Altering their cell's target site for the antibiotic • Bacteria develop resistant through their own genetic mutations or by receiving resistant genetics from other bacterial cells through transposons and plasmids **Argument Against the Use of Antibiotics in Livestock** • Livestock consume most of the world's antibiotics • Most antibiotics are given at low loses over prolonged periods • Antibiotics used in livestock are also relied upon by humans • Bacteria can develop cross resistance to different antibiotics • Humans are exposed to resistant bacteria by working in barns • Production benefits of many antibiotics are now less effective than in the past • Use of antibiotics on farms is associated with the presence of antibiotic resistance

2.4 Economics of Antibiotic Use	**Argument for the Use of Antibiotics in Livestock** • Antibiotics have been administered to billions of animals over the past 75 years • There is no evidence to show this has impacted human health • Livestock antibiotic use is believed to be a scapegoat for resistance problem created through the human health system • At the high end, estimate of $3.00 increase in profit per pig • Profit comes from improved growth and more uniform growth among pigs • This reduces production risk and allows for more investment in the industry
2.5 Livestock Antibiotic Use in Canada	• There is no centralized system for recording antibiotic use on farms • Canadian Integrated Program for Antibiotic Resistance Surveillance (CIPARS) has been responsible for monitoring antibiotic use and resistance since 2006 • Data collected for CIPARS are mostly from finishing pig barns across major pork producing provinces • There was a 12% decrease in antibiotic use between 2006 and 2014 on Canadian pig farms • There are differences in the preference for certain antibiotics across provinces • Popular antibiotics in Ontario include tylosin (highest priority), carbadox*, tetracycline (highly important), sulfonamides (highly important) and penicillin (highly important) • In Alberta and Saskatchewan, tiamulin (important), lincomycin (highly important), spectinomycin (important) and tylosin (highest priority) were most common • >90% of all Canadian pig farmers use antibiotics >90% of the time in some type of their feed rations

2.6 Antibiotic Alternatives	• Diet and water acidification
	• Vaccines
	• Feed Supplements
	  ○ Oligosaccharides
	  ○ Enzymes
	  ○ Herbs
	  ○ Minerals
	  ○ Probiotics
	  ○ Non-Starch Polysaccharides

	• Metals
	  ○ Zinc Oxide
	  ○ Copper Sulfate
	• Improved Management
	  ○ Cleaning rooms between groups
	  ○ All-in-all-out pig flows
	  ○ Isolating sick animals
	  ○ Biosecurity
	  ○ Age segregation
	  ○ Reducing stress at weaning and transportation
	  ○ Benchmarking use with other farmers

*Carbadox is no longer legal for livestock use in Canada	

Table 2: Production Parameters of Farrow-to-Finish Swine Farm

Parameter	**Value**	**Source**
Breeding Herd Numbers		
Sow Herd Size	1000	
Breeding Cycle (days)		
Wean-Breed Interval	5	Weng et al. 2016
Breeding Time	2	Weng et al. 2016
Gestation Length	115	Author's Assumption
Nursing Period	21	Author's Assumption
Total	**143**	
Annual Performance		
Days per Year	365	
Days per Cycle	143	
Cycles per Year	**2.55**	
Breeding Groups		
Farrowing per Year (Weekly)	52	
Cycles per Year	2.55	
Number of Breeding Groups	**20**	
Size of Herd	1000	
Size of Breeding Group	**50**	
Sow Replacement per Parity		
<6 Parity Sow Herd Mortality	0.8%	Author's Assumption
Sows >6 Parity	16.7%	Author's Assumption
Replacement Rate	**17.5%**	
Group Breakdown		
Sows per Group	50	
Gilts per Group	9	
>1 Parity Sows per Group	41	

Sow Performance		
Farrowing Rate	85%	Weng et al. 2016
Gilts		
Gilts Successfully Bred	7.4	
Born Alive	11	Weng et al. 2016
Preweaning Litter Mortality	15%	Weng et al. 2016
Weaned per Gilt	**9.4**	
>1 Parity Sows		
>1Parity Sows Successfully Bred	34.7	
Born Alive	13	Author's Assumption
Preweaning Litter Mortality	13%	Weng et al. 2016
Weaned per >1Parity Sows	**11.3**	
Piglets sent to Nursery per Week	**466**	
Piglets sent to Nursery per Year	**24,239.1**	
Nursery Barn Numbers		
Pigs Entering per Week	466	
Weeks in Nursery	8	Author's Assumption
Barn Mortality	3%	Author's Assumption
Total Nursery Inventory	3660.2	
Piglets Moved to Finishing Barn per Week	**452.2**	
Piglets Moved to Finishing Barn per Year	**23,512.0**	
Finishing Barn Numbers		
Pigs Entering per Week	452.2	
Weeks in Finisher	16	Author's Assumption
Barn Mortality	2%	Author's Assumption
Total Finisher Inventory	7,157.6	
Market Pigs Shipped for Processing per Week	**443.1**	
Market Pigs Shipped for Processing per Year	**23,041.7**	

Table 3: Production Impact of *Lawsonia intracellularis* on a Farrow-to-Finish Swine Farm

	Baseline-Healthy Scenario	**Best-Case Scenario**	**Expected Scenario**	**Worst-Case Scenario**
Length of Symptoms	-	2 Weeks	5 Weeks	9 Weeks
Nursery Barn Mortality	3%	4%	6%	8%
Average Daily Gain	-	↓6%	↓13%	↓20%
Feed Conversion Ratio	-	↑6%	↑15%	↑25%

Table 4: Summary of *L. Intracellularis* Medications listed in the Compendium of Vet. Products

	Age that Administration Begins	Length of Treatment	Given via	Average Body Weight	Average Daily Feed/Water Intake	Dose	Cost per Gram or Millilitre	Cost to Medicate Pig
Chlortetracycline	3 weeks	14 days	Feed	7.66 kg	0.34 kg	22 mg per kg body weight	$1.49	$0.25
Tylosin	3 weeks	21 days	Feed		0.40 kg	110 g per kg of feed	$0.26	$0.24
Enterisol Ileitis	3 weeks	Once	Drench			2 mL	$0.68	$1.36
Porcilis Ileitis	3 weeks	Once	Injection			2 mL	$0.69	$1.38
Tylosin	10 weeks	21 days	Feed		1.40 kg	110 g per kg of feed	$0.26	$0.83
Tylosin	10 weeks	21 days 21 days	Feed Feed		1.40 kg 1.57 kg	110 g per kg of feed 44 g per kg of feed	$0.26	$1.20
Tylosin	10 weeks	7 days 7 days	Water Feed	31.85 kg	3.18 L 1.33 kg	83 mg per litre of water 110 g per kg of feed	$0.41 $0.26	$1.03
Tylosin	10 weeks	14 days	Water	34.13 kg	3.41 L	83 mg per litre of water	$0.41	$1.25
Tiamulin	10 weeks	14 days	Feed		1.26 kg	121.4 g per 1000 kg of feed	$0.10	$0.21
Lincomycin	10 weeks	21 days	Feed		1.40 kg	110 kg per 1000 kg of feed	$0.19	$0.63
Tylvalosin	10 weeks	14 days	Feed		1.26 kg	42.5 g per 1000 kg of feed	$0.62	$0.46
Tylvalosin	10 weeks	5 days	Water	31.85 kg	3.18 L	50 mg per litre of water	$0.66	$1.04

Table 5: Change in Production Performance after using Disease Management Options

No Management = 100%		Prevention Management				Treatment Management							
		Chlortetracycline[1]	Tylosin[2]	Enterisol Ileitis[3]	Porcilis Ileitis[4]	Tylosin[5,6]	Tylosin[5,6]	Tylosin[5,6,7]	Tylosin[7]	Tiamulin[8]	Lincomycin[9]	Tylvalosin[10,6]	Tylvalosin[11]
Description:		In-feed, 100 ppm, two weeks	In-feed, 110 ppm, three weeks	Injection	Drench	In-feed, 110 ppm, three weeks	In-feed, 110 ppm, three weeks, then in-feed, 44 ppm, three weeks	In-water, 83 mg/L, one week, then in-feed, 110 ppm, one week	In-water, 83 mg/L, two weeks	In-feed, 100 ppm, two weeks	In-feed, 100 ppm, three weeks	In-feed, 42.5 ppm, two weeks	In-water, 50 ppm, 5 days
Worst Case	Δ Average Daily Gain	183%	191%	117%	106%	120%	120%	158%	196%	129%	123%	120%	155%
Expected Case		163%	168%	113%	104%	115%	115%	144%	172%	122%	117%	115%	141%
Best Case		142%	146%	108%	103%	110%	110%	129%	148%	115%	111%	110%	127%
Worst Case	Δ Feed Efficiency	79%	67%	90%	92%	86%	86%	71%	55%	86%	81%	86%	76%
Expected Case		85%	75%	93%	94%	90%	90%	78%	66%	89%	86%	89%	82%
Best Case		90%	83%	95%	96%	93%	93%	85%	77%	93%	91%	93%	88%
Worst Case	Δ Mortality	50%	93%	65%	49%	50%	50%	53%	56%	0%	62%	91%	0%
Expected Case		62%	95%	73%	62%	63%	63%	65%	67%	25%	71%	93%	25%
Best Case		75%	97%	82%	74%	75%	75%	77%	78%	50%	81%	96%	50%

