The Role of Pig Diseases in Structural Change in the Canadian Pig Industry

by

Yanan Zheng

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Agricultural and Resource Economics

Department of Resource Economics and Environmental Sociology
University of Alberta

Abstract

Since their first discoveries in the early 1990s in Canada, pig diseases, especially porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD), have plagued the Canadian pig industry, and the problem became more severe with the onset of porcine epidemic diarrhea (PED) in 2014. In the meantime, the industry has also seen dramatic structural change with a decrease in pig farm numbers and an increase in total pig numbers. Using the census division (CD) level data obtained from the Census of Agriculture Questionnaires, we find not every CD across the country experienced the same type of structural change. Indeed, about 69% of the CDs in Canada went through decreases in both pig farm numbers and pig numbers over the period 1981 to 2016.

This research examines how pig diseases (PRRS, PCVAD, and PED) have affected structural change in the Canadian pig industry at the individual census division level while controlling for the effect of other key economic explanatory variables over the period 1981 to 2016. Farm structure in our study is defined by farm size (i.e., average number of pigs per farm), and the impacts of various economic factors including the U.S. country of origin labelling on the industry's structural change are empirically assessed using random effects generalized least squares models. The empirical results indicate pig diseases did affect the Canadian pig industry's structure, and they have played a more significant role in the structure of farms in eastern Canada.

Given that pig diseases had played a significant role in pig farming operations in some geographical regions in Canada, we further investigate how various factors including: 1) on-farm disease status; 2) management variables; 3) farmers' knowledge about and attitudes towards various treatment methods play a role in pig farmers' decisions regarding the uptake of preventive measures. In general, we find : 1) farmers who experienced disease outbreaks are more likely to implement more preventive measures than those haven no experience; 2) farm and farmer characteristics such as production type and operators' age are important determinants of adoption decisions; and 3) the better the farmers' knowledge about a particular practice, the stronger their biosecurity behavior.

Dedication

For my family.

Acknowledgements

First and foremost I would like to express my deepest gratitude to my dear supervisors Dr. Ellen Goddard and Dr. Feng Qiu for all of the time, support and advice they have given to me. I am so grateful that they set aside time in their busy schedule to provide me with constructive suggestions and precious guidance. I have learned a lot from them and have enjoyed the work we have done together. I want to thank my committee member, Dr. James Rude, for always being supportive and encouraging throughout the past two years. He is always there whenever I need his help or suggestions. I also want to thank Dr. Albert Boaitey, Dr. Violet Muringai and all the EGGs (Dr. Ellen Goddard's students) for the help they gave during my studies.

I would also want to thank Genome Canada as well as Genome Alberta for funding GE^{3}LS research and all our collaborators and partners including Genome Prairie, PigGen Canada, Alberta Livestock and Meat Agency (ALMA), Swine Innovation Porc, Saskatchewan Ministry of Agriculture, French National Institute for Agricultural Research (INRA), National Pork Board, UK BBSRC, Ontario Ministry of Research Innovation and Science, Centre de développement du porc du Québec Inc. (CDPQ), and Alberta Pork.

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Chapter 1: Introduction

1.1 Background

Over the last four decades, Canada has seen significant structural change in the pig industry with a huge decrease in the number of pig farms and an increase in pig numbers per farm (national level). From 1981 to 2016, the number of pig farms decreased by 85% (from 55765 to 8402), but the average number of pigs per farm was 8.5-fold higher (from 177 head per farm to 1677 head per farm). In total, the industry produced approximately 4.2 million more pigs in 2016 as compared to 1981 (Statistics Canada, 1982; Statistics Canada). In the agricultural economics literature, such changes are usually attributed to the realization of scale economies with increased farm size (Gervais et al., 2008; Komirenko, 2015). Accompanying the increases in national average number of pigs per farm, pig production has also changed to become more specialized. Farms have moved away from the traditional farrow-to-finish operations to specialization on a single phase of production (Brisson, 2015), which allows lower per unit production costs. According to the Agricultural Division of Statistics Canada, the proportion of the pig farms that were farrow-to-finish operations decreased from 45% in 1981 to 23% in 2016 (Statistics Canada, 2017a). Figure 1.1 presents the percentage change in the number of farrow-to-finish farms within each census division/district (CD) (see definition in Statistics Canada, 2015) over the period 1981 to 2016, and it shows the majority of the CDs (76%) have farms moving away from farrow-to-finish units. In addition to cost considerations, another reason for the production restructuring may be to control and prevent disease transmission, as a greater proportion of farrow-to-finish farms reported seeing clinical signs of pig diseases than farms with single-phase production (Young et al., 2010).

However, not every CD in Canada went through the same type of structural change with a decrease in pig farm numbers but an increase in total pig numbers. Take the province of Ontario as an example, among the 42 CDs that have pig farming operations, only 9 of them possessed fewer pig farms but raised more pigs in 2016 than in 1981, while the rest (33 CDs) underwent decreases in both pig farm numbers and total pig production (i.e., number of pigs) at that time period. For the country as a whole, about 69% of the CDs across the country experienced both pig farm losses and total pig number reductions over the last eight census years, and the extent of changes in pig farm numbers and total pig numbers are quite different across different regions (Figure 1.2) (Statistics Canada, 1982; Statistics Canada). These trends imply that the Canadian pig industry has gone through different types of structural change in the past four decades. In some geographic regions, the industry expanded in spite of the declining farm numbers, while in other regions the industry shrank (in terms of reduction in total pig numbers). Figure 1.3-1.9 further present the regional differences regarding the simultaneous pig farm decreases and total pig number changes (i.e., exhibiting different types of structural change) across each census period. From 1981 to 2011, almost all CDs in Canada experienced pig farm decreases across census years, but a slight increase in pig farm numbers was seen in the majority (63%) of the CDs in the 2016 census (Statistics Canada, 1982; Statistics Canada, 1987; Statistics Canada, 1992; Statistics Canada, 1997; Statistics Canada, 2002; Statistics Canada, 2007; Statistics Canada, 2012; Statistics Canada). Another thing of note is that a CD that experiences one type of structural change in one census period might experience another type of structural change in the following census period. Even if the type of structural change did not change, the extent of structural change, which is defined by changes in pig farm numbers and total pig numbers, would definitely vary across time.

In a wide range of studies discussing an industry's structural transformation and the factors contributing to it, technological forces (e.g., new technologies available), market conditions (e.g., price variations and value of dollar), farm structure (e.g., farm characteristics) and institutional factors (e.g., farm programs) have been comprehensively identified as the determinants by researchers. In the Canadian pig industry context, factors including mandatory country of origin labelling (COOL) in U.S., feed price spikes, and technology improvements (e.g., Brisson, 2015; Rude and Unterschultz, 2013) have been extensively discussed. However, the impact of disease outbreaks on a livestock industry's structural change has rarely been documented.

From an economic point of view, an investigation into the role of pig diseases in an industry's structural change is critical in the sense that the diseases have caused losses of billions of dollars to the Canadian pig industry (Office of Audit and Evaluation, 2015). Disease outbreaks not only caused net losses for farmers by reducing the number of pigs they could bring to market (Johnson et al., 2005), they also shrank profit margins by increasing the costs of disease control and prevention strategies (e.g., veterinary service fees, vaccination purchase) (McInerney et al., 1992). Since the early 1990s, two major infectious pig diseases (porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD)) have had big impacts in Canada. With the onset of porcine epidemic diarrhea (PED) in 2014, the negative effects resulting from pig disease outbreaks became even bigger. Due to the additional costs incurred from animal losses and disease management, high cost producers might find their operations no longer viable and adjust out of the industry (Australian Bureau of Agricultural and Resource Economics, 2007).

In response to the detrimental costs associated with pig disease outbreaks, farmers also make adaptation changes such as the adoption of disease preventative strategies (e.g., vaccination) to control the introduction and spread of pathogens and farm size adjustments to minimize the per unit production costs. For disease management strategies, strict biosecurity standards such as entrance protocol and transportation rules have to be respected at all times and it is necessary to have isolation areas for replacement animals and dead stock. Such protocols are especially critical for the Canadian pig industry, where production is large-scale and animals are raised indoors. More recently, genomic technologies have drawn increasing research attention, as the use of genomics may allow breeders to select animals that will be more resilient to disease or that will recover from the diseases faster (Bishop and Woolliams, 2014). However, due to the practical difficulties in the development of specific genome selection programs, this technique is yet not available to the pig industry (Samorè and Fontanesi, 2016) In addition to the application of various disease preventive measures, herd management has also changed and farms have moved away from farrow-to-finish operations to avoid pig disease infections. In terms of farmers' management strategies with regard to farm size adjustments, some farm operators might decide to enlarge their operations to minimize per unit production costs. On the other hand, other farmers might want to downsize their operations and eventually adapt out of the industry due to the high operating expenses. The interplay between farmers' reactions to disease control and their considerations on size adaptations leads to their final strategic outcomes.

The ultimate goal of conducting this study is to examine the role of different economic factors including pig disease outbreaks on the changing pig industry structure at the individual CD level in Canada while controlling for the effect of other key economic variables. Since diseases can be transmitted spatially either through pig movements or by intermediaries (e.g., personnel and trucking), who make decisions based on their own beliefs as well as information from other entities such as breeding companies and industry associations, the spatial configuration of the pig industry may be an important dimension to the analyses. In this study, spatial relationships between farms and other intermediaries such as processors are examined to investigate how geography and social proximity lead to the sector's structural change. Apart from farm size adjustments, pig farmers may also make adaptation changes with the adoption of more or less disease prevention strategies. Based on a national survey of pig farmers conducted in Canada, data relating to farm, farmer, as well as production characteristics and to the adoption of preventive measures were collected. We further evaluate how disease outbreaks impact the actual uptake of disease control and prevention strategies. In addition to on-farm disease status, management variables (e.g., production type and farmers' education level) as well as farmers' knowledge about and attitudes towards various treatment methods are also considered as the determinants of a particular treatment's adoption. Results from the present study will foster an improved understanding of the drivers of structural adjustments in the Canadian pig industry. They will also shed insights on public policy recommendations related to disease management and help producers minimize the impacts of pig diseases in the context of how they should make decisions around disease outbreaks.

1.2 Overview of Pig Diseases

1.2.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

Porcine reproductive respiratory syndrome (PRRS), also called blue ear disease, is a contagious viral disease affecting all stages of pig production (Lunney and Chen, 2010). Porcine reproductive and respiratory syndrome virus (PRRSV) was first recognized in the late 1980s in North America and is currently the most expensive endemic disease in the pig industry (Kappes and Faaberg, 2015; MacDougald, 2013). In the U.S., the annual economic losses caused by PRRS were estimated to be US$ 664 million dollars (Holtkamp et al., 2013), while for Canada, it was estimated at CAD$130 million dollars (Mussell, 2010).

Porcine reproductive and respiratory syndrome virus (PRRSV) is a small, enveloped, single stranded positive sense RNA virus classified in the order *Nidovirales*, family *Arteriviridae* and genus *Arterivirus* (Cavanagh, 1997). This virus is host specific and capable of infecting only pigs (Pitkin et al., 2009), so it has no negative impacts on human health status. In terms of the virus' impacts on pigs, PRRSV can cause significant production losses due to reproductive failure in sow herds including abortions, mummies, stillbirth, and premature farrowing. In growing pigs, it can cause increased mortality, poor growth performance and an increased number of cull pigs (Rossow, 1998; Zhang et al., 2012).

Porcine reproductive respiratory syndrome (PRRS) vaccine was first introduced to Canadian pig farmers in 1997, and two types of PRRS vaccines are now commercially available in Canada (Canadian Food Inspection Agency). One is a modified-live virus (MLV) vaccine and the other is a killed virus (KV) vaccine. However, both vaccines have only been partially effective. On the one hand, PRRS MLV is well recognized for its protective efficacy against PRRSV that is genetically homologous to the vaccine virus, but it is not safe or effective against the heterologous PRRSV challenge. On the other hand, PRRS KV vaccine is well recognized for its safety, but it confers limited protection (Charerntantanakul, 2012). At present, the development of effective vaccines against a wide range of PRRSV strains is still challenging due to the knowledge gaps in PRRS biology, pathogenesis and immunity (Karniychuk and Nauwynck, 2013).

1.2.2 Porcine Circovirus Associated Disease (PCVAD)

Also known as post-weaning multi-systemic wasting syndrome (PMWS), porcine circovirus associated disease (PCVAD) has long been a major threat to the Canadian pig industry since its initial detection in the province of Saskatchewan in the early 1990s (Harding, 2007). Starting in the Fall of 2004, the Canadian pig industry experienced significant economic losses due to PCVAD outbreaks, and a possible reason that we suddenly had such frequent and severe problems in 2004 is the introduction of new and more virulent isolates of the PCVAD virus (Desrosiers, 2007a). From 2004 through 2009, the economic impact of PCVAD on the Canadian and North American pork industries was estimated at $560 million dollars (eBiz Professionals Inc., 2010).

Porcine circovirus associated disease (PCVAD) is a small, non-enveloped, single stranded DNA virus with a circular genome (Tischer et al., 1982). The clinical and subclinical signs of PCVAD include wasting in pigs of 4-14 weeks of age, reduced growth rate and increased mortality in finishing pigs. Mortality can vary significantly from one herd to another. In some situations, the cases are sporadic, while in others mortality rate can reach 10-15% and sometimes even higher (Desrosiers, 2007b). Other clinical signs include reproductive disorders (e.g., abortions, stillbirth, and mummies) in sows, respiratory diseases, diarrhea and jaundice (Harding and Clark, 1997).

A special aspect of PCAVD is its co-infection with other viral and bacterial pathogens that have the possibility to induce more severe clinical outcomes. On one hand, a previous infection with PRRSV could result in a higher PCVAD load in the serum of PCVAD infected pigs (Kim et al., 2003). On the other hand, PCVAD could also enhance the replication of PRRSV, since a longer PRRSV viremia and a higher proportion of PRRS-viremic pigs were found when both viruses were inoculated (Rovira et al., 2002).

By 2006 when the PCVAD vaccine was first available in Canada, Canadian pig producers requested aid and access to vaccines from the provincial and the national governments to help them control PCVAD outbreaks and to reduce their impacts on the industry (Office of Audit and Evaluation, 2015). Since then, commercial vaccines have become one of the most commonly used disease preventive measures in growing pigs and several studies have reported that the application of PCVAD vaccines significantly reduced the impacts of this disease on the herd (Desrosier et al., 2007a). Unlike the PRRS case, experimental and empirical studies have proved the efficacy of PCVAD vaccines (e.g., Trible et al., 2012).

In addition to the availability of vaccines, the success of PCVAD control should also be attributed to government support. In response to the producers’ requests for help, Agriculture and Agri-Food Canada (AAFC) announced a contribution of $76 million for the establishment of Control of Disease in the Hog Industry (CDHI) programming in 2007 to combat disease and enhance prosperity and stability in the pig sector (Office of Audit and Evaluation, 2015). This program was delivered in two phases. Phase 1 particularly catered to the provision of financial assistance to pig farmers for the detection and mitigation of PCVAD (specifically for diagnosing tests and vaccination). In Phase 2, CDHI supported the development of an industry-led framework to achieve long-term health and stability of the Canadian pig herd through biosecurity, research and long-term disease risk management solutions. This national program was wound up in 2015.

1.2.3 Porcine Epidemic Diarrhea (PED)

Porcine epidemic diarrhea (PED), the most recent emerging pig disease in Canada, was first confirmed in a swine herd in southern Ontario in January 2014 (Kochhar, 2014). The initial detection of PED in the U.S. was in May 2013 (Huang et al., 2013). Because of PED's quick spread in the U.S. and the fact that Canada and the U.S. share extensive borders, PED quickly became a great concern for Canadian pig farmers. Since its first detection, PED has killed millions of pigs and cost the industry hundreds of $millions (CBCnews, 2016).

Porcine epidemic diarrhea (PED) is caused by an enveloped, single-strand and positive-sense RNA virus belonging to the family *Corobaviridae* and genus *Alphacoroenteritis* (Kocherhans et al., 2001). It is characterized by watery diarrhea, vomiting, and high mortality in nursing pigs (Dufresne, 2015). It also affects older pigs, finishers, and farrowing herds, with low mortality and the clinical signs being variable ranging from unapparent infections to diarrhea, anorexia, and depression (Kochhar, 2014).

Although U.S. vaccines for PED are available in Canada, they are only recommended for use in the case of disease outbreaks (Manitoba Co-operator, 2016). So far, there's no commercial vaccine available in Canada to prevent PED. In 2015, the University of Saskatchewan's Vaccine and Infectious Disease Organization-International Vaccine Centre (VIDO-InterVao) reported the development of a new vaccine that is a prophylactic aimed at preventing the disease altogether, and field testing in Manitoba and Saskatchewan is underway (Vanraes, 2015).

1.2.4 Disease Transmission and Biosecurity Measures

Transmission of diseases is known to be carried out through both direct and indirect ways. The virus can directly be shed from infected pigs via blood, saliva, milk and colostrum, urine and feces, as well as contaminated semen (Pitkin et al., 2009). One of the most important direct routes is direct pig-to-pig contact-mainly through nose-to-nose contact or by contact with urine and feces of infected pigs (Albina, 1997). Transplacental transmission to foetuses, use of virus contaminated semen for artificial insemination, and the transmission of the virus from infected sows to suckling piglets have also been documented as the direct routes (Karniychuk and Nauwynck, 2013; Yaeger et al., 1993).

The indirect routes refer to the transmissions of pathogens through vectors and fomites and are intensified by the dynamics of modern hog production, which is characterized by a higher degree of connectedness between sectors of the industry and the concentration of swine herds in production systems (Arruda et al., 2015). Facilities, pig feed, drinking water, insects, aerosol spread, and more importantly, transport vehicles and personnel all are the possible sources of indirect disease dissemination. Transport vehicles can transmit pathogens when manure containing pathogens adhered to vehicle tyres or bodywork, while pig workers, service providers and intermediaries such as pig transporters can transport pathogens on footwear, clothing, hands, etc. Another possible indirect transmission route is through air.

With the thorough knowledge of the routes of disease transmission, biosecurity, which is defined as “the implementation of measures that reduce the risk of the introduction and spread of disease agents” (Food and Agriculture Organization of the United Nations (FAO)/World Organization for Animal Health (OIE)/World Bank, 2010), has been considered increasingly important to control the introduction, persistence, and spread of pathogens. Corresponding to the means of disease transmissions, Chapple et al (2010) from the Canadian Swine Health Board (CSHB) summarized four general principles for the measures and procedures applied at the farm and production system level to reduce the risk of pathogen introduction and spread:

1) Segregation: Implementing barriers (including physical barriers, temporal separation of activities, and procedures) to limit risk of pathogens from infected animals and from contaminated materials from entering an uninfected site or group of animals.
2) Sanitation: Cleaning and washing the barn (including facilities and equipment) to remove visible organic materials; disinfecting and drying the barn after washing.
3) Flow Management: Preventing the cross-contamination of uninfected pigs by organizing the flow of pigs, people and materials within a farm or a production system.
4) Personal Records Keeping: Requiring documentation to support the application of Best Management Practices (BMPs), training and compliance with biosecurity protocols. A verification process may be performed by internal or external inspection or by an independent third-party audit and is important to confirm that biosecurity BMPs are applied.

1.2.5 The Effects of Pig Diseases on Costs of Production

Through the negative effects of diseases on production and animal populations, the outbreaks of the major pig diseases have had enormous economic impacts on the pig industry in Canada and worldwide (Gillespie et al., 2009; Holtkamp et al., 2013). A Canadian investigation of 205 production sites in 2014 estimated the production losses due to PRRS were $73.44 per sow place, $9.06 per piglet place in nurseries and $31.18 per pig place in grow-finish units (Global PRRS Solutions, 2016). While for PCVAD, the losses associated with increased mortality and decreased average daily gain as well as feed efficiency cost the U.S. industry US$6.6 per pig (Gillespie et al., 2006). The costs of PED in Canada were estimated to be approximately $20 per market hog (Weng, 2015).

In addition to the economic costs from immediate production losses, the presence of pig diseases can also incur higher expenses for intervention strategies and lower the competitiveness of the sector with diseases, and thus the profitability of the pig sector within a region or a country. For instance, Russia imposes import bans against meat derived from animals with clinical signs of PRRS (Canadian Food Inspection Agency, 2015). As a result, the presence of pig diseases could put Canadian exporters in a disadvantageous position, even though these diseases have no negative effects on human health.

Productions costs would not only increase in the herds affected by disease incidence, but also in disease-free herds in endemic areas through the increased costs of biosecurity. In general, the costs of animal diseases can be divided into two broad categories: (1) direct costs caused by reduced production/livestock population and changes in herd structure (Oxford Analytica, 2012); and (2) indirect costs from disease control and elimination efforts, losses in trade and other revenues, and limited use of improved production technologies (Knight-Jones and Rushton, 2013). At the 83rd General Session of the OIE in May 2015 the technical term "The Economics of Animal Health: Direct and Indirect Costs of Animal Disease Outbreaks" was confirmed (Rushton and Gilbert, 2016).

1.2.5.1 Direct Costs

Direct costs, as the name implies, are related to the production losses due directly to the disease outbreaks. Such direct losses include reductions in production and can further be separated into visible and invisible losses (Knight-Jones and Rushton, 2013). Visible losses include high mortality contributing to fewer pigs for sale as well as increased mobility resulting in reduced daily live weight gain and depressed feed conversion efficiency (Christianson and Joo, 1994; Escobar et al., 2006). Speaking of the invisible losses, they are caused by reduced fertility and changes in herd, which result in the need to have a larger proportion of breeding animals for a given output (Knight-Jones and Rushton, 2013; Oxford Analytica, 2012).

1.2.5.2 Indirect Costs

Alongside the direct costs, pig producers also need to absorb the associated indirect costs, which include the money spent on disease control and mitigation as well as losses in revenue (Oxford Analytica, 2012). To manage and eventually eradicate the diseases, pig producers have to pay more for medication (including vaccines), veterinary services, and surveillance activities. Increased labor costs owing to extra working hours can also be significant. These costs are generally classified as mitigation and control costs. In terms of losses in revenue, they are referred as the forgone revenues resulting from the denied access to important markets (for example, Russia, Australia, New Zealand and Mexico) (Canadian Food Inspection Agency, 2015; Canadian Food Inspection Agency, 2016).

1.2.6 Genomic Selection

Genomic selection was first proposed by Meuwissen et al (2001) and is based on information generated by a large number of polymorphic markers distributed across the genome in individuals without phenotypes. Although genomic selection enables the prediction of the genetic merit of animals using genome-wide SNP (single-nucleotide polymorphisms) and has already been adopted by some livestock species worldwide (Hayes et al., 2013), the introduction of genomic selection in pigs is still associated with some limitations that include:

> “(1) the high cost of genotyping, compared to the individual animal level; (2) the limitation on the amount of available phenotype data resulting from crossbreeding in pigs; (3) the short time available for the genetic evaluation (compared to dairy cattle); (4) the possibility to better control inbreeding; (5) the possibility to perform selection among full siblings; and (6) the overall implementation of the logistics aspects such as storage of DNA and other biological materials from the animals.” (Samorè and Fontanesi, 2016).

Due to the high costs and the challenges associated with the introduction and the implementation of genomic selection in pigs, it is imperative to know whether pig producers are willing to practice genomic technologies for traits such as disease resilience against PRRS, PCVAD, and PED or not before any policy recommendation or industry support is proposed. In addition, producers’ decision-making may also be related to their perceptions on the future availability, efficacy, and applicability of genomic technologies.

1.3 Economic Problem

Since the 1980s, the Canadian pig industry has been constantly changing and facing many challenges including the U.S. country of origin labelling (COOL) regulations, feed price spikes, and pig disease outbreaks. Although many empirical studies have been conducted to investigate how the livestock industry has involved and the causative factors behind the industry's structural change, there have been few studies that have looked at the role of animal disease(s) in an industry's transition. From an economic point of view, an examination of the impacts of disease outbreaks on the pig industry's structural adjustment is essential as global epidemics of porcine reproductive respiratory syndrome (PRRS), porcine circovirus associated disease (PCVAD), and porcine epidemic diarrhea (PED) appear to be increasing. As compared to the situations with no disease outbreaks, farm operators whose farms are affected by pig diseases might make very different operational decisions to better manage pig diseases and to enhance production efficiency. In the extreme case, the high extra costs incurred from disease outbreaks might force some pig farmers to exit the business.

Among the studies addressing the impacts of different economic factors on changes in farm structure, the vast majority of them conducted their analyses at a national level, which neglects the heterogeneities in structural change in different regions. Therefore, any one-size-fits-all policy resulting from economic analyses conducted at a national level might not benefit farm operators in some regions at all. In addition to the wide variations in structural change, the challenges faced by the Canadian pig farmers are also very heterogeneous in different parts of Canada. For example, the U.S. country-of-origin-labeling might have had especially significant impacts on pig operations in Ontario and Manitoba because of their stronger integration and the proximity of their pig farms to the border (Office of Audit and Evaluation, 2015). As a result, it is necessary to take the regional differences and spatial interactions of farmers into account. The different patterns of industry's structural change in different regions may be then explained by the relative importance of disease versus other economic pressures.

Given the variations in the economic pressures faced by pig producers and the different values held by them, producers might make quite different decisions in the presence of endemic diseases-decisions on whether or not applying preventive strategies including vaccination and strict biosecurity measures, expanding their herds, exiting the industry, etc. In the field of animal health management, many empirical studies have been conducted to analyze how different risk factors affect disease outbreaks and infections, the patterns of disease transmissions, and the efficiency of available disease management strategies (e.g., Lambert et al., 2012; Shi et al., 2013; Weerapong et al., 2014). However, few studies have been made to look at the determinants (including on-farm disease status) affecting farmers' operational decisions in respect to the usage of disease control and prevention strategies and the adaptation of their farm structures to combat diseases. Based on previous work, farm's physical and economic attributes, farmer's socio-demographics characteristics and their access to information, and farm disease status will undoubtedly have significant impacts on farmers' understanding of the issues and their adoption of disease control and prevention strategies (Heffernan et al., 2008; Toma et al., 2013). Therefore, it is necessary to understand which factors influence farmers' behavior to facilitate behavioral changes.

Disease outbreaks often result in government programs. Because PRRS and PCVAD are not reportable or immediately notifiable diseases in Canada, although some regional programs such as Area Regional Control and Elimination (ARC&E) projects are in place in some census divisions, there still exists a gap in who does what within the federal, provincial government and industry regarding the control and elimination of pig diseases (MacDougald, 2016). For PED, the disease is provincially regulated in the provinces of Alberta, Saskatchewan, Manitoba, Ontario, and Quebec. As aforementioned, there has been only one national program (i.e., the Control of Disease in the Hog Industry (CDHI)), which was initiated by Agriculture and Agri-Food Canada (AAFC) aiming to minimize the impact of PCVAD and to support activities related to biosecurity, research and long-term disease risk management solutions (Office of Audit and Evaluation, 2015). The program was wound up in 2015. Therefore, a better understanding of the role of pig diseases in farmers' production decisions and the sector's transitions would help pig producers to make better decisions in response to disease outbreaks. From a policy standpoint, it will also assist governments to understand how diseases and other economic challenges have affected pig producers and what they can do to encourage farmers' behavioral changes (i.e., the application of disease control and prevention strategies).

1.4 Research Objectives

The objectives of this study are:

1. To assess how pig diseases (PRRS, PCVAD and PED) have affected structural change in the Canadian pig industry at the individual census division level while controlling for the effect of other key economic explanatory variables (e.g., the U.S. country of origin labelling).
2. To explore the role of pig diseases at the farm operation level and identify the factors that impact or might impact pig producers' decisions on the adoption of various disease treatments.

1.5 Thesis Structure

The rest of this thesis is structured as follows. The following chapter is a literature review regarding the impacts of various economic factors on the pig industry's structural change and studies (including the methodologies used) that were conducted to investigate structural change in agriculture. The role of pig diseases in the industry's transition and producers' intentions with respect to disease management are also discussed. In Chapter 3, the dataset used to address the first objective of this research, the empirical methodology and results are presented. In Chapter 4, we focus on exploring the role of pig diseases in farm operations by identifying the determinants that affect pig farmers' actual uptake of various disease preventive measures, which is our secondary objective. In Chapter 5, the study is summarized with discussions of the results and key findings in the context of policy implications and suggestions for future studies.

Figures

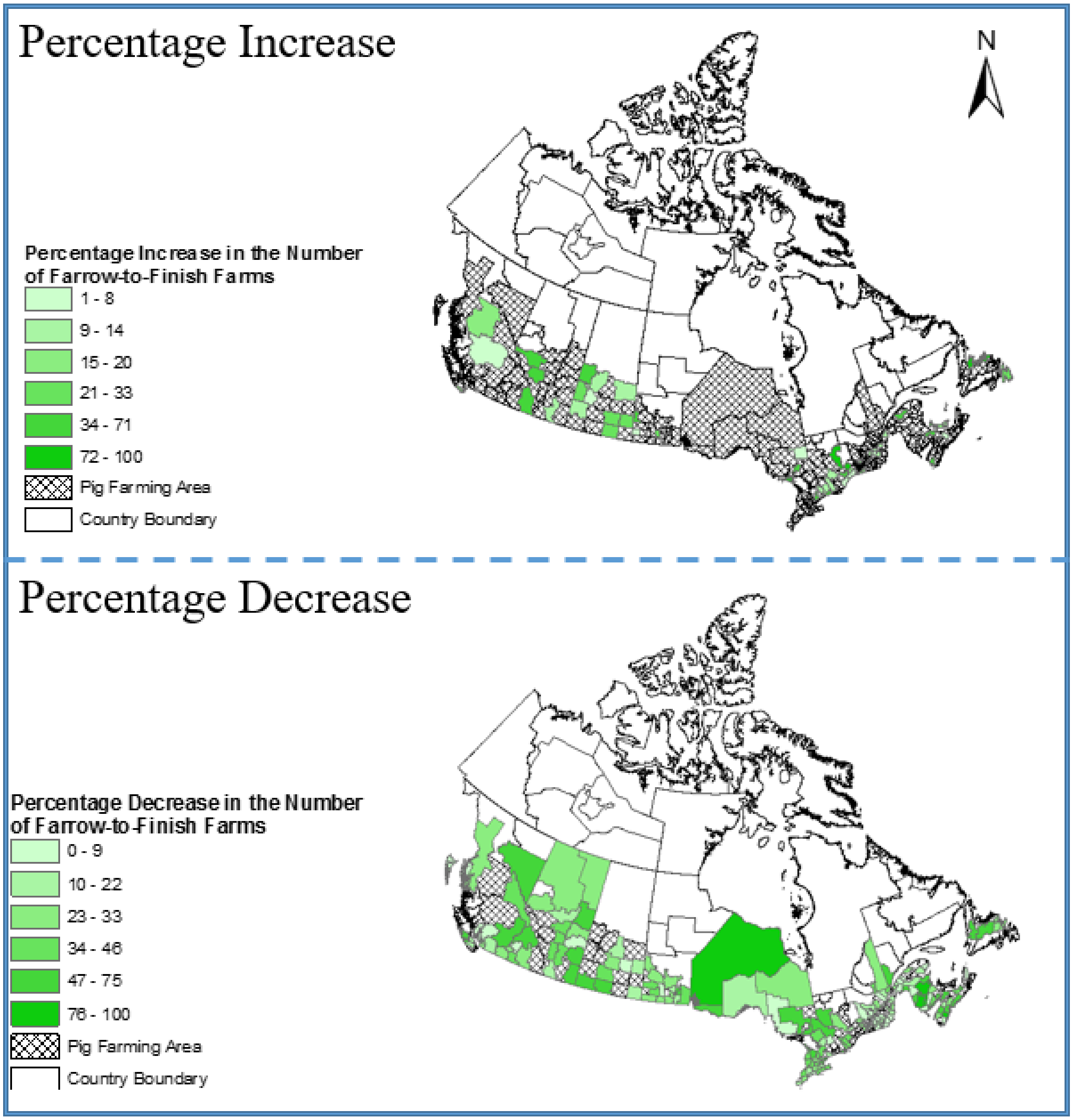

Figure 1.1. Percentage Change in the Number of Farrow-to-Finish Farms, Canada, by Census Division (CD), 1981-2016.