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Table 6: Financial Parameters of Farrow-to-Finish Swine Farm

Parameter	Value	Source
Sow Barn		
Cycles per Year	2.55	
Dry Feed Consumption per Day	2.55 kg	Adapted from Weng et al., 2016
Cost per Kilogram	$0.26	Industry Representative
Cost per Day	$0.66	
Dry Days per Cycle	122	
Cost per Year	$206.26	
Lactation Feed Consumption per Day	6.37 kg	Adapted from Weng et al., 2016
Cost per Kilogram	$0.32	Industry Representative
Cost per Day	$2.04	
Lactating Days per Cycle	21	
Cost per Year	$109.16	
Sow Feed Cost per Year	**$316.22**	
Number of Sows	1000	
Sow Feed Cost per Year	$**316,221.88**	
Marketed Pigs per Year	23,042	
Sow Feed Cost per Marketed Pig	**$13.72**	
Nursery Barn		
Total Feed Consumption	40.91 kg	See Appendix 1
Cost per Kilogram	$0.35	Industry Representative
Barn Mortality	3%	Author's Assumption
Feed Cost per Pig	**$16.19**	
Finishing Barn		
Total Grower Consumption	98.75 kg	See Appendix 1
Grower Cost per Kilogram	$0.32/kg	Industry Representative
Total Finisher Consumption	212.06 kg	See Appendix 1
Finisher Cost per Kilogram	$0.29/kg	Industry Representative
Barn Mortality	2%	Author's Assumption
Feed Cost per Pig	**$85.42**	
Total Feed Costs		
Feed Cost per Marketed Pig	**$115.33**	
Feed Cost per Week	**$51,105.70**	
Feed Cost per Year	**$2,657,496.19**	
Variable Costs per Marketed Pig		
Sow Barn	$18.07	Weng et al. 2016
Replacement Breeding Stock	$2.01	Weng et al. 2016
Nursery Barn	$6.50	Weng et al. 2016
Finishing Barn	$14.19	Weng et al. 2016
Total	$40.76	
Fixed Costs per Marketed Pig		
Sow Barn	$7.23	Weng et al. 2016
Nursery Barn	$3.74	Weng et al. 2016
Finishing Barn	$12.18	Weng et al. 2016
Total	$23.15	

Revenue		
Index	110.00	OMAFRA 2000-2017
Price per Hundred-Weight	$153.74	OMAFRA 2000-2017
Market Price with Index	$169.12	
Weight at Shipping	135.87 kg	
Dressed Weight (80%)	108.70 kg	OMAFRA 2000-2017
Revenue per Pig	$183.83	
Profit		
Cost per Pig	$178.83	
Revenue per Pig	$183.83	
Profit per Pig	**$4.99**	
Pigs Shipped per Week	443.1	
Profit per Week	**$2,213.28**	
Profit per Year	**$115,090.39**	

Table 7: Financial Impact of *Lawsonia intracellularis* on a Farrow-to-Finish Swine Farm

	Healthy Scenario	**Best-Case Scenario**	**Expected Scenario**	**Worst-Case Scenario**
Costs				
Feed Costs	$115.33	$115.51	$115.95	$116.37
Variable Costs	$40.35	$40.37	$40.40	$40.44
Fixed Costs	$23.15	$23.39	$23.89	$24.41
Cost/Marketed Pig	$178.83	$179.27	$180.24	$181.21
Revenue/Marketed Pig	$183.83	$183.08	$179.64	$170.68
Profit/Marketed Pig	$4.99	$3.81	-$0.60	-$10.53
Weekly Profit	$2,213.28	$1,670.56	-$258.70	-$4,427.12
Annual Profit	$115,090.39	$86,869.01	-$13,452.49	-$230,209.99

Table 8: Impact of Disease Management Options for Best-Case Scenario on Farm Business

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.48	$ 180.46	$ 180.18	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.35	$ 3.37	$ 3.23	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,910.30	$ 1,487.92	$ 1,430.35	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 99,335.62	$ 77,371.58	$ 74,378.22	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 15,754.77	-$ 37,718.81	-$ 40,712.18	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 12,466.61	-$ 9,497.43	-$ 12,490.80	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	12	14	7	11	10	13	3	5	8	9

Table 9: Impact of Disease Management Options for Expected Scenario on Farm Business

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.53	$ 180.34	$ 181.62	$ 180.28	$ 180.44	$ 180.82	$ 180.29	$ 180.58	$ 179.39	$ 180.05	$ 180.85	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.30	$ 3.49	$ 1.34	$ 0.46	$ 2.57	$ 2.19	$ 2.72	$ 2.44	$ 3.63	$ 2.96	$ 2.16	$ 3.11
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,890.78	$ 1,501.32	$ 586.03	$ 201.66	$ 1,131.74	$ 964.07	$ 1,194.44	$ 1,067.93	$ 1,607.03	$ 1,294.32	$ 933.41	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 98,320.31	$ 78,068.66	$ 30,473.40	$ 10,486.11	$ 58,850.49	$ 50,131.74	$ 62,110.62	$ 55,532.20	$ 83,565.80	$ 67,304.78	$ 48,537.51	$ 71,679.19
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 16,770.09	-$ 37,021.73	-$ 84,617.00	-$ 104,604.29	-$ 56,239.91	-$ 64,958.65	-$ 52,979.77	-$ 59,558.20	-$ 31,524.59	-$ 47,785.62	-$ 66,552.89	-$ 43,411.20
Δ Annual Profit from Expected Scenario	$ 128,542.89	$ -	$ 111,772.80	$ 91,521.15	$ 43,925.89	$ 23,938.60	$ 72,302.98	$ 63,584.23	$ 75,563.11	$ 68,984.69	$ 97,018.30	$ 80,757.27	$ 61,990.00	$ 85,131.68
Rank	1	14	2	4	12	13	8	10	7	9	3	6	11	5

Table 10: Impact of Disease Management Options for Worst-Case Scenario on Farm Business

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 179.89	$ 181.33	$ 183.23	$ 179.64	$ 181.37	$ 181.75	$ 180.46	$ 180.79	$ 181.34	$ 180.33	$ 182.23	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 3.93	$ 2.50	-$ 4.08	-$ 6.15	-$ 1.12	-$ 1.50	$ 2.12	$ 1.78	$ 1.24	$ 1.12	-$ 2.06	$ 2.67
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,724.77	$ 1,056.23	-$ 1,768.18	-$ 2,698.60	-$ 489.22	-$ 656.51	$ 927.13	$ 778.78	$ 547.26	$ 487.07	-$ 871.57	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 89,687.78	$ 54,924.22	-$ 91,945.60	-$ 140,327.04	-$ 25,439.43	-$ 34,138.45	$ 48,210.69	$ 40,496.38	$ 28,457.56	$ 25,327.67	-$ 45,321.86	$ 61,629.89
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 25,402.61	-$ 60,166.18	-$ 207,035.99	-$ 255,417.43	-$ 140,529.82	-$ 149,228.85	-$ 66,879.71	-$ 74,594.02	-$ 86,632.84	-$ 89,762.73	-$ 160,412.26	-$ 53,460.51
Δ Annual Profit from Worst-Case Scenario	$ 345,300.38	$ -	$ 319,897.77	$ 285,134.20	$ 138,264.39	$ 89,882.95	$ 204,770.56	$ 196,071.53	$ 278,420.67	$ 270,706.36	$ 258,667.54	$ 255,537.65	$ 184,888.12	$ 291,839.87
Rank	1	14	2	4	12	13	9	10	5	6	7	8	11	3

Table 11: Impact of Disease Management Options for Best-Case Scenario - 10% Mortality Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.39	$ 180.40	$ 180.18	$ 179.66	$ 180.04	$ 179.88	$ 180.10	$ 179.03	$ 179.50	$ 179.58	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.44	$ 3.43	$ 3.23	$ 3.79	$ 3.41	$ 3.57	$ 3.35	$ 4.42	$ 3.95	$ 3.88	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,951.94	$ 1,516.72	$ 1,430.35	$ 1,680.09	$ 1,511.28	$ 1,584.05	$ 1,483.98	$ 1,958.02	$ 1,747.12	$ 1,705.83	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 101,501.01	$ 78,869.35	$ 74,518.22	$ 87,364.60	$ 78,586.70	$ 82,369.94	$ 77,166.97	$ 101,817.03	$ 90,850.41	$ 88,703.16	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 13,589.39	-$ 36,221.04	-$ 40,712.18	-$ 27,725.79	-$ 36,503.70	-$ 32,720.46	-$ 51,923.43	-$ 13,273.37	-$ 24,239.98	-$ 26,387.24	-$ 33,063.52
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 14,631.99	-$ 7,999.66	-$ 12,490.80	$ 495.59	-$ 8,282.32	-$ 4,499.08	-$ 9,702.05	$ 14,948.01	$ 3,981.40	$ 1,834.14	-$ 4,841.99
Rank	1	7	2	3	11	14	8	12	9	13	4	5	6	10

Table 12: Impact of Disease Management Options for Expected Scenario - 10% Mortality Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.42	$ 180.14	$ 181.48	$ 180.18	$ 180.34	$ 180.72	$ 180.18	$ 180.46	$ 179.39	$ 179.92	$ 180.65	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.40	$ 3.69	$ 1.48	$ 0.56	$ 2.68	$ 2.30	$ 2.83	$ 2.55	$ 3.63	$ 3.09	$ 2.36	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,940.81	$ 1,595.01	$ 648.86	$ 247.80	$ 1,179.91	$ 1,011.90	$ 1,245.77	$ 1,121.96	$ 1,607.03	$ 1,354.73	$ 1,022.10	$ 1,518.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 100,922.04	$ 82,940.78	$ 35,140.64	$ 12,885.54	$ 61,355.32	$ 52,618.83	$ 64,780.11	$ 58,342.09	$ 83,565.80	$ 70,446.17	$ 53,149.01	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 14,168.35	-$ 32,149.62	-$ 81,349.76	-$ 102,204.85	-$ 55,135.08	-$ 62,471.57	-$ 50,310.29	-$ 56,748.30	-$ 31,524.59	-$ 44,644.23	-$ 61,941.39	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 114,514.54	$ 96,393.27	$ 47,193.13	$ 26,338.03	$ 74,807.81	$ 66,071.32	$ 78,232.60	$ 71,794.58	$ 97,018.30	$ 83,898.66	$ 66,601.50	$ 85,131.68
Rank	1	14	2	3	12	13	8	11	7	9	4	6	10	5

Table 13: Impact of Disease Management Options for Worst-Case Scenario - 10% Mortality Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 179.71	$ 180.96	$ 182.99	$ 179.45	$ 181.19	$ 181.57	$ 180.26	$ 180.58	$ 181.34	$ 180.10	$ 181.88	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 4.12	$ 2.87	-$ 3.83	-$ 5.96	-$ 0.93	-$ 1.31	$ 2.32	$ 1.99	$ 1.24	$ 1.35	-$ 1.70	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,813.31	$ 1,222.45	-$ 1,668.42	-$ 2,628.15	-$ 410.12	-$ 578.01	$ 1,017.55	$ 873.95	$ 547.26	$ 591.02	-$ 725.25	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 94,292.20	$ 63,567.22	-$ 86,757.92	-$ 136,663.91	-$ 21,326.02	-$ 30,056.60	$ 52,912.48	$ 45,445.28	$ 28,457.56	$ 30,732.80	-$ 51,713.00	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 20,798.19	-$ 51,523.17	-$ 201,848.32	-$ 251,754.31	-$ 136,416.42	-$ 145,147.00	-$ 62,177.92	-$ 69,645.11	-$ 86,632.85	-$ 84,357.60	-$ 152,803.40	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 324,502.19	$ 295,177.21	$ 143,452.06	$ 93,546.07	$ 208,883.96	$ 200,153.38	$ 283,122.46	$ 275,655.27	$ 258,667.54	$ 260,942.78	$ 192,496.98	$ 291,839.87
Rank	1	14	2	3	12	13	9	10	5	6	8	7	11	4

Table 14: Impact of Disease Management Options for Best-Case Scenario - 10% Mortality Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.14	$ 179.54	$ 180.52	$ 180.21	$ 179.71	$ 180.09	$ 179.95	$ 180.20	$ 179.03	$ 179.62	$ 179.74	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.69	$ 4.29	$ 3.31	$ 3.19	$ 3.75	$ 3.37	$ 3.50	$ 3.25	$ 4.42	$ 3.83	$ 3.71	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,074.68	$ 1,880.54	$ 1,459.11	$ 1,414.44	$ 1,658.28	$ 1,489.63	$ 1,547.89	$ 1,435.49	$ 1,958.02	$ 1,692.92	$ 1,625.68	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 107,883.28	$ 97,788.09	$ 75,873.82	$ 73,550.78	$ 86,230.59	$ 77,460.57	$ 80,490.33	$ 74,645.45	$ 101,817.03	$ 88,031.73	$ 84,535.56	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 7,207.11	-$ 17,302.30	-$ 39,216.58	-$ 41,539.61	-$ 28,859.80	-$ 37,629.82	-$ 34,600.06	-$ 40,444.95	-$ 13,273.37	-$ 27,058.66	-$ 30,554.83	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 21,014.27	$ 10,919.08	-$ 10,995.19	-$ 13,318.23	-$ 638.42	-$ 9,408.44	-$ 6,378.68	-$ 12,223.56	$ 14,948.01	$ 1,162.72	-$ 2,333.45	-$ 4,841.99
Rank	1	6	2	4	12	14	7	11	10	13	3	5	8	9

Table 15: Impact of Disease Management Options for Expected Scenario - 10% Mortality Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.63	$ 180.49	$ 181.76	$ 180.39	$ 180.54	$ 180.93	$ 180.40	$ 180.70	$ 179.39	$ 180.18	$ 181.05	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.20	$ 3.34	$ 1.20	$ 0.35	$ 2.47	$ 2.09	$ 2.61	$ 2.32	$ 3.63	$ 2.83	$ 1.97	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,840.74	$ 1,434.36	$ 523.20	$ 155.51	$ 1,083.57	$ 916.24	$ 1,143.10	$ 1,013.89	$ 1,607.03	$ 1,233.91	$ 844.73	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 95,718.57	$ 74,586.72	$ 27,206.16	$ 8,086.68	$ 56,345.66	$ 47,644.66	$ 59,441.14	$ 52,722.30	$ 83,565.80	$ 64,163.38	$ 43,926.00	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 19,371.83	-$ 40,503.68	-$ 87,884.24	-$ 107,003.72	-$ 58,744.74	-$ 67,445.74	-$ 55,649.26	-$ 62,368.10	-$ 31,524.59	-$ 50,927.01	-$ 71,164.39	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 109,171.06	$ 88,039.21	$ 40,658.65	$ 21,539.17	$ 69,798.15	$ 61,097.15	$ 72,893.63	$ 66,174.79	$ 97,018.30	$ 77,615.87	$ 57,378.50	$ 85,131.68
Rank	1	14	2	4	12	13	8	10	7	9	3	6	11	5

Table 16: Impact of Disease Management Options for Worst-Case Scenario - 10% Mortality Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 180.08	$ 181.60	$ 183.49	$ 179.83	$ 181.56	$ 181.94	$ 180.66	$ 181.00	$ 181.34	$ 180.57	$ 182.60	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 3.75	$ 2.23	-$ 4.34	-$ 6.33	-$ 1.30	-$ 1.68	$ 1.92	$ 1.57	$ 1.24	$ 0.89	-$ 2.42	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,636.22	$ 937.45	-$ 1,867.95	-$ 2,769.04	-$ 568.32	-$ 735.01	$ 836.71	$ 683.61	$ 547.26	$ 383.13	-$ 1,017.90	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 85,083.36	$ 48,747.33	-$ 97,133.28	-$ 143,990.16	-$ 29,552.83	-$ 38,220.31	$ 43,508.90	$ 35,547.47	$ 28,457.56	$ 19,922.54	-$ 52,930.72	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 30,007.04	-$ 66,343.06	-$ 212,223.67	-$ 259,080.55	-$ 144,643.22	-$ 153,310.70	-$ 71,581.50	-$ 79,542.93	-$ 86,632.84	-$ 95,167.86	-$ 168,021.11	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 315,293.34	$ 278,957.32	$ 133,076.71	$ 86,219.83	$ 200,657.16	$ 191,989.68	$ 273,718.88	$ 265,757.45	$ 258,667.54	$ 250,132.52	$ 177,279.27	$ 291,839.87
Rank	1	14	2	4	12	13	9	10	5	6	7	8	11	3