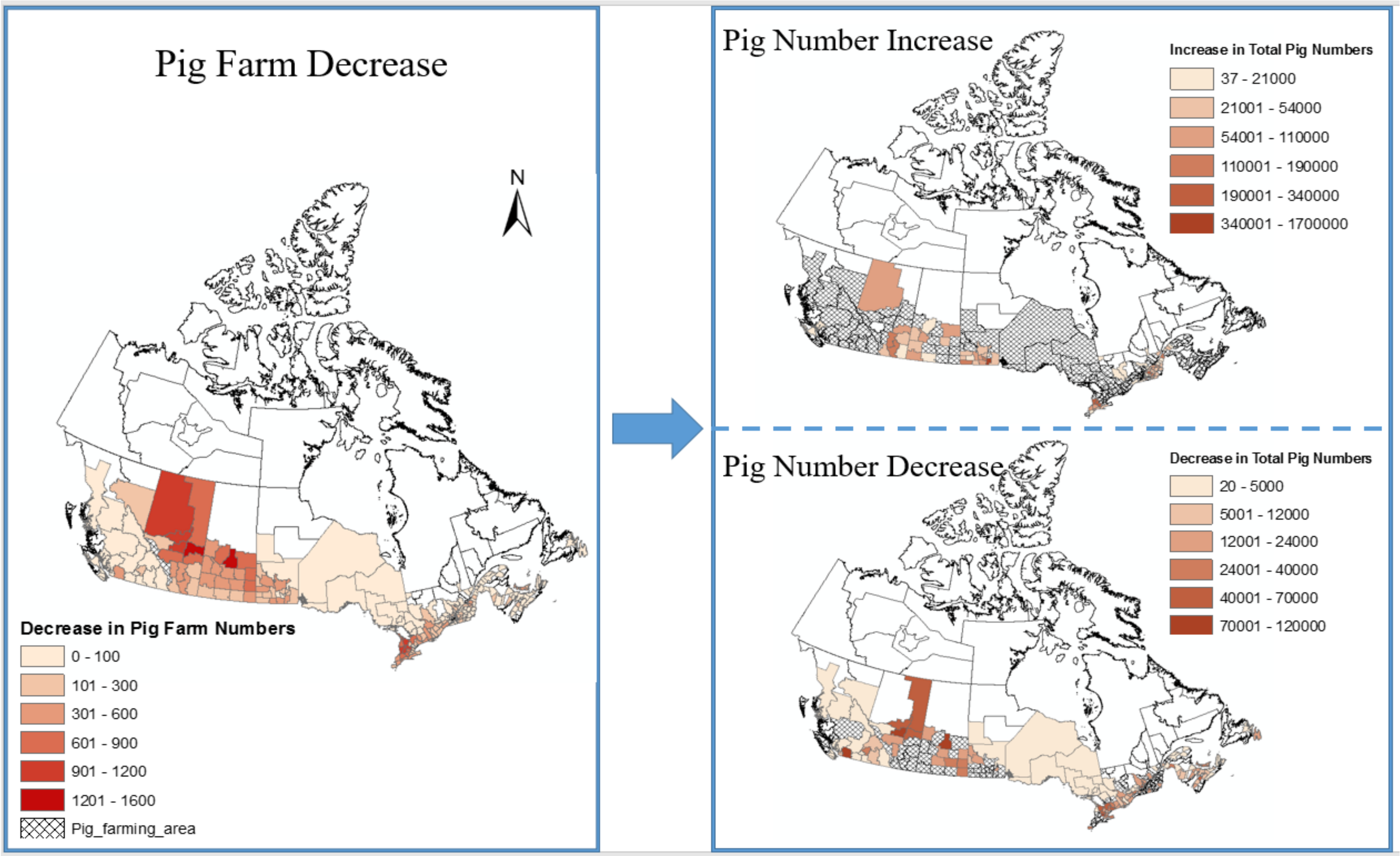

Figure 1.2. Regional Differences Regarding Simultaneous Pig farm decreases and total pig number changes, Canada, by CD, 1981-2016.

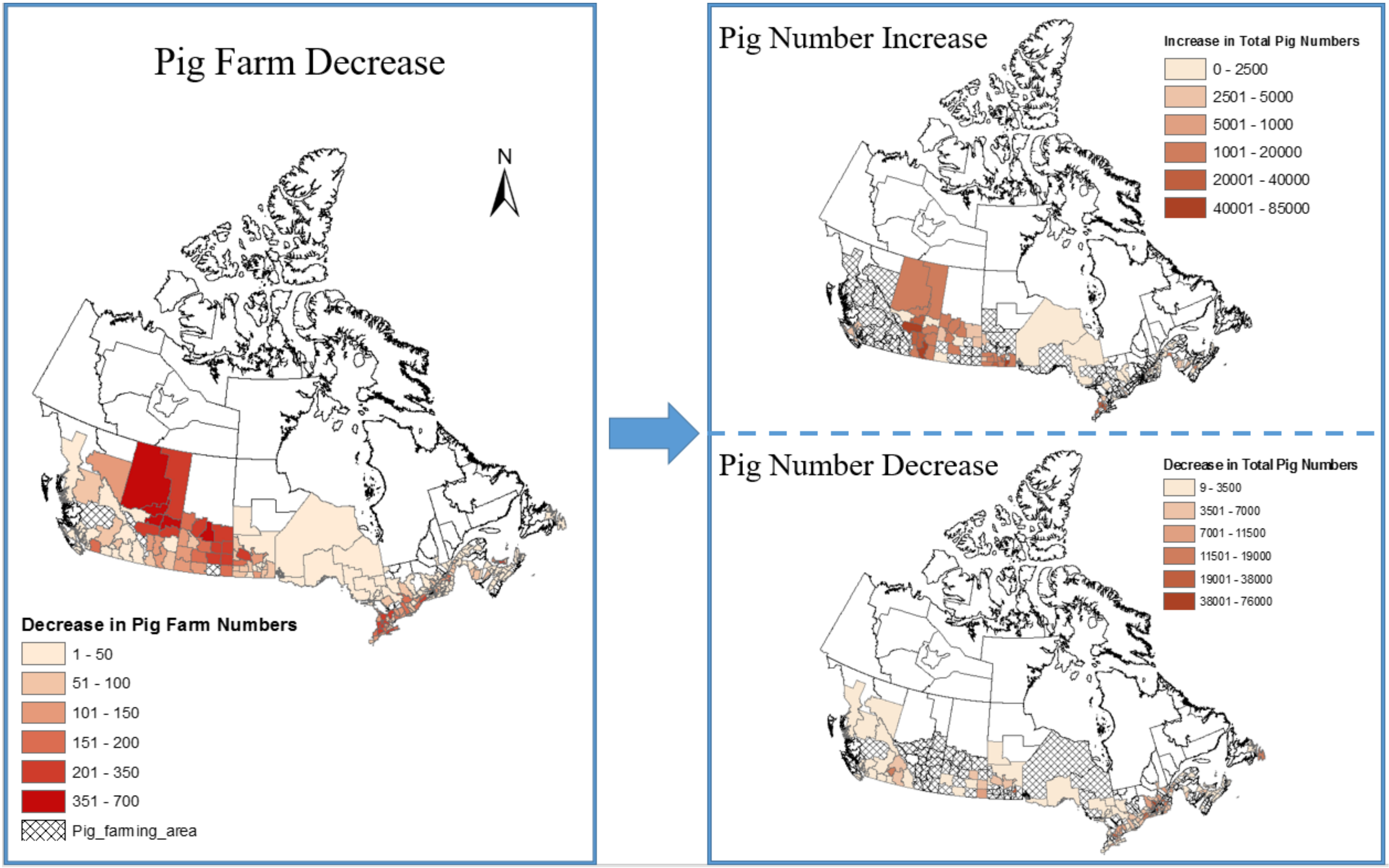

Figure 1.3. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 1981-1986.

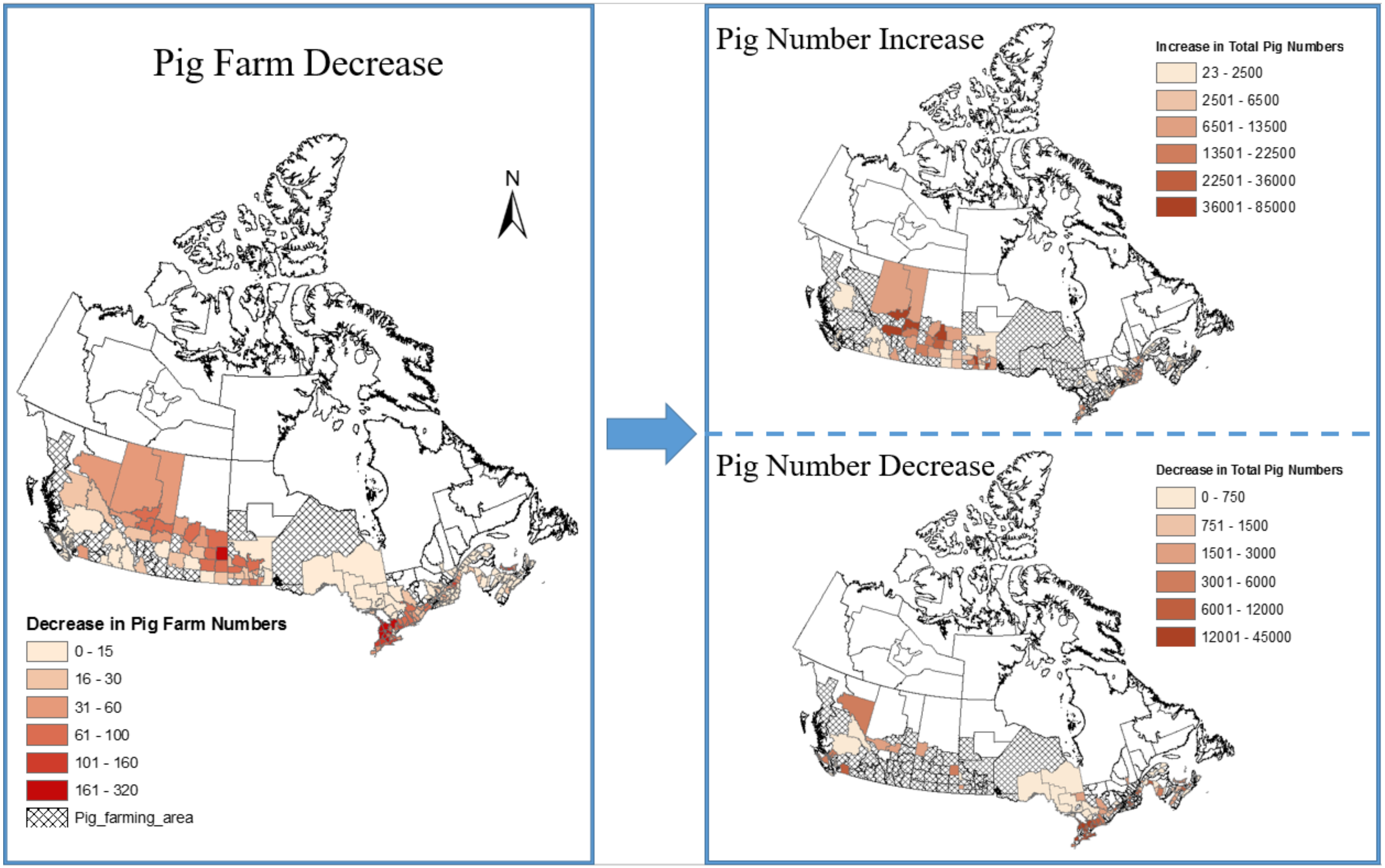

Figure 1.4. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 1986-1991.

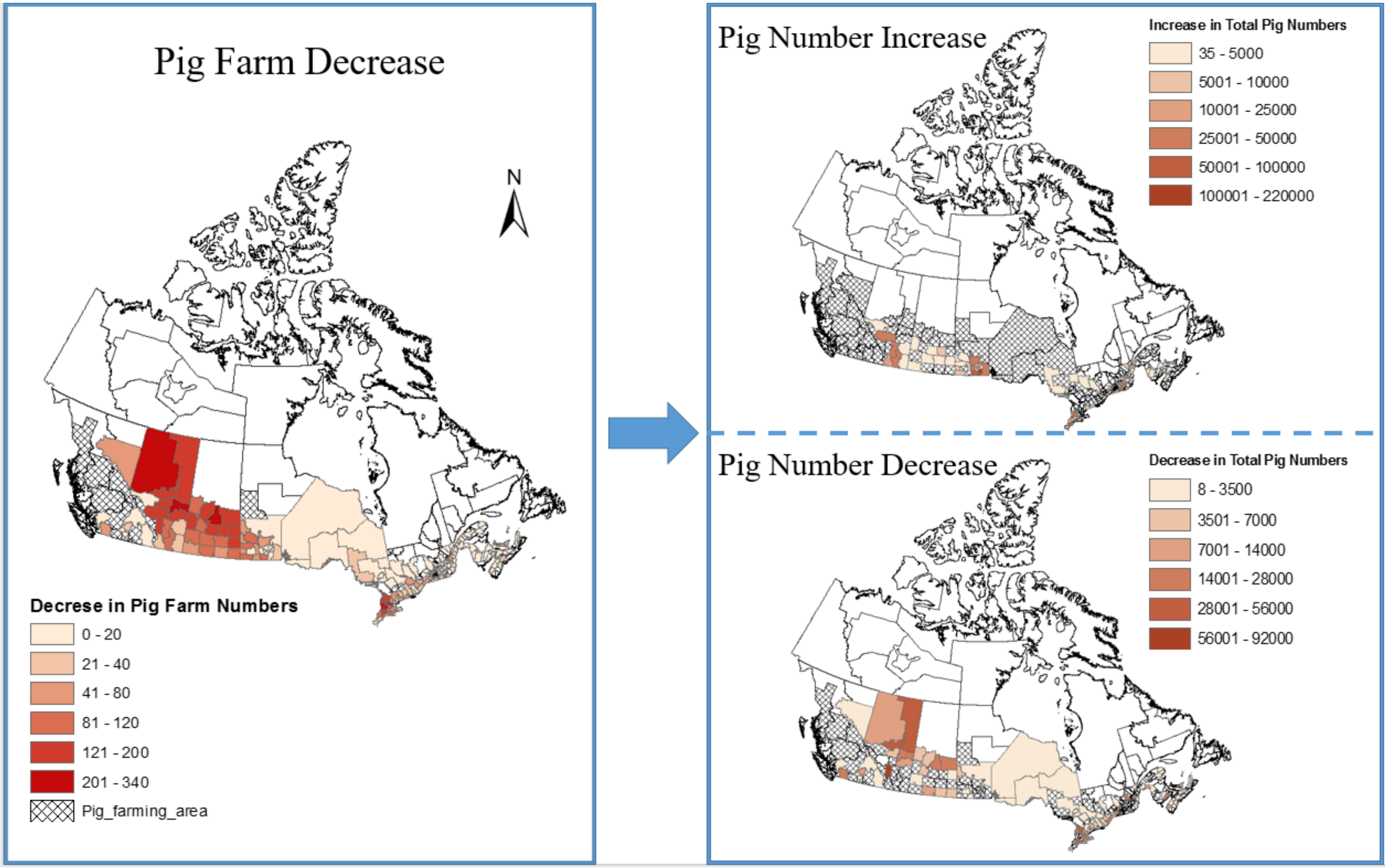

Figure 1.5. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 1991-1996.

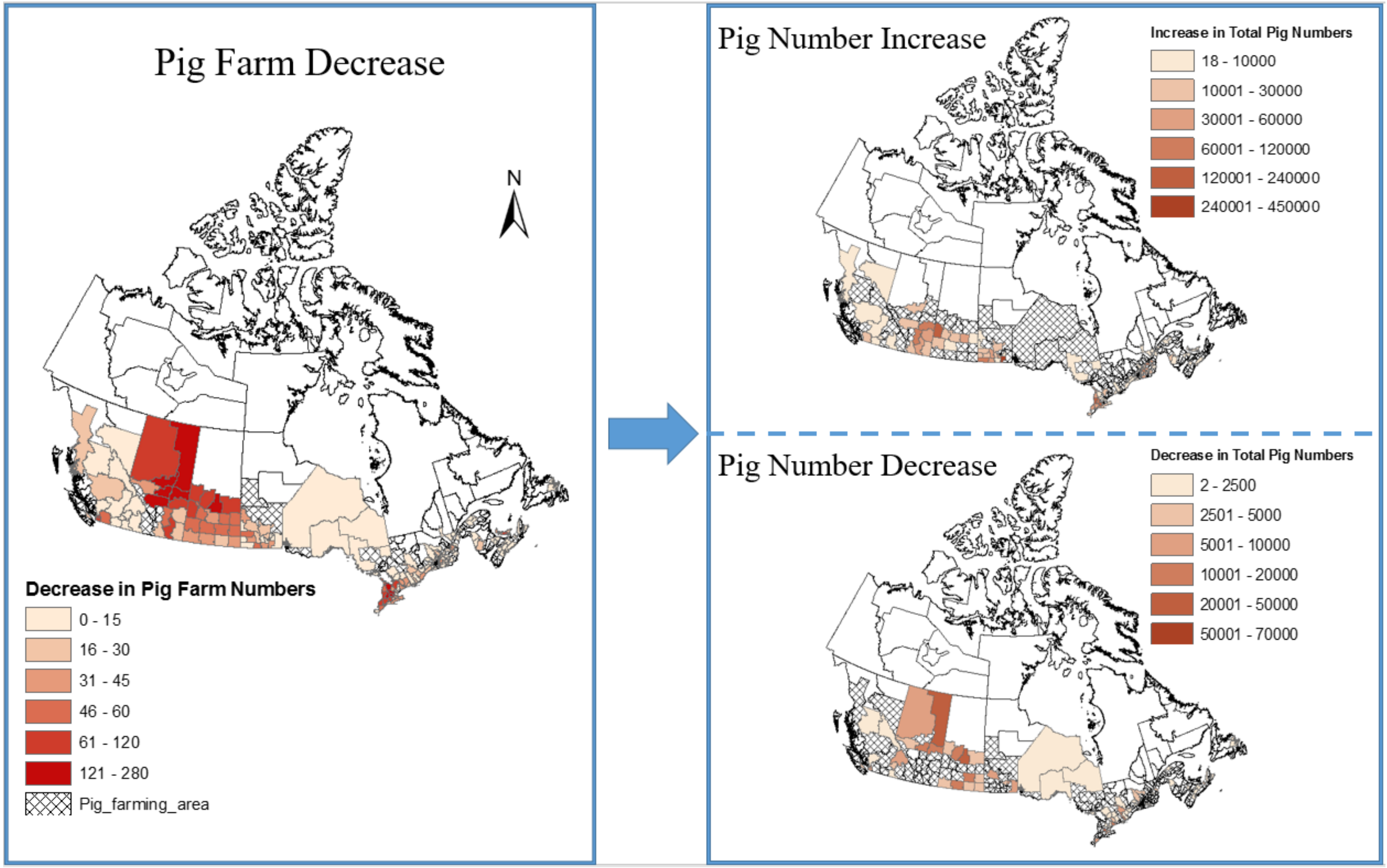

Figure 1.6. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 1996-2001.

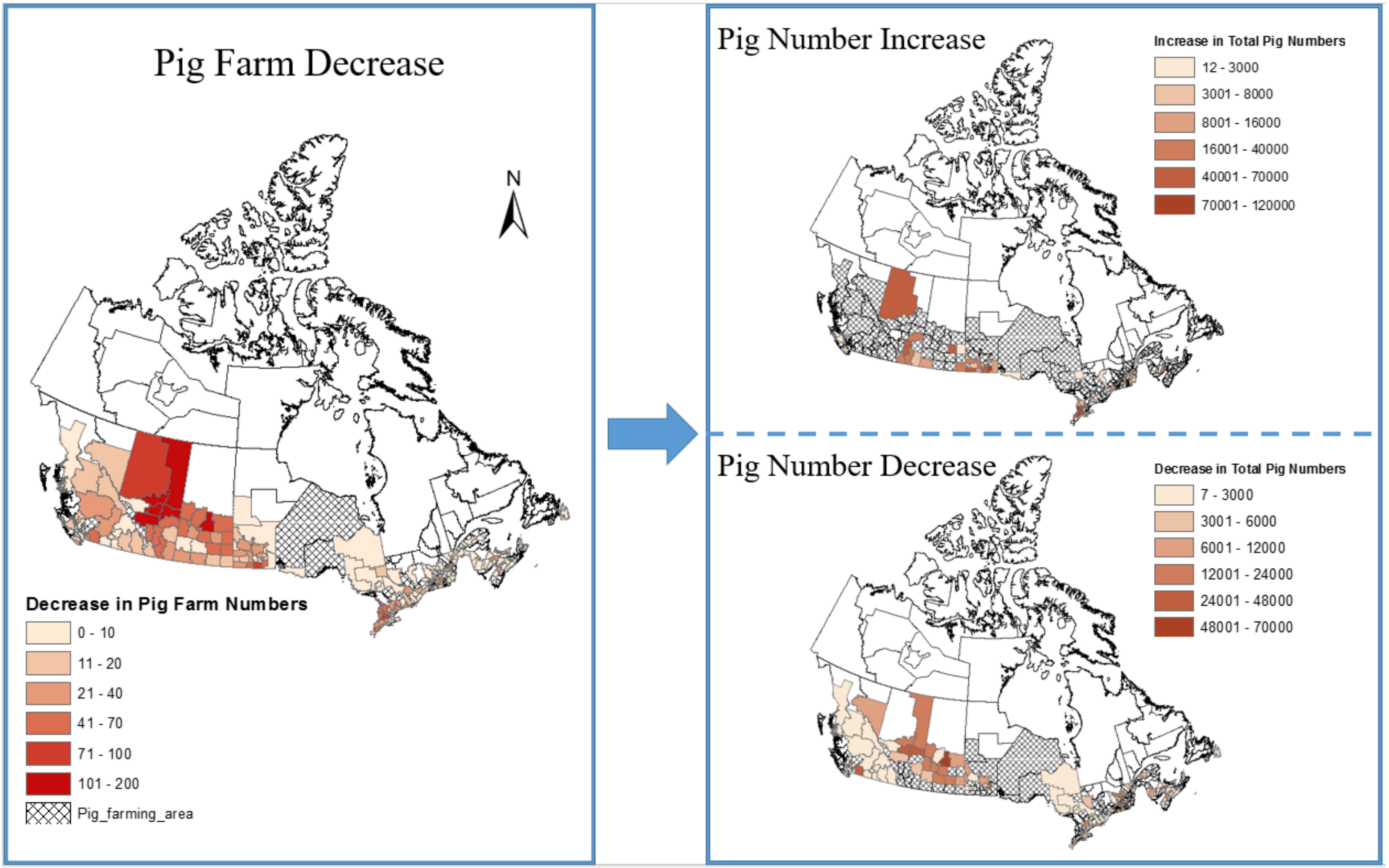

Figure 1.7. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 2001-2006.

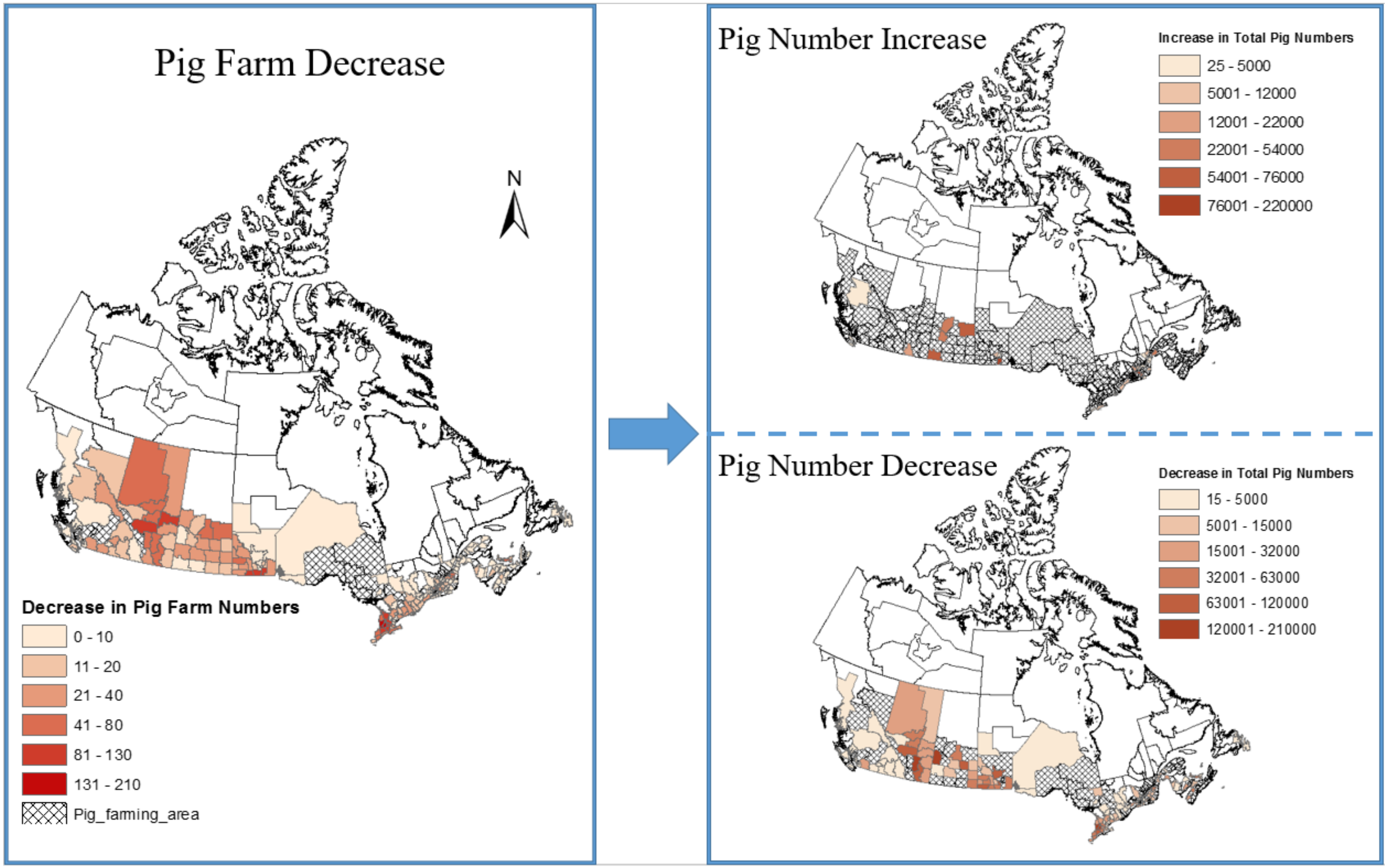

Figure 1.8. . Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 2006-2011.

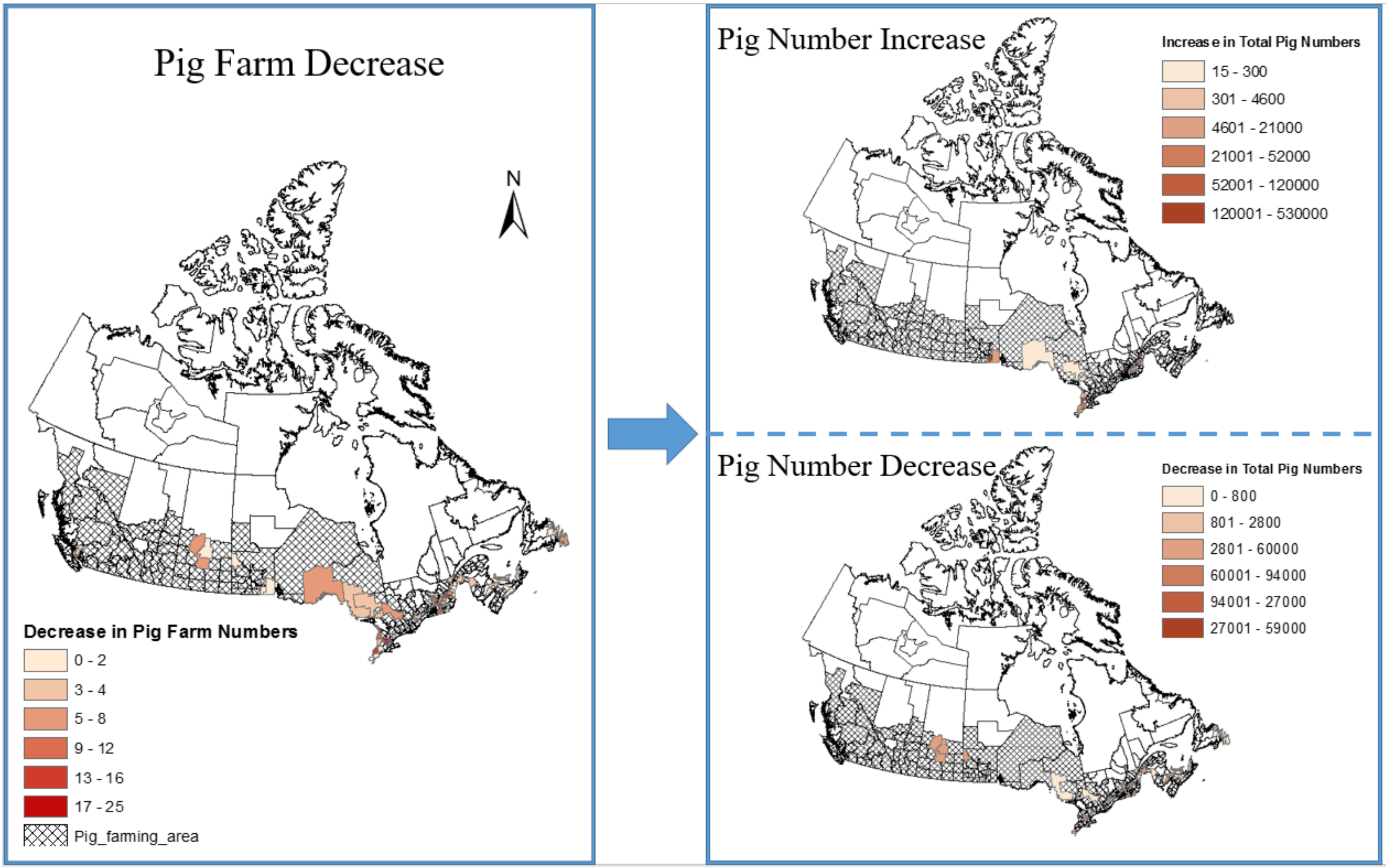

Figure 1.9. Regional differences regarding simultaneous pig farm decreases and total pig number changes, Canada, by CD, 2011-2016.

Chapter 2: Literature Review

2.1 Introduction

The objective of this research is to examine how the Canadian pig industry has evolved spatially with the presence of pig diseases and to foster an improved understanding of pig producers' decision-making process that led to the current farm structure. Since a multitude of economic factors may play a role in the pig industry's structural change, relevant determinants of the industry's transition are examined in this literature review. For the secondary objective, we are primarily interested in how pig farmers make operational decisions in reaction to disease outbreaks. Specifically, this chapter reviews the literature pertaining to producer theory on operational decision-making, the decisive factors affecting the industry's transitions, methodologies used to analyze structural change in agriculture, and the role of animal diseases in producer decisions.

2.1.1 Definition of Structural Change

As the primary objective of this study is to investigate the forces behind the Canadian pig industry's structural change, we should define the concept of structural change and its measures first. Structural change can be defined in many different ways as it consists of both organizational and institutional changes (Goddard et al., 1993). Among others, the most common definition refers to the long-term persistent change in the sectoral composition of the aggregate indicators for the economy (Syrquin, 2010). In the specific literature regarding structural change in agriculture, there are many alternatives to it and researchers often assess the changes in farm size, number of farms, ownership, asset values, technology use, and operating as well as marketing arrangements (Knutson et al., 1998; Welsh, 1996). Typically, most of the emphasis has been placed on analyzing changes in farm numbers and farm size (Ahearn et al., 2002; Ben Arfa et al., 2015; Stanton, 1993). This study examines the structural change in the Canadian pig industry from the standpoint of farm size changes, which reflects the expansion/shrinkage of total production as they respond to market forces and government policies (Huffman and Evenson, 2001). The structure of production then refers to the size of pig operations (i.e., average number of pig inventories per farm). In addition to farm size change, another farm structure change which occurred in Canada is that pig farms became more specialized with farmers moving away from farrow-to-finish operations to single-phase production, which further plays a role in farm size change as specialization allows mass production with lower per unit production costs and reduced disease outbreak cases. Reduced disease incidence is achieved as specialization helps stop pathogen transmission among pigs at different life stages, especially from the older pigs to the younger and more susceptible piglets.

2.1.2 Understanding Producer's Decision Making Process

To further facilitate the designing of effective policies and programs in response to pig disease outbreaks, the secondary objective of this study is to understand pig producer's intentions regarding disease management by identifying the factors that affect or might affect pig producers' decisions on the employment of various disease preventive measures. Resulting from the different values held by different pig farmers and the various determinants that influence their operational decisions, farmers would make very different choices in respect to farm practices, capital investment, operational scale and so on.

In the case of disease outbreaks, a livestock farmer’s behavior would likely be influenced by their financial situation, their knowledge about diseases and disease management tools, their views on the efficacy of the disease management strategies that are currently available, their previous experience of combating animal diseases, and the current on-farm disease status (Fountas et al., 2006; Garforth, 2015; Wolf, 2005). The social network surrounding farmers is also an influential factor as farmers often have conversations over how to operate their farms with some important others such as their neighbors and veterinarians. Given the diverse forces and their variations, it is therefore important to understand the different economic factors and the way they are handled in the producers’ decision-making process by regions. The aggregation of individual producer’s operational decisions facilitates the transition of the industry and lead the sector to the current state.