Table 17: Impact of Disease Management Options for Best-Case Scenario - 10% Average Daily Gain Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.48	$ 180.46	$ 180.38	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.83	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.35	$ 3.37	$ 3.45	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,910.30	$ 1,487.92	$ 1,527.38	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 99,335.62	$ 77,371.58	$ 79,424.01	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 15,754.77	-$ 37,718.81	-$ 35,666.38	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 12,466.61	-$ 9,497.43	-$ 7,445.00	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	13	11	7	12	10	14	3	5	8	9

Table 18: Impact of Disease Management Options for Expected Scenario - 10% Average Daily Gain Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.53	$ 180.34	$ 182.05	$ 181.38	$ 180.44	$ 180.82	$ 180.29	$ 180.58	$ 179.39	$ 180.05	$ 180.85	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 183.79	$ 182.82	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.30	$ 3.49	$ 1.74	$ 1.44	$ 2.57	$ 2.19	$ 2.72	$ 2.44	$ 3.63	$ 2.96	$ 2.16	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,890.78	$ 1,501.32	$ 761.71	$ 634.41	$ 1,131.74	$ 964.07	$ 1,194.44	$ 1,067.93	$ 1,607.03	$ 1,294.32	$ 933.41	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 98,320.31	$ 78,068.66	$ 39,608.79	$ 32,989.33	$ 58,850.49	$ 50,131.74	$ 62,110.62	$ 55,532.20	$ 83,565.80	$ 67,304.78	$ 48,537.51	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 16,770.09	-$ 37,021.73	-$ 75,481.61	-$ 82,101.06	-$ 56,239.91	-$ 64,958.65	-$ 52,979.77	-$ 59,558.20	-$ 31,524.59	-$ 47,785.62	-$ 66,552.89	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 111,772.80	$ 91,521.15	$ 53,061.28	$ 46,441.82	$ 72,302.98	$ 63,584.23	$ 75,563.11	$ 68,984.69	$ 97,018.30	$ 80,757.27	$ 61,990.00	$ 85,131.68
Rank	1	14	2	4	12	13	8	10	7	9	3	6	11	5

Table 19: Impact of Disease Management Options for Worst-Case Scenario - 10% Average Daily Gain Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 179.89	$ 181.33	$ 185.74	$ 182.90	$ 182.73	$ 183.11	$ 180.46	$ 180.79	$ 181.34	$ 180.95	$ 183.63	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 183.29	$ 178.78	$ 182.58	$ 182.58	$ 182.58	$ 182.58	$ 182.58	$ 182.58	$ 182.58	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 3.93	$ 2.50	-$ 2.45	-$ 4.12	-$ 0.15	-$ 0.53	$ 2.12	$ 1.78	$ 1.24	$ 1.63	-$ 1.05	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,724.77	$ 1,056.23	-$ 1,062.34	-$ 1,806.60	-$ 66.84	-$ 234.13	$ 927.13	$ 778.78	$ 547.26	$ 705.93	-$ 444.26	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 89,687.78	$ 54,924.22	-$ 55,241.47	-$ 93,943.04	-$ 3,475.89	-$ 12,174.92	$ 48,210.69	$ 40,496.38	$ 28,457.56	$ 36,708.11	-$ 23,101.65	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 25,402.61	-$ 60,166.18	-$ 170,331.87	-$ 209,033.43	-$ 118,566.29	-$ 127,265.31	-$ 66,879.71	-$ 74,594.02	-$ 86,632.84	-$ 78,382.28	-$ 138,192.04	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 319,897.77	$ 285,134.20	$ 174,968.51	$ 136,266.95	$ 226,734.10	$ 218,035.07	$ 278,420.67	$ 270,706.36	$ 258,667.54	$ 266,918.10	$ 207,108.34	$ 291,839.87
Rank	1	14	2	4	12	13	9	10	5	6	8	7	11	3

Table 20: Impact of Disease Management Options for Best-Case Scenario - 10% Average Daily Gain Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.48	$ 180.25	$ 180.02	$ 179.59	$ 179.97	$ 179.90	$ 180.15	$ 179.03	$ 179.53	$ 179.59	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.38	$ 183.08	$ 183.31	$ 183.31	$ 183.45	$ 183.45	$ 183.45	$ 183.38	$ 183.31	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.35	$ 3.14	$ 3.06	$ 3.72	$ 3.34	$ 3.55	$ 3.30	$ 4.42	$ 3.86	$ 3.72	$ 3.56
			$ -	$ -	$ -		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,910.30	$ 1,385.33	$ 1,354.18	$ 1,649.34	$ 1,480.53	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,704.27	$ 1,634.26	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 99,335.62	$ 72,037.19	$ 70,417.43	$ 85,765.54	$ 76,987.63	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 88,622.17	$ 84,981.72	$ 82,027.02
			$ -	$ -	$ -		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 15,754.77	-$ 43,053.21	-$ 44,672.97	-$ 29,324.86	-$ 38,102.76	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 26,468.22	-$ 30,108.67	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 12,466.61	-$ 14,831.83	-$ 16,451.59	-$ 1,103.47	-$ 9,881.38	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 1,753.16	-$ 1,887.29	-$ 4,841.99
Rank	1	6	2	4	13	14	7	11	10	12	3	5	8	9

Table 21: Impact of Disease Management Options for Expected Scenario - 10% Average Daily Gain Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.53	$ 180.34	$ 180.42	$ 179.70	$ 179.42	$ 179.80	$ 180.29	$ 180.58	$ 179.07	$ 179.26	$ 179.82	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 180.66	$ 179.64	$ 181.01	$ 181.01	$ 183.01	$ 183.01	$ 182.38	$ 181.40	$ 180.99	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.30	$ 3.49	$ 0.24	-$ 0.06	$ 1.59	$ 1.21	$ 2.72	$ 2.44	$ 3.31	$ 2.14	$ 1.16	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,890.78	$ 1,501.32	$ 105.59	-$ 28.38	$ 699.70	$ 532.03	$ 1,194.44	$ 1,067.93	$ 1,468.34	$ 935.45	$ 501.39	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 98,320.31	$ 78,068.66	$ 5,490.42	-$ 1,475.74	$ 36,384.24	$ 27,665.49	$ 62,110.62	$ 55,532.20	$ 76,353.86	$ 48,643.28	$ 26,072.10	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 16,770.09	-$ 37,021.73	-$ 109,599.97	-$ 116,566.13	-$ 78,706.15	-$ 87,424.90	-$ 52,979.77	-$ 59,558.20	-$ 38,736.53	-$ 66,447.11	-$ 89,018.30	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 111,772.80	$ 91,521.15	$ 18,942.91	$ 11,976.76	$ 49,836.73	$ 41,117.99	$ 75,563.11	$ 68,984.69	$ 89,806.35	$ 62,095.78	$ 39,524.59	$ 85,131.68
Rank	1	14	2	3	12	13	9	10	6	7	4	8	11	5

Table 22: Impact of Disease Management Options for Worst-Case Scenario - 10% Average Daily Gain Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 179.89	$ 181.33	$ 179.68	$ 177.91	$ 178.03	$ 178.41	$ 180.46	$ 180.79	$ 178.91	$ 177.12	$ 178.93	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 173.30	$ 170.68	$ 174.54	$ 174.54	$ 182.58	$ 182.58	$ 178.38	$ 175.62	$ 174.47	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 3.93	$ 2.50	-$ 6.38	-$ 7.23	-$ 3.49	-$ 3.87	$ 2.12	$ 1.78	-$ 0.53	-$ 1.50	-$ 4.46	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,724.77	$ 1,056.23	-$ 2,763.07	-$ 3,172.75	-$ 1,530.17	-$ 1,697.46	$ 927.13	$ 778.78	-$ 233.94	-$ 650.97	-$ 1,887.73	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 89,687.78	$ 54,924.22	-$ 143,679.64	-$ 164,982.98	-$ 79,568.92	-$ 88,267.94	$ 48,210.69	$ 40,496.38	-$ 12,164.85	-$ 33,850.64	-$ 98,162.02	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 25,402.61	-$ 60,166.18	-$ 258,770.03	-$ 280,073.38	-$ 194,659.31	-$ 203,358.34	-$ 66,879.71	-$ 74,594.02	-$ 127,255.24	-$ 148,941.03	-$ 213,252.41	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 319,897.77	$ 285,134.20	$ 86,530.35	$ 65,227.01	$ 150,641.07	$ 141,942.04	$ 278,420.67	$ 270,706.36	$ 218,045.14	$ 196,359.35	$ 132,047.97	$ 291,839.87
Rank	1	14	2	4	12	13	9	10	5	6	7	8	11	3