2.2 Economic Theory (Producer Theory)

In the field of agricultural economics, the traditional research paradigm with regard to producer decisions usually assumes an idealized decision situation in which farm operators know all of the alternatives as well as their consequences and probabilities, have fixed preferences and possess the cognitive capacity to efficiently process the alternatives (Daydé et al., 2014). When making production decisions, it is assumed that producers are maximizing their profits subject to the constraints of existing technologies and know-how. However, risks and/or uncertainties are always present in operational decisions in the actual marketplace. In agricultural production, sources of uncertainty consist of production uncertainty, price uncertainty, technological uncertainty, and policy uncertainty (Moschini and Hennessy, 2001), all of which make the decision environment of producers very complex. Instead of assuming farmers make decisions based on the principle of profit maximization, which fails to encompass producer's beliefs, attitudes and preferences that can influence their economic behaviors (Becker, 1993; Jongeneel and Ge, 2010), an increasing literature regarding producer behavior recognizes utility maximization as the more appropriate modelling framework (Jongeneel et al., 2008; Willock et al., 1999). In deciding how to change their farm structures (e.g., whether to expand or downsize their farm operations) and operating practices, farmers would compare the utilities derived from the alternatives.

Given the different demographic, cultural and socio-economic backgrounds within the farming population (Sovann and Sorn, 2002), pig producers might differ in the degree to which they perceive and estimate production risks in the event of disease occurrences (Borges and Machado, 2012). Differences in risk perceptions and financial situations faced by farmers would further lead to different operational decisions (e.g., different diseases treatment methods) and production systems. Moreover, these differences might amplify when we take geographic settings into consideration. For example, some farmers might expand their operations in response to pig disease outbreaks to spread out the additional costs incurred from disease prevention strategies. However, this was not applicable for pig farmers in the province of Manitoba (Canada) when the hog barn moratorium was in place over the period 2006 to 2015[1] (although industry expansion in the province was significant prior to that time) (Manitoba Agriculture, 2008; Manitoba Pork, 2015).

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[1] Hog barn moratorium in Manitoba was temporary over the period 2006 to 2008. It remained mandatory over the period 2008 to 2015.

2.3 Forces Driving Structural Change

Structural change in a livestock industry, or agriculture in general, is the adjustment of the sector to multiple changing factors that have impacts on farm operations. Understanding the trends of the industry's structural change and the forces behind the sector's structural change might be useful to policymakers who are interested in the development process. This section endeavors to provide a comprehensive overview of how individual pig producer makes operational decisions in face of different economic pressures. The purpose of listing the causative factors is to identify and analyze how they might be associated with structural change in agricultural production. According to this literature, these factors can be divided into internal and external determinants that would lead to different producer decisions on farm operations (Figure 2.1), which finally drive the sector to the current state. Internal factors are those pertaining to the characteristics of farms (e.g., farm type and land tenure) and farmers (e.g., demographic characteristics), while external factors refer to the situation in which pig farming occurs. This conceptual framework was adapted from various studies examining the decisive factors for structural change in agriculture (Breustedt and Glauben, 2007; Chilonda and Van Huylenbroeck, 2001; Happe et al., 2011; Zimmermann et al., 2009).

2.3.1 Internal Factors

2.3.1.1 Farm characteristics

1) *Land tenure arrangements.* Land tenure, indicating the extent of ownership and control of farmland, has long been considered as a factor influencing the industry's transitions (Daloğlu et al., 2014; Key and Roberts, 2003). Generally, tenure arrangements can be divided into full-owner, part-owner and non-operator types: full-owners own all of the farmland; part-owners

own a portion of the farmland and rent the rest from others (including government); while non-operators do not carry any farm operations but rent out all of their farmland (Daloğlu et al., 2014). Different types of owners will take different stands when they make operational decisions. For example, some studies suggested farmers may expand their operations by renting additional land or may alternatively downsize farm sizes by renting their land to others (e.g., Gallacher, 2010). Another set of studies found operators who owned all their land expanded their operations more than those that owned only a share of their land (e.g., Key and Roberts, 2003).

2) *Farm numbers within a region.* Number of farms within a region is often incorporated to investigate the persistence of the industry's adjustment behavior (Glauben et al., 2006). In general, farm numbers would contribute to the industry's transition in two different directions. On one hand, large farms could be more efficient on a unit cost of production basis. As the number of farms decreases, farm size might increase to realize scale economies, which refer to the ability of a farm to lower costs of production by increasing production (Duffy, 2009). On the other hand, some farm operators (especially small business holders) might choose to have smaller farms to meet the needs of high-priced niche market (Maynard and Nault, 2005) and to compete against the larger operators who are able to achieve economies of scale.
3) *Farm production type.* The common pig production/herd types in Canada include farrow-to-finish, farrow-to-wean, farrow-to-grower, gilts only, nursery only, finisher only, and nursery-to-finish. Over time, pig farms have moved away from the traditional farrow-to-finish operations and pig production has become more intensive and specialized (Brisson, 2015). Given that specialization can lead to economies of scale with increased output and lower per

unit production cost, farms with single-phase production tend to be bigger, and on the contrary, farrow-to-finish farms would be more likely to become smaller. Another reason for farrow-to-finish operations tending to be smaller is they have a higher risk of being infected with pig diseases (Young et al., 2010), and the high mortality rate resulting from disease outbreaks leads to smaller farm size.

4) *Human population density.* Rapid human population growth has raised considerable concerns over its negative impacts on farm operations. Farmlands in more population-dense areas are usually subject to competition for alternative uses. Population density is thus often used as a proxy of competition between civil and agricultural uses of the land. Due to the scarce farmland resources and the higher opportunity costs of land use in more population-dense regions, increases in population density are more likely to be associated with reduced farm size (Goetz and Debertin, 2001; Ricker-Gilbert et al., 2014).
5) *Availability of slaughter plants.* Measured by farm distance to the nearest slaughter plant, the location and/or availability of slaughter plants is an important determinant of farm structures. Generally speaking, farmers tend to benefit from buyer competition in their localities, and they are more likely to have larger herds resulting from the lower transportation costs and higher profitability. However, as the slaughter plants becoming less available and the transportation costs becoming higher, farmers might choose to downsize their farming operations or even exit.
6) *Family farm*[2]. Farm structure can also be affected by the farm's operational arrangements (family farm in our case). One contributor to this impact is the availability of successors. The family farm sector is found to be highly related to intergenerational succession (Pesquin et

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[2] Family farm is defined as an operation where an individual or members of a family owns the majority of the corporation shares (Statistic Canada, 2014). Available at: https://www.statcan.gc.ca/ca-ra2006/gloss-eng.htm .

al., 1999), and Gale (1994) pointed out succession played an important role in the determination of farm structures. When a successor was present, the operators would have an incentive to expand their farms for the next generations (Chilonda and Van Huylenbroeck, 2001). Thus, a relationship between being family farm and the structure of farm might exist. Another contributor is the improved labor-saving technologies. Labor-saving technologies have helped reduce the labor-to-capital ratio greatly. When a family farm is not able or willing to lay off members, they are somewhat forced to purchase or rent more land to expand production. Such a situation is particularly relevant to pig farmers in Hutterite colonies in Canada.

2.3.1.2 Farm characteristics

1) *Farmer age.* The impact of a farm operators' age on farm structure is ambiguous and can be summarized by two sets of literature. One set of literature suggested younger farmers tended to be more business focused and were more likely to pursue long-term goals and to expand their production (Kim et al., 2005). Another set of studies claimed farmer's age was positively related to the size of the farm (e.g., Sumner and Leiby, 1987) because age was usually associated with lower effective interest rates. According to this set of literature, older farms are less risky and older farm operators tend to have more wealth. Therefore, the lower costs of borrowing would encourage older farmers to have larger farm sizes.
2) *Farmer gender*. Operator's gender can also be included as a contributor to the sector's structural change. In agricultural production, male and female farm operators would make different operational decisions as they have different tendencies of risk taking. An overwhelming number of studies have suggested men are more inclined to take risks than

women are (Byrnes et al., 1999; Harris et al., 2006). For studies looking at the agricultural sector, Weiss (1999) reported if the operator was female, this had a negative impact on farm survival and farm growth. Akimowicz et al (2013) found men tended to run larger farms in southwestern France. All else being equal, Ferjani et al (2015) found farms operated by a woman were more likely to exit than farms operated by a man.

3) *Off-farm work status.* The operator's off-farm work status is often associated with changes in farm structure. When farm operators spend more time working off-farm, they would have less time available for working on the farm (Ahearn et al., 2002), and these part-time farmers tended not to expand their productions as labor may not be perfectly mobile. Key and Roberts (2003) confirmed this tendency with the finding that operators who farmed as a primary occupation increased the size of their operation 8-20% more than did operators for whom farming was not their primary occupation. However, many researchers claimed that off-farm income has a stabilizing impact on structural change in agriculture as it could serve as a stabilizer for the farm-income volatility (Glauben et al., 2006; Goetz and Debertin, 2001; Mishra and Goodwin, 1997). It is thus possible for farmers to use off-farm income to expand their farm operations. In the Canadian context, Kimhi (2000) found farmers' exit probability decreased with off-farm work.
4) *Operators living on farm.* Having a variable showing whether the operators live on farm or not is a proxy of farm distance, which is also a causative factor of structural change. If farm operators do not live on farm, they typically have higher transportation costs, as compared to those that live on farm. The farther a farmer has to travel to reach the farm, the greater the cost. Therefore, for farmers who do not live on their operations, they might be less likely to

expand their production, as they have to travel long distances and absorb higher transportation costs.

2.3.2 External Factors

2.3.2.1 Market Conditions

The profitability of farming, usually measured by output and/or input prices, output-input price ratio or net farm income, has been documented by many researchers as one of the causes of structural change in agriculture (e.g., Breusted and Glauben, 2007, Dolev and Kimni, 2010). Because prices play a central role in production decisions (Tomek and Kaiser, 2014), farm operators have been shown to be very responsive to the changing output and input prices by adjusting the size of their operations (i.e., the quantity supplied of outputs). For example, Evenson and Huffman (1997) found farmers would expand production in reaction to a decrease in input price.

2.3.2.2 Institutional Factors

The institutional setting in which livestock farmers operate encompasses government investments as well as interventions in the sector and the organization of agricultural extension system (including farmers' access to information sources, veterinary and extension services) (Chilonda and Van Huylenbroeck, 2001). Among other institutional drivers, the impact of government programs on structural change in agriculture has drawn considerable research interests (e.g., Ahearn et al., 2005; Kersting et al., 2013; Kirchweger and Kantelfardt, 2015). For domestic programs taking the form of government payments, several empirical studies found high subsidy payments slowed down structural change in agriculture because they led to increased profitability that discouraged farmers from exiting or leaving from their status quo (e.g., Breustedt and Glauben, 2007). In contrast, Barkley (1990) suggested government payments did not necessarily lead to changes in farm structures. He argued the multifaceted effects of government payments may offset and eventually have no impacts on farm structures at all. Key and Roberts (2003) found government payments were weakly associated with structural change in agriculture, which is measured by changes in farm size. In addition to domestic policies, foreign policies implemented by important trading partners would also have influences on the domestic farm operations. For example, Rude et al (2016) found evidence showing the mandatory country of origin labeling in the U.S. had significantly affected U.S./Canada hog trade flows.

For the organization of agricultural extension system, it is indeed related to farmers' access to know-how and the availability of consulting services and veterinary personnel. The institutional environment in which the farmers operate is an important decision variable as it sets the transaction costs and affects the availability and the quality of the services (Chilonda and Van Huylenbroeck, 2001). For example, Ahearn et al (2002) detected a positive relationship between extension and farm size. Gallacher (2010) also detected farm size is correlated to access to information-providers. Mburu et al (2014) found most farmers were not accessing extension services and knew less about the available information technology mainly due to the unavailability of extensions. Thus, farmers located far away from these extension sources tend to be limited in their production decision choices. In our study, farm distance to agricultural universities and veterinary institutions that provides extension services for pig farmers is used as the proxy of service availability.

2.3.2.3 Biophysical Factors

Biophysical factors consist of disease incidence itself and the factors that determine their occurrences (e.g., weather) (Putt et al., 1987). For animal diseases themselves, their occurrences would negatively affect farm production and incur extra costs for disease management and prevention. When diseases are present, farm operators need to adjust their farm structure to control the spread of disease and to absorb the additional production costs. For the determinants of disease occurrences, they could be intrinsic and extrinsic. Chilonda and Van Huylenbroeck (2001) summarized the intrinsic determinants including the physical and physiological characteristics of the host animal (e.g., breed, age and sex susceptibilities) or disease agent (e.g., virulence, method of transmission). Extrinsic determinants involve environmental causes of disease and climate factors such as temperature and rainfall. For example, porcine reproductive and respiratory syndrome virus (PRRSV) survival is optimal when temperature is cold and when ultra-violet light exposure is low (Albina, 1997). In addition to weather’s impacts on diseases occurrences, environmental factors also play a significant role in production systems as extreme weather would affect feed availability, logistics and level of production (Thornton et al., 2014).

2.3.2.4 Technology

Another determinant that have been suggested by many empirical studies as an explanatory factor for structural change is technological innovations (Bustos et al., 2016; Eastwood et al., 2010; Goddard et al., 1993; Stokes, 2006). New production technologies, either in mechanical or biological nature, have been pushing considerable changes upon agriculture, because they help farm operators realize scale economies with increased output and significant decreases in per unit production costs (Chavas, 2001). This scale increasing effect facilitates structural transformation in agriculture characterized by increasing farm size and declining farm numbers (Reimund et al., 1981). Various studies have confirmed this positive relationship between farm size and technology improvement (Chand et al., 2011; Sheng et al., 2015). Information and communication technologies (including marketing), on the other hand, allow farmers to obtain new knowledge quickly and facilitate communications between farmers and some important others (Chilonda and Van Huylenbroeck, 2001). Because these technologies would be relatively fixed in prices (Duffy, 2009), the adoption of information and communication technologies might encourage farmers to have larger farms as the more units of production, the lower the costs per unit.

2.4 Studies on Structural Change in Agriculture

Structural change in agriculture has long been the focus of agricultural economics literature to address the impacts of different economic factors such as agricultural policies on changes in farm structure and/or the use of productive factors. Because structural change can be defined in different ways (e.g., organizational changes, institutional changes), a broad range of methods has been applied to examine the forces behind an industry's structural change and to predict the trends of structural change in the future. For the purpose of the present study, we restrict our attention to the studies that define structural change as farm number and farm size changes. Of all relevant empirical methodologies used, they can be categorized into three methodological approaches: 1) Simulation models; 2) Markov models; and 3) Econometric models. The criterion for selecting the method are its suitability for data type and the model's explanatory power.

2.4.1 Simulation Models

The first methodological category is simulation models, which aim to investigate the ex ante impacts of some economic factors such as policy changes on the industry's structural change by simulating farm size changes under different factor conditions (e.g., Viaggi et al., 2011). Within the category of simulation models, they can be further grouped into linear or non-linear models, static or dynamic models, and multi-agent models (Gardebroek and Qude Lansink, 2008; Happe et al., 2008). Recently, multi-agent modelling approach has received increasing research interests and been applied in various agricultural settings because of its ability to understand the complicated spatial and dynamic process of farm structure changes (e.g., Berger, 2001).

Compared with other statistical approaches applied to structural change analysis, the multi-agent model has the potential to account for heterogeneity and interaction between agents (Happe, 2004). However, this advantage also induces increased complexity given the requirement of individual farm accountancy data, which is very limited due to the data protection rules in many organizations (Zimmermann et al., 2009).

2.4.2 Markov Models

The second category of the empirical methodologies is Markov models, which try to retrieve the specific patterns of structural change from historical experiences and to predict future adjustments by estimating the probability of farm movement from one state (transition probability) to another over time (Ben Arfa et al., 2015; Gillespie and Fulton, 2001; Piet, 2010; Piet, 2011; Zimmermann et al., 2009). Under this set of models, structural change is defined as the change of farm numbers in different class sizes (Adelman, 1958; Piet, 2008). Early applications of Markov models are stationary ones, which assume transitional probabilities did not change over time (Stanton and Kettunen, 1967; Tonini and Jongeneel, 2009). However, test results demonstrated that stationarity did not accurately reflect reality in many cases (Ben Arfa et al., 2015). To address this issue, non-stationary Markov models were developed to allow for the presence of non-stationarity by accounting for the influence of changes in exogenous variables (Huettel and Jongeneel, 2011; Stavins and Stanton, 1980). When comparing the explanatory power of these two types of models, many researchers found the non-stationary models performed much better in predicting than the stationary ones (e.g., Karantininis, 2002; Von Massow et al., 1992).

In comparison to other modelling approaches, a major advantage of a Markov model is its ability to jointly investigate farm size changes and farm exits, whilst taking the interrelation between farm-size classes into consideration (Huettel and Margarian, 2009). The major disadvantage is that Markov models usually impose restrictions on the movement of farms between states. For example, Krenz (1964) imposes a “rule-of-thumb” method, according to which, farms in the largest category would not change category, farm number increases in any category come from the next smallest state, and decreases in size are not allowed. Such an assumption is too restrictive as it is quite possible that farms can move by more than one category or experience a decrease in size (Karantininis, 2002).

2.4.3 Econometric Models

A large share of the literature falls within the third category, econometric methodologies, which are used to assess the factors that actually affect changes in farm structures, and such approaches can be carried out using either panel, time series, or cross section data (Ahearn et al., 2005; Chenery and Syrquin, 1975; Goetz and Debertin, 2001; Rahelizatovo and Gillespie, 1999). Another reason that econometric framework is preferred by researchers to deal with the analysis of farm structural changes is it allows some sort of statistical validation of the results (Landi et al., 2016).

Among various econometric methods, a panel regression model is the most commonly used one for the analysis of farm size adjustments (Ahearn et al., 2005). For example, Key and Roberts (2003) estimated a panel regression model to explain the relationship between government payments and farm size changes and farm survival. Foltz (2004) investigated the forces behind changes in dairy farm size by estimating a random effects generalized least squares (GLS) model. Aside from farm size changes, there also exist many empirical studies which concern the determinants of farm entry/exit and farm succession with the adoption of ordinary least squares and discrete choice models (e.g., Goodwin and Mishra, 2005; Lobley and Butler, 2010).

As aforementioned, the availability of data would affect model choice. When analyzing the structural change in agriculture, data are analyzed either at individual farm level (e.g., Hoppe and Korbe, 2006) or at an aggregate level (i.e., area or country level) (e.g., Goetz and Debertin, 2001). Because our research aims to specify a model to analyze the actual structural changes across time and census data are only available at the census division level, we will employ panel regression models to examine the impacts of pig disease incidence, farm and farmer characteristics, and social proximity while accounting for the regional specificity of structural change.

2.5 Producer Decision Making Process with Regards to the Application of Disease Preventive Measures

Porcine reproductive respiratory syndrome (PRRS), porcine circovirus associated disease (PCVAD), and porcine epidemic diarrhea (PED) have been continually plaguing Canadian producers since their first discoveries in the early 1990's. When diseases were introduced to the country or the regions where pig producers farm, farmers would need to make various operational decisions that are either ex ante or ex post to disease occurrences in order to prevent disease introduction or control their spread and reintroduction. These management decisions are usually made based on farmers attitudes toward: 1) maximizing the efficiency of disease management practices; and 2) minimizing the costs associated with these diseases and their control. Farmers' final decisions on measure adoption would be ambiguous as farmers would consider both aspects and weigh the importance of efficiency and costs. For example, herd size is often considered to be a risk factor for many pig diseases (Holtkamp et al., 2010; Murtaugh et al., 2010). On one hand, larger pig farms are usually more inclined to be infected with diseases since they use more sources of materials such as gilts and semen, hire more workers, and have higher pig densities. On the other hand, larger farms tend to have better biosecurity measures to prevent pathogen introduction and are more likely to take advantage of veterinary services, because the costs per unit are much lower than for small herds (De Haan and Umali, 1992). As a result, farmers might need to make operational decisions by balancing the efficacy of the adopted management practices and the associated economic costs.

The secondary objective of this research is to determine how various factors might affect pig farmers' decisions on the employment of certain farm operating strategies that would help to control and prevent pig diseases. This section reviews the literature on farmer decision-making in relation to the application of disease preventive measures and makes general statements on how different factors might affect farmers' decisions on the uptake of disease control and prevention strategies.

2.5.1 The Role of Pig Diseases in Producer Decision Making Process

2.5.1.1 Maximizing the Efficiency of Disease Management Practices

To maximize the efficiency of disease management practices, farm operators endeavor to control and prevent pig diseases through: 1) minimizing the number of pathogens to pigs; and 2) interrupting the natural build-up of pathogens within the pig's environment. Practices that have the potential to minimize the number of pathogens to pigs include segregated and medicated early weaning, boar testing, antibiotics, management changing practices, and regional elimination programs. In addition to these practices, special attention needs to be paid for the maintenance of acceptable on-farm pig density and the compliance of animal transportation protocols, which also have the potential to influence pathogen introduction. For practices that are able to block the natural build-up of pathogens within the pig's environment, they include vaccination, sow herd stabilization, serotherapy, depopulation-repopulation, nursey depopulation, all-in-all-out, test and removal, herd closure and rollover. Moving away from the traditional farrow-to-finish operations is also a practice that blocks the natural build-up of pathogens. Detailed descriptions of these disease control and prevention strategies would be provided in Chapter 4 (Please see section 4.3).

2.5.1.2 Minimizing the Costs of Diseases and Their Control

The total economic costs of animal diseases take two forms. They include not only output losses following disease outbreaks, but also expenditures made to treat diseases or prevent their occurrence and/or reoccurrence (McInerney et al., 1992). According to McInerney (1996), output losses result from: 1) destruction of the basic resource (mortality of animals), 2) lowering of the efficiency of the production process and the productivity of the applied resources (reduced rates of growth or feed conversion), and 3) reduction of the product's unit value (quality). For the expenditures made on disease control and prevention strategies, they include: 1) additional costs in the production system (costs from changes in management systems such as diet changing); 2) disease treatment and eradication costs (costs from veterinary services, ex post use of resources to restore animal performance and to eradicate diseases); and 3) disease prevention costs (costs from ex ante use of resource such as vaccination and biosecurity measures) (see Chilonda and Van Huylenbroeck, 2001). Because of the increased operating costs, farmers might endeavor to adjust the sizes of their operations to minimize per unit costs of production.

2.5.2 Other Economic Factors Affecting the Producer Decision-Making Process

2.5.2.1 Internal Factors

For farm characteristics, the financial situation and the physical characteristics of the farms will significantly affect what measures the farms can use depending on cost and applicability (e.g., insufficient space to implement the strategies). Farm size is also documented as a factor influencing the adoption of farm management practices. Because larger farms are able to spread the costs over more units of production, they are expected to adopt more disease treatments (Kim et al., 2005). Other farm characteristics include farm type (e.g., farrow-to-finish) and labor usage (Siekkinen et al., 2012; Susilowati et al., 2013).

Speaking of farmer characteristics, findings from the literature suggest age, gender, level of education, experience, lifestyle attitudes, and values held by farm operators have played a significant role in animal health management (Blackstock et al., 2010; Fairweather and Keating, 1994; Small et al., 2005). For example, Tuyttens et al (2008) found older farmers with no successors were more likely to stay at the status quo with no additional disease prevention strategies. Curry (1992) reported knowledge and attitudes of farmers had impacts on their decisions with regard to animal health management. Tambi et al (1999) and Austin et al (2001) also detected similar results showing more education and experience seemed to encourage farmers to make changes in management practices.

2.5.2.2 External Factors

Institutional factors concern farmers' access to information on animal health issues and the availability of extension services and veterinary personnel. A vast amount of studies has demonstrated that farmers are more likely make management changes when they are offered information and instructions by trusted institutions and advisors such as veterinarians (e.g., Blackstock et al., 2010; Mills et al., 2006). On-farm disease status, on the other hand, will also largely affect farmer behavior. When diseases are present in the premises, farmers would be more likely to implement extra disease control and prevention strategies (Delabbio, 2004; Lindberg et al., 2006). The introduction of new technologies, training and implementation demonstration should be provided as several studies found these would increase the level of adoption (e.g., Braun et al., 2006). Market conditions are related to the prices of the disease treatments. Producers are price sensitive, they might implement more disease management strategies if these strategies are offered at lower prices.

2.6 Conclusion

In Canada, the pig industry has experienced significant structural change over the past four decades. As outlined by the conceptual framework described in section 2.3, there exist various determinants influencing the industry's structural change. Due to the significant economic losses from disease outbreaks, our first objective is to assess how pig diseases have affected the industry's transition in different parts of Canada while controlling for the effect of other key decisive factors (e.g., farm and farmer characteristics, market conditions).

In the presence of disease incidence, farmers might need to take extra biosecurity measures to control and prevent disease introduction and/or reintroduction. In order to come up with policies that can help farmers manage pig diseases efficiently and make farm structure adjustment rapidly, our second objective is to understand farmers' decision-making in reaction to disease outbreaks and their intentions regarding disease management strategies using data collected by a national pig producer survey.

Figures

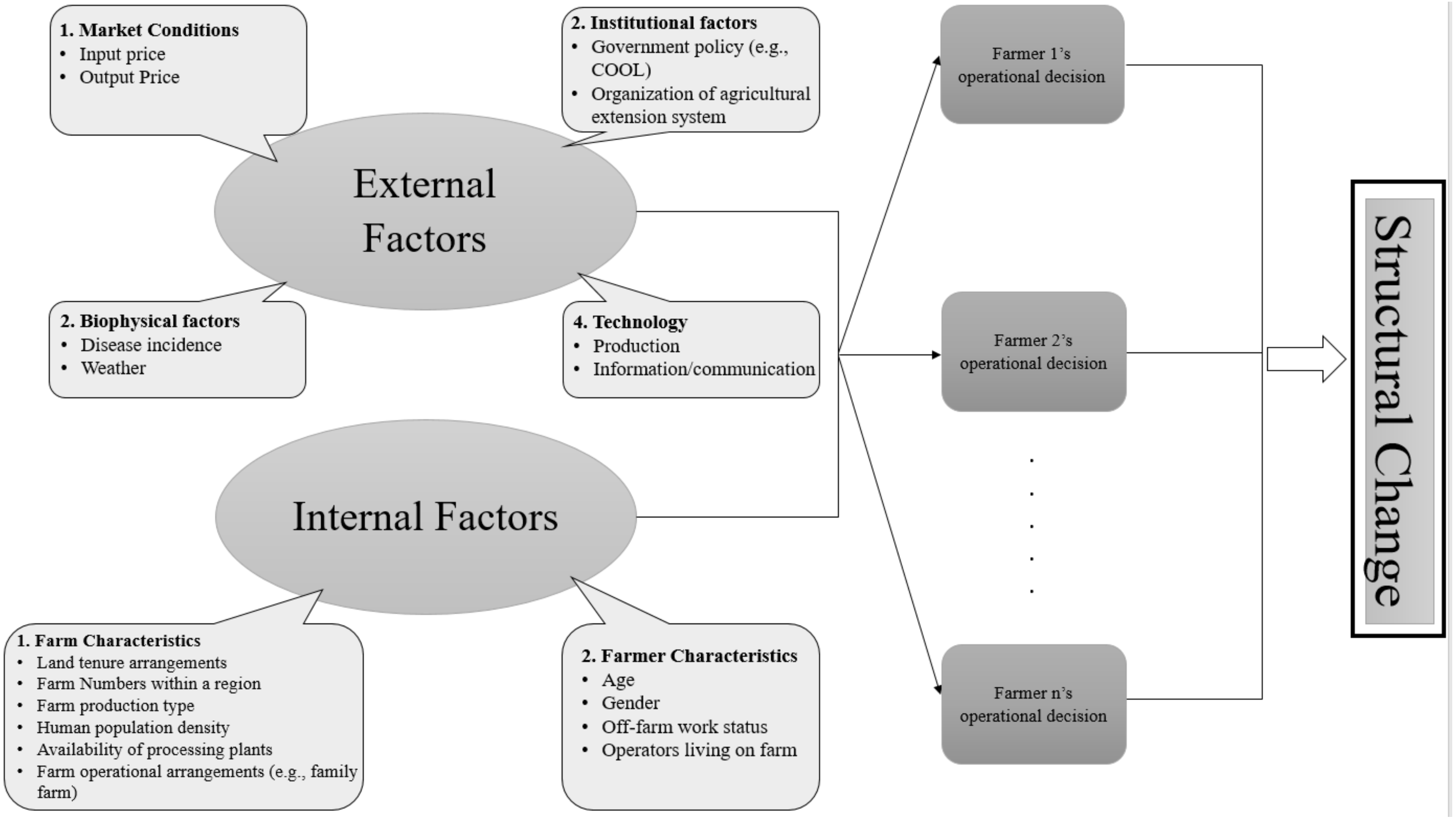

Figure 2.1. Conceptual Framework: Factors Affecting the Canadian Pig Industry's Structural Change.

Chapter 3: The Role of Pig Diseases in the Industry's Structural Change - Methods, Data, and Empirical Results

3.1 Introduction

In the conceptual framework presented in chapter 2, a multitude of factors were identified, which could play a role in the Canadian pig industry's structural change. In this chapter, we aim to empirically examine how these factors have influenced the industry's structural changes by using a panel dataset, which was constructed at the census division (CD)[3] level, from 1981 to 2016 for all provinces in Canada. Analyses are conducted with the differentiation of the CDs that experienced different types of structural change to examine how the same determinant could affect the structure of farms differently. In order to achieve this objective, the rest of the chapter is structured as follows. Beginning with the model specification, section 2 describes the empirical models used in this study. Section 3 describes the data collection process and discussed the expected effects of the explanatory variables used in the models. Empirical results are shown and discussed in section 4. Finally, section 5 concludes the chapter.

3.2 Empirical Model

In order to investigate the factors that actually affect farm structural changes across time, this study employs econometric models using panel data. Panel data is more preferable to time series or cross-sectional datasets as it gives a large number of data points, increases the degrees of freedom, and has the ability to reduce the problem of multi-collinearity (Hsiao, 1985).

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[3] Census division (CD) is the general term for provincially legislated areas (such as county, municipalité régionale de comté and regional district) or their equivalents and generally consists of a group of neighboring municipalities (Statistics Canada, 2015).

In our study, the Canadian pig industry's structural change is examined by farm size change, which reflects the farms' expansion or shrinkage of total production. As outlined by the conceptual framework in Chapter 2, farm characteristics, farmer characteristics, market conditions, institutional factors, biophysical factors, and technology all have the possibility to play a role in the industry's structural change. In particular, farm characteristics (F) consist of land tenure (i.e., whether or not renting land for pig farming), farm numbers within the census division (CD), production type (whether or not the operation is in farrow-to-finish units), human population density, the availability of slaughter plants (i.e., distance to nearest federally inspected slaughter plants), and farm operational arrangement (i.e., family farm or not). Farmer characteristics (FM) include operator's age, gender, off-farm work status, and living on farm variables. Market condition (M) includes the hog-feed price ratio. Biophysical factors encompass disease incidences and weather conditions (i.e., temperature). For institutional factors (I), both government policy (i.e., the implementation of U.S. country of origin labeling) and the organization of agricultural system (i.e., distance to the nearest research institutions) are included. Technology (T) is related to the usage of computers in farm businesses. The equation for farm structural change could be specified as:

$$y_{it} = \mathrm{f}\,(\mathrm{F}, \mathrm{FM}, \mathrm{M}, \mathrm{I}, \mathrm{T}) + u_{it} \qquad (1)$$

where F, FM, M, I, and T are as defined above. y_{it} is the dependent variable denoting the size of i^{th} pig farm in the t^{th} year, and u_{it} is the error term.

Due to the data protection rules from Statistics Canada, individual farm accountancy data is not available, we then conduct the empirical analyses at the CD level and employ the CD's average farm size as the measure of farm structure. Therefore, Eq. (1) can be rewritten in the form:

$$Y_{it} = \frac{1}{N_{it}}\sum_{i=1}^{n} y_{it} = \text{g (F, FM, M, I, T)} + \frac{1}{N_{it}}\sum_{i=1}^{n} u_{it} \qquad (2)$$

where Y_{it} is the dependent variable denoting the average pig farm size in the i^{th} CD in the t^{th} year, N_{it} is the number of pig farms in the i^{th} CD in the t^{th} year, and u_{it} is the error term.

Following Foltz (2004), this study employs random-effects generalized least squares (GLS) to estimate the effects of various economic factors on farm structural change. Panel models are superior as they account for individual (i.e., CD) heterogeneity, and the random effects model assumes CD heterogeneity to be random and uncorrelated with the independent variables included in the model. A random effects model is preferable to the fixed effects model because: 1) the time-invariant causes of the dependent variable (e.g., distance) can be estimated, rather than just be controlled, and 2) the standard errors of the estimates tend to be smaller. The equation for random effects model is specified in the form:

$$Y_{it} = \alpha + \beta_1 F_{it} + \beta_2 FM_{it} + \beta_3 M_{it} + \beta_4 I_{it} + \beta_5 T_{it} + \mu_i + \varepsilon_{it} \qquad (3)$$

where Y_{it} denotes average farm size (i.e., average number of pigs per farm) in the i^{th} CD in the t^{th} year, term α is a constant, terms β_1- β_5 are the coefficients of the independent variables, term μ_i is the between-CDs error, and term ε_{it} is the within-CDs error. For the rest of the independent variables, F_{it} represents farm characteristics, FM_{it} represents farmer characteristics, M_{it} denotes market conditions, I_{it} stands for institutional factors, and T_{it} denotes technology, as defined earlier.

When using geographical data to estimate regression models, the residuals tend to be spatially autocorrelated due to the coincidence of value similarity with locational similarity (i.e., spatial dependence). A clustering approach, which assumes the residuals are correlated within a certain geographic cluster but uncorrelated across the clusters, is thus employed in our study to address spatial autocorrelation. Census agricultural regions (CAR), which are composed of groups of adjacent CDs (Statistics Canada, 2015), are used to define clusters.

The models are estimated using Stata 14 statistical software. To empirically test whether the random effects model is more suitable than the fixed effects model, we conduct Hausman tests, and the null for the Hausman test is that the random effects model is appropriate. To ascertain the adequacy of the models, three diagnostic tests including variance inflation factor (VIF) test of collinearity (O'Brien, 2007), the likelihood ratio (LR) test for Heteroscedasticity, and the Lagrange Multiplier (LM) test for serial correlation are conducted after running the regressions (Griliches and Intriligator, 1984). In general, a VIF value less than 10 would indicate the nonexistence of collinearity among the independent variables. For LR and LM tests, the null hypotheses are homoscedasticity and no autocorrelation, respectively.

Given the explanatory variables employed in our study are of different units of measurement, it is difficult to decide which of the independent variables are most important for determining the dependent variable (i.e., farm size). In order to determine which explanatory variables have greater impacts on farm size, standardized coefficients are derived after running the regressions to account for the differences in units of measurement of the explanatory variables. The intuition behind coefficient standardization is we now measure the explanatory variables on a common unit of standard deviation, rather than the units of the explanatory variables. The formula for deriving standardized coefficients (SC) is given by:

$$\mathrm{SC} = \frac{Independent\ variable's\ coefficient \times Independent\ variable's\ standard\ deviation}{Dependent\ variable's\ standard\ deviation} \qquad (4)$$

Because there exist heterogeneities in the types of structural change in different regions, we divide the regions (i.e., CDs) into two groups to investigate how various factors contribute to the different types of structural change in the Canadian pig industry. The first group consists of CDs that underwent structural change with decreases in pig farm numbers and an increase in total pig numbers over the period 1981 to 2016 (type 1 structural change), and the second group includes CDs that experienced structural change with decreases in both pig farm numbers and total pig numbers over the same time period (type 2 structural change). To empirically compare the effects of the same explanatory variables on the structure of the farms that are categorized into the two groups (shown as Eq. (5) and Eq. (6)), Wald tests are conducted to test whether the same explanatory variable's effects are statistically different between two groups (shown as Eq. (7)) (Griliches and Intriligator, 1984). The null hypothesis is the effects are not statistically different.

$$Y_{it} = \alpha + \beta_1 F_{it} + \beta_2 FM_{it} + \beta_3 M_{it} + \beta_4 I_{it} + \beta_5 T_{it} + \mu_i + \varepsilon_{it} \tag{5}$$

$$Y_{it}' = \alpha' + \beta_1' F_{it} + \beta_2' FM_{it} + \beta_3' M_{it} + \beta_4' I_{it} + \beta_5' T_{it} + \mu_i' + \varepsilon_{it}' \tag{6}$$

$$\begin{aligned} H_0&: \beta_i = \beta_i' \\ H_1&: \beta_i \neq \beta_i' \end{aligned} \tag{7}$$

In agricultural economics, regional dummies are usually incorporated to depict the impact of different regions. Instead of using provincial dummies to control for the factors that are common within the same province, our study conducts the empirical analyses for each province separately. The reason, provided by Weiss (2006), claims that the impact of a certain independent variable on structural change depends not only on the value of the variable itself, but also on the level of other explanatory variables. Such an explanation also confirms the necessity of analyzing different types of structural change separately. Another reason for doing the empirical analyses provincially is the three pig diseases (i.e., porcine reproductive respiratory syndrome (PRRS), porcine circovirus associated disease (PCVAD), and porcine epidemic diarrhea (PED)) examined in our study are not reportable or immediately notifiable diseases in Canada. Because they are not nationally reported, PRRS, PCVAD, and PED are managed by each province, and different provinces have different codes of practice for the care and handling of pigs. Thus, it would be more appropriate and informative to examine how pig diseases play a role in different provinces.

However, a disadvantage associated with running regressions provincially is a waste of econometric estimation efficiency as we now have fewer data points for each regression. In our study, we investigate the Canadian pig industry’s structural change with the segregation of both types of structural change and provinces. Another reason behind the segregation of provinces is that the challenges (especially disease outbreaks) faced by the Canadian pig farmers are very heterogeneous in different parts of Canada. Take disease outbreaks as an example, as compared to the western provinces like Alberta and Saskatchewan, pig disease outbreaks are relatively more common in the eastern provinces such as Ontario and Quebec. The reasons that pig diseases are more prevalent in eastern Canada include: 1) the diversity of the disease genotypes is more pronounced in the eastern provinces, while more limited in the western provinces (Brar et al., 2011; Brar et al., 2015); and 2) pig farming in the eastern provinces is more geographically concentrated with higher pig density, which increases the possibility of pig infection, while production in western provinces is more geographically separated (Dewey, 2000).

3.3 Data Collection and Variable Descriptions

Data by census division (CD) for all provinces in Canada from 1981 to 2016, giving a total of 209 observations[4], are used in this study. Since census data are available from Statistics Canada every five years, this study covers 8 census years (i.e., 1981, 1986, 1991, 1996, 2001, 2006, 2011, and 2016). Farm characteristics relating to the number of pigs and number of farms reporting pigs, land tenure, farm operational arrangements, production type, the usage of computers in pig farming, as well as farmer characteristics including age, gender, and off-farm status are census data (by CDs) obtained from the Agriculture Division of Statistics Canada (Statistics Canada, 1982;, Statistics Canada, 1987; Statistics Canada, 1992; Statistics Canada, 1997; Statistics Canada, 2002; Statistics Canada, 2007; Statistics Canada, 2012; Statistics Canada, 2017b; Statistics Canada). The spatial boundary file is also from Statistics Canada for the calculation of each CD's land areas (Statistics Canada, 2017c). Data on human population (by CDs) is extracted from the National Household Survey (NSH), which is also conducted every five years and is coincidental with the timing of the Census of Agriculture Survey, available through the CHASS Data Center from the University of Toronto. The number and location of the federally inspected processing plants for each year are available from the Market Analysis section of Agriculture and Agri-Food Canada (AAFC). For the locations of the agricultural universities and veterinary institutions, we collect the data by browsing all of the research institutions (including all campuses) and extracting those that provide agricultural education and veterinary services for each census year. Provided by the locations, distance variables are calculated using ESRI ArcGIS software version 10.3.

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[4] In total, Canada possessed 266 CDs in 1981 and 1986 census, 290 CDs in 1991 census, 288 CDs in 1996, 2001, and 2006 census, 293CDs in 2011 and 2016 census. After removing the CDs that had no pig farming operations and matching the CDs that underwent annexations, we ended up with 209 CDs for model estimation.

Prices of hogs (index 100 hogs), corn, and barley are of monthly frequency, and these price series are collected from Statistics Canada and are available at the provincial level (Statistics Canada, 2017d). To remove the impacts of inflation, all price series are deflated to real levels using the Consumer Price Index (CPI) from June 2002 (Statistics Canada, 2017e) as the base. Weather data including temperature is also of monthly frequency and is collected from the Department of Environmental and Natural Resources from Government of Canada (Government of Canada, 2017). For the impact of the U.S. country of origin labelling (COOL), a time dummy is included covering the census period of 2006-2016. Time dummies capturing the peak period of pig diseases (including porcine reproductive respiratory syndrome (PRRS), porcine circovirus associated disease (PCVAD) and porcine epidemic outbreaks diarrhea (PED)) are created to examine the impacts of pig diseases. Since some data series are available from the CD level, and some are only available from the provincial level, a summary of the data's level of availability and variable definitions is presented in Table 3.1. Summary statistics of all variables used in the regressions[5] for the census year of 1981 are provided in Table 3.2 - 3.7[6]. Descriptive statistics for all other census years are provided in Appendix 1-36.

3.3.1 Internal Factors

Farm Characteristics

1) *Number of pigs and pig farms.* As previously mentioned, the objective of our study is to investigate how various factors have affected farm structure changes. Therefore, it is critical

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[5] Due to the small sample size of CDs in the Atlantic Provinces (very few CDs reports pig numbers given confidentiality consideration), this study would not conduct empirical analysis for these provinces. In addition, the Atlantic Provinces only accounted for 0.6% of the country's hog production.

[6] Time dummies are not included since they have no variations across years.

to define the measure of farm structure. In this study, farm structure is denoted by the size of the pig farms to reflect the farm expansion and shrinkage activities, and the average number of pigs per farm in every Census Division (CD) is thus used for the analyses.

a) *Farm size.* From 1981 to 2016, the Canadian pig industry saw significant expansion with the size of Canadian pig farms increasing from 177 head per farm to 1677 head per farm (8.5-fold higher) (Table 3.8). In 1981, farm size in Quebec (QC) was the largest (430 head per farm), and the smallest size was in Saskatchewan (SK) (63). While in 2016, the provinces with the largest pig farms were Manitoba (MB) (5087 head per farm), followed by QC (2316) and SK (1548). On the other hand, the provinces with smallest farms were the Atlantic provinces [7] (341) and British Columbia (BC) (98). Figure 3.1 presents the trends in pig farm size during the period of 1981 to 2016 for all provinces. For the country as a whole, the average farm size had been consistently and significantly increasing over the period 1981 to 2011, but it slightly decreased over the period 2011 to 2016, and the provinces of SK and Alberta (AB) also followed this trend. Whereas the average farm size had been consistently increasing for the provinces of MB, QC and Ontario (ON) over the past four decades. For the Atlantic provinces, farm size had been consistently increasing over the period 1981 to 2006, and then decreased in the last decade. In terms of BC, it had been experiencing inconsistent changes in farm size, but the average farm size decreased from 1981 to 2016.

b) *Farm numbers.* Over the last four decades, the number of pig farms in Canada decreased from 55765 to 8402 (by 85%), and the rate of decrease was especially high for the provinces of SK and the Atlantic provinces. The evolution of pig farm numbers is shown

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[7] Atlantic Provinces include the provinces of New Brunswick, Prince Edward Island, Newfoundland and Labrador, and Nova Scotia.

in Figure 3.2. From 1981 to 2011, all provinces in Canada have been consistently losing pig farms, while a slight increase in pig farm numbers was seen over the period 2011 to 2016. In the last decade, the number of farms reporting pigs increased in almost all provinces, and QC was the only province that lost pig farms.

c) *Pig numbers.* From 1981 to 2016, strong growth in pig production was seen in Canada with the national herd increasing from 9,875,065 head to 14,091,503 (by 42%) (Figure 3.3). In addition to the production growth, the distribution of production has also changed significantly (Table 3.9). In 1981, the provinces of QC, ON, and AB accounted for 79% of the hog production in Canada. While in 2016, about 81% of the Canadian pigs were in QC, ON and MB. Across all provinces, the strongest growth in hog production from 1981 to 2016 was detected in MB with total production (i.e., total pig numbers) rising from 874, 995 head to 3,382,897 (2.9-fold higher). Dramatic production expansion was also seen in other provinces such as SK and QC with the growth rates being 80% and 31%, respectively (Table 3.10). However, not all provinces in Canada experienced production expansion in the last four decades. For BC and the Atlantic provinces, hog production dropped by 65% and 76%, respectively. Between 2006 and 2011, hog production in all provinces across the country fell significantly with a national rate of 16%, and the largest decrease was in the Atlantic provinces (61%), followed by BC (34%) and AB (32%) (Table 3.11).

Although the Canadian pig industry has seen significant structural change with a huge decrease in the number of pig farms and an increase in national pig herds over the period 1981 to 2016, not every CD experienced the same type of structural change. Indeed, 69% of the CDs across the country went through both pig farm losses and total reductions in pig numbers over the last four decades. The heterogeneities in the types of structural change further confirmed the necessity to analyze the industry's structural change with differentiation of regions. For the relationship between farm size and farm numbers, no prior expectation is assumed as previous studies' results regarding the relationship have been ambiguous (i.e., Duffy et al (2007) found a positive relationship, while Maynard and Nault (2005) found a negative correlation between farm number and farm size).

2) *Production type*. In order to lower per unit production costs, Canadian pig farms have gradually shifted from the traditional farrow-to-finish farms to specialization on a single phase of production. In 1981, a large share of the hog farms was in farrow-to-finish operations (45%), followed by farrowing operations (28%) and finishing operations (21%). While in 2016, most of the pig herds were in finishing units (49%), followed by farrow-to-finish (23%) and farrowing units (23%) (Table 3.12). Figure 3.4 presents the percentage of the farms that were in farrow to finish units. Although there was a slight increase in the percentage of farrow to finish operations from 1981 to 1991, consistent decreases in the number of farrow to finish farms were found in all provinces (except for the Atlantic provinces and SK) over the period of 1991-2016. In addition to cost considerations, another possible reason for such a change is farmers have been trying to make adjustments in reaction to disease outbreaks. Given that production flows could positively contribute to pathogen buildup, farrow-to-finish farms were found to be more inclined to disease infections, and farmers might be more motivated to move away from farrow-to-finish units to prevent disease incidents. Porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) were first confirmed in Canada in the early 1990s, which coincides with the timing of production restructuring. In our study, we measure the

percentage of farrow-to-finish units in each CD to investigate how the change in production type might have affected the structure of farms, and a negative relationship between the "farrow-to-finish" variable and farm size is expected.

3) *Land tenure.* Previous studies suggested different tenure arrangements would result in different operational decisions, and it is generally held that full-owners are more motivated to expand their operations. However, some studies found partly owners, who own a portion of the farmland and rent the rest from others (including government) for hog farming, were more likely to expand their operations by renting additional land (e.g., Gallacher, 2010). In our study, land tenure is measured by the percentage of farms that leased land from the government and/or other farm operators for pig farming in each CD. No expectation is assumed for the sign of the coefficient on the "land tenure" variable.
4) *Human population density.* Farmlands in more population-dense areas are usually subject to competition for alternative uses. Due to the higher opportunity costs of land use in these areas, a negative relationship is expected between farm size and population density. In our study, we employs population density per kilometer in each CD to investigate the relationship.
5) *Availability of slaughter plants.* Since pig farmers could benefit from buyer competition in their localities, the availability of slaughter plants might positively influence the size of the pig farms. In addition, farms that are closer to the plants might be larger due to the lower transportations costs associated. Over time, the number of federally inspected slaughter plants, which accounts for approximately 95% of hog processing in Canada, have changed significantly. From 1981 to 2001, the number of slaughter plants increased by 28 (from 27 to 55). Since then the number of plants has kept decreasing, and the number of plants in 2016

went back to 27. In this study, the availability of processing plants is measured by the distance (in kilometers) from the centroid of the CD to the nearest federally inspected processing plant. It is expected that being located further away from processing plants might discourage farmers from expansion.

6) *Family farm.* According to the previous literature, the impact of farm operational arrangement (i.e., whether the farm is a family farm or not) on farm structure is conditional. Particularly, family farm operators were found to be more likely to expand their operations if they have successors and/or if they are not willing to lay off family members (Chilonda and Van Huylenbroeck, 2001). Therefore, no expectation is assumed as farmers may face different situations regarding succession and family employment.

Farmer Characteristics

1) *Gender*. Many empirical studies have suggested male and female farm operators tended to have different tendencies of risk taking, and male operators were more inclined to run larger farms by taking more risks (Akimowicz et al., 2013; Harris et al., 2006). In our study, gender is captured by the percentage of male operators in every CD. According to 2016 census, 72% of the Canadian pig farm operators were male. MB is the province that had the largest share of male operators (81%), followed by SK (78%) and QC (74%), while BC has the least share (58%). A positive relationship between "male" variable and farm size is expected.
2) *Age*. In this study, age is measured by the farm operators' average age in each CD. The average age of all Canadian pig farmers in 2016 was 49, with half of them aged in the range of 35 to 54. Farmers in ON and BC seemed to be younger with an average age of 48, while those in the Atlantic provinces and SK are older with an average age of 53. Previous studies'

results regarding the impact of age on farm structure changes are contradictory. For example, Kim et al (2005) found younger farmers were more likely to expand farm productions, while Sumner and Leiby (1987) claimed older farmers tended to have larger farms as they have more wealth. Due to the mixed results, no prior expectation is assumed for the sign of the coefficient on "age" variable.

3) *Off-farm work.* The impact of off-farm employment on the structure of farms is also ambiguous. On one hand, farmers who have off-farm work may be less likely to expand production as they may have less time available for pig farming. On the other hand, these farmers may be inclined to expansion as they could finance with their off-farm income. The percentage of farmers who had no off-farm work is analyzed in this study. According to the 2016 census, 64% of the farm operators in Canada had no off-farm work. QC is the province that had more famers taking pig farming as their only occupation (68%), followed by ON and AB (63%), while only 36% of the farmers from BC farmed as their main job.
4) *Operator living on farm.* As a proxy for farm distance, farmers who living on their holdings might be more likely to expand their operations as they absorb lower transportation costs. Across time, we found an increasing number of farm operators chose to live on their farms. In our study, "operator living on farm" variable is measured by the percentage of farms reporting on-farm living, and a positive relationship between the "operator living on farm" variable and farm size is expected.

3.3.2 External Factors

Market conditions

Barley and corn are the common feed grains for hogs in Western and Eastern Canada[8], respectively. Depicted by the hog-feed price ratio (i.e., hog-barley price ratio for Western Canada, and hog-corn price ratio for Eastern Canada), the profitability of pig farming is one of the most important determinants of farm structural changes, and a high price feed ratio could positively impact hog production. As the ratio increases, farm operators would earn more and might be more motivated to invest more money into their farm operations. Therefore, we expect a positive relationship between farm size and the hog feed price ratio. Since the Census of Agriculture questionnaires often contain questions relating to the production status from January, one year before census year, to the data collection date[9], we take the monthly average of the price series during this time period.

Institutional factors

1) *Country of origin labeling*. The 2002 U.S. Farm Security and Rural Investment Act (or 2002 Farm Bill), which was effective on May 2002, contained a country of origin labeling (COOL) provision that required retail-level labeling for fresh fruits and vegetables, beef, pork, lamb, seafood and peanuts to begin in 2004 (Jones et al., 2009). Under COOL, Canadian pigs must be segregated in the U.S. feedlots and packing plants. As a result, the recordkeeping and

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[8] Eastern Canada encompasses the Ontario, Quebec, and the Atlantic Provinces (i.e., New Brunswick, Prince Edward Island, Newfoundland and Labrador, and Nova Scotia), while Western Canada includes the provinces of Manitoba, Alberta, Saskatchewan and British Columbia.

[9] Census data collection date varies across census years. It was June 3rd for the census years of 1981 and 1986, June 4th for the year of 1991, May 14th for the year of 1996, May 15th for the year of 2001, May 16th for the year of 2011, and May 10th for the year of 2016.

verification requirements imposed under the COOL measure led to detrimental impact on Canadian pigs in the US market, since the increased transaction costs reduced the desirability of procuring the Canadian born pigs. In early October, 2009, Canada along with Mexico requested a World Trade Organization (WTO) panel on whether or not COOL discriminated against imports (Jurenas and Greene, 2012). Even with some regulation reformations by the U.S. in May 2013, which resulted in more discrimination against Canadian pigs (Carroll, 2015), the removal of COOL for beef and pork muscle cuts, ground beef and ground pork was not confirmed until March, 2016 (AMS-LPS-16-0002). Therefore, a time dummy capturing the effect of COOL implementation is created. The "COOL" variable takes the value of one from 2006 census to 2016 census, and zero otherwise. Because COOL made Canadian pigs less attractive to the U.S. buyers and forced a considerable number of pigs to remain in Canada (Economics Research Group-University of Guelph, 2010), we expect a positive relationship between a "COOL" variable and farm size.

2) *Availability of agricultural universities and veterinary institutions*. The relationship between farm size and the availability of extension services has been documented by many studies (e.g., Chilonda and Van Huylenbroeck, 2001). Farmers' operational decisions (i.e. expansion or shrinkage activities in our study) might be highly related to their access to the services as research extension provides pig farmers with information with respect to new technology and consulting services, which affect daily operation. In our study, the locations of all agricultural universities (including all campuses) and veterinary institutions are collected. In total, there are 89 research stations in 2016. The availability of consulting service and veterinary personnel is captured by the travel distance (in kilometers) from the centroid of a CD to the nearest research station.

Biophysical factors

1) *Disease outbreaks*. As mentioned in Chapter 1, Canadian pig farmers have been significantly plagued by porcine reproductive respiratory syndrome (PRRS), porcine circovirus associated disease (PCVAD), and porcine epidemic diarrhea (PED) since their first discoveries in 1990s. Because these three pig diseases are not federally reportable (Canadian Food Inspection Agency, 2017), data on total number of PRRS and PCVAD incidences are not available, and only the number of PED cases is recorded by the provincial agencies.
    a) In our study, the impacts of PRRS and PCVAD outbreaks are captured by a time dummy indicating the timing of the dramatic increases of disease incidences. From the Fall of 2003 to the Winter of 2006 , both Animal Health Laboratory (AHL) at the University of Guelf (Guelph, Ontario) and Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ, Québec) detected an increase in the frequency of reported lesions associated with PRRS (Carman et al, 2011; MAPAQ[10]). For PCVAD, concurrent with a shift of genotype (Poljak et al., 2010), dramatic increases in its outbreaks occurred in the period Fall 2004 to Winter 2006. The reason that we suddenly had frequent and severe problems during the period of 2003 to 2006 is we were dealing with new and more virulent isolates of the viruses (Carman et al, 2011; MAPAQ). Please see Figures 3.5 for the plots of the number of PRRS and PCVAD positive cases submitted to MAPAQ in Quebec. In our study, we create a dummy variable, which takes the value of one for the 2006 census and zero otherwise to examine the impacts of PRRS and PCVAD outbreaks on the industry's structural change.

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[10] Unpublished data

b) For the impact of PED, since it was first detected in January 2014, we create another time dummy, which takes the value of one for the 2016 census and zero otherwise, to denote the presence of PED on Canadian pig farms. Since PED has been only found in the provinces of Ontario, Quebec, Manitoba, and Prince Edward Island (Alberta Pork, 2016), this variable is only included in the regressions of these four provinces.

Given the increased mortality and mobility rates caused by the presence of pathogens, we would expect decreases in pig farm size during the periods of severe diseases outbreaks (i.e., the period of severe PRRS and PCVAD outbreak, and the period of PED outbreak).

2) *Temperature.* Climate factor, captured by temperature, could also play a role in the farm structural changes. In general, high temperature (especially in the planting season) would negatively affect feed production, and thus the level of hog production resulting from the increased feed price. In our study, we denote weather by summer temperature (by CDs), which is captured by the average monthly temperature during summer months (April to September, the year before census year), and expect a negative relationship between the "temperature" variable and farm size.

Technology

Technology innovation has been pushing significant changes upon agricultural production. Instead of using a time dummy capturing the trends of technology improvement, our study uses the percentage of computer usage in each CD as the measure of technology. As discussed in Chapter 2, new technologies could help farm operators realize scale economies with increased output and decreases in per unit production costs, we thus expect a positive relationship between the "technology" variable and farm size.

3.4 Empirical Results

In this section, the results from the estimations are reported. Rather than only including the statistically significant variables for each regression, we employed the same explanatory variables for all regressions for the purpose of maintaining consistency and making comparisons between groups and among provinces.

3.4.1 Estimation Result – British Columbia

The estimation results for the province of British Columbia are presented in Table 3.13. Unlike other provinces, all census divisions (CDs) in British Columbia experienced type 2 structural change with decreases in both pig farm numbers and total pig numbers. The regression results show during the period of severe porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) outbreaks (2003-2006), farm size (i.e., average number of pigs per farm) was negatively influenced. The U.S. country of origin labeling (COOL) is found to have no impacts on farm size changes in British Columbia, which could be explained by the minimal exportation of the pigs from British Columbia to the U.S. market.

As expected, being located far away from slaughter plants discouraged farm expansion, and human population density also negatively affected farm size. Family farms and farms that rented land for pig farming are found to be more likely to expand farm operations. In terms of the effect of age on farm structure changes, younger farmers seemed to be more likely to operate larger pig farms. We find temperature significantly and positively affected farm size. Such a positive relationship is related to pathogen survival, which was found to be more optimal when the temperature is low (Albina, 1997). Therefore, high temperature might suppress disease transmissions and lead to increased number of pigs on farm.

After running the regressions, standardized coefficients are derived and also listed in Table 3.13. A one standard deviation increase in human population density would lead to 0.48 standard deviation decrease in the average farm size. The other variables listed in the table can also be explained similarly. Among the determinants examined in our study, we find farm operational arrangement (i.e., whether the farm is a family farm or not) had the biggest impact on farm size changes, followed by land tenure. In addition, these two factors are found to have positive impacts on the structure of farms. For external factors pertaining to the situations in which pig farming occur, disease outbreaks are found to have a more significant role in determining the size of pig farms than other external factors.

3.4.2 Estimation Result – Alberta

The estimation results for the province of Alberta are presented in Table 3.14. The left column displays the results for the group of CDs that experienced the first type of structural change with a decrease in pig farm numbers and an increase in total pig numbers (type 1 structural change), and the right column reports the results for the group of the CDs that went through the second type of structural change with decreases in both pig farm numbers and total pig numbers (type 2 structural change). The regression results show during the period of severe PRRS and PCVAD outbreaks (2003-2006), farm size in Alberta was not affected, which is reasonable as fewer diseases incidences were seen in Alberta (Batista, 2007). For the impact of the U.S. COOL, we find the average number of pigs per farm was higher when COOL was in place. Such a finding could be attributable to the reduced exportation of pigs, especially weaner and feeder pigs, to the U.S. market. Due to the implementation of the U.S. COOL, more hogs were finished and slaughtered in Canada (Grier and Kohl, 2003). The Wald test result further reveals that COOL had a larger impact on the structure of farms located in the CDs that underwent type 1 structural change.

As expected, the hog-feed price ratio had a positive impact on the size of farms, but we find only the CDs that experienced type 2 structural change were price sensitive. One thing of note is that the CDs that experienced type 2 structural change were dominated by small scale farmers with the average farm size being 418 head per farm, while the average farm size for CDs experiencing type 1 structural change was 1382 head per farm. Similar result was also detected by Mburu et al (2014) stating small-scale farmers were more price sensitive than large scale farmers. Technology improvement had facilitated farm expansions, and it is shown CDs that underwent type 1 structural change were affected more by technology change, which is also confirmed by Wald test results. Summer temperature, on the other hand, negatively affected farm size. A possible explanation for such a finding is pig diseases other than PRRS, PCVAD, and PED might be triggered off when the temperature becomes too high (The Pig Site, 2017).

For the impacts of farm characteristics, being located a further distance from the slaughter plants and research institutions (i.e., agricultural universities and veterinary institutions) is found to have discouraged farm expansion, which could be attributed to the higher transportation costs and the unavailability of consulting services. For those who live nearby research institutions or have college/university students working on their farms, they may know more about technology innovations and gain disease treatments information more quickly.

Human population density is found to significantly and negatively affect farm size, due to the higher opportunity costs of land use and possible negative feedback from people living in population-dense areas. This finding is also in accordance with the literature that detected a negative relationship between population density and farm size (e.g., Muyanga and Jayne, 2014). Surprisingly, no relationship is detected between farm size and number of farms within the region. As mentioned earlier, farm numbers could contribute to the industry's transition in two different directions. One is a negative contribution to realizing scale economies, and another is a positive one to meet the needs of high-priced niche markets. These two contradictory effects might offset each other and lead to the coefficient's insignificance.

In terms of the effects of farmer characteristics, female farm operators in Alberta are found to be more likely to expand their farms. For operators who had pig farming operations in the CDs that experienced type 1 structural change, older pig farmers are found to be more likely to expand their operations, while it is the opposite for farmers in the CDs that underwent type 2 structural change. In addition, farmers who lived on their farms are found to be more likely to expand their production.

After running the regressions, standardized coefficients are derived and also listed in Table 3.14. Among the economic variables examined in our study, technology, which is an external factor, was found to be the biggest factor affecting farm structural changes in Alberta, followed by an institutional factor measured by the distance to the research institutions. In addition, both technology and the availability of research institutions had played a positive role in farm size changes. Among the internal factors that are pertaining to the characteristics of farms and farmers, we find human population density and operators' living status (i.e., whether operators living on farm or not) had greater impacts on farm size. Human population density was negatively related to farm size, but the “operators’ living status” was positively related to farm size. These findings are common for both groups.

3.4.3 Estimation Result – Saskatchewan

The estimation results for the province of Saskatchewan are shown in Table 3.15. The left column shows the results for CDs that experienced type 1 structural change, while the right column displays the results for the CDs that went through type 2 structural change. Like the Alberta case, farm structure in Saskatchewan was not impacted during the period of severe pig diseases (i.e., PRRS and PCVAD) outbreaks, since these two diseases were not very prevalent in the province of Saskatchewan (Batista, 2007). Similarly, COOL had been played a more significant role in the CDs that experienced type 1 structural change. Technology innovation had encouraged farm expansions and had a larger impact on the structure of the farms that went through type 1 structural change, which is further confirmed by the Wald test results. On the other hand, human population density and temperature had significantly and negatively influenced farm size. Again, no relationship is detected between farm size and number of pig farms. Surprisingly, the impact of hog-feed price ratio on farm structure changes is not significant, but the coefficients have positive signs and their magnitudes are small, which might imply the variable is economically significant.

For farms located in the CDs that experienced type 1 structural change, we find being located far away from the research institutions would negatively affect farm size, which is as expected. However, an anomaly is detected indicating being located far away from slaughter plants would positively affect farm size. A possible explanation might be some hogs must be slaughtered in specific plants, for those plants are newer and more efficient, and thus the availability of processing plants might not play a significant role. Indeed, many Saskatchewan farmers sent their pigs to Maple Leaf's slaughter plant at Brandon (Manitoba) or Olymel's plant at Red Deer (Alberta) (Briere, 2007; CBCnews, 2007) for slaughter. Speaking of farmer characteristics, older and female farmers are found to be more likely to expand their productions.

For farms located in the CDs that went through type 2 structural change, family farms are detected to be less likely to expand their productions, which might be attributable to the nonexistence of successors. In comparison to farmers aged below 45, we found farmers aged in the range of 45 to 54 were less likely to expand farm operations, while those older than 55 were more likely to expand their farms.

When determining which factors have greater impacts on farm structure changes, we found external factors including technology had played a more significant role in the determination of farm size in the CDs that experienced type 1 structural change. In terms of the internal factors, human population density and farm operators' gender are found to have greater impacts on farm structure adjustments. For CDs that experienced type 2 structural change, the implementation of COOL is detected as the most important external factor affecting farm size changes. The internal factors that had the biggest impacts on farm size are human population density and farm operational arrangement (i.e., whether the farm is family farm or not).

3.4.4 Estimation Result – Manitoba

The estimation results (including standardized coefficients) for the province of Manitoba are shown in Table 3.16. For the province of Manitoba, only five CDs experienced type 2 structural change. Given the limited observations, this study would only make empirical analyses for the CDs that underwent type 1 structural change. Like the Alberta and Saskatchewan cases, farm size seemed to be not affected by the severe PRRS and PCVAD outbreaks, since western Canada had seen few disease incidents (Batista, 2007). In addition, PED outbreaks also seem to have no impacts on farm structures, yet. Up until the Winter of 2016, only 10 premises in Manitoba confirmed PED (Manitoba Agriculture, 2017), which helps explain the variable's insignificance. Speaking of the U.S. implementation of COOL, a positive relationship between farm size and "COOL implementation" variables is detected. One thing of note is that hog moratorium was implemented in Manitoba for environmental reasons during the same time period. If there was no restriction on hog barn expansion, we would expect COOL to have an even larger impact on farm size. Technology innovation is also found to significantly and positively affect farm structures.

In terms of the impacts of internal factors (i.e., farm and farmer characteristics) on the structure of farms, farm number is found to positively influence farm size, but the magnitude is small. Farm size would decrease as the distance to the nearest research institution increases. Human population density had negatively affected farm structures. In addition, older and full owners (i.e., operators use their own lands for pig farming) seemed to be more incentivized to expand their farms.

When examining the factors that had greater impacts on the structure of farms, the standardized coefficients suggest technology and the implementation of COOL had played a more significant role in farm structure changes. For internal factors pertaining to the characteristics of farms and farmers, farm operators' age and farm number are found to have bigger impacts on farm size than the rest of the internal factors.