Table 23: Impact of Disease Management Options for Best-Case Scenario - 10% Feed Efficiency Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.48	$ 180.40	$ 180.09	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.35	$ 3.42	$ 3.32	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,910.30	$ 1,511.94	$ 1,470.19	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 99,335.62	$ 78,621.02	$ 76,449.82	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 15,754.77	-$ 36,469.37	-$ 38,640.57	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 12,466.61	-$ 8,247.99	-$ 10,419.19	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	11	13	7	12	10	14	3	5	8	9

Table 24: Impact of Disease Management Options for Expected Scenario - 10% Feed Efficiency Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.44	$ 180.34	$ 180.64	$ 179.24	$ 180.01	$ 180.40	$ 180.29	$ 180.58	$ 179.04	$ 180.05	$ 180.51	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.39	$ 3.49	$ 2.33	$ 1.50	$ 3.00	$ 2.62	$ 2.72	$ 2.44	$ 3.97	$ 2.96	$ 2.51	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,930.09	$ 1,501.32	$ 1,015.83	$ 658.76	$ 1,319.07	$ 1,151.40	$ 1,194.44	$ 1,067.93	$ 1,759.02	$ 1,294.32	$ 1,080.97	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 100,364.61	$ 78,068.66	$ 52,823.34	$ 34,255.76	$ 68,591.44	$ 59,872.69	$ 62,110.62	$ 55,532.20	$ 91,469.20	$ 67,304.78	$ 56,210.23	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 14,725.78	-$ 37,021.73	-$ 62,267.05	-$ 80,834.64	-$ 46,498.96	-$ 55,217.70	-$ 52,979.77	-$ 59,558.20	-$ 23,621.19	-$ 47,785.62	-$ 58,880.17	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 113,817.10	$ 91,521.15	$ 66,275.83	$ 47,708.25	$ 82,043.93	$ 73,325.18	$ 75,563.11	$ 68,984.69	$ 104,921.69	$ 80,757.27	$ 69,662.72	$ 85,131.68
Rank	1	14	2	4	12	13	6	9	8	11	3	7	10	5

Table 25: Impact of Disease Management Options for Worst-Case Scenario - 10% Feed Efficiency Improvement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 179.75	$ 181.21	$ 179.69	$ 176.39	$ 178.87	$ 179.25	$ 180.46	$ 180.79	$ 179.04	$ 179.76	$ 180.03	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 4.07	$ 2.62	-$ 0.54	-$ 2.90	$ 1.38	$ 1.00	$ 2.12	$ 1.78	$ 3.53	$ 1.70	$ 0.14	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,786.17	$ 1,106.25	-$ 234.48	-$ 1,272.71	$ 606.94	$ 439.65	$ 927.13	$ 778.78	$ 1,565.77	$ 736.73	$ 61.29	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 92,880.61	$ 57,525.25	-$ 12,192.85	-$ 66,181.13	$ 31,560.95	$ 22,861.92	$ 48,210.69	$ 40,496.38	$ 81,419.89	$ 38,309.86	$ 3,187.24	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 22,209.78	-$ 57,565.15	-$ 127,283.25	-$ 181,271.52	-$ 83,529.45	-$ 92,228.47	-$ 66,879.71	-$ 74,594.02	-$ 33,670.50	-$ 76,780.54	-$ 111,903.16	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 323,090.60	$ 287,735.23	$ 218,017.13	$ 164,028.86	$ 261,770.94	$ 253,071.91	$ 278,420.67	$ 270,706.36	$ 311,629.88	$ 268,519.84	$ 233,397.22	$ 291,839.87
Rank	1	14	2	5	12	13	9	10	6	7	3	8	11	4

Table 26: Impact of Disease Management Options for Best-Case Scenario - 10% Feed Efficiency Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.09	$ 179.48	$ 180.74	$ 180.43	$ 179.76	$ 180.15	$ 179.90	$ 180.15	$ 179.12	$ 179.58	$ 179.75	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.73	$ 4.35	$ 3.09	$ 2.98	$ 3.69	$ 3.31	$ 3.55	$ 3.30	$ 4.33	$ 3.88	$ 3.70	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,096.59	$ 1,910.30	$ 1,363.12	$ 1,318.77	$ 1,633.60	$ 1,464.79	$ 1,570.92	$ 1,459.73	$ 1,917.50	$ 1,713.36	$ 1,625.64	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 109,022.52	$ 99,335.62	$ 70,882.26	$ 68,575.90	$ 84,947.02	$ 76,169.12	$ 81,688.05	$ 75,906.21	$ 99,710.24	$ 89,094.93	$ 84,533.53	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,067.88	-$ 15,754.77	-$ 44,208.14	-$ 46,514.50	-$ 30,143.37	-$ 38,921.28	-$ 33,402.35	-$ 39,184.19	-$ 15,380.15	-$ 25,995.46	-$ 30,556.87	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 22,153.51	$ 12,466.61	-$ 15,986.75	-$ 18,293.11	-$ 1,921.99	-$ 10,699.89	-$ 5,180.97	-$ 10,962.81	$ 12,841.23	$ 2,225.92	-$ 2,335.49	-$ 4,841.99
Rank	1	6	2	3	13	14	8	11	10	12	4	5	7	9

Table 27: Impact of Disease Management Options for Expected Scenario - 10% Feed Efficiency Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 180.18	$ 180.34	$ 182.74	$ 181.24	$ 181.39	$ 181.78	$ 180.29	$ 180.58	$ 180.33	$ 180.83	$ 181.80	$ 179.99
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 3.65	$ 3.49	$ 0.22	-$ 0.50	$ 1.62	$ 1.24	$ 2.72	$ 2.44	$ 2.68	$ 2.19	$ 1.22	$ 3.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,602.86	$ 1,501.32	$ 98.04	-$ 219.07	$ 711.84	$ 544.18	$ 1,194.44	$ 1,067.93	$ 1,187.55	$ 956.57	$ 525.23	$ 1,339.64
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 83,348.93	$ 78,068.66	$ 5,097.84	-$ 11,391.47	$ 37,015.91	$ 28,297.16	$ 62,110.62	$ 55,532.20	$ 61,752.43	$ 49,741.83	$ 27,312.06	$ 69,661.23
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 31,741.47	-$ 37,021.73	-$ 109,992.55	-$ 126,481.87	-$ 78,074.49	-$ 86,793.23	-$ 52,979.77	-$ 59,558.20	-$ 53,337.97	-$ 65,348.57	-$ 87,778.34	-$ 45,429.16
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 96,801.42	$ 91,521.15	$ 18,550.33	$ 2,061.02	$ 50,468.40	$ 41,749.65	$ 75,563.11	$ 68,984.69	$ 75,204.92	$ 63,194.32	$ 40,764.55	$ 83,113.73
Rank	1	14	2	3	12	13	9	10	5	7	6	8	11	4

Table 28: Impact of Disease Management Options for Worst-Case Scenario - 10% Feed Efficiency Disimprovement

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 183.00	$ 181.45	$ 186.78	$ 182.60	$ 184.71	$ 185.10	$ 180.46	$ 180.79	$ 184.79	$ 183.55	$ 185.54	$ 181.27
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 0.83	$ 2.38	-$ 7.62	-$ 9.10	-$ 4.46	-$ 4.84	$ 2.12	$ 1.78	-$ 2.21	-$ 2.09	-$ 5.37	$ 1.31
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 362.95	$ 1,006.22	-$ 3,301.89	-$ 3,996.38	-$ 1,955.02	-$ 2,122.31	$ 927.13	$ 778.78	-$ 980.50	-$ 908.74	-$ 2,272.57	$ 578.89
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 18,873.28	$ 52,323.19	-$ 171,698.35	-$ 207,811.51	-$ 101,660.86	-$ 110,359.89	$ 48,210.69	$ 40,496.38	-$ 50,985.95	-$ 47,254.57	-$ 118,173.55	$ 30,102.10
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 96,217.11	-$ 62,767.21	-$ 286,788.74	-$ 322,901.90	-$ 216,751.25	-$ 225,450.28	-$ 66,879.71	-$ 74,594.02	-$ 166,076.34	-$ 162,344.96	-$ 233,263.94	-$ 84,988.29
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 249,083.27	$ 282,533.17	$ 58,511.64	$ 22,398.48	$ 128,549.13	$ 119,850.10	$ 278,420.67	$ 270,706.36	$ 179,224.04	$ 182,955.42	$ 112,036.44	$ 260,312.09
Rank	1	14	6	2	12	13	9	10	3	4	8	7	11	5