3.4.5 Estimation Result – Ontario

The estimation results (including standardized coefficients) for the province of Ontario are presented in Table 3.17. The results for the CDs that experienced type 1 structural change are displayed in the left column, and the results for the CDs that experienced type 2 structural change are shown in the right column. For the impact of diseases outbreaks, we detect that the structure of the farms located in the CDs that underwent type 1 structural change were affected more by PRRS and PCVAD outbreaks, while the structure of the farms located in the CDs that underwent type 2 structural change were affected more by PED outbreaks. For the U.S. COOL, we find it only affected the size of the farms located in the CDs that underwent type 1 structural change. A possible explanation might be the farms located in the CDs that experienced type 2 structural change were more reliant on interprovincial trade, rather than international trade.

As expected, a negative relationship between farm size and farm numbers is detected, and this implies that Ontario farmers had chosen to have larger pig farms to realize economies of scale. Being located far away from the slaughter plants would discourage farm expansions. Moreover, younger pig farmers in Ontario seemed to be more likely to have larger pig farms. Given the negative relationship between the "production type" variable and farm size, farrow-to-finish farmers are found to be more likely to have smaller farms, and this could be attributable to cost considerations and farmers' tendency to decrease the risk of infection from the older pigs to the younger and more susceptible piglets. Although the coefficient on technology variable are not statistically significant, their small magnitudes and positive signs indicate they are economically significant.

For farms located in the CDs that experienced type 1 structural change, we find part owner, who own a portion of the farmland and rent the rest, were more likely to expand their production by renting more farmland. Farmers who operated a family farm and had no off-farm work also seemed to be more likely to have larger farms as they were had more incentives and more time available for pig farming. Surprisingly, we detect a negative relationship between "distance to research institution" variable and farm size. For farms located in the CDs that experienced type 2 structural change, a positive relationship between temperature and farm size is detected. Again, pathogen survival is more optimal when the temperature is low (Albina, 1997), so high temperature suppresses disease transmissions and leads to increased number of pigs on farm.

The standardized coefficients show institutional factors, which include both COOL implementation and the availability of agricultural universities and veterinary services (measured by distance to research institutions), had the biggest impacts on the structure of farms located in the CDs that experienced type 1 structural change. For factors pertaining to farm and farmer characteristics, farm operational arrangement (i.e., whether the farm is a family farm) and production type (i.e., whether the farms is a farrow-to-finish operation) are found to have greater influences on farm size. For the CDs that went through type 2 structural change, the availability of slaughter plants is found to have the biggest impact on farm structure adjustments. For external factors referring to the situations in which pig farming occur, biophysical factors (including both disease outbreaks and temperature) are found to have greater impacts on farm size changes.

3.4.6 Estimation Result – Quebec

The estimation results (including standardized coefficients) for the province of Quebec[11] are shown in Table 3.18. Again, the results for the CDs that experienced type 1 structural change are displayed in the left column, and the results for the CDs that experienced type 2 structural change are shown in the right column. Like the Ontario case, the structure of the farms located in the CDs that underwent type 1 structural change were affected more by PRRS and PCVAD outbreaks, while the structure of the farms located in the CDs that underwent type 2 structural change was affected more by PED outbreaks. A positive relationship between farm number and farm size is detected, implying Quebec farmers might have been trying to have smaller pig farms to satisfy demand in a higher-priced niche market. Technology adoption had encouraged farm operators to expand their production. In addition, farmers who had no off-farm work are found to be more likely to operate larger pig farms.

The U.S. COOL is found to positively influence farm size in Quebec, but such a finding is unexpected. Unlike Ontario and Quebec which have specialized in exports of hogs that end up being slaughtered in the U.S., Quebec is specialized in pork exports (Jeddy, 2011), so we would expect COOL had a minimal or no impact on farm size. A possible reason for such an anomaly is it is rather than COOL that facilitated farm expansion. In 2008/2009, the Cull Breeding Swine Program (CBSP) and the Hog Farm Transition Program (HFTP) were introduced by the federal government to facilitate the transition of hog producers who want to adapt to the current market condition or exit from production (Brisson, 2015). Therefore, it might be the implementation of

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[11] Given the changes made for the CDs in Quebec in 1991 (i.e., number of CDs increased from 76 to 99 as a result of changes in Census Subdivisions (CSD)), variable adjustments based on Census Subdivisions for the Census years of 1981 and 1986 were made. Available at: http://publications.gc.ca/collections/collection_2012/statcan/rh-hc/CS92-311-1993-eng.pdf .

these programs that positively affect farm size, as many pig small farms were out of business and fewer and larger pig farms are currently dominating the Quebec industry.

For farms located in the CDs that went through type 1 structural change, though not statistically significant, the coefficients of "human population density" variables possess negative signs and may imply farm size would decrease in more population dense area. In addition, male and older pig farmers are found to be more likely to have larger farms. For the impact of temperature, a positive relationship between summer temperature and farm size is found. Again, some pig diseases can be triggered off when the temperature is too high.

For farms located in the CDs that experienced type 2 structural change, family farms and farms that farming with rented land are found to be more likely to expand production. On the other hand, farrow-to-finish farms would be less likely to expand production. Being located a further distance away from research institutions had discouraged farm expansion, given farmers' consideration over the availability of newly released information and consulting services. For age variables, we find younger pig farmers would be more likely to operate larger farms.

The derived standardized coefficients indicate the size of farms located in CDs that experienced type 1 structural change was more significantly affected by technology and the implementation of COOL. For internal factors, we detect farm operators' gender and age had greater impacts on farm structure adjustments. When examining CDs that underwent type 2 structural change, the implementation of COOL is found to be the biggest factor influencing farm structure changes, followed by technology and disease outbreaks. The internal factors that had more significant impacts on farm structure adjustments include off-farm work status and farm operational arrangement.

3.4.7 Comparisons among CDs experiencing Type 1 Structural Change, by Province

Regression results for the CDs (all provinces) that experienced type 1 structural change are presented in Table 3.19. We find during the period reporting dramatic increase in PRRS and PCVAD outbreak incidences (2003-2006), only the eastern provinces' farm structure was severely affected. COOL and technology innovation had positive impacts on the size of farms for all provinces. In terms of the impact of hog feed price ratio, we find only farmers in eastern province were price sensitive, and a possible explanation is that the western provinces enjoy the feeding advantage with lower feed costs (please see Figure 3.6).

For the impacts of farm characteristics, a negative relationship between farm size and farm numbers is detected in Ontario, while a positive one is found in Quebec and Manitoba. As the farm number decreased, pig farmers in Ontario chose to have larger farms to realize economies of scale, while operators in Quebec and Manitoba seemed to have smaller farms to meet the needs of niche markets. Part owners, who rent additional land for pig farming, in Ontario were more likely to have larger farm operations, while it is the full owners in Manitoba tended to have large pig farms. For the impacts of farmer characteristics, female operators in western provinces are found to be more likely to expand their operations, while male farmers in eastern provinces seemed to be more inclined to do so. Unlike other provinces, we find younger farmers in Quebec tended to operate larger farms.

The standardized coefficients suggest technology innovation, the implementation of COOL in U.S., and the availability of agricultural universities and veterinary services are the top three external factors that have greater impacts on the structure of farms located in CDs that experienced type 1 structural change. All three external factors are found to have positive effects on farm size. For internal factors, human population density, farm operators' gender and farm operational arrangement tended to play a more significant role in the determination of farm structure (i.e., farm size) than others. In particular, farm size is more likely to decrease in population-dense areas, while it is more likely to increase if the farms are family farms. For the impact of farm operators' gender, female farmers in western Canada are found to be more likely to expand their operations, while it is male farmers in eastern Canada are more inclined to do so.

3.4.8 Comparisons among CDs experiencing Type 2 Structural Change, by Province

Regression results for the CDs (all provinces) that experienced type 2 structural change are presented in Table 3.20. During the period reporting dramatic increase in PRRS and PCVAD outbreaks, only British Columbia was severely affected, and the eastern provinces were significantly affected by PED outbreaks. The reason that CDs experienced type 2 structural change were more affected by PED is these divisions are dominated by small pig farms. Unlike PRRS and PCVAD cases, the connection between farm size and PED prevalence is tenuous. Rather, it's the birds who play a significant role in PED transmission (McWilliams, 2014). With small farms having relatively poor biosecurity levels (e.g., no screens installed), they are at very high risks of getting infected. In addition, we find the U.S. COOL has affected the size of farms in Alberta, Saskatchewan, and Quebec. The reason that COOL is found to have no impact on the structure of farms in Ontario and British Columbia is they were more reliant on inter-provincial hog trade.

For the effects of farm characteristics on farm structure, a negative relationship between farm size and farm number is detected in Ontario, while a positive one is found in Quebec.

Farrow-to-finish farmers are found to be more likely to have smaller farms, given cost considerations and farmers' tendency to reduce the risk of infection from older pigs to younger and more susceptible piglets. Family farms in Saskatchewan were less likely to expand farm operations, while those in British Columbia and Quebec were more likely to operate larger farms. For the effects of farmer characteristics on farm structure, younger farmers in all provinces are found to be more likely to have larger pig farms.

For CDs underwent type 2 structural changes, the external factors that had played a more significant role in the determination of farm size include disease outbreaks and technology. In addition, disease outbreaks are found to have negative impacts on farm size, while technology is detected to have positive effect on farm size. For internal factors, farm operators' age and the availability of slaughter plants are found to have bigger impacts on the structure of farms. Particularly, farm operators' age has a negative influence on farm size, while the availability of slaughter plants has a positive impact on farm size.

To ascertain a cluster approach is a necessary tool to address spatial autocorrelation, we first run Lagrange Multiplier (LM) tests to examine whether spatial autocorrelation is present. The results from LM tests are shown in Table 3.21 and exhibit the existence of spatial autocorrelation. Thus, we employ the cluster approach and re-estimate the models. To further ascertain the appropriateness of the estimated models, a Hausman test for the choice of panel model, variance inflation factor (VIF) test of collinearity, likelihood ratio test (LR) of Heteroscedasticity, and LM test of autocorrelation are conducted right after model estimations. The results from Hausman tests (Table 3.22) confirm random effects models are appropriate for estimations, and VIF values affirm multicollinearity is not a problem as the values are lower than 10. The results from the LR tests (Table 3.23) show no violation of homoscedasticity. In terms of the LM tests (Table 3.24), although we fail to reject the null of autocorrelation in some regressions, serial correlation is not a concern as the data we used is micro panels (Greene, 2008).

3.5 Conclusion

In this chapter, the method employed for the empirical analyses, variables used for the estimations, and the empirical results are described. In particular, the factors (both external and internal) influencing the farm structure are examined to address the objective of investigating how these factors influenced the Canadian pig industry’s structure. The estimation results indicate pig diseases did affect the Canadian pig industry’s structure. For the regions that experienced a decrease in pig farm numbers and an increase in total pig numbers (type 1 structural change), they seemed to be affected more by porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) outbreaks, while the regions that went through decreases in both pig farm numbers and total pig numbers (type 2 structural change) seemed to be affected more by porcine epidemic outbreaks diarrhea (PED) outbreaks. The reason that CDs experiencing type 1 structural change are affected more by PRRS and PCVAD is due to the strong connection between farm size and these two diseases. Large pig farms with higher pig densities are more likely to get infected with PRRS and PCVAD. For PED, it is the intermediary (especially birds) that plays a more significant role in its spread. With small pig farms lacking biosecurity measures (e.g., no screens installed), CDs undergoing type 2 structural change are more influenced by PED. Moreover, our results suggest pig diseases have played a more significant role in the structure of farms in eastern Canada, which is in accordance with previous literature claiming pig diseases are more prevalent in eastern provinces (e.g., Dewey, 2000; Brar et al., 2015).

When examining which factors have greater impacts on farm structure changes, the standardized coefficients indicate technology, the implementation of U.S. country of origin labelling (COOL), and the availability of agricultural universities and veterinary services were the top three external factors that have greater impacts on the structure of farms located in CDs that experienced type 1 structural change. The internal factors that had played a more significant role in the determination of farm structure include human population density, farm operators' gender and farm operational arrangement. For CDs that underwent type 2 structural change, the external factors that had bigger impacts on farm size consist of disease outbreaks and technology innovations. For internal factors, farm operators' age and the accessibility of slaughter plants are found to have greater influences on the structure of farms.

Heterogeneity in structural change across different regions does exist. If the empirical analyses were conducted at the national level, over-and under-estimations of the impacts of different factors on farm structure would be present. Take Alberta as an example, older farmers farmed in the regions that experienced type 1 structural change were found to be more likely to operate larger pig farms, while it is the younger farmers who farmed in the regions that experienced type 2 structural change were more inclined to do so. Therefore, it is necessary to examine the industry's structural change with the differentiation of types of structural change. Also important to note is that the impact a certain factor has on the industry's structural change depends not only on the value of the variable itself, but also on the level of other factors, and this confirms the necessity to estimate farm structure changes with differentiation of regions (by Province in our case) and types of structural change.

Figures

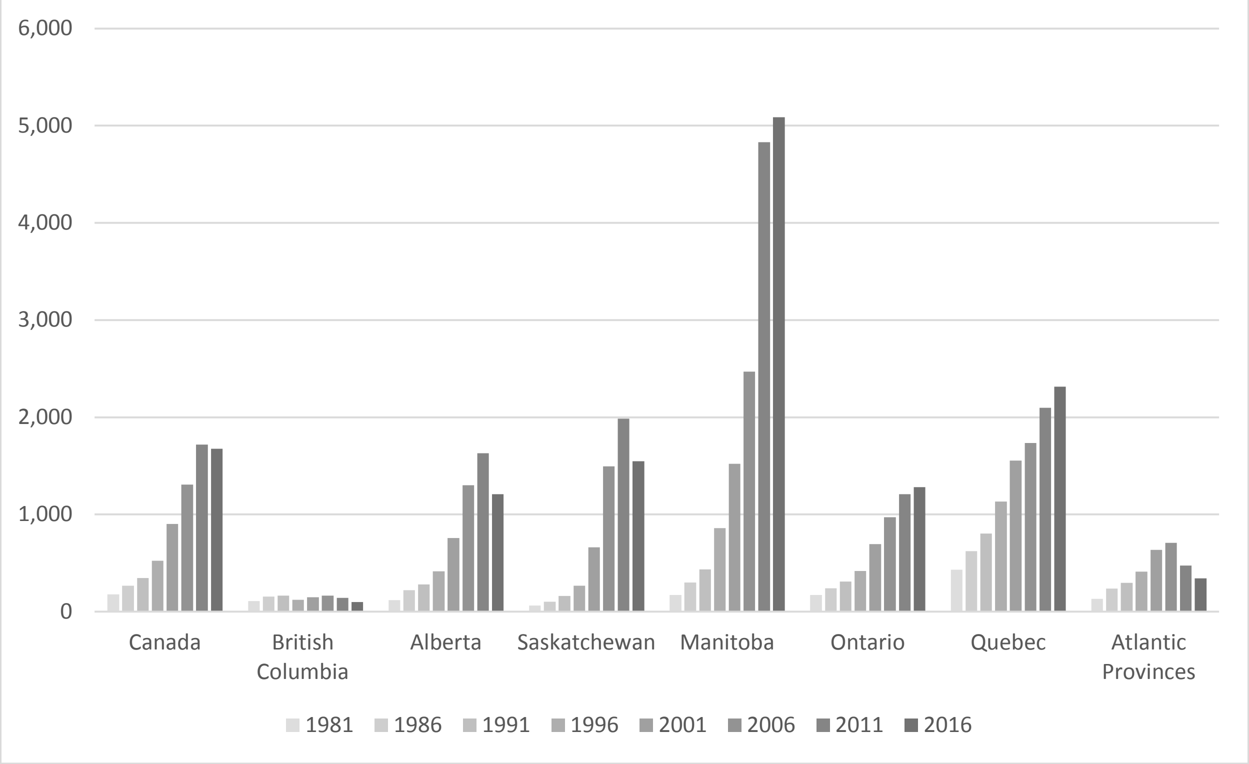

Figure 3.1. The Evolution of Pig Farm Size, by Province, 1981-2016.

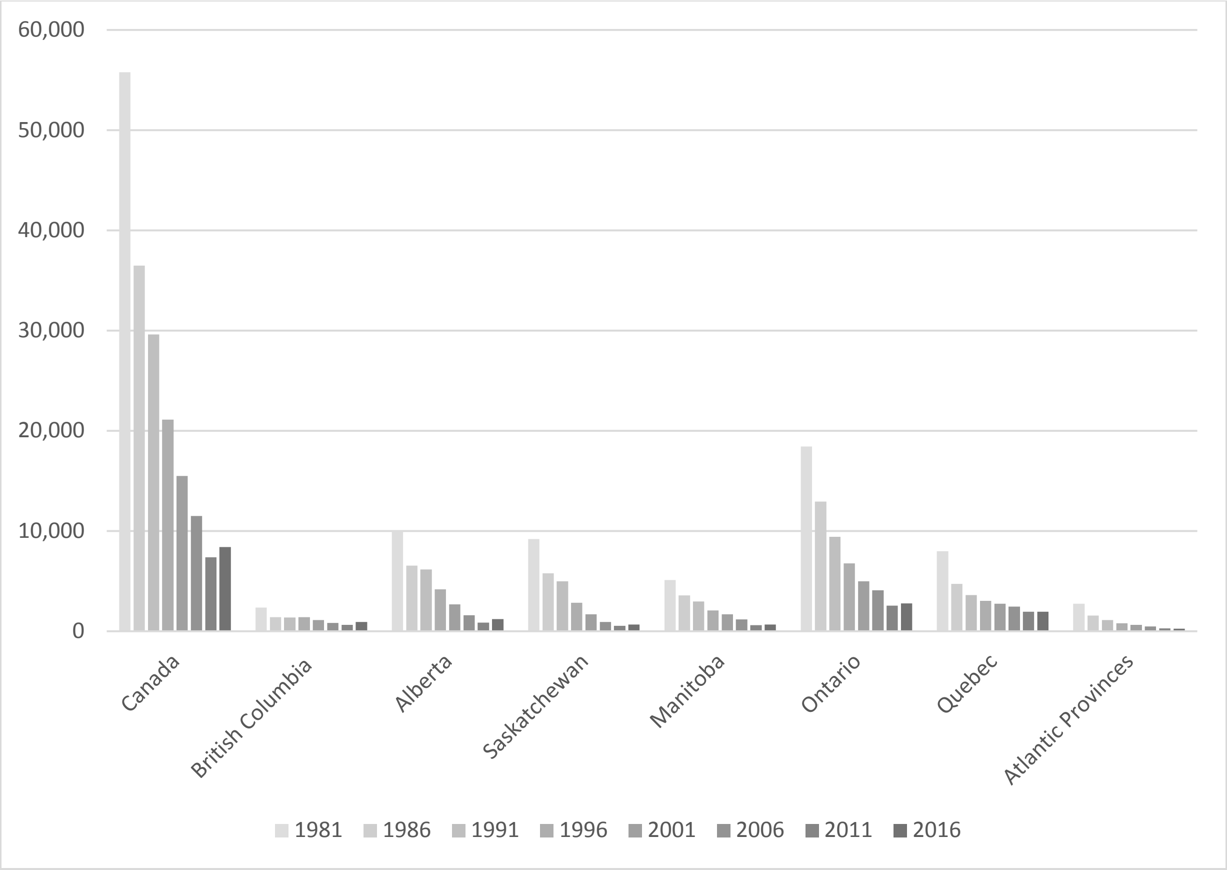

Figure 3.2. The Evolution of Pig Farm Numbers, by Province, 1981-2016.

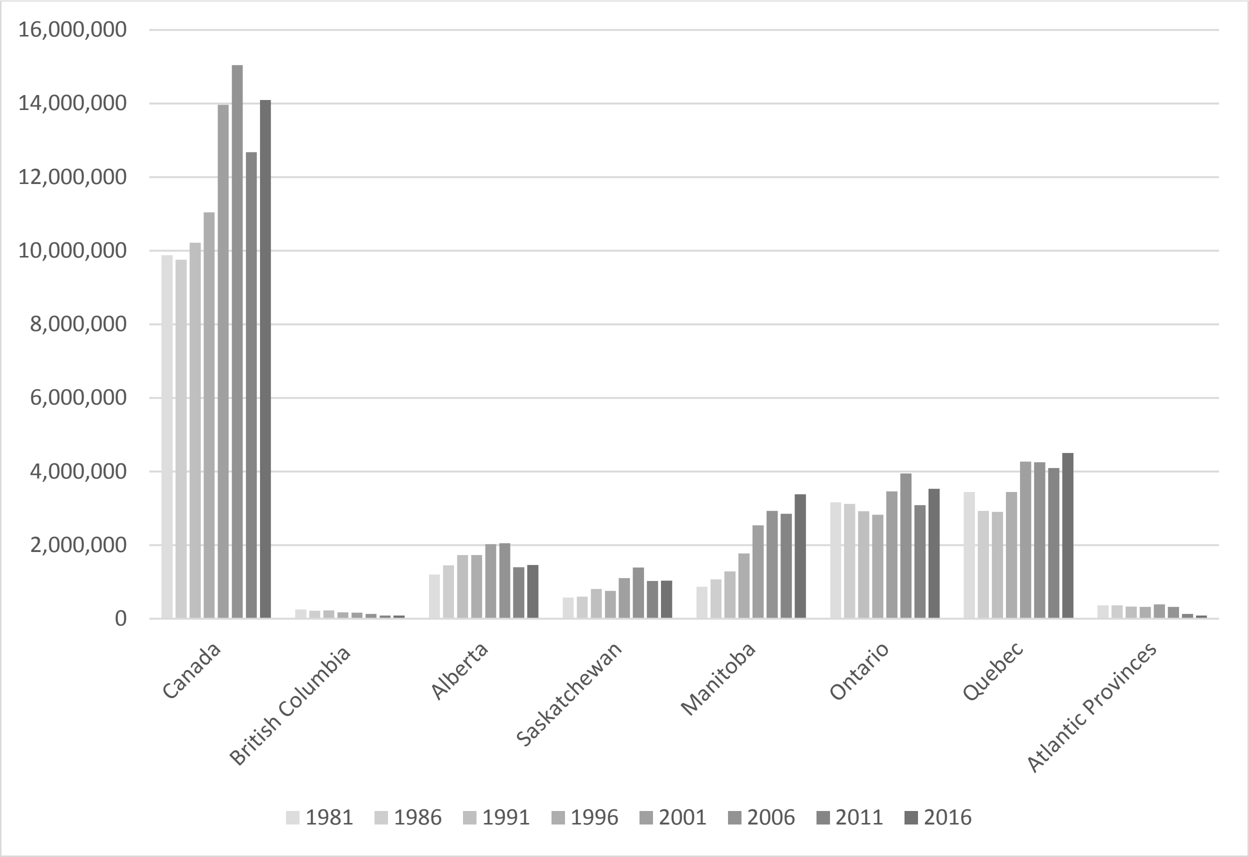

Figure 3.3. The Evolution of Pig Numbers, by Province, 1981-2016.

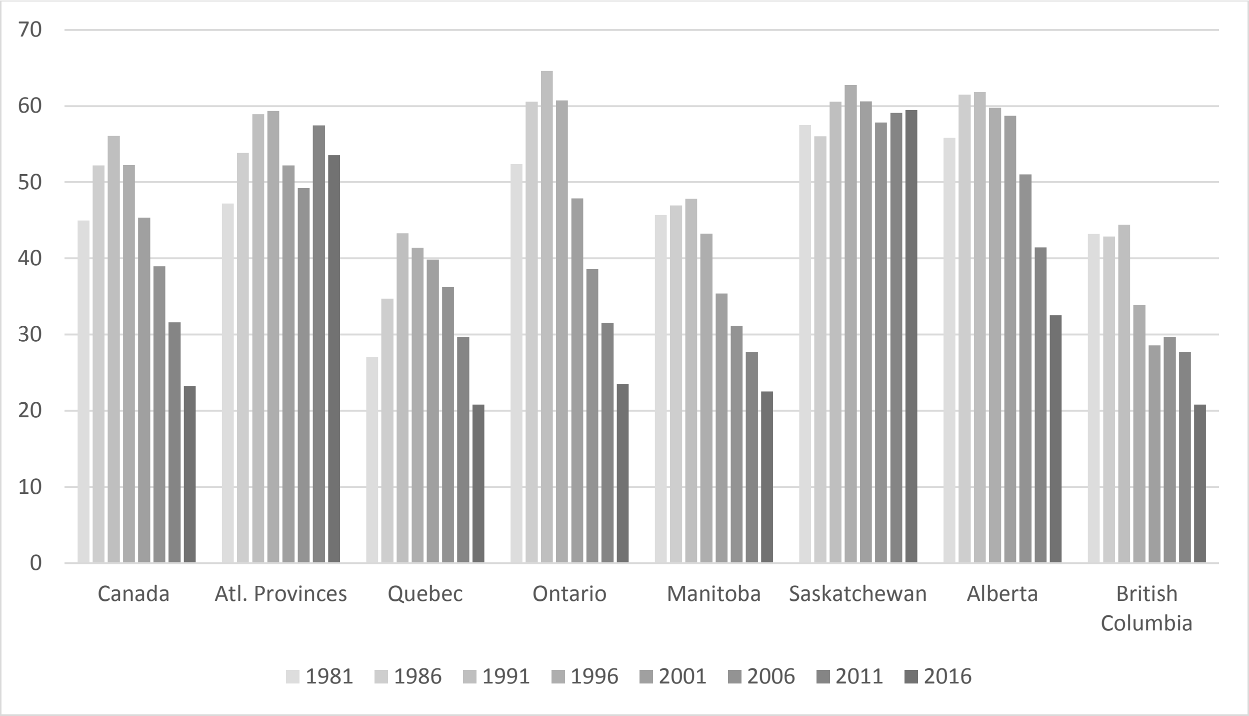

Figure 3.4. The Percentage of the Farms that were in Farrow-to-Finish Units, by Province, 1981-2016.

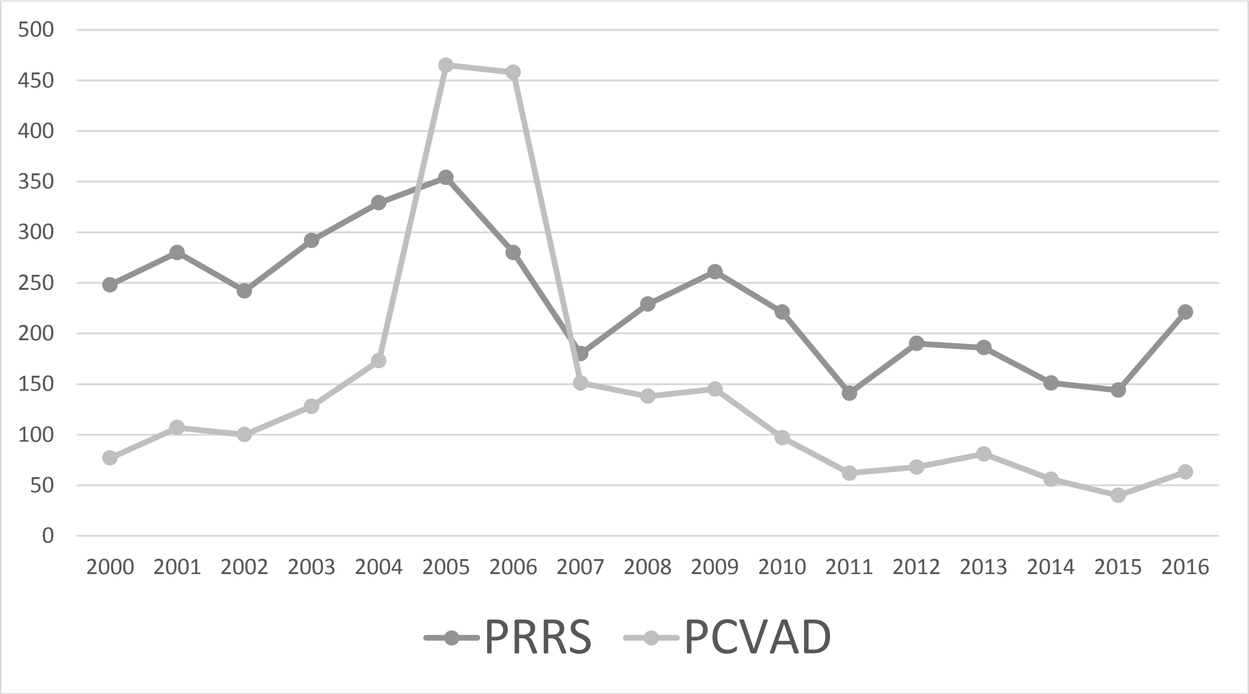

Figure 3.5. Number of PRRS and PCVAD Positive Cases Submitted to MAPAQ, Quebec, 2000-2016.

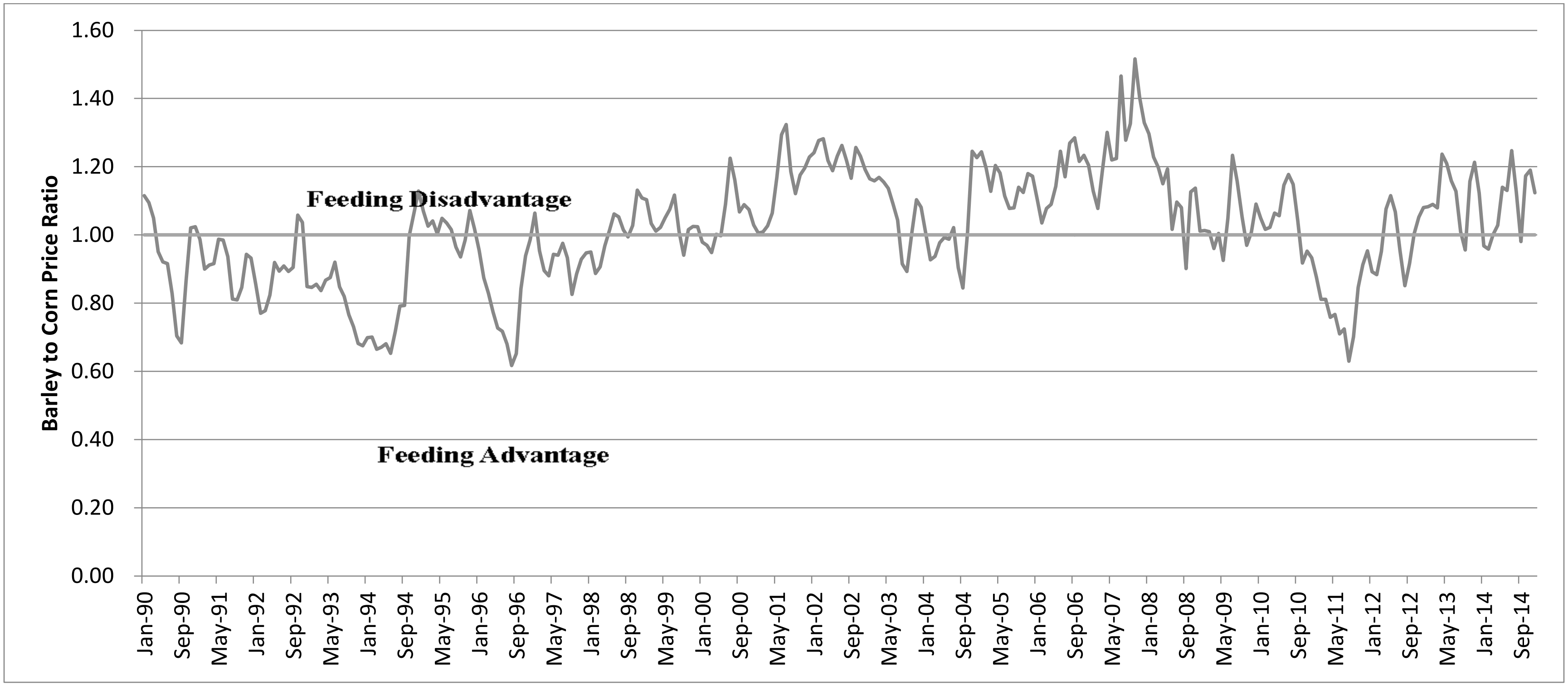

Figure 3.6. Western Canada Feeding Advantage (Alberta Barley versus Ontario Corn in CAN$).

Tables

Table 3.1. Data Definition and Level of Availability

Variables	**Definition**
Provincial level data	
COOL implementation (D)	Time dummy indicating the implementation of U.S. country of origin labeling
Disease variables	
Dramatic increase in PRRS and outbreak (D)	Time dummy indicating the dramatic increase in PRRS and PCVAD cases
PED outbreak (D)	Time dummy indicating the presence of PED
Hog-feed price ratio (C)	The ratio of the market hog price in dollars per 100 pounds to the price of feed per bushel
Census Division level data	
Dependent variable	
Farm Size (C)	The census division (CD)'s average number of pigs per farm
Independent variable	
Distance to research institutions (C)	Distance (in km) from the centroid of the CD to the nearest research institution
Distance to slaughter plant (C)	Distance (in km) from the centroid of the CD to the nearest slaughter plant
Family farm (C)	% of family farms within the CD
Human population density (C)	Population density per square kilometer within the CD
Gender (C)	% of male operators within the CD
Land tenure (C)	% of farms that rent land from government or others for hog farming within the CD
No Off-farm work (C)	% of farmers who have no off-farm work within the CD
Number of pig farms (C)	Number of pig farms within the CD
Operator's average age (C)	The average age of the farmers within the CD
Operator living on farm (C)	% of farmers who live on farm within the CD
Production type (C)	% of farrow-to-finish-units within the CD
Technology (C)	% of farms using computers in farm business within the CD
Temperature (C)	The average summer temperature (in °C) within the CD

Table 3.2. Descriptive Statistics of Variables Specified in the Model, British Columbia, 1981.

	1981			
	Mean	Std. Dev	Min	Max
Provincial level data				
Hog-feed price ratio (C)	50.02	0	50.02	50.02
Census Division level data				
Dependent variable				
Farm Size (C)	67.59	87.84	8	335
Independent variable				
Distance to Slaughter plant (C)	3.12	2.19	0.14	9.32
Distance to Research institutions (0≤ d <0.5km) (D)	0.24	0.44	0	1
Distance to Research institutions (0.5≤ d <1km) (D)	0.06	0.24	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0	0	0	0
Distance to Research institutions (1.5≤ d <2km) (D)	0.12	0.33	0	1
Distance to Research institutions (2≤ d <3km) (D)	0.12	0.33	0	1
Distance to Research institutions (3≤ d <4km) (D)	0.29	119.03	0	1
Distance to Research institutions (d ≥4km) (D)	0.18	0.39	0	1
Family farm (C)	6.59	8.49	0	29
Human population density (C)	6.81	12.67	0.23	54.14
Gender (% of male operators) (C)	82.71	22.19	33	100
Land tenure (C)	15.59	11.54	0	39
No Off-farm work (C)	44.06	31.43	0	100
Number of pig farms (C)	121.24	106.45	32	446
Operator's average age (age ≤45) (D)	0.41	0.51	0	1
Operator's average age (45≤ age <50) (D)	0.41	0.51	0	1
Operator's average age (age ≥50) (D)	0.18	0.39	0	1
Operator living on farm (C)	79.65	23.86	0	99
Production type (C)	35.94	17.21	0	59
Technology (C)	0	0	0	0
Temperature (C)	12.75	1.30	10.25	14.46
Number of observations				17

Table 3.3. Descriptive Statistics of Variables Specified in the Model, Alberta, 1981.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	50.02	0	50.02	50.02	50.02	0	50.02	50.02
Census Division level data								
Dependent variable								
Farm size (C)	175.86	93.87	38	297	102.71	51.81	29	196
Independent variable								
Distance to Slaughter plant (C)	2.72	0.73	1.58	3.96				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0	0	0	0
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.14	0.38	0	0
Distance to Slaughter plant (d ≥3km) (D)					0.14	0.38	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	4.71	3.64	0	11	3.86	2.85	0	9
Human population density (C)					14.76	20.16	1.63	44.67
Human population density (0< p ≤1) (D)	0.57	0.53	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	1				
Human population density (2< p ≤4) (D)	0.14	0.38	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Gender (% of male operators) (C)	98	3	92	100	97.71	1.70	96	100
Land tenure (C)	31.43	9.40	17	42	30.71	11.10	9	42
No Off-farm work (C)	48.57	15.04	25	69	38	29.56	0	67
Number of pig farms (C)	486.29	385.20	144	1239	941.43	511.50	146	1682
Operator's average age (C)	46.03	3.68	42	52	48.83	6.29	43.70	62.30
Operator living on farm (C)	90.43	12.69	63	99	54.14	14.16	25	68
Production type (C)	31.43	9.40	35	100	55.00	6.06	45	62
Technology (C)	0	0	0	0	0	0	0	0
Temperature (C)	13.42	1.12	11.88	14.75	11.81	1.06	10.16	13.17
Number of observations				7				7

Table 3.4. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 1981.

	Type 1 structural change				**Type 2 Structural Change**			
Variables	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	50.02	0	50.02	50.02	50.02	0	50.02	50.02
Census Division level data								
Dependent variable								
Farm size (C)	467	189	245	750	63	29	16	98
Independent variable								
Distance to Slaughter plant (C)					1.14	0.80	0.36	2.81
Distance to Slaughter plant (1≤ d <2km) (D)	0.63	0.52	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.13	0.35	0	1				
Distance to Research institutions (C)	1.40	0.51	0.75	2.02				
Distance to Research institutions (0≤ d <0.5km) (D)					0.38	0.52	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.38	0.52	0	1
Distance to Research institutions (d ≥1km) (D)					0	0	0	0
Family farm (C)	2.5	3.30	0	8	4.5	2.62	0	9
Human population density (0≤ p <1) (D)	0	0	0	0				
Human population density (1≤ p <1.5) (D)	0	0	0	0				
Human population density (1.5≤ p <2) (D)	0	0	0	0	0	0	0	0
Human population density (2≤ p <2.5) (D)	1	0	1	1	0.13	0.35	0	1
Human population density (2.5≤ p <5) (D)					0.13	0.35	0	1
Human population density (5≤ p <10) (D)					0.38	0.52	0	1
Human population density (10≤ p <15) (D)					0	0	0	0
Human population density (p ≥15) (D)					0.38	0.52	0	1
Gender (% of male operators) (C)	92.75	17.50	50	100	97.25	5.34	86	100
Land tenure (C)	36	9.86	14	45	41.38	7.01	30	52
No Off-farm work (C)	41	19.77	0	60	58.13	15.82	40	89
Number of pig farms (C)	467.38	188.87	245	750	646	320.05	342	1322
Operator's average age (age ≤45) (D)	0.38	0.52	0	1	0.25	0.46	0	1
Operator's average age (45≤ age <50) (D)	0.63	0.52	0	1	0.75	0.46	0	1
Operator's average age (age ≥50) (D)	0	0	0	0	0	0	0	0
Operator living on farm (C)	87	16.56	53	100	92.13	4.76	83	97
Production type (C)	61	17.12	36	87	56.88	13.47	37	78
Technology (C)	0	0	0	0	0	0	0	0
Temperature (C)	13.56	0.61	12.59	14.25	13.74	0.70	12.64	14.43
Number of observations				8				8

Table 3.5. Descriptive Statistics of Variables Specified in the Model, Manitoba, 1981.

	Mean	Std. Dev	Min	Max
Provincial level data				
Hog-feed price ratio (C)	50.02	0	50.02	50.02
Census Division level data				
Dependent variable				
Farm size (C)	222	157	81	687
Independent variable				
Distance to Slaughter plant (C)	1.04	0.77	0.12	2.41
Distance to Research institutions (0≤ d <1km) (D)	0.40	0.51	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.20	0.41	0	1
Distance to Research institutions (d ≥1.5km) (D)	0.40	0.51	0	1
Family farm (C)	4.33	4.95	0	18
Human population density (C)	15.06	33.75	1.37	135.41
Gender (% of male operators) (C)	84.87	11.43	54	100
Land tenure (C)	33.07	12.38	0	48
No Off-farm work (C)	56.27	14.71	33	78
Number of pig farms (C)	262.73	172.00	6	592
Operator's average age (C)	44.66	2.99	37	48
Operator living on farm (C)	84.87	25.34	0	100
Production type (C)	44.13	17.36	0	76
Technology (C)	0	0	0	0
Temperature (C)	13.90	0.54	12.73	14.51
Number of observations				15

Table 3.6. Descriptive Statistics of Variables Specified in the Model, Ontario, 1981.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	50.02	0	50.02	50.02	50.02	0	50.02	50.02
Census Division level data								
Dependent variable								
Farm size (C)	230	70	96	319	104	71	7	242
Independent variable								
Distance to Slaughter plant (C)	1.29	0.54	0.67	2.2				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.24	0.44	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.18	0.39	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.18	0.39	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.27	0.45	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.12	0.33	0	1
Distance to Research institutions (C)	0.38	0.18	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.24	0.44	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.24	0.44	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.27	0.45	0	1
Distance to Research institutions (d ≥1km) (D)					0.24	0.44	0	1
Family farm (C)	3.33	1.41	1	6	3.33	4.01	0	14
Human population density (C)	33.37	10.77	17.36	53.32	79.26	108.99	1.47	394.99
Gender (% of male operators) (C)	96.44	2.55	92	100	91.78	19.51	0	100
Land tenure (C)	29.56	3.78	22	34	29.58	13.25	0	61
No Off-farm work (C)	57.11	6.92	42	67	45.39	16.35	0	78
Number of pig farms (C)	804.89	406.22	421	1481	330.94	306.08	32	1255
Operator's average age (C)	45.99	1.56	43.8	49	47.13	2.61	39.9	51.9
Operator living on farm (C)	95.44	1.51	92	97	90.12	10.56	56	100
Production type (C)	52.33	12.09	21	63	45.00	16.33	0	100
Technology (C)	0	0	0	0	0	0	0	0
Temperature (C)	15.49	0.48	14.68	16.13	14.45	1.47	10.92	16.92
Number of observations				9				30

Table 3.7. Descriptive Statistics of Variables Specified in the Model, Quebec, 1981.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	50.02	0.00	50.02	50.02	50.02	0.00	50.02	50.02
Census Division level data								
Dependent variable								
Farm size (C)	139	152	15	635	388	325	3	1236
Independent variable								
Distance to Slaughter plant (C)	0.62	0.50	0.12	2.85	0.63	0.52	0.07	2.45
Distance to Research institutions (C)	0.74	0.87	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.08	0.28	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.29	0.46	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.21	0.41	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.29	0.46	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	7.28	5.80	0	25	5.75	5.88	0	25
Human population density (0< p <100) (D)	0.06	0.23	0	1	0.13	0.34	0	1
Human population density (10< p <20) (D)	0.39	0.49	0	1	0.21	0.41	0	1
Human population density (20≤ p <30) (D)	0.11	0.32	0	1	0.08	0.28	0	1
Human population density (30≤ p <60) (D)	0.06	0.23	0	1	0.17	0.38	0	1
Human population density (60≤ p <90) (D)	0.19	0.40	0	1	0.13	0.34	0	1
Human population density (90≤ p <180) (D)	0.14	0.35	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.06	0.23	0	1	0.13	0.34	0	1
Gender (% of male operators) (C)	97.03	5.29	80	100	93.77	21.19	0	100
Land tenure (C)	15.56	11.04	0	55	16.63	12.62		57
No Off-farm work (C)	66.83	22.53	0	100	61.70	29.38	0	100
Number of pig farms (C)	139.25	151.96	15	635	79.29	78.15	11	311
Operator's average age (age ≤45) (D)	0.61	0.49	0	1	0.50	0.51	0	1
Operator's average age (45≤ age <50) (D)	0.39	0.49	0	1	0.42	0.50	0	1
Operator's average age (age ≥50) (D)	0	0	0	0	0.08	0.28	0	1
Operator living on farm (C)	86.47	13.81	50	100	81.54	28.07	0	100
Production type (C)	28.28	15.40	6	89	26.96	17.61	0	72
Technology (C)	0	0	0	0	0	0	0	0
Temperature (C)	13.64	1.26	11.48	15.64	13.66	1.55	9.97	15.78
Number of observations				36				24

Table 3.8. Pig Farm Size (Average Herd), Canada and Provinces, 1981 to 2016.

Province	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**	**2016**
Canada	177	268	345	523	902	1,308	1,720	1,677
British Columbia	109	155	166	123	148	166	142	98
Alberta	120	223	281	415	757	1,302	1,631	1,207
Saskatchewan	63	104	163	266	662	1,493	1,986	1,548
Manitoba	172	301	434	861	1,523	2,468	4,831	5,087
Ontario	172	241	310	418	695	971	1,208	1,280
Quebec	430	622	805	1,133	1,556	1,734	2,098	2,316
Atlantic Provinces	133	237	298	413	635	709	474	341

Table 3.9. Distribution of Hog Production (Number of Hogs), by Provinces, 1981 and 2016.

Provinces	**1981**	**2016**
British Columbia	2.6%	0.6%
Alberta	12.1%	10.4%
Saskatchewan	5.8%	7.3%
Manitoba	8.9%	24.0%
Ontario	32.1%	25.1%
Quebec	34.8%	32.0%
Atlantic Provinces	3.7%	0.6%

Table 3.10. Hog Production, by Provinces, 1981 and 2016.

Provinces	1981 (head)	2016(head)	Difference between 1981 and 2016 (%)
Canada	9,875,065	14,091,503	42.7%
British Columbia	254,895	88,862	-65.1%
Alberta	1,199,397	1,462,247	21.9%
Saskatchewan	574,334	1,033,778	80.0%
Manitoba	874,995	3,382,897	286.6%
Ontario	3,165,837	3,534,104	11.6%
Quebec	3,440,724	4,504,600	30.9%
Atlantic Provinces	364,883	85,015	-76.7%

Table 3.11. Hog Production, by Provinces, 2006 and 2011.

Provinces	2006 (heads)	2011 (heads)	Difference between 2006 and 2011 (%)
Canada	15,043,132	12,679,104	-15.7%
British Columbia	135,826	89,067	-34.4%
Alberta	2,052,067	1,397,534	-31.9%
Saskatchewan	1,388,886	1,028,530	-25.9%
Manitoba	2,932,548	2,850,581	-2.8%
Ontario	3,950,592	3,088,646	-21.8%
Quebec	4,255,637	4,096,678	-3.7%
Atlantic Provinces	327,576	128,068	-60.9%

Table 3.12. Type of Pig Production, Canada and Provinces, 1981 and 2016.

Provinces	**1981**				**2016**			
	Farrowing	**Finishing**	**Farrow to Finish**	**Unclassified**	**Farrowing**	**Finishing**	**Farrow to Finish**	**Unclassified**
Canada	28.5%	21.0%	45.0%	5.5%	22.6%	48.9%	23.2%	5.3%
British Columbia	17.8%	10.4%	43.2%	28.6%	8.9%	9.9%	20.8%	60.4%
Alberta	18.4%	19.0%	55.8%	6.7%	21.1%	34.9%	32.5%	11.4%
Saskatchewan	18.9%	17.9%	57.5%	5.7%	18.9%	10.8%	59.5%	10.8%
Manitoba	26.9%	23.8%	45.7%	3.6%	24.4%	48.1%	22.5%	5.0%
Ontario	24.1%	18.0%	52.3%	5.6%	23.8%	50.4%	23.5%	2.3%
Quebec	43.1%	28.2%	27.0%	1.8%	22.4%	54.0%	20.8%	2.8%
Atlantic provinces	29.9%	17.9%	43.1%	9.1%	25.5%	17.0%	40.4%	17.0%

Table 3.13. Estimates of the Economic Impacts of Various Factors on Farm Size, British Columbia.

	Type 2 structural change		
	Coeff	Std. dev	SC
Provincial level data			
COOL implementation (D)	338.434	227.756	0.799
Dramatic increase in pig disease outbreak (D)	-205.163*	122.288	-0.328*
Hog-feed price ratio (C)	7.656	9.559	0.463
Census Division level data			
Distance to Slaughter plant (C)	6.566	12.202	0.067
Distance to Research institutions (0.5≤ d <1km) (D)	-220.567**	105.266	-0.251**
Distance to Research institutions (1≤ d <1.5km) (D)	-247.963**	111.204	-0.144**
Distance to Research institutions (1.5≤ d <2km) (D)	-279.637***	111.013	-0.423***
Distance to Research institutions (2≤ d <3km) (D)	-178.035*	92.441	-0.284*
Distance to Research institutions (3≤ d <4km) (D)	-137.171	119.025	-0.309
Distance to Research institutions (d ≥4km) (D)	-111.327	89.725	-0.198
Family farm (C)	12.051***	2.977	0.816***
Human population density (C)	-0.482***	0.104	-0.351***
Gender (% of male operators) (C)	0.128	0.623	0.019
Land tenure (C)	6.390***	1.875	0.379***
Number of pig farms (C)	-0.098	0.419	-0.028
No Off-farm work (C)	0.118	0.44	0.021
Operator living on farm (C)	-0.158	0.654	-0.019
Operator's average age (45≤ age <50) (D)	-48.439*	26.384	-0.111*
Operator's average age (age ≥50) (D)	-180.382*	103.212	-0.353*
Production type (C)	1.043	1.131	0.129
Technology (C)	0.945	1.155	0.140
Temperature (C)	22.268***	7.632	0.206***
Constant	-553.922	428.147	
R_Squared		0.8	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.14. Estimates of the Economic Impacts of Various Factors on Farm size, Alberta.

	Type 1 structural change			**Type 2 structural change**		
	Coeff	Std. dev	SC	Coeff	Std. dev	SC
Provincial level data						
COOL implementation (D)	595.474*	429.339	0.190*	495.432***	184.879	0.499***
Dramatic increase in pig disease outbreak (D)	447.349	487.596	0.097	-105.492	195.834	-0.073
Hog-feed price ratio (C)	2.813	18.409	0.026	10.466***	2.129	0.301***
Census Division level data						
Distance to Slaughter plant (C)	91.818	239.91	0.052			
Distance to Slaughter plant (0 .5≤ d <1km) (D)				-68.167	81.847	-0.056
Distance to Slaughter plant (1≤ d < 1.5km) (D)				156.336	114.121	0.133
Distance to Slaughter plant (1 .5≤ d <2km) (D)				-320.914	207.24	-0.150
Distance to Slaughter plant (2≤ d <2.5km) (D)				-370.043***	46.258	-0.238***
Distance to Slaughter plant (2.5≤ d < 3km) (D)				-489.781	332.371	-0.374
Distance to Slaughter plant (d ≥3km) (D)				172.438	152.804	0.119
Distance to Research institutions (1≤ d <2km) (D)	-96.769	313.92	-0.032	-634.894***	147.862	-0.596***
Distance to Research institutions (d ≥2km) (D)	-1915.170***	603.464	-0.441***	35.524	319.035	0.026
Family farm (C)	-3.159	10.149	-0.042	5.294	5.318	0.180
Gender (% of male operators) (C)	-6.716**	2.885	-0.110**	-4.058***	1.533	-0.208***
Human population density (C)				-7.659***	2.654	-0.515***
Human population density (1< p <2) (D)	-491.188	416.732	-0.107			
Human population density (2≤ p <4) (D)	-612.667***	91.27	-0.200***			
Human population density (p ≥4) (D)	76.605	274.503	0.019			
Land tenure (C)	-5.33	5.182	-0.059	-0.593	3.936	-0.021
Number of pig farms (C)	1.769	0.941	0.264	0.099	0.112	0.076
No Off-farm work (C)	-11.883	7.484	-0.176	5.957	5.705	0.244
Operator's average age (C)	130.483***	28.144	0.430***	-11.011*	6.001	-0.174*
Operator living on farm (C)	10.761	6.944	0.071	10.221***	3.663	0.507***
Production type (C)	8.297	12.606	0.104	-3.748	3.943	-0.145
Technology (C)	32.922***	8.437	0.708***	9.269**	3.773	0.604**
Temperature (C)	-430.943*	240.968	-0.344*	-59.807**	28.225	-0.129
Constant	-672.933	571.043		318.79	783.206	
R_Squared		0.89			0.86	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.15. Estimates of the Economic Impacts of Various Factors on Farm size, Saskatchewan.

	Type 1 structural change			**Type 2 structural change**		
	Coeff	Std. dev	SC	Coeff	Std. dev	SC
Provincial level data						
COOL implementation (D)	1062.950**	468.679	0.362**	545.718*	328.301	0.796*
Dramatic increase in pig disease outbreak (D)	508.854	420.784	0.115	-295.996	281.019	-0.316
Hog-feed price ratio (C)	1.031	9.799	0.012	1.308	4.291	0.064
Census Division level data						
Distance to Slaughter plant (C)				-190.464***	61.848	-0.451***
Distance to Slaughter plant (2≤ d <3km) (D)	1314.697***	283.658	0.391***			
Distance to Slaughter plant (d ≥2km) (D)	186.485	207.287	0.058			
Distance to Research institutions (C)	-865.365***	207.627	-0.285***			
Distance to Research institutions (0.5≤ d <1km) (D)				307.556***	53.762	0.476***
Distance to Research institutions (d ≥1km) (D)				519.049***	59.016	0.726***
Family farm (C)	5.674	18.952	0.069	-9.061***	3.512	-0.480***
Gender (% of male operators) (C)	-13.762**	5.579	-0.276**	4.259	2.864	0.369
Human population density (1≤ p <1.5) (D)	-1530.449***	274.539	-0.515***			
Human population density (1.5≤ p <2) (D)	-1162.912***	150.584	-0.354***			
Human population density (2≤ p <2.5) (D)	-292.968	465.008	-0.091	-592.348***	259.268	-0.847***
Human population density (2.5≤ p <5) (D)				-305.220***	184.257	-0.416***
Human population density (5≤ p <10) (D)				-770.004***	337.961	-0.769***
Human population density (10≤ p <15) (D)				-244.860***	120.133	-0.290***
Human population density (p ≥15) (D)				-586.394***	339.077	-0.696***
Land tenure (C)	-7.611	9.225	-0.108	0.896	0.721	0.060
Number of pig farms (C)	-0.49	1.108	-0.059	0.332	0.088	0.279
No Off-farm work (C)	-0.155	3.805	-0.004	-0.293	3.376	-0.016
Operator's average age (45≤ age <50) (D)	278.789	304.948	0.096	-97.155***	34.546	-0.147***
Operator's average age (age ≥50) (D)	598.321***	264.081	0.182***	192.818***	72.314	0.229***
Operator living on farm (C)	5.733	21.864	0.053	3.027	2.554	0.116
Production type (C)	4.527	3.639	0.062	5.349	3.658	0.347
Technology (C)	17.661***	5.887	0.432***	5.991***	0.574	0.573***
Temperature (C)	-233.492***	56.39	-0.145***	18.11	33.777	0.055
Constant	5023.406	1920.878		-769.791	800.876	
R_Squared		0.77			0.8	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.16. Estimates of the Economic Impacts of Various Factors on Farm size, Manitoba.

	Type 1 structural change		
	Coeff	Std. dev	SC
Provincial level data			
COOL implementation (D)	1045.867*	625.585	0.241*
Disease variables			
Dramatic increase in pig disease outbreak (D)	-278.65	594.944	-0.043
PED outbreak (D)	502.992	547.799	0.081
Hog-feed price ratio (C)	4.755	12.706	0.030
Census Division level data			
Distance to Slaughter plant (C)	281.522	386.334	0.068
Distance to Research institutions (1≤ d <1.5km) (D)	-1160.968**	589.662	-0.225**
Distance to Research institutions (d ≥1.5km) (D)	-885.998**	430.491	-0.208**
Family farm (C)	22.351	21.714	0.182
Gender (% of male operators) (C)	-2.838	6.778	-0.033
Human population density (C)	-1.091*	0.627	-0.107*
Land tenure (C)	-16.708**	7.415	-0.116**
Number of pig farms (C)	2.496***	0.841	0.151***
No Off-farm work (C)	3.408	5.671	0.027
Operator's average age (C)	68.372**	33.682	0.155**
Operator living on farm (C)	-9.326	10.387	-0.072
Production type (C)	8.456	17.482	0.069
Technology (C)	22.811***	8.561	0.372***
Temperature (C)	-47.014	78.073	-0.025
Constant	-2512.05	2051.78	
R_Squared		0.64	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.17. Estimates of the Economic Impacts of Various Factors on Farm size, Ontario.

	Type 1 structural change			**Type 2 structural change**		
	Coeff	Std. dev	SC	Coeff	Std. dev	SC
Provincial level data						
COOL implementation (D)	719.504***	244.961	0.470***	45.583	36.952	0.103
Disease variables						
Dramatic increase in pig disease outbreak (D)	-510.595***	198.14	-0.228***	-8.876	50.154	-0.014
PED outbreak (D)	94.458	152.304	0.042	-87.451*	49.518	-0.125*
Hog-feed price ratio (C)	20.428***	1.008	0.320***	0.505	0.947	0.028
Census Division level data						
Distance to Slaughter plant (C)	-196.880***	25.937	-0.139***			
Distance to Slaughter plant (0 .5≤ d <1km) (D)				-58.922	37.012	-0.114
Distance to Slaughter plant (1≤ d < 2km) (D)				-219.874***	42.334	-0.470***
Distance to Slaughter plant (2≤ d <3km) (D)				-207.262***	89.566	-0.355***
Distance to Slaughter plant (d ≥3m) (D)				-228.693***	102.118	-0.312***
Distance to Research institutions (C)	729.439***	60.599	0.469***			
Distance to Research institutions (0.25≤ d <0.5km) (D)				49.634	67.921	0.108
Distance to Research institutions (0.5≤ d <1km) (D)				-2.148	60.263	-0.004
Distance to Research institutions (d ≥1km) (D)				43.543	87.388	0.087
Family farm (C)	11.531***	1.045	0.295***	5.707	3.288	0.414
Gender (% of male operators) (C)	-0.243	2.23	-0.007	0.188	0.231	0.028
Human population density (C)	0.853***	0.185	0.030***	-0.199***	0.068	-0.158***
Land tenure (C)	14.025***	1.282	0.171***	0.934	0.793	0.100
Number of pig farms (C)	-0.154**	0.065	-0.068**	-0.250***	0.075	-0.250***
No Off-farm work (C)	21.816***	4.023	0.261***	0.252	0.315	0.035
Operator's average age (C)	-18.237**	9.197	-0.070**	-3.532***	2.011	-0.102***
Operator living on farm (C)	0.62	6.12	0.008	-0.147	0.579	-0.015
Production type (C)	-13.721***	1.844	-0.293***	-1.895**	0.819	-0.206**
Technology (C)	3.189	2.18	0.139	0.804	0.648	0.123
Temperature (C)	76.766	57.634	0.086	24.048**	11.419	0.165**
Constant	-2079.941	1308.035		553.272***	192.682	
R_Squared		0.95			0.52	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.18. Estimates of the Economic Impacts of Various Factors on Farm size, Quebec.

	Type 1 structural change			**Type 2 structural change**		
	Coeff	Std. dev	SC	Coeff	Std. dev	SC
Provincial level data						
COOL implementation (D)	613.712***	123.576	0.290***	751.416*	452.5	0.417*
Disease variables						
Dramatic increase in pig disease outbreak (D)	-256.671***	69.352	-0.083***	-341.991	491.238	-0.130
PED outbreak (D)	419.165	212.921	0.138	-814.623**	401.399	-0.305**
Hog-feed price ratio (C)	12.743***	4.068	0.141***	11.727*	6.192	0.151*
Census Division level data						
Distance to Slaughter plant (C)	-113.909	101.126	-0.045	332.051	243.396	0.192
Distance to Research institutions (C)	33.616	51.739	0.027			
Distance to Research institutions (0.2≤ d <0.4km) (D)				-378.612*	95.738	-0.202*
Distance to Research institutions (0.4≤ d <0.6km) (D)				-196.361	234.73	-0.087
Distance to Research institutions (0.6≤ d <1.2km) (D)				-273.604	229.551	-0.140
Distance to Research institutions (1.2≤ d <2.4km) (D)				-378.884*	235.826	-0.144*
Family farm (C)	0.222	6.721	0.004	6.376**	2.916	0.202**
Gender (% of male operators) (C)	3.796*	1.974	0.098*	0.959	2.108	0.035
Human population density (10< p <20) (D)	-78.038	125.049	-0.035	243.508*	107.048	0.104*
Human population density (20≤ p <30) (D)	22.349	199.784	0.009	403.995	332.598	0.125
Human population density (30≤ p <60) (D)	-72.347	163.87	-0.023	293.712	208.349	0.119
Human population density (60≤ p <90) (D)	-105.957	220.305	-0.029	264.303	279.669	0.074
Human population density (90≤ p <180) (D)	154.749	196.345	0.046	126.175	230.169	0.055
Human population density (p ≥180) (D)	-128.179	170.363	-0.028	46.964	304.119	0.019
Land tenure (C)	-3.806	2.525	-0.055	7.877*	4.097	0.155*
Number of pig farms (C)	0.603*	0.376	0.057*	2.884*	1.526	0.153*
No Off-farm work (C)	2.730*	1.629	0.060*	7.508***	1.356	0.248***
Operator's average age (45≤ age <50) (D)	6.966	88.245	0.003	-140.099*	83.125	-0.075*
Operator's average age (age ≥50) (D)	232.143*	128.254	0.075*	-39.005	200.935	-0.017
Operator living on farm (C)	0.638	2.272	0.011	2.36	2.954	0.079
Production type (C)	2.672	3.707	0.051	-5.306*	2.916	-0.162*
Technology (C)	10.656***	2.224	0.346***	9.480**	3.895	0.386**
Temperature (C)	136.412***	40.51	0.201***	47.087	42.269	0.099
Constant	-1509.297	635.603		-779.533	758.056	
R_Squared		0.64			0.61	

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.19. Estimates of the Economic Impacts of Various Factors on Farm size, CDs that experienced Type 1 Structural Change.

	Alberta	Saskatchewan	Manitoba	Ontario	Quebec
Provincial level data					
COOL implementation (D)	595.474*	1062.950**	1045.867*	719.504***	613.712***
Disease variables					
Dramatic increase in pig disease outbreak (D)	447.349	508.854	-278.65	-510.595***	-256.671***
PED outbreak (D)			502.992	94.458	419.165
Hog-feed price ratio (C)	2.813	1.031	4.755	20.428***	12.743***
Census Division level data					
Distance to Slaughter plant (C)	91.818		281.522	-196.880***	-113.909
Distance to Slaughter plant (0 .5≤ d <1km) (D)					
Distance to Slaughter plant (1≤ d < 1.5km) (D)			-1160.968**		
Distance to Slaughter plant (1 .5≤ d <2km) (D)			-885.998**		
Distance to Slaughter plant (2≤ d <2.5km) (D)					
Distance to Slaughter plant (2.5≤ d < 3km) (D)		1314.697***			
Distance to Slaughter plant (d ≥3km) (D)		186.485			
Distance to Research institutions (C)		-865.365***		729.439***	33.616
Distance to Research institutions (1≤ d <2km) (D)	-96.769				
Distance to Research institutions (d ≥2km) (D)	-1915.170***				
Family farm (C)	-3.159	5.674	22.351	11.531***	0.222
Gender (% of male operators) (C)	-6.716**	-13.762**	-2.838	-0.243	3.796*
Human population density (C)			-1.091*	0.853***	
Human population density (1< p <2) (D)	-491.188				
Human population density (2≤ p <4) (D)	-612.667***				
Human population density (p ≥4) (D)	76.605				
Human population density (1≤ p <1.5) (D)		-1530.449***			
Human population density (1.5≤ p <2) (D)		-1162.912***			
Human population density (2≤ p <2.5) (D)		-292.968			
Human population density (10< p <20) (D)					-78.038
Human population density (20≤ p <30) (D)					22.349
Human population density (30≤ p <60) (D)					-72.347
Human population density (60≤ p <90) (D)					-105.957
Human population density (90≤ p <180) (D)					154.749
Human population density (p ≥180) (D)					-128.179

Land tenure (C)	-5.33	-7.611	-16.708**	14.025***	-3.806
Number of pig farms (C)	1.769	-0.49	2.496***	-0.154**	0.603*
No Off-farm work (C)	-11.883	-0.155	3.408	21.816***	2.730*
Operator's average age (C)	130.483***		68.372**	-18.237**	
Operator's average age (45≤ age <50) (D)		278.789			6.966
Operator's average age (age ≥50) (D)		598.321***			232.143*
Operator living on farm (C)	10.761	5.733	-9.326	0.62	0.638
Production type (C)	8.297	4.527	8.456	-13.721***	2.672
Technology (C)	32.922***	17.661***	22.811***	3.189	10.656***
Temperature (C)	-430.943*	-233.492***	-47.014	76.766	136.412***
Constant	-672.933	5023.406	-2512.046	-2079.941	-1509.297

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.20. Estimates of the Economic Impacts of Various Factors on Farm size, CDs that experienced Type 2 Structural Change.