Table 29: Impact of Disease Management Options for Best-Case Scenario - 5% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.12	$ 179.52	$ 180.46	$ 180.18	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.71	$ 4.31	$ 3.37	$ 3.23	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,085.81	$ 1,889.48	$ 1,487.92	$ 1,430.35	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 108,462.37	$ 98,252.93	$ 77,371.58	$ 74,378.22	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 6,628.03	-$ 16,837.46	-$ 37,718.81	-$ 40,712.18	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 21,593.36	$ 11,383.92	-$ 9,497.43	-$ 12,490.80	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	12	14	7	11	10	13	3	5	8	9

Table 30: Impact of Disease Management Options for Expected Scenario - 5% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 179.73	$ 180.44	$ 181.62	$ 180.28	$ 180.44	$ 180.82	$ 180.29	$ 180.58	$ 179.39	$ 180.05	$ 180.85	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 4.10	$ 3.38	$ 1.34	$ 0.46	$ 2.57	$ 2.19	$ 2.72	$ 2.44	$ 3.63	$ 2.96	$ 2.16	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,799.10	$ 1,454.47	$ 586.03	$ 201.66	$ 1,131.74	$ 964.07	$ 1,194.44	$ 1,067.93	$ 1,607.03	$ 1,294.32	$ 933.41	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 93,552.98	$ 75,632.61	$ 30,473.40	$ 10,486.11	$ 58,850.49	$ 50,131.74	$ 62,110.62	$ 55,532.20	$ 83,565.80	$ 67,304.78	$ 48,537.51	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 21,537.42	-$ 39,457.79	-$ 84,617.00	-$ 104,604.29	-$ 56,239.91	-$ 64,958.65	-$ 52,979.77	-$ 59,558.20	-$ 31,524.59	-$ 47,785.62	-$ 66,552.89	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 107,005.47	$ 89,085.10	$ 43,925.89	$ 23,938.60	$ 72,302.98	$ 63,584.23	$ 75,563.11	$ 68,984.69	$ 97,018.30	$ 80,757.27	$ 61,990.00	$ 85,131.68
Rank	1	14	2	4	12	13	8	10	7	9	3	6	11	5

Table 31: Impact of Disease Management Options for Worst-Case Scenario - 5% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 181.42	$ 181.57	$ 183.23	$ 179.64	$ 181.37	$ 181.75	$ 180.46	$ 180.79	$ 181.34	$ 180.33	$ 182.23	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 2.40	$ 2.25	-$ 4.08	-$ 6.15	-$ 1.12	-$ 1.50	$ 2.12	$ 1.78	$ 1.24	$ 1.12	-$ 2.06	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 1,051.29	$ 948.21	-$ 1,768.18	-$ 2,698.60	-$ 489.22	-$ 656.51	$ 927.13	$ 778.78	$ 547.26	$ 487.07	-$ 871.57	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 54,667.07	$ 49,306.75	-$ 91,945.60	-$ 140,327.04	-$ 25,439.43	-$ 34,138.45	$ 48,210.69	$ 40,496.38	$ 28,457.56	$ 25,327.67	-$ 45,321.86	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 60,423.32	-$ 65,783.65	-$ 207,035.99	-$ 255,417.43	-$ 140,529.82	-$ 149,228.85	-$ 66,879.71	-$ 74,594.02	-$ 86,632.84	-$ 89,762.73	-$ 160,412.26	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 284,877.06	$ 279,516.73	$ 138,264.39	$ 89,882.95	$ 204,770.56	$ 196,071.53	$ 278,420.67	$ 270,706.36	$ 258,667.54	$ 255,537.65	$ 184,888.12	$ 291,839.87
Rank	1	14	3	4	12	13	9	10	5	6	7	8	11	2

Table 32: Impact of Disease Management Options for Best-Case Scenario - 10% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.14	$ 179.54	$ 180.46	$ 180.18	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.69	$ 4.29	$ 3.37	$ 3.23	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 2,074.68	$ 1,880.54	$ 1,487.92	$ 1,430.35	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 107,883.28	$ 97,788.09	$ 77,371.58	$ 74,378.22	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 7,207.11	-$ 17,302.30	-$ 37,718.81	-$ 40,712.18	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 21,014.27	$ 10,919.08	-$ 9,497.43	-$ 12,490.80	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	12	14	7	11	10	13	3	5	8	9

Table 33: Impact of Disease Management Options for Expected Scenario - 10% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 180.29	$ 180.49	$ 181.62	$ 180.28	$ 180.44	$ 180.82	$ 180.29	$ 180.58	$ 179.39	$ 180.05	$ 180.85	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 3.54	$ 3.34	$ 1.34	$ 0.46	$ 2.57	$ 2.19	$ 2.72	$ 2.44	$ 3.63	$ 2.96	$ 2.16	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,553.49	$ 1,434.36	$ 586.03	$ 201.66	$ 1,131.74	$ 964.07	$ 1,194.44	$ 1,067.93	$ 1,607.03	$ 1,294.32	$ 933.41	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 80,781.24	$ 74,586.72	$ 30,473.40	$ 10,486.11	$ 58,850.49	$ 50,131.74	$ 62,110.62	$ 55,532.20	$ 83,565.80	$ 67,304.78	$ 48,537.51	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 34,309.16	-$ 40,503.68	-$ 84,617.00	-$ 104,604.29	-$ 56,239.91	-$ 64,958.65	-$ 52,979.77	-$ 59,558.20	-$ 31,524.59	-$ 47,785.62	-$ 66,552.89	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 94,233.73	$ 88,039.21	$ 43,925.89	$ 23,938.60	$ 72,302.98	$ 63,584.23	$ 75,563.11	$ 68,984.69	$ 97,018.30	$ 80,757.27	$ 61,990.00	$ 85,131.68
Rank	1	14	3	4	12	13	8	10	7	9	2	6	11	5

Table 34: Impact of Disease Management Options for Worst-Case Scenario - 10% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 183.19	$ 181.71	$ 183.23	$ 179.64	$ 181.37	$ 181.75	$ 180.46	$ 180.79	$ 181.34	$ 180.33	$ 182.23	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.83	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	$ 0.64	$ 2.11	-$ 4.08	-$ 6.15	-$ 1.12	-$ 1.50	$ 2.12	$ 1.78	$ 1.24	$ 1.12	-$ 2.06	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	$ 280.03	$ 887.68	-$ 1,768.18	-$ 2,698.60	-$ 489.22	-$ 656.51	$ 927.13	$ 778.78	$ 547.26	$ 487.07	-$ 871.57	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	$ 14,561.70	$ 46,159.30	-$ 91,945.60	-$ 140,327.04	-$ 25,439.43	-$ 34,138.45	$ 48,210.69	$ 40,496.38	$ 28,457.56	$ 25,327.67	-$ 45,321.86	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 100,528.70	-$ 68,931.10	-$ 207,035.99	-$ 255,417.43	-$ 140,529.82	-$ 149,228.85	-$ 66,879.71	-$ 74,594.02	-$ 86,632.84	-$ 89,762.73	-$ 160,412.26	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 244,771.68	$ 276,369.28	$ 138,264.39	$ 89,882.95	$ 204,770.56	$ 196,071.53	$ 278,420.67	$ 270,706.36	$ 258,667.54	$ 255,537.65	$ 184,888.12	$ 291,839.87
Rank	1	14	8	4	12	13	9	10	3	5	6	7	11	2

Table 35: Impact of Disease Management Options for Best-Case Scenario - 20% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Best-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 179.27	$ 179.39	$ 179.54	$ 180.46	$ 180.18	$ 179.66	$ 180.04	$ 179.90	$ 180.15	$ 179.03	$ 179.56	$ 179.66	$ 179.89
Revenue per Marketed Pig	$ 183.83	$ 183.08	$ 183.83	$ 183.83	$ 183.83	$ 183.41	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45	$ 183.45
Profit per Marketed Pig	$ 4.99	$ 3.81	$ 4.43	$ 4.29	$ 3.37	$ 3.23	$ 3.79	$ 3.41	$ 3.55	$ 3.30	$ 4.42	$ 3.89	$ 3.79	$ 3.56
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	$ 1,670.56	$ 1,960.75	$ 1,880.54	$ 1,487.92	$ 1,430.35	$ 1,680.09	$ 1,511.28	$ 1,570.92	$ 1,459.73	$ 1,958.02	$ 1,720.02	$ 1,665.76	$ 1,577.44
Profit per Year	$ 115,090.39	$ 86,869.01	$ 101,958.87	$ 97,788.09	$ 77,371.58	$ 74,378.22	$ 87,364.60	$ 78,586.70	$ 81,688.05	$ 75,906.21	$ 101,817.03	$ 89,441.07	$ 86,619.36	$ 82,027.02
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 28,221.38	-$ 13,131.53	-$ 17,302.30	-$ 37,718.81	-$ 40,712.18	-$ 27,725.79	-$ 36,503.70	-$ 33,402.35	-$ 39,184.19	-$ 13,273.37	-$ 25,649.32	-$ 28,471.03	-$ 33,063.38
Δ Annual Profit from Best-Case Scenario	$ 28,221.38	$ -	$ 15,089.86	$ 10,919.08	-$ 9,497.43	-$ 12,490.80	$ 495.59	-$ 8,282.32	-$ 5,180.97	-$ 10,962.81	$ 14,948.01	$ 2,572.06	-$ 249.65	-$ 4,841.99
Rank	1	6	2	4	12	14	7	11	10	13	3	5	8	9

Table 36: Impact of Disease Management Options for Expected Scenario - 20% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Expected Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 180.24	$ 181.40	$ 180.59	$ 181.62	$ 180.28	$ 180.44	$ 180.82	$ 180.29	$ 180.58	$ 179.39	$ 180.05	$ 180.85	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 179.64	$ 183.83	$ 183.83	$ 182.96	$ 180.74	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01	$ 183.01
Profit per Marketed Pig	$ 4.99	-$ 0.60	$ 2.43	$ 3.24	$ 1.34	$ 0.46	$ 2.57	$ 2.19	$ 2.72	$ 2.44	$ 3.63	$ 2.96	$ 2.16	$ 3.11
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 258.70	$ 1,063.79	$ 1,390.66	$ 586.03	$ 201.66	$ 1,131.74	$ 964.07	$ 1,194.44	$ 1,067.93	$ 1,607.03	$ 1,294.32	$ 933.41	$ 1,378.45
Profit per Year	$ 115,090.39	-$ 13,452.49	$ 55,316.95	$ 72,314.16	$ 30,473.40	$ 10,486.11	$ 58,850.49	$ 50,131.74	$ 62,110.62	$ 55,532.20	$ 83,565.80	$ 67,304.78	$ 48,537.51	$ 71,679.19
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 128,542.89	-$ 59,773.44	-$ 42,776.24	-$ 84,617.00	-$ 104,604.29	-$ 56,239.91	-$ 64,958.65	-$ 52,979.77	-$ 59,558.20	-$ 31,524.59	-$ 47,785.62	-$ 66,552.89	-$ 43,411.20
Δ Annual Profit from Best-Case Scenario	$ 128,542.89	$ -	$ 68,769.44	$ 85,766.65	$ 43,925.89	$ 23,938.60	$ 72,302.98	$ 63,584.23	$ 75,563.11	$ 68,984.69	$ 97,018.30	$ 80,757.27	$ 61,990.00	$ 85,131.68
Rank	1	14	9	3	12	13	7	10	6	8	2	5	11	4

Table 37: Impact of Disease Management Options for Worst-Case Scenario - 20% Disimprovement for Antibiotics for Prevention

	Baselines		Prevention Management				Treatment Management							
	Baseline Scenario	Worst-Case Scenario	Chlortetracycline	Tylosin	Enterisol Ileitis	Porcilis Ileitis	Tylosin	Tylosin	Tylosin	Tylosin	Tiamulin	Lincomycin	Tylvalosin	Tylvalosin
Cost per Marketed Pig	$ 178.83	$ 181.21	$ 186.66	$ 181.90	$ 183.23	$ 179.64	$ 181.37	$ 181.75	$ 180.46	$ 180.79	$ 181.34	$ 180.33	$ 182.23	$ 179.90
Revenue per Marketed Pig	$ 183.83	$ 170.68	$ 183.74	$ 183.83	$ 179.15	$ 173.49	$ 180.26	$ 180.26	$ 182.58	$ 182.58	$ 182.58	$ 181.45	$ 180.18	$ 182.58
Profit per Marketed Pig	$ 4.99	-$ 10.53	-$ 2.92	$ 1.92	-$ 4.08	-$ 6.15	-$ 1.12	-$ 1.50	$ 2.12	$ 1.78	$ 1.24	$ 1.12	-$ 2.06	$ 2.67
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Profit per Week	$ 2,213.28	-$ 4,427.12	-$ 1,269.67	$ 808.83	-$ 1,768.18	-$ 2,698.60	-$ 489.22	-$ 656.51	$ 927.13	$ 778.78	$ 547.26	$ 487.07	-$ 871.57	$ 1,185.19
Profit per Year	$ 115,090.39	-$ 230,209.99	-$ 66,022.70	$ 42,059.27	-$ 91,945.60	-$ 140,327.04	-$ 25,439.43	-$ 34,138.45	$ 48,210.69	$ 40,496.38	$ 28,457.56	$ 25,327.67	-$ 45,321.86	$ 61,629.89
			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Δ Annual Profit from Baseline Scenario	$ -	-$ 345,300.38	-$ 181,113.10	-$ 73,031.12	-$ 207,035.99	-$ 255,417.43	-$ 140,529.82	-$ 149,228.85	-$ 66,879.71	-$ 74,594.02	-$ 86,632.84	-$ 89,762.73	-$ 160,412.26	-$ 53,460.51
Δ Annual Profit from Best-Case Scenario	$ 345,300.38	$ -	$ 164,187.28	$ 272,269.26	$ 138,264.39	$ 89,882.95	$ 204,770.56	$ 196,071.53	$ 278,420.67	$ 270,706.36	$ 258,667.54	$ 255,537.65	$ 184,888.12	$ 291,839.87
Rank	1	14	11	4	12	13	8	9	3	5	6	7	10	2

Table 38: Feed and Weight Assumptions for Growing Pigs – Adopted from "The Pig Site" (http://www.thepigsite.com/stockstds/17/growth-rate/)

	Weight (kg)	**Feed Conversion (Feed Consumed/Weight Gained)**	**Average Daily Gain (kg)**
Weaning	6.00		
Nursery Barn			
Week 4	7.51	1.30	0.22
Week 5	9.64	1.30	0.31
Week 6	12.41	1.30	0.40
Week 7	15.99	1.35	0.51
Week 8	20.40	1.40	0.63
Week 9	24.92	1.45	0.65
Week 10	29.54	1.55	0.66
Week 11	34.16	1.70	0.66
Finishing Barn			
Week 12	38.66	2.07	0.64
Week 13	43.70	2.34	0.72
Week 14	48.74	2.34	0.72
Week 15	54.82	2.43	0.87
Week 16	60.90	2.43	0.87
Week 17	67.20	2.88	0.90
Week 18	73.50	2.88	0.90
Week 19	80.43	3.06	0.99
Week 20	87.36	3.06	0.99
Week 21	94.29	3.24	0.99
Week 22	101.22	3.24	0.99
Week 23	108.15	3.60	0.99
Week 24	115.08	3.60	0.99
Week 25	122.01	3.60	0.99
Week 26	128.94	3.42	0.99
Week 27	135.87	3.42	0.99
Shipping	135.87		