	Alberta	Saskatchewan	British Columbia	Ontario	Quebec
Provincial level data					
COOL implementation (D)	495.432***	545.718*	338.434	45.583	751.416*
Disease variables					
Dramatic increase in pig disease outbreak (D)	-105.492	-295.996	-205.163*	-8.876	-341.99
PED outbreak (D)				-87.451*	-814.623**
Hog-feed price ratio (C)	10.466***	1.308	7.656	0.505	11.727*
Census Division level data					
Distance to Slaughter plant (C)		-190.464***	6.566		332.051
Distance to Slaughter plant (0 .5≤ d <1km) (D)	-68.167			-58.922	
Distance to Slaughter plant (1≤ d < 1.5km) (D)	156.336				
Distance to Slaughter plant (1 .5≤ d <2km) (D)	-320.914			-219.874***	
Distance to Slaughter plant (1≤ d < 2km) (D)					
Distance to Slaughter plant (2≤ d <2.5km) (D)	-370.043***				
Distance to Slaughter plant (2.5≤ d < 3km) (D)	-489.781				
Distance to Slaughter plant (2≤ d <3km) (D)				-207.262***	
Distance to Slaughter plant (d ≥3km) (D)	172.438			-228.693***	
Distance to Research institutions (0.2≤ d <0.4km) (D)					-378.612*
Distance to Research institutions (0.4≤ d <0.6km) (D)					-196.36
Distance to Research institutions (0.6≤ d <1.2km) (D)					-273.6
Distance to Research institutions (1.2≤ d <2.4km) (D)					-378.884*
Distance to Research institutions (0.25≤ d <0.5km) (D)				49.634	
Distance to Research institutions (0.5≤ d <1km) (D)			-220.567**	-2.148	
Distance to Research institutions (d ≥1km) (D)				43.543	
Distance to Research institutions (1≤ d <1.5km) (D)			-247.963**		
Distance to Research institutions (1≤ d <2km) (D)	-634.894***	307.556***			
Distance to Research institutions (1.5≤ d <2km) (D)			-279.637***		
Distance to Research institutions (d ≥2km) (D)	35.524	519.049***			
Distance to Research institutions (2≤ d <3km) (D)			-178.035*		
Distance to Research institutions (3≤ d <4km) (D)			-137.171		

Distance to Research institutions (d ≥4km) (D)			-111.327		
Family farm (C)	5.294	-9.061***	12.051***	5.707	6.376**
Gender (% of male operators) (C)	-4.058***	4.259	0.128	0.188	0.959
Human population density (C)	-7.659***		-0.482***	-0.199***	
Human population density (2≤ p <2.5) (D)		-592.348***			
Human population density (2.5≤ p <5) (D)		-305.220***			
Human population density (5≤ p <10) (D)		-770.004***			
Human population density (10≤ p <15) (D)		-244.860***			
Human population density (p ≥15) (D)		-586.394***			
Human population density (10< p <20) (D)					243.508*
Human population density (20≤ p <30) (D)					403.995
Human population density (30≤ p <60) (D)					293.712
Human population density (60≤ p <90) (D)					264.303
Human population density (90≤ p <180) (D)					126.175
Human population density (p ≥180) (D)					46.964
Land tenure (C)	-0.593	0.896	6.390***	0.934	7.877*
Number of pig farms (C)	0.099	0.332	-0.098	-0.250***	2.884*
No Off-farm work (C)	5.957	-0.293	0.118	0.252	7.508***
Operator's average age (C)	-11.011*			-3.532***	
Operator's average age (45≤ age <50) (D)		-97.155***	-48.439*		-140.099*
Operator's average age (age ≥50) (D)		192.818***	-180.382*		-39.005
Operator living on farm (C)	10.221***	3.027	-0.158	-0.147	2.36
Production type (C)	-3.748	5.349	1.043	-1.895**	-5.306*
Technology (C)	9.269**	5.991***	0.945	0.804	9.480**
Temperature (C)	-59.807**	18.11	22.268***	24.048**	47.087
Constant	318.79	-769.791	-553.922	553.272***	-779.53

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 3.21. Results from the Lagrange Multiplier (LM) Test of Spatial Autocorrelation.

	Type 1 Structural Change	**Type 2 Structural Change**
British Columbia		F(1, 17) = 39.657 Prob > F = 0.000
Alberta	F(1, 6) = 8.176 Prob>F = 0.011	F(1, 6) = 9.850 Prob>F = 0.020
Saskatchewan	F(1, 7) = 16.685 Prob > F = 0.005	F(1, 7) = 28.571 Prob > F = 0.001
Manitoba	F(1, 14) = 4.244 Prob > F = 0.058	
Ontario	F(1, 8) = 10.504 Prob > F = 0.012	F(1, 29) = 18.974 Prob > F = 0.000
Quebec	F(1, 35) = 17.512 Prob > F = 0.000	F(1, 18) = 24.007 Prob > F = 0.000

Table 3.22. Hausman Tests for Random Effects vs. Fixed Effects Models.

	Type 1 Structural Change	**Type 2 Structural Change**
British Columbia		chi2(5) = 3.77 Prob>chi2 = 0.68
Alberta	chi2(4) = 2.02 Prob>chi2 = 0.73	chi2(5) = 1.15 Prob>chi2 = 0.95
Saskatchewan	chi2(7) = 11.71 Prob>chi2 = 0.11	chi2(5) = 4.50 Prob>chi2 = 0.37
Manitoba	chi2(7) = 13.78 Prob>chi2 = 0.13	
Ontario	chi (7) = 12.33 Prob>chi2 = 0.10	chi2(18) = 25.14 Prob>chi2 = 0.12
Quebec	chi2(20) = 16.73 Prob>chi2 = 0.67	chi2(22) = 35.32 Prob>chi2 = 0.04

Note: Choices were made based on values that are statistically significant at 1% level.

Table 3.23. Results from the Likelihood Ratio Test (LR) of Heteroscedasticity.

	Type 1 Structural Change	**Type 2 Structural Change**
British Columbia		LR chi2(17) = -932.43 Prob > chi2 =1.00
Alberta	LR chi2(6) = -213.92 Prob > chi2 = 1.00	LR chi2(6) = -228.49 Prob > chi2 = 1.00
Saskatchewan	LR chi2(7) = -595.27 Prob > chi2 = 1.00	LR chi2(7) = -899.10 Prob > chi2 = 1.00
Manitoba	LR chi2(14) = -706.23 Prob > chi2 = 1.00	
Ontario	LR chi2(8) = -88.97 Prob > chi2 = 1.00	LR chi2(32) = -461.48 Prob > chi2 = 1.00
Quebec	LR chi2(36) = -162.51 Prob > chi2 = 1.00	LR chi2(23) = -29.55 Prob > chi2 = 1.00

Table 3.24. Results from the Lagrange Multiplier (LM) Test of Autocorrelation.

	Type 1 Structural Change	**Type 2 Structural Change**
British Columbia		F(1, 8) = 5.359 Prob > F = 0.049
Alberta	F(1, 6) = 0.014 Prob>F = 0.910	F(1, 6) = 0.032 Prob>F = 0.835
Saskatchewan	F(1, 7) = 16.69 Prob > F = 0.005	F(1, 7) = 28.57 Prob > F = 0.001
Manitoba	F(1, 13) = 4.293 Prob > F = 0.059	
Ontario	F(1, 8) = 11.742 Prob > F = 0.0090	F(1, 8) = 9.742 Prob > F = 0.032
Quebec	F(1, 35) = 13.774 Prob > F = 0.0007	F(1, 18) = 24.007 Prob > F = 0.0001

Chapter 4: The Role of Pig Diseases in Farmers' Decision-Making Process-A Preliminary Analysis

4.1 Introduction

The study of the economic impacts of pig diseases aims to understand more about pig producer farm characteristics and the impact of disease outbreaks on farmers' decision-making process. To achieve these objectives, a preliminary national survey of pig farmers (52 pig farmers in total) was conducted in 2014 and 2017[12]. Data relating to farm, farmer, as well as production characteristics and to the adoption of preventive measures were collected. Although many empirical studies in this field have analyzed pig diseases (especially disease transmission) and farmers' applications of various disease control and prevention measures (e.g., Andres and Davies, 2015; Bellini et al., 2016; Lambert et al., 2012; Polijak et al., 2010; Rosendal et al., 2014), the majority of these studies focused on what had been done by the pig farmers, but not the reasons why. Based on the survey results, our study endeavors to fill this gap by exploring the role of pig diseases at the farm operation level and identifying the factors that influence or might influence pig producers' decisions about the adoption of various disease treatments, which is our secondary objective.

Since their first discoveries in the early 1990s, pig diseases such as porcine reproductive and respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) have plagued Canadian pig farmers. More recently, a new pig disease - porcine epidemic diarrhea (PED) was detected in 2014 and has quickly spread among pig farms located in the provinces of Ontario, Quebec and Manitoba. To the present, these pig diseases have severely affected the Canadian pig industry with losses of billions of dollars (Office of Audit and

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[12] 45 in 2014 and 7 in 2017

Evaluation, 2015). Economically speaking, outbreaks of infectious diseases would cause losses for individual farmers by reducing the number of marketable hogs (Johnson et al., 2005), and our sample showed 61% of the pig deaths reported by respondents were attributable to pig diseases. When asking the surveyed farm operators to rank the causes of hog mortality on their farms in terms of their frequency of occurrence, 42% of the farmers reported PRRS as one of the most important three causes, and 38% of them claimed PCVAD. However, only 12% of the farmers mentioned PED because it is a relatively new disease (Figure 4.1). Since PED is newer to Canadian pig farmers, this study focuses only on PRRS and PCVAD.

In addition to the production losses, disease outbreaks would also incur additional production costs for disease control and prevention strategies (McInerney et al., 1992). In our study, veterinary service (i.e., animal disease treatment and animal disease prevention) costs are found to account for the second largest share of total costs (after feed costs), and the distribution of disease treatment and prevention costs is presented in Figure 4.2. On average, pig farmers spent about 8% of their total costs on veterinary services, but about 27% of the farm operators reported they spent more than 10% of their total costs on veterinary services. Besides increased production costs, disease outbreaks would also lead to farmers' losses through reduced market and export opportunities (Desrosiers, 2011).

In Canada, not enough money, time, and effort have been provided to quantify transmission risks for some important pig disease pathogens and to guide pig producers' decision-making in response to disease outbreaks. As aforementioned, the Control of Disease in the Hog Industry (CDHI) was the only national program provided to combat pig diseases and it was wound up in 2015. A better understanding of farmers' biosecurity behavior might encourage government to propose more efficient programs to help pig farmers improve biosecurity on their farms. This chapter aims to understand pig producers' intentions in respect to disease management strategies by analyzing the various factors that might affect the application of disease control and prevention methods. Specifically, disease prevalence and prevention methods are discussed in section 2 and 3, respectively. In the following sections, we examine how on-farm disease status (section 4), management variables (e.g., production type and farmers' education level) (section 5), farmers' knowledge about and attitudes towards various treatment methods impact the actual application of these methods (section 6).

4.2 Disease Prevalence

To reflect the biology and the ecology of the viruses, a herd classification system for porcine reproductive and respiratory syndrome (PRRS) was developed by Holtkamp et al (2011) and employed in this study. Based on the shedding and exposure status of the breeding herds, five categories of PRRS status are defined: 1) positive unstable; 2) positive stable; 3) positive stable undergoing elimination; 4) provisional negative; and 5) negative (defined in Appendix 37). Growing herds are categorized simply as positive and negative herds (defined in Appendix 38). For porcine circovirus associated disease (PCVAD), three different manifestations were summarized by Batista (2007), and they are: 1) sporadic occurrence; 2) persistent PCVAD; and 3) epizootic (defined in Appendix 39).

In our survey, all breeding herds responded they at least experienced sporadic occurrence of PCVAD (89%). The overall PRRS prevalence in breeding herds found in our sample is 48%. Among these PRRS positive herds, the majority of them were characterized as "positive stable", implying the exposure status was positive and these pig herds had not initiated an elimination program. For growing herds, the overall PRRS prevalence is 27%. A note to growing herds is that only 20 out of 52 farms reported they had growing pigs on their premises. Due to the small sample size for growing herds, further analyses will only focus on the disease status of the breeding herds. The specific PRRS and PCVAD statuses of the pig herds are shown in Figure 4.3 – 4.5.

When taking production types into consideration, we find a large share of disease (both PRRS and PCVAD) positive herds were in farrow-to-finish operations, followed by farrow-to-wean units. To examine the correlation between two factors, our study employs three types of correlation coefficients based on the types of the variables considered. Spearman's correlation is used to examine the correlation between the two continuous variables (Spearman, 1904), and tetrachoric correlation is employed for the two binary/dummy variables (Carroll, 1961). For the correlation between one binary variable and one continuous variable, point-biserial correlation is examined (Gupta, 1960). As regards to the correlations between herd types and PRRS status, the statistically significant tetrachoric coefficient (0.4318) indicated farrow-to-finish farms were more likely to be infected with PRRS, and these farms typically fell into the category of "positive stable" (tetrachoric coefficient=0.5868, significant at 0.05 level). Previous literature also supports this finding as more farrow-to-finish sites claimed seeing clinical signs of PRRS than did farrow-to-wean sites (Harding, 2007; Larochelle et al., 2003; Young et al., 2010). For the relationship between farm size and disease status, the positive point-biserial correlation between them suggested the possibility of being infected with PRRS would increase with farm size. This is also in accordance with previous literature which showed increased farm size is associated with increased risk of PRRSV infection (Evans et al., 2008; Velasova et al., 2012). In addition, larger farms tended to fall into the category of "provincial negative".

A special attribute of PCVAD is its co-infection with other viral and/or bacterial pathogens, and many empirical studies found pigs with PCAVD were also diagnosed with PRRS (e.g., Pallarés et al., 2002; Wellenberg et al., 2004). In particular, researchers claimed PRRS can either trigger PCVAD infections or make the problems worse. For example, Pogranichniy et al (2002) asserted compared to pigs that were only infected with PCVAD, the severity of diseases in co-infected pigs would be much more serious. Our sample confirmed the presence of coinfection, and we detect a combination of PRRS and PCAVD viruses in 43% of the investigated cases. A retrospective study conducted by Drolet et al (2003) also reported a very similar coinfection rate (42%).

4.3 Disease Prevention Methods

To control the introduction, persistence, and spread of pathogens, Chapple et al (2010) from the Canadian Swine Health Board (CSHB) summarized four general disease prevention protocols in 2010, and they are: 1) segregation – applying barriers to limit pathogens from entering an uninfected site or infecting susceptible animals; 2) sanitation – washing, disinfecting, and drying to remove visible organic materials and to reduce or inactivate pathogens; 3) flow management – organizing the flow of pigs, people and materials within a farm or a production system to prevent cross-contamination; and 4) personal record keeping – documenting the application of BMPs, training, and compliance with biosecurity measures. All of these basic biosecurity measures are highly recommended by the organization with the aim to limit the routes of disease transmission and to better manage pig diseases.

Though highly suggested, our sample suggested not all pig farms practiced these four recommended strategies (Figure 4.6). Among these four basic biosecurity measures, sanitation is detected as the most commonly implemented strategy. In the academic and veterinary communities, direct contact between an infected pig to the susceptible one is the most important disease transmission route (Andruad et al., 2013; Food and Agriculture Organization of the United Nations (FAO)/World Organization for Animal Health (OIE)/World Bank, 2010), but we find segregation, which aims to block the contacts, is the least commonly practiced strategy among surveyed pig farmers. This is also found by Moore et al (2008) stating pig farmers preferred the biosecurity methods relating to disease transmissions through people, rather than those relating to direct animal contacts. Such a finding indicates there might be a lack of communication among researchers, veterinarians and farmers. When examining the total number of biosecurity measures employed by pig producers, we find only 22% of the farm operators implemented all four methods, while the vast majority took only one or two into practice.

Following the four protocols proposed by Chapple et al (2010), various treatments were further developed by researchers and veterinarians for the control and prevention of different pig diseases. Treatments and preventive measures are generally different across pig diseases as various diseases possess different clinical signs and routes of transmissions, while it is accepted that porcine reproductive and respiratory syndrome (PRRS) and porcine circovirus associated disease (PCAVD) might share some common practices. For example, vaccination and the uptake of biosecurity measures were recommended as disease treatment methods for both pig diseases.

When diseases were first introduced to the country or the regions where pig producers farm, pig farmers would need to make operational decisions that are either ex ante or ex post to disease occurrences in order to prevent disease introduction and control their spread. In general, these management decisions would be made based on farmers' objectives of: 1) maximizing the efficiency of disease management practices; and 2) minimizing the costs associated with these diseases and their control. Farmers' final decisions on treatments adoption would be made after the consideration of both aspects and the weighing of the importance of efficiency and costs. To effectively evaluate the application of each available treatment, PRRS and PCAVD treatments and their associated application rates will be discussed in the following two subsections, and the complete lists of PRRS and PCVAD treatments are provided in Appendix 40 and 41, separately.

4.3.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

1) *Vaccination*. Pig producers commonly implement vaccination with the aim to develop an immunity to protect animals from clinical diseases. However, many empirical studies have demonstrated that the efficacy of PRRS vaccines is ambiguous. For example, some studies confirmed the beneficial effects of PRRS vaccines with reduced clinical signs and improved average daily gain (Cano et al., 2007; Opriessnig et al., 2005), while others found no reduction in clinical signs (Goldberg et al., 2000; Zuckermann et al., 2007). Currently, ReproCyc® PRRS-PLE, Ingelvac® PRRS MLV, Ingelvac® PRRS ATP, and Fostera PRRS (Pfitzer) are the four common used vaccines in Canada for the treatment of PRRS. In our sample, only 30% of the surveyed pig farmers reported use of at least one type of PRRS vaccine, and such low rate might be attributable to the partial effectiveness of these vaccines (Charerntantanakul, 2012). When looking at PRRS positive farms, we find the majority of them indeed applied vaccination. In total, 24/52 farms were tested positive for porcine reproductive and respiratory syndrome virus (PRRSV) and of those, 17 applied at least one type of vaccine on their farms. Despite the concerns over the effectiveness of PRRS vaccines,

it is shown pig producers still used them as aids to control clinical PRRS. To achieve stable immunity of the entire herd, pig producers are also suggested by researchers to apply whole-herd vaccination with herd closure (Gillespie and Carroll, 2003). In our sample, 10 surveyed producers followed this rule with the simultaneous applications of vaccination and herd closure.

2) *Boar testing*. Epidemiologic investigations have revealed boar semen as a potential source of disease transmissions (Maes et al., 2008; Yaeger et al., 1993). Because the health status of a boar stud has a significant impact on the entire production flow, pig farmers should ensure that semen comes from a disease negative boar stud. In addition, testing of boar studs should be done as early as possible to prevent or to minimize the possibility of downstream infections (Reicks, 2012). Rather than semen, the ideal samples of boar stud testing are serum or blood as the viruses can be detected sooner and more rapidly in blood and serum (Christopher-Hennings, 2001; Reicks et al., 2006). In our study, boar testing was implemented by 35% of the pig farmers. While among the PRRS positive farms, only 4/24 of them (17%) applied boar testing. A possible reason for its low application rate is the surveyed farmers only sourced semen from certain trusted sources. As a result, it might be not necessary to do boar testing. This is somewhat confirmed by our finding with 71% of the breeding herds reporting usage of only one type of semen source. In addition, the majority of these herds claimed they used self-produced sources with semen being produced from boars with either productivity traits or disease resistance traits.

3) *Application of strict biosecurity measures*. Biosecurity is defined as "the implementation of measures that reduce the risk of introduction and spread of disease agents" (FAO/OIE/World Bank, 2008), and the regular measures, which were summarized by Dee et al (2004) and

Ménard (2008), include: 1) limiting access to facilities through restricting entrance of people and practicing entrance protocols; 2) introducing materials that must be free of feces and dust; 3) using screens and insecticides to limit virus introduction through insects; 4) installing air filters to prevent PRRSV introduction through airborne transmissions; and 5) washing, disinfecting and drying transport vehicles to control the spread through contaminated vehicles. Our sample reveals the implementation of general biosecurity measures is a regularly used method for PRRS prevention and treatment with half of surveyed farmers claiming the application of strict biosecurity measures. As regards to PRRS positive farms, 10 out of 24 (42%) of them reported the application of strict biosecurity measures.

4) *Sow herd stabilization.* Also well-known as gilt acclimation, sow herd stabilization has been employed by many pig farmers to reduce the transmission of pathogens from sows and gilts to their offspring. Like boar stud, the health status of replacement gilts also has a major impact on the entire production flow (Ménard 2008). Generally speaking, sow herd stabilization is a practice that exposes replacement gilts to specific strains of viruses that are present in the sow herd to induce specific viruses' antibody prior to their introduction into the herd (Batista et al., 2002). To be more specific, acclimatization is performed by inoculating negative gilts with serum and tonsillar scrapings that are obtained from viremic nursery pigs (McCaw et al., 2003). After a period of recovery, the acclimatized gilts would become disease-positive with high rates of success. Because sow herd stabilization needs a large amount of positive serum or tissue to treat all gilts, this treatment is very labor intensive and would incur huge additional production costs to implement (Batista et al., 2002). In comparison to other treatment methods, we find sow herd stabilization was a relatively common used practice to control or prevent PRRS, and its application rate in our sample is

58%. Speaking of PRRS positive farms, the application rate is even higher with 16/24 pig farms (67%) applying it as a measure of treatment.

5) *All-in-all-out*. Unlike continuous flow system with animals moving individually, all-in-all-out (AIAO) is a production system that keeps and moves animals together in groups (either by rooms or by buildings). Such flow system requires pigs from the same group are moved into the next phase of production altogether to break the chain of infection. Aside from its advantages of reducing exposure levels of disease-causing pathogens in the pigs' environment and limiting the spread of pathogens from one stage of production to the next, AIAO also helps producers improve management by allowing better environmental control and making record-keeping easier (Levis and Baker, 2011). Better environmental control is reached because pigs within each group have similar nutritional and environmental requirements, farmers then could easily adapt their facilities to meet pigs' needs. The records keeping become easier as pigs are now managed as a group (Owsley, 2012). In our sample, about 34% of the surveyed pig producers employed AIAO on their farms, and these farms were of medium to large size. Among the 24 pig farms that were PRRS positive, however, only 5 of them used AIAO for the treatment of PRRS. Interestingly, these 5 farms were all large farms that raised more than 3000 pigs. As a result, the low application of AIAO might be attributable to the small farms who have less labor and fewer facilities to make the practice workable.
6) *Depopulation-repopulation*. Depopulation-repopulation is another effective but very expensive means of eliminating viruses from a pig herd. This strategy consists of emptying the whole barn, disinfecting all equipment and facilities, and re-stocking pigs coming from unaffected pig farms (Corzo et al., 2010; Ménard, 2008). According to Roberts (2002), herds

with multiple strains of a virus and/or a significant number of diseases are better candidates for depopulation-repopulation. For this treatment to be effectively implemented, pig producers must ensure reliable supply of seronegative animals are available after the depopulation process (DeBuse, 2007). Aside from pathogen eliminations, another advantage of this technique is its ability to enhance genetic improvements (Yeske, 2010). Although this method has been used by many producers to eradicate PRRS (Dewey, 2000), the long disruption in production comes at significant financial costs, which have discouraged many pig farmers from adopting it. The application rate of depopulation-repopulation in our study is only 20%, and only 3/24 PRRS positive farms (12.5%) implemented it as a disease control method.

7) *Nursery depopulation*. Besides the introduction of viruses by infected pigs at weaning, viruses can also circulate in the nursery by the shedding of the virus from the older, infected pigs to the younger ones (Dee et al., 1998). Like depopulation-repopulation, nursery depopulation is also a method of interrupting re-infection by involving emptying all nursery rooms and disinfecting all rooms and facilities before negative pigs are introduced. In comparison to depopulation-repopulation, this strategy is less costly as it induces relatively small disruption in production, but has higher risk of re-infection (Yeske, 2010). In our sample, we find nursery depopulation is the least commonly used strategy by surveyed farmers for the prevention and control of PRRS. As regards to PRRS positive pig herds, 3/24 of them (12.5%) applied nursery depopulation.

8) *Segregated/medicated early weaning*. Segregated early weaning has become increasingly popular among pig producers with the aim of producing high health status breeding stocks that are free from infectious pathogens. The procedure involves weaning piglets early and

then moving them to a site isolated from sows and other animals (Fangman and Tubbs, 1997; Robert et al., 1999). Medicated early weaning, on the other hand, is very similar to segregated early weaning but may be done with the use of medications and longer isolation distances. Aside from their ability to control and eliminate PRRSV, a research conducted at Purdue University on segregated early weaning found it could also enhance productivity though reduction in days to market, better feed efficiency, and reduced mortality (Clark et al., 1995). In total, we detect 42 % of the surveyed pig farmers applied segregated and/or medicated early weaning. Among these farmers, 34% of them implemented medicated early weaning, and 24% implemented segregated early weaning. When infected with PRRS, farmers are found to be more likely to employ medicated early weaning with an application rate of 38%.

9) *Monitoring*. Monitoring generally encompasses conducting serum or oral fluid testing in sows, piglets, and cross-sectional to detect PRRSV (Kuiek et al., 2015; Ontario Pork Industry Council, 2011). During the disease control and prevention process, frequent monitoring is imperative for early detection of disease infections. Surprising, only a few pig farmers (29%) practiced monitoring on their farms, and the adoption rate (8%) is even lower for PRRS positive farms.
10) *Herd closure and rollover*. Herd closure and rollover was first introduced by Torremorell et al (2003) and is a method consisting of stopping the introduction of replacement animals for a period of time, eliminating animals that were previously exposed to the viruses, and rolling over the breeding herd to a negative status by introducing naïve replacement gilts. This strategy was reported to be frequently applied in North America with the aim of interrupting the replication and build-up of disease pathogens (Corzo et al., 2010). A special aspect of

herd closure and rollover is the requirement of routine serologic monitoring throughout the process (Ontario Pork Industry Council, 2011). Unlike test and removal, herd closure and rollover is less labor intensive and less expensive. However, it requires a long time to complete (Sandri, 2001; Yeske, 2010). Another special aspect of this technique is that in some chronically infected herds, herd closure alone might be enough to eliminate the virus (Wright, 2011). In the present study, we find only 10% of surveyed pig farmers implemented herd closure and rollover altogether as a method to eliminate PRRSV. However, half of the farm operators practiced herd closure alone as the treatment method. As regards to the herds infected with PRRS, 13/24 pig herds (54%) adopted herd closure as a measure of PRRS treatment.

11) *Risk based testing and surveillance.* Stärk et al (2006) defined risk based testing and surveillance as "a surveillance programme in the design of which exposure and risk assessment methods have been applied together with traditional design approaches to assure appropriate and cost-effective data collection" with the objectives of: 1) identifying surveillance needs to protect animals; 2) setting priorities for animals with higher risks; and 3) allocating resources effectively and efficiently to reach a higher benefit-cost ratio. The main idea behind this treatment method is that pig herds that present higher risks of infection merit higher priority for surveillance resources and deserve more frequent testing (Morrison, 2011; Thornton, 2004). In our sample, 30% of the pig farmers reported the implementation of risk based testing and surveillance, while its application rate (12.5%) is very low among PRRS positive farms.

12) *Regional elimination program.* Although a variety of on-farm strategies have been developed by researchers and veterinarians to effectively control and eradicate the PRRSV from pig

herds, the possibility of re-infection remains high as area spread from neighboring units through airborne transmissions and pig movements (especially through animal transportations) is still threatening the farms within an area. Rather than combating pig diseases individually, collaborative efforts by farm operators within a region seems to be very necessary to limit the spread of emerging and re-emerging of pig diseases. According to Ontario Pork Industry Council (2011), regional elimination program looks at farm specific and area wide risks and often results in situations that would not be possible if addressed in isolation. Overall speaking, the program participation rate was relatively low. Indeed, only 26% of the surveyed pig producers reported their participation into the regional PRRS elimination programs. As regards to PRRS positive farms, a similar rate (25%) is found with 6/24 surveyed farms participating in the regional elimination programs.

Figure 4.7 presents the distribution of the PRRS treatments which were applied by the surveyed pig farmers. On average, farmers would implement 5 treatment methods for the control and prevention of PRRS, though 19 treatments were available and asked in the survey. In comparison to other preventive measures, sow herd stabilization is found to be a relatively common-used practice to eradicate PRRSV, but the application of vaccination is not very common. In total, only 30% of the surveyed producers reported usage of PRRS vaccine(s). When we further examined the pig herds that were infected with PRRS, vaccination is found to be a common method for the treatment of PRRS with an application rate of 59%. Other popular PRRS preventive strategies include the implementation of strict biosecurity measures and herd closure. Among the three treatments that consist of emptying the herd or whole barn (i.e., herd closure, nursery depopulation, and depopulation-repopulation), herd closure was widely employed by pig farms as it induces minimal disruption in production and is less expensive.

4.3.2 Porcine Circovirus Associated Disease (PCVAD)

1) *Vaccination*. Like PRRS, vaccination is also a commonly implemented practice for the treatment of PCAVD through the development of immunity. But unlike PRRS vaccines, PCVAD vaccines have been proved by many empirical studies as very effective in reducing the severity and incidence rate for pigs of different ages (Genzow et al., 2009; O'Neill et al., 2011; Opriessnig et al., 2014), and vaccination is even documented as the most efficacious method for controlling PCVAD today (Segalés et al., 2013). In Canada, Circovac (Merial), CircoFlex (Boehringer Ingelheim), Circumvent (Intervet / Schering - Plough), and Fostera PCV (Pfizer) are the four common used vaccines to combat PCVAD, and we find about 90% of the surveyed pig farmers applied at least one of them. Among these four types of vaccines, CircoFlex (Boehringer Ingelheim) is the most popular one, followed by Circumvent (Intervet / Schering - Plough), Circovac (Merial), and Fostera PCV (Pfizer).
2) *Management changing practices.* One of the most well-known management changing practices is McRebel, which stands for "Management Changes to Reduce Exposure to Bacteria to Eliminate Losses". This strategy was first described by McCaw (2000) to control the spread of pathogens in suckling pigs, and the measures under McRebel system consist of decreasing cross-fostering, culling poor doing non-responsive pigs, and changing needles between liters or pens. This management changing practice is highly recommended by veterinarians to avoid recirculation of the virus in the pig population (Polson et al., 2010; Zimmerman et al., 2006). In addition to McRebel, diet changing for weaning pigs is also a regularly used practice by pig farmers in reaction to disease outbreaks. In our sample, almost half of the farm operators changed management practices for the treatment of PCAVD.

3) *Decreasing load of pathogens and bacteria in the environment.* The method of decreasing load of pathogens and bacteria in the environment has been widely used in the cattle industry and is increasingly practiced by pig farmers for the treatment of PCVAD (Manyi-Loh et al., 2016). In general, the pig's environment encompasses feed and water, materials and facilities used for the distribution of feed and water, and the physical housing environment which provides shelter. Pathogen load remediation is achieved by preventing the introduction of new pathogens (e.g., minimizing sources of semen and gilts), limiting the amplification of pathogens (e.g., all-in-all-out), and developing interventions on the farm to decrease the load of pathogens in the environment (e.g., sanitation and hygiene of the buildings) (Levis and Baker, 2011). By and large, pathogen load remediation is one of the most popular PCVAD treatments with 68% surveyed pig producers reporting its application.

4) *Serotherapy*. Serotherapy was first proposed by Ferreira et al (2001) as a control measure for PCVAD affected herds and is implemented through injecting serum that are collected from infected animals to growing pigs. The intuition behind this preventive method is the serum from convalescent pigs has the potential to confer passive immunity on piglets. Although serotherapy has been used successfully in some European countries such as Spain and UK, its application rate in our sample is very low, and this might be attributed to the complicated procedure and risks associated with this measure. In addition, a control study conducted in the province of Quebec showed serotherapy did not fully prevent PCVAD infection (Desrosiers, 2007), and this might further discourage the Canadian farmers from adopting it.

5) *Antibiotics*. Being given in feed, water or as an injectable, antibiotics are used to treat and prevent diseases in swine due to their potential to suppress secondary infections of diseases (Osei Sekyere, 2014). However, because of the availability of PCVAD vaccines, the

implementation of antibiotics in Canada had been reported to have dropped (Western Hog Journal, 2011). Currently, the adoption of antibiotics still seem to be relatively popular as 55% of the surveyed pig farmers claiming its application to prevent concurrent bacterial infections.

6) *Application of general biosecurity measures*. Similar with PRRS, the application of biosecurity measures is also a method for the treatment of PCVAD by preventing the entrance of infection and controlling the spread of infection within a pig farm. In general, biosecurity can be divided into three categories: 1) bio-exclusion – preventing the introduction of disease agents into the farm (e.g., entrance protocols); 2) bio-management – reducing the spread of pathogens within the farm (e.g., room disinfection), and 3) bio-containment – preventing the spared and escape of pathogens to another population of animals (e.g., air filters) (Chapple et al., 2010). In our sample, about 80% of the surveyed farm operators reported the application of general biosecurity measures to prevent or limit the introduction of disease agents into pig herds.

The distribution of the application of PCVAD treatments is shown in Figure 4.8. Among the 9 available PCVAD treatments, the average number of treatments used by surveyed pig farmers was 4. In comparison to the available PRRS treatment methods, although pig farmers seem to have fewer options, the application rate for each preventive measure was very high. Unlike PRRS vaccine, PCVAD vaccination is proved to be quite effective, and its application rate even reached 90%. Besides vaccination, the employment of general biosecurity measures and pathogen load remediation are also very commonly used methods for the treatment of PCVAD. On the other hand, we detect fewer pig farmers changed management practices to control PCVAD.