Figures

Figure 1: Pig Barn Scenarios Simulated

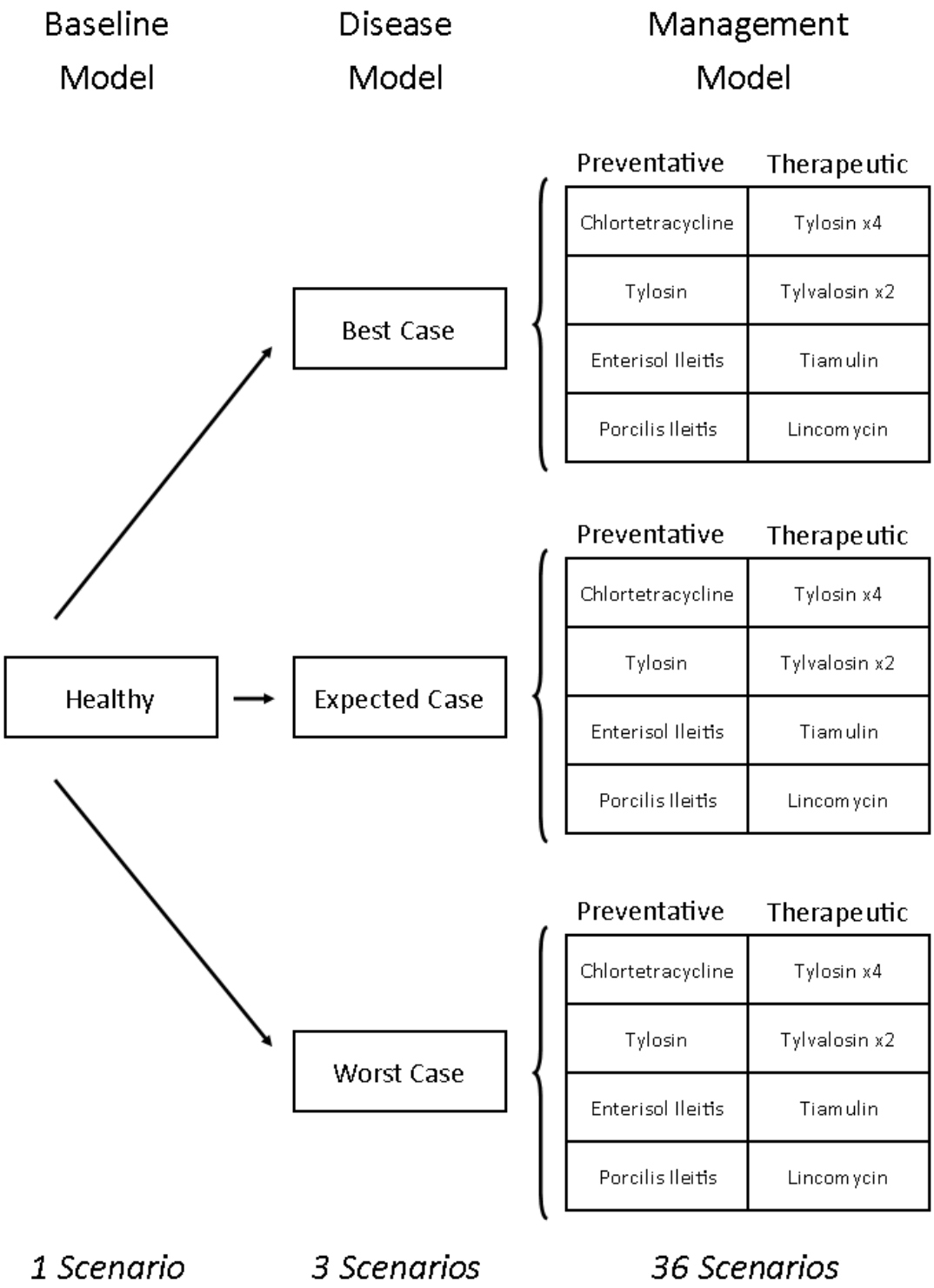

Figure 2: Pig Barn Animal Flow

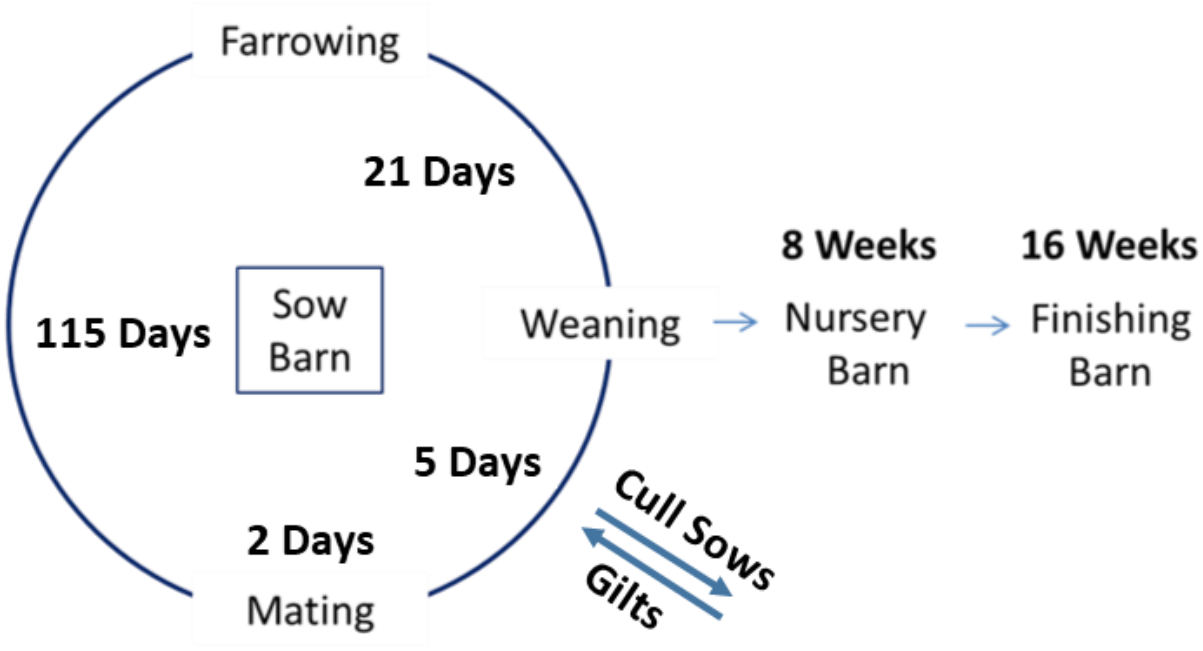

Figure 3: Frequency of Monthly Ontario Hog Prices ($/cwt)

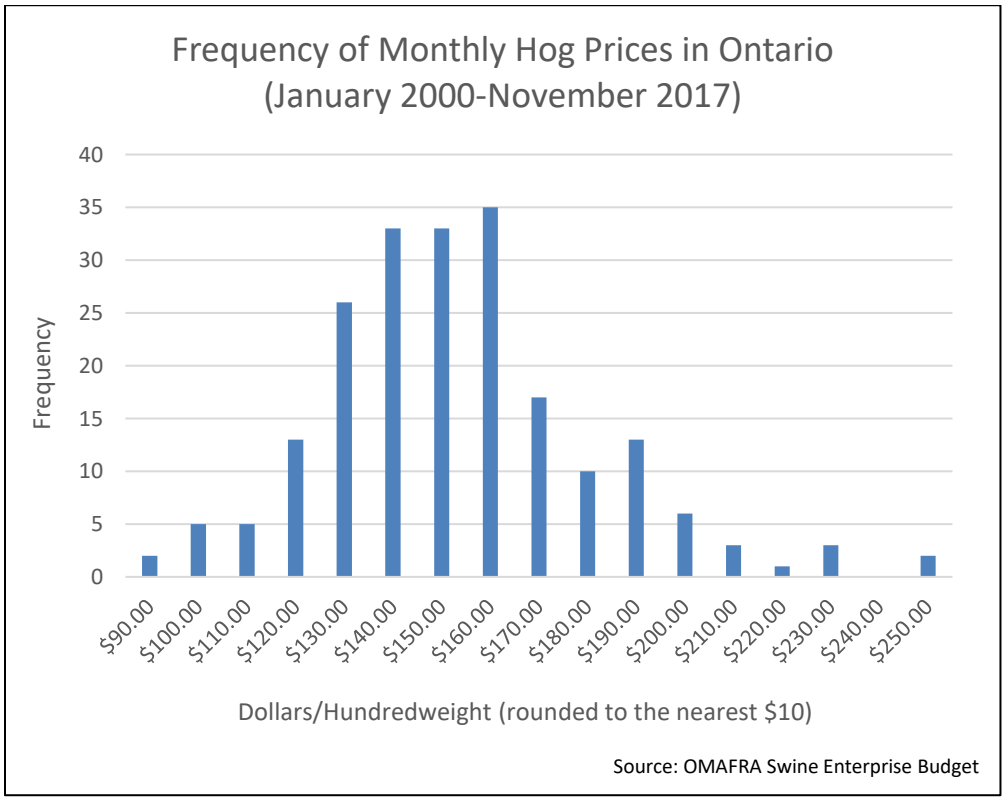

Figure 4: Monthly Ontario Hog Prices over Time ($/cwt)