The lack of implementations of these disease control and prevention strategies might be attributable to numerous factors. It may be due to the lack of information or training, of trust to information providers or trading partners, of communication among the personnel, of motivation for following the rules, and of understanding of the potential risks of a breach (Heffernan et al., 2008; Racicot et al., 2012; Vaillancourt and Carver, 1998). Figure 4.9 presents farmers' perceptions over the usefulness of various resources regarding hog health. In comparison to other information sources, we find fewer pig farmers perceived information provided by representatives of the feed or pharmaceutical industry and government agriculture-oriented publications as useful. On the other hand, most farmers considered information obtained from lecture events or informational talks and other farmers in the business as very useful and informative. In terms of the intensity of information source usage, which is shown in Figure 4.10, 90% of the surveyed farmers frequently followed veterinarian recommendations in daily operations to improve hog health. About 67% of the farm operators frequently made operational decisions based on animal health test results. However, only half of the pig farmers claimed they frequently used consultant recommendations and organ test results in daily operations to optimize hog health, and the infrequent usage of these two information sources might result in farmers' inactions.

Also, there might be gaps between what pig farmers perceived of high importance and what was being actually applied by them (Casal et al., 2007). Another possibility is due to the confusion of farm operators when they are provided with a multitude of suggestions coming from different sources, which can include publications, lecture events and online sources. Inconsistencies among these sources may discourage farmers from adopting certain practices or lead them to adopt the wrong ones (Moore et al., 2008). Finally, financial and physical constraints may also result in non-compliance. For example, Fraser et al (2010) detected an inverse relationship between a farmer's willingness to implement a disease prevention measure and its estimated costs.

To ensure pig farmers could quickly and effectively detect pig diseases on their farms and have access to the newly released diseases information, a good pig producer-veterinarian relationship must be maintained through farmers' frequent contacts with the veterinarians. Overall speaking, the surveyed pig farmers performed well in terms of keeping a good relationship with veterinarians. In our study, 47% of the farm operators had at least monthly contacts with their veterinarians, and about half of the pig farmers contacted their veterinarians either bi-monthly or quarterly.

4.4 Relationship between Disease Status and the Application of Preventive Measures

Relationships between the management and incidence of certain disease in pig herds have been documented by many researchers (e.g., Lambert et al., 2012; Maes et al., 2008; Velasova et al., 2012). However, most of these studies aimed to identify the risk factors for disease infection or to evaluate the impacts of site characteristics and biosecurity practices on disease status by exploring the interaction of biosecurity practices on the probability of swine disease occurrence, and only a few studies considered the other way around.

There's no doubt that improved biosecurity standards and hygiene management would have positive impacts on animal health, but in the real world, pig farmers might not follow all of the preventive protocols and may only practice certain biosecurity measures to mitigate pig disease (Gunn et al., 2004; Nerlich and Wright, 2006). In addition to financial constraints and limited access to know-how, the application of the preventive measures might also be determined by the health status of the pig herds. In this section, we focus on examining how the application of different disease control and prevention strategies varies with disease status. A good insight into the relationship between the application of different preventive measures and disease status would be important to understand the effectiveness of various alternatives and to help pig farmers optimize their management practices.

4.4.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

In total, 50 pig herds reported on-farm porcine reproductive and respiratory syndrome (PRRS) status. Among theses pig herds, 3 were positive unstable, 14 were positive stable, 1 was positive stable undergoing elimination, 6 were provincial negative, and the rest 26 were negative. Because of the small sample of herds that were positive unstable and positive stable undergoing elimination, our study would mainly focus on analyzing the pig herds that were classified as positive stable, provincial negative, and negative.

Before introducing the practice of specific PRRS treatments, we first look at the application of basic biosecurity measures. In our sample, sanitation is found to be employed by most of the pig farmers, and segregation is the least commonly applied measure, regardless of PRRS status. In comparison to farms that fell into other PRRS status categories, we find a greater proportion of positive stable farms implemented the basic disease prevention methods, while negative farms were in the opposite spectrum (Figure 4.11). This suggests farmers who experienced disease outbreaks were more likely to apply more basic biosecurity measures on their farms. Such a finding is in accordance with previous studies which found some farmers considered biosecurity unnecessary unless they experienced a disease outbreak (e.g., Frössling and Nöremark, 2016).

In terms of the adoption of specific PRRS treatments, we detect farms that were PRRS positive stable appeared to be more likely to apply more treatment methods (point-biserial correlation is shown to be positive and statistically significant). Such a finding is also in accordance with the literature (Brennan and Christley, 2012; Lindberg et al., 2006). On the other hand, PRRS negative farms tended to implement fewer disease control and prevention strategies (point-biserial correlation is shown to be negative and significant). Among the available PRRS preventive measures, sow herd stabilization and herd closure were the most commonly applied treatment methods, and rollover was the least commonly used one, regardless of the herds' PRRS status. Within each category of the pig farms, we detect most PRRS positive stable farms applied sow herd stabilization and herd closure, the majority of provincial negative herds adopted sow herd stabilization, herd closure, strict biosecurity measure, medicated early weaning, and boar testing. For PRRS negative herds, most of them practiced strict biosecurity measures, sow herd stabilization, and boar testing.

When examining the application rate of each PRRS treatment, we find PRRS positive (i.e., positive stable and provincial negative) herds were more likely to implement medicated early weaning, rather than segregated early weaning. As regards to the usage of PRRS vaccines, the sample shows the application rate of vaccination is higher for farms that fell into the category of provincial negative. In addition, these farms appeared to be more likely to apply vaccine Ingelvac® PRRS MLV (tetrachoric correlation coefficient is significant at the 0.05 level). On the contrary, we detected PRRS negative farms were less likely to use any type of vaccines (tetrachoric correlation coefficient is significant at the 0.05 level). Please see Figure 4.12 for the distribution of PRRS treatment usage.

4.4.2 Porcine Circovirus Associated Disease (PCVAD)

In total, 47 pig farms reported their on-farm porcine circovirus associated disease (PCVAD) status. Among these farms, 42 reported sporadic occurrences of PCVAD, 4 farms reported persistent PCVAD, and only 1 farm claimed epizootic PCVAD. Since the surveyed farm operators stated they at least experienced sporadic occurrence of PCVAD, this sub-section would explore the relationships between treatments' applications and PCVAD outbreaks without the differentiation of manifestations. In terms of the application of the four basic biosecurity measures, once again, sanitation was the most commonly used measure, and segregation was the least applied one (Figure 4.13).

For the implementation of specific PCVAD treatment method, vaccination and the application of general biosecurity measures were the most popular PCVAD treatments adopted by the surveyed pig farmers. Among the four listed vaccines, CircoFlex (Pfizer) was more frequently applied by farm operators, and Fostera PCV was relatively of infrequent usage. In comparison to other PCVAD treatment measures, serotherapy was the least commonly used method for the treatment of PCVAD. Please see Figure 4.14 for the distribution of PCAVD treatment usage.

4.5 Relationships between Management Variables and Biosecurity Behaviors

One of the most important decisions made by pig producers is the application of disease preventive measures to minimize the risk of pathogen incursion. Like other operational decisions, the implementation of biosecurity measures might also be influenced by factors pertaining to the characteristics of farms and farmers (Howley et al., 2012). Given the heterogeneous farm attributes and the different attitudes held by different pig farmers (Fairweather and Keating, 1994; Heffernan et al., 2008), the possibility of biosecurity adoption may vary across farms and farmers. For example, Levis and Baker (2011) claimed the application of biosecurity measures differed among farms due to the distinct types of swine operation and epidemiological situations. Lawal and Oluyole (2008) found farm operators' age had a strong statistical influence on farmers' adoption decisions. This section aims to untangle how various farm and farmer characteristics affect the application of various disease control and prevention strategies. A better understanding of the determinants might assist policy makers to propose policies that could lead to behavioral changes.

4.5.1 Herd Type

The 52 surveyed farms consisted of 36 (69%) farrow-to-finish farms, 9 (15%) farrow-to-wean farms, 2 (4%) feeder operations, and 4 (10%) breeding stock units. Because of the small samples of feeder operations and breeding stock units, our analyses in this subsection would mainly focus on farrow-to-finish and farrow-to-wean farms.

For the uptake of basic biosecurity measures, the positive and statistically significant point-biserial correlation (significant at 0.05 level) shows farrow-to-wean farmers tended to apply more biosecurity measures. For each herd type, we further examine the percentage of the farms that practiced each biosecurity measure, and the results indicate herd type might influence the probability of measure's application. Among others, sanitation was the most commonly used practice for any herd type, while flow management was applied by neither breeding stock nor feeder operations. For personal record keeping, farrow-to-finish operations seemed to be more likely to employ it than other herd types, and this was also confirmed by the positive and statistically significant tetrachoric coefficient (at 0.1 level). A possible explanation for this is increasing farrow-to-finish operators that are at a crossroads with their operations are moving into contract finishing, with the contractor usually specifying a record-keeping system (Groover, 2012).

4.5.1.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

When looking at the specific treatments used for the control and prevention of porcine reproductive and respiratory syndrome (PRRS), we find farrow-to-wean farms were more likely to implement more PRRS control and prevention measures than farms with other herd types, which might be explained by the age of the physical facilities and the level of investments required to improve biosecurity level. In general, farrow-to-finish operations are older, family-owned facilitates, which are limited to the existing structures and require substantial investments to meet current biosecurity standards. On the contrary, farrow-to-wean operations involve newer, multi-site operations that can be built with specific preventive measures with relatively lower costs (Bottoms et al., 2013).

As suggested by the positive and statistically significant tetrachoric coefficients, farrow-to-wean farms are found to be more likely to adopt all-in-all-out, depopulation-repopulation, segregated early weaning, nursey depopulation, and herd closure (Table 4.1). On the other hand, vaccination, medicated early weaning, and regional elimination programs were measures applied by most of the farrow-to-finish farms. Because of the significant disruptions in pig production, we find farrow-to-finish operators were discouraged from implementing practices associated with emptying the farm or barns (e.g., depopulation-repopulation).

As regards to sow herd stabilization and the application of strict biosecurity measures, they were commonly used practices for any herd type. In terms of the specific vaccines used by different farms, we detect farrow-to-finish farms applied all four types of modified live vaccines (ReproCyc® PRRS-PLE, Ingelvac® PRRS MLV, Ingelvac® PRRS ATP, and Fostera PRRS (Pfitzer)), while farrow-to-wean operators only used vaccines Ingelvac® PRRS ATP and Fostera PRRS (Pfitzer).

4.5.1.2 Porcine Circovirus Associated Disease (PCVAD)

Regardless of herd type, most of the pig farms applied vaccination and antibiotics, changed management practices, and decreased load of pathogens and bacteria in the environment to control porcine circovirus associated disease (PCVAD). For the specific usage of vaccines, CircoFlex (Boehringer Ingelheim) was the most popular one among any types of farms, while neither Circumvent (Intervet/ Schering- Plough) nor Fostera PCV (Pfizer) was applied by farrow-to-wean farms. Like PRRS case, farrow-to-wean units were found to be more likely to adopt more PCVAD treatments than farrow-to-finish farms (as suggested by the positive point-biserial correlation coefficient). A possible explanation for such a finding is farrow-to-wean farmers have newer facilities and thus are able to implement the practices at lower costs (Bottoms et al., 2013). In addition, general biosecurity measures were found to be more likely to be implemented by farrow-to-wean operations, since these operations can be more easily built with certain biosecurity measures.

4.5.2 Herd Size

A large herd may be expected to have more between-animal contacts and may thereby be more susceptible to infections. In our sample, the size of the surveyed farms ranged from 1 to more than 3000 pigs. Among these pig farms, 22% of them raised less than 1000 head, 39% raised pigs in the range of 1000-2000 head, and the rest 39% of the farms raised more than 3000 head. To avoid the potentially significant losses caused by pig disease outbreaks, larger farms are usually expected to take extra precautions on the control and prevention of pig diseases by employing higher levels of biosecurity. The positive spearman's correlation coefficient between farm size and the total number of biosecurity measures undertaken further confirms the expectation and indicates larger pig farms would take more basic biosecurity measures into practice. In addition, it appeares that medium-to-large sized farms tended to apply all four types of disease prevention methods. Our findings are consistent with the literature showing larger farms paid more attention to biosecurity and were more likely to comply than smaller ones (e.g., Garforth et al., 2013).

4.5.2.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

The application of PRRS treatment methods seemed to be varied with the size of pig farms, and the basis of decision making might be the minimization of per unit costs of production. Basically, we find larger farms tended to implement depopulation-repopulation, monitoring, segregated and medicated early weaning, vaccine Ingelvac® PRRS ATP, and nursery depopulation, which are the practices that usually incur high production costs. However, larger pig farms are in an advantageous position as they are capable of minimizing per unit costs due to mass production. While small farm holders are found to have more possibility to employ all-in-all-out and sow herd stabilization (Table 4.2).

4.5.2.2 Porcine Circovirus Associated Disease (PCVAD)

For the control of PCVAD, larger farms are found to be more likely to apply more preventive measures due to cost considerations. As suggested by the statistically significant point-biserial correlation coefficients, large farm holders were more likely to apply vaccine Circovac (Merial) (0.1649) and to change management practices (0.1871). Small farm holders, on the other hand, were more likely to adopt antibiotics (-0.1764) and general biosecurity measures (-0.1324).

4.5.3 Operational Arrangement

Farm ownership type, defined by the operating arrangements, may also influence the adoption of disease prevention strategies. In our sample, 55% of the surveyed pig herds were owner operated, 16% were in partnership, and 29% were managed by corporations[13]. Across all farm sites, corporations are found to be more likely to apply any type of basic biosecurity measures, followed by part owners and owner operators. This might be attributable to the financial feasibility and asset availability for each type of farm owner structure. In general,

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[13] Corporation is an incorporated business registered with a provincial or federal agency as a legal entity separate from the owner.

corporately owners have more wealth than part owners, and part owners have more wealth than owner operators.

4.5.3.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

In terms of the specific strategies used to prevent PRRS infection, it seems owner operators were more likely to implement vaccination (Tetrachoric coefficient is significantly positive at 0.01 level). On the other hand, corporately owned farms are found to be more likely to take more PRRS treatments into practice (as suggested by the positive point-biserial correlation coefficient), and the commonly used practices included all-in-all-out, monitoring, boar testing, herd closure, and risk based testing and surveillance. These practices tend to require significant investments and are more affordable by corporately owners. For sow herd stabilization, it was a practice applied by most of the pig farms, regardless of their farm ownership type.

4.5.3.2 Porcine Circovirus Associated Disease (PCVAD)

As suggested by the positive point-biserial correlation estimate (0.142), owner operators are found to be more likely to take PCVAD treatment methods into practice. In particular, they were more likely to adopt vaccine CircoFlex (Boehringer Ingelheim). As compared to farms with other operational arrangements, serotherapy was applied by more owner operators. Due to the complicated procedures associated with this strategy, it may be that owner operators have more incentive to improve production as they work directly on the farm (Susilowati et al., 2013). For the rest of listed strategies such as antibiotics and vaccination, most of the farm operators would apply them no matter what their operational arrangements are.

4.5.4 Pig Farming as the Primary Occupation

If farmers take pig farming as the primary occupation and pig farming is the main source of income, farm operators are expected to have more incentives to employ higher levels of biosecurity practices as production and efficiency may be more important to these operators (Susilowati et al., 2013). In our study, if the percentage of hog farming receipts (out of total revenue) was above 60%, we would consider hog farming as the farmer's primary occupation. In total, 37/52 (71%) farm operators reported pig farming as their primary occupation. As the literature suggested, farmers who took pig farming as the primary occupation tended to practice more basic biosecurity measures on their farms, and the most likely applied ones were segregation and personal record keeping (Tetrachoric coefficients are positive and statistically significant at 0.01 level).

4.5.4.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

In comparison to farmers who did not take pig farming as their primary occupation, again, those who did were found to be more likely to apply more PRRS preventive measures. This is also confirmed by the positive and statistically significant point-biserial correlation coefficient (0.144). Particularly, these pig farmers appeared to be more likely to participate in regional elimination programs and to apply medicated and segregated early weaning, herd closure and rollover, and risk based testing and surveillance. In general, these practices are labor intensive and require a long time to complete. Operators who farmed as a main occupation tend to implement them as they have more time available for working on the farm.

4.5.4.2 Porcine Circovirus Associated Disease (PCVAD)

Like PRRS case, farmers who took pig farming as their main occupation were also found to be more likely to implement more PCVAD treatment methods than those who had off-farm work as their main job. In particular, operators who farmed as their primary occupation would be more likely to make changes in their management practices, to apply general biosecurity measures as well as vaccination, and to decrease the load of pathogens and bacteria in the environment.

4.5.5 Operator's Age

Various studies have shown farmers of different ages would make very different management decisions, and the effect of farm operator's age on the adoption of disease prevention strategies might be mixed. On one hand, older farmers may be more set in their ways and less likely to make operational changes (e.g., Tuyttens et al., 2008). On the other hand, older farmers might have better understanding of diseases and the associated treatments and have more control over their decision making due to wealth (Nöremark et al., 2016). The age distribution showed the age of the farm operators ranged from 18 to 69 years old, and the sample consisted of 21 operators aged below 40, 11 aged in the range of 40-50, and 19 aged above 50. Our sample suggests older farmers were more willing to take more basic biosecurity measures. Particularly, sanitation, flow management, and personal record keeping are found to be more commonly employed by older farmers.

4.5.5.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

As expected, farmers at different life stages would adopt different treatments to control PRRS. Moreover, the positive spearman's correlation coefficient between age and total number of measures undertaken suggests older farmers tended to apply more treatment methods, as they usually have more wealth. In comparison to younger farmers, the positive point-biserial correlation coefficients indicate older pig farmers were more likely to participate in regional elimination programs and to apply vaccines Ingelvac® PRRS ATP and Fostera PRRS (Pfitzer), all-in-all-out, and monitoring (Table 4.3). While for younger farmers, they tended practice herd closure and rollover, nursey depopulation, medicated early weaning, boar testing, sow herd stabilization, risk based testing and surveillance, vaccine Ingelvac® PRRS MLV, and depopulation-repopulation. Surprisingly, younger farmers, who tend to have less wealth, are found to be more likely to apply depopulation-repopulation, herd closure and rollover, and nursey depopulation, which usually incur high costs due to the significant disruptions in production.

4.5.5.2 Porcine Circovirus Associated Disease (PCVAD)

As suggested by the point-biserial correlation coefficients (Table 4.4), younger pig farmers are found to have more possibility to apply general biosecurity measures, pathogen load remediation, vaccination (especially Circovac (Merial)), and antibiotics. For older farmers, they were more likely to employ serotherapy and to change management practices.

4.5.6 Operator's Education Level

Given its relationship with producers' ability to perceive the risk of a disease outbreak and to analyze various disease preventive measures (Susilowati et al., 2013), education may also be a key factor influencing the adoption of various biosecurity measures. For education level, the sample includes 6% of the farm operators having less than high school education, 35% obtaining a high school diploma, 37% finishing college study, and the rest 22% having either undergraduate or post-graduate degree. Because farmers with higher levels of education may have a better knowledge of disease causation and transmission and be more able to understand the biosecurity concepts (Udeh et al., 2010), we would expect the higher the farmers' educational level, the greater the likelihood of biosecurity adoption (Austin et al., 2001; Gasson, 1998). In our sample, the positive point-biserial correlation coefficients confirm the expectation and indicate pig farmers with higher level of education seemed to be more likely to implement sanitation (0.2174) and flow management (0.2503).

4.5.6.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

Pig farmers with higher education level are found to have higher compliance with PRRS treatments, which is consistent with the previous literature suggesting farmers with a higher level of education had a better understanding of the preventive measures (e.g., Racicot et al., 2012). As implied by the statistically significant point-biserial correlation estimates (Table 4.5), farmers with higher education level are found to be more likely to implement sow herd stabilization, nursery depopulation, medicated early weaning, vaccine Ingelvac® PRRS MLV, and all-in-all-out on their pig herds. On the other hand, those with lower education tended to employ boar testing, risk based testing and surveillance, and vaccines Fostera PRRS (Pfitzer) and ReproCyc® PRRS-PLE.

4.5.6.2 Porcine Circovirus Associated Disease (PCVAD)

For the control and prevention of PCVAD, farmer's education level was also significantly associated with the level of preventive measures (Table 4.6). More educated pig farmers are found to be more likely to apply antibiotics, general biosecurity measures, vaccine Fostera PCV (Pfizer), pathogen load remediation, and management changing practices. While vaccine Circumvent (Intervet / Schering - Plough) tended to be more commonly used by less educated farm operators.

4.5.7 Operators' Experience

As with operator's educational level, farmers' pig farming experience may also play a vital role in biosecurity adoption, as farmer's ability to understand the disease issue and the available biosecurity measures might be enhanced with experience. More experienced farmers are expected to be more likely to practice more biosecurity measures on their farms. In our study, experience distribution shows 27% of the farm operators had been raising pigs for less than 15 years, while half of them had been raising pigs between 15 and 30 years, and the rest 23% had been in the business for more than 30 years. On average, the surveyed pig producers had 23 years of experience in pig farming, implying their good experience on how to handle their farms. In accordance with previous literature (e.g., Racicot et al., 2012), pig farming experience is found to be significantly related to the application of disease treatment methods. As regards to the adoption of biosecurity measures, more experienced pig farmers tended to apply more basic biosecurity measures, since a positive relationship between the number of preventive measures adopted and experience is detected. In addition, we find more experienced pig farmers were more likely to practice segregation, as suggested by the positive point-biserial correlation (0.1582).

4.5.7.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

For the control and prevention of PRRS, the positive spearman's correlation between experience and number of treatments undertaken indicates more experienced farmers were more likely to take more PRRS treatments. More experienced farmers usually possess more disease control knowledge, which might further strengthen farmers' motivation to apply more treatment methods. To be more specific, the significant point-biserial correlation coefficients (Table 4.7) suggests more experienced farm operators tended to apply vaccine Ingelvac® PRRS ATP and to participate in regional elimination programs. On the other hand, less experienced farmers are found to be were more likely to implement vaccines ReproCyc® PRRS-PLE and Ingelvac® PRRS MLV, boar testing, and herd closure.

4.5.7.2 Porcine Circovirus Associated Disease (PCVAD)

Like PRRS case, more experienced pig farmers are also found to be more likely to implement more PCVAD treatment methods. In addition, the statistically significant point-biserial correlation coefficients suggest these operators were more likely to change management practices (0.1986) and to decrease the load of pathogens and bacteria in the environment (0.1723). Whereas farmers with less experience tended to apply vaccination on their farms.

4.5.8 Operator's Gender

Apart from other farmer characteristics, gender may also affect the level of biosecurity measures as males and females may have different extents of risk perceptions when facing pig diseases. In particular, several studies found female farm operators were more responsive to health and hygiene information and were more likely to perform precautionary behavior (Wright et al., 2008). In our sample, the gender distribution includes 85% male farmers and 15% female farmers, and we confirm the findings from previous literature showing female operators were more likely to apply more basic biosecurity measures. In terms of the particular measures undertaken by male operators, we detect they were more likely to apply sanitation, as confirmed by the positive tetrachoric correlation coefficient (0.5752, significant at 0.1).

4.5.8.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

To prevent the introduction and spread of PRRS, female farm operators tended to apply more PRRS treatments, as suggested by the point-biserial correlation estimate (significant at 0.05 level). Females generally have higher empathy for animals (Erlanger and Tsytsarev, 2012), so they might be more willing to take as many measures as they can to treat PRRS. Particularly, female farmers are found to be more likely to participate in regional elimination programs than male farmers. Regional elimination programs are usually initiated or supported by veterinarians. Since female operators have been shown to have higher medical compliance than male operators (Courtenay et al., 2002), and this might be the one of the reasons behind the high participation rate. For male farm operators, the majority of them applied sow herd stabilization, strict biosecurity measures, and herd closure.

4.5.8.2 Porcine Circovirus Associated Disease (PCVAD)

As expected, female operators also tended to implement more preventive measures to combat PCVAD, and our sample suggests they were more likely to apply serotherapy than male farmers. Again, because females usually have higher empathy for animals and tend to be more responsive to health and hygiene information, they would be more willing to apply various treatments, even though some treatments are very complicated to implement.

Although segregation was the least commonly practiced biosecurity measure, we detect pig farmers with more farming experience and those who took pig farming as their main occupation were more likely to apply segregation on their farms. For the control and prevention of PRRS, older and more experienced farmers are found to be more likely to implement more treatment methods. Moreover, pig farmers who farmed as the primary occupation had shown stronger biosecurity behavior with more preventive measures being adopted. In comparison to farrow-to-finish farms, farrow-to-wean operations were more willing to take more treatments into practice. Therefore, strategies that are tailored to encourage younger farmers, farmers who took off-farm work as their main job, and farmers operating farrow-to-finish units to be more engaged might be very necessary. For example, vaccine Ingelvac® PRRS ATP and regional elimination programs should be encouraged among younger and less experienced pig farmers though education. More training in regards to herd closure and rollover, segregated and medicated early weaning, and risk based testing and surveillance should be provided and it should be targeted to farmers who have off-farm work as their primary job.

As regards to PCVAD and its control, younger and more educated pig farmers tended to have stronger biosecurity behavior. In particular, they are found to be more likely to practice antibiotics, pathogen load remediation, and general biosecurity measures on their farms. Farm operators with larger herd size would take higher biosecurity levels with vaccine Circovac (Merial) and management changing practices being the most commonly used measures. For farmers who had pig farming as their primary occupation, they were more likely to implement more treatment measures, and their commonly practiced measures include changes in management practices, application of general biosecurity measures, vaccination, and pathogen load remediation. To effectively control the spread of PCVAD, younger farmers should be provided with more information and training regarding vaccination and management changing practices; large farm holders should be educated on how to efficiently apply general biosecurity measures on their farms; and all farmers should be given more information in respect to the usage of serotherapy.

4.6 Understanding What Affects the Actual Application of Treatments

In addition to the health status of the pig herds as well as farm and farmer characteristics, the uptake of preventive measures may also depend on producers' understanding of the measures' protocols and their attitudes towards these measures (Gilmour et al., 2011). This section aims to describe how farmers' knowledge about the treatments affects their implementation of the practices and to explore the relationship between farmers' perceptions over the measures and their actual applications. Further understanding of the determinants that affect pig farmers' adoption decisions, especially their knowledge about and attitudes towards practices, may help veterinarians and the government understand how to engage pig farmers in disease control and prevention activities with programs that are tailored to their specific needs (Brennan and Christley, 2012).

4.6.1 Relationship between Farmers’ Knowledge about the Treatments and Their Application

Knowledge about or familiarity with biosecurity measures has been found to be a strong determinant of farmers’ biosecurity behavior (e.g., Ajewole and Akinwumi, 2014; Delabbio, 2004). Since farmers usually base their decisions on their knowledge, those who have greater familiarity with the specific preventive measures might be more motivated to employ them. It is expected that the better the farmer’s knowledge about the biosecurity measures, the stronger their biosecurity behavior.

4.6.1.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

Among the 52 surveyed pig producers, the majority reported they knew a lot about all-in-all-out (67%; n=35), depopulation-repopulation (65%; n=34), herd closure (65%; n=34), strict biosecurity measures (63%; n=33), nursery depopulation (58%; n=30), and sow herd stabilization (56%; n=29). Interestingly, only 37% (n=19) of the pig farmers claimed they were very familiar with at least one type of vaccination. As regards to practices such as rollover, risk based testing and surveillance, and regional elimination program, less than 30% of the farmers stated they were very familiar with them, and farmers’ unfamiliarity with these practices might be the reason for their low applications.

In general, our sample confirms the expectation and suggests farmers who were very familiar with a particular treatment were more likely to apply that treatment, and this is confirmed by the positive and statistically significant tetrachoric correlation coefficients (Table 4.8). Such a result is in accordance with the literature claiming knowledge plays an important role in farmers’ biosecurity behaviors (Delabbio, 2004; Ellis-Iversen et al., 2010). However, they exist some disconnections. For depopulation-repopulation and nursery depopulation, although the majority of the surveyed farmers reported they knew a lot about these two treatment methods, not many of them did actually take these two treatments into practice. In addition, no statistical relationships are found between knowledge and the application of these two porcine reproductive and respiratory syndrome (PRRS) treatments. Disconnections might be attributable to farmers' considerations over the additional production costs resulting from production disruptions.

4.6.1.2 Porcine Circovirus Associated Disease (PCVAD)

For farmers' familiarity with porcine circovirus associated disease (PCVAD) treatments, most farmers claimed they were very familiar with vaccination (77%; n=40/52) and general biosecurity measures (73%; n=38/52), while only 6 farmers (12%) stated they knew a lot about serotherapy. For the rest of the available practices (i.e., antibiotics, management changing practice, pathogens load remediation), over 90% of the farmers stated they at least heard of them, though some farmers may not know much about them. As regards to the relationship between farmer's knowledge of a practice and it being undertaken, again, the better the farmers' knowledge about a particular practice the stronger their biosecurity behavior (Table 4.9).

4.6.2 Relationship between Farmers' Perceptions over the Treatments and Their Application

In order to investigate how farmers' attitudes towards the treatments affect the applications, we asked whether they deemed the available PRRS and PCVAD measures effective, animal welfare friendly, safe for human health, environmental friendly, and affordable. As the questions in respect to farmers' attitudes towards disease's treatments were asked at the aggregated level, the exploration of how farmers' attitudes affect the application of PRRS or

PCVAD treatments was done with the creation of application index. In our study, application index is defined as the percentage of applied treatments by farmers out of the maximum of available treatments. It is expected that farmers with positive attitudes towards the available treatments would be more likely to adopt more treatments.

4.6.2.1 Porcine Reproductive and Respiratory Syndrome (PRRS)

For the 17 PRRS treatments listed, most farmers deemed them effective (58%; n=30/52), animal welfare friendly (65%; n=34/52), safe for human health (73%; n=38/52), and environmental friendly (65%; n=34/52). However, only 35% of the surveyed farmers (n=18) deemed them affordable. If farmers perceive the practices were unaffordable, this might result in inaction. The application index for PRRS treatments ranged from 6% to 82%, and the average index was 26%.

When examining how farmers' perceptions affect the percentage of treatments' adoption, we find the stronger the farmers' perceived effectiveness of PRRS measures the more likely they are to exhibit stronger biosecurity behavior (point biserial showed a significant correlation at 0.05 level). Such a finding is consistent with the literature showing farmers will adopt the disease control strategies if they believe the measures are effective (e.g., Jemberu et al., 2015). If farmers deemed the available treatments to be more animal welfare friendly and more environmentally friendly, they would also be more likely to implement more PRRS treatments. Although most farmers deemed the treatments safe for human health, there was no agreements between the safety of the treatments and they being undertaken.

4.6.2.2 Porcine Circovirus Associated Disease (PCVAD)

In terms of the 9 available PCVAD treatments, the majority of the pig farmers claimed they were effective (80%; n=42/52), animal welfare friendly (75%; n=39/52), safe for human health (73%; n=38/52), and environmental friendly (69%; n=36/52). Like PRRS case, fewer (less than 40%) farmers thought the listed practices were affordable. When making treatment adoption decisions, farmers would not only consider the direct costs on the purchase of vaccines and other building maintenance or improvement materials (Brennan et al., 2008), but also indirect costs from extra labor (Morgan-Davies et al., 2006). The costly investments might discourage farmers from adopting more preventive measures. The application index for PCVAD treatments was in the range of 11-67%, and the average index was 41%.

Like PRRS case, the stronger the farmers' perceived efficacy of the available strategies, the more likely they are to apply a higher number of PCVAD treatments on their farms (0.1271, point biserial shows a significant correlation at 0.05 level). This is in accordance with the literature as farmers would apply the treatments when they consider them as effective and useful for their farms (Casal et al., 2007; Olmstead and Rhode, 2007). In addition, farmers' attitudes towards animal welfare, human health (0.2731), and environment (0.0826) also significantly influenced farmers' biosecurity behavior. In terms of the treatments' affordability, we detect farmers would apply more treatments if they considered the available treatments were affordable. Fraser et al (2010) also found a farmer's willingness to implement a biosecurity protocol was negatively related to its estimated cost.

4.7 Conclusion

This chapter analyzes how on-farm disease status, management variables, farmers' knowledge about and attitudes towards various treatment methods affect the actual application of various porcine reproductive and respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) treatment methods. In our study, farmers who experienced disease outbreaks are found to be more likely to implement more preventive measures to prevent the spread of pathogens within a farm and pathogen reintroduction. For those who haven't experienced disease outbreaks, they seemed to be less motivated to do so. Provided by our findings, pig farmer are highly recommended to participate in risk based surveillance program as it can provide early warnings about disease outbreaks and let them be more aware of local and national situations (Garforth et al., 2013). Once pig diseases are introduced to the region, farmers could be well prepared in advance to curb the introduction of pathogens to their own pig herds.

Given the physical and financial constraints faced by farrow-to-finish farmers, although farrow-to-finish farms were more likely to be infected with pig diseases, it was farrow-to-wean unit being more likely to adopt more disease control and prevention methods. As compared to small farms, more preventive measures tended to be implemented by medium-to-large sized farms as they are more susceptible to infections due to higher pig densities. In addition to farm characteristics, famer characteristics such as farm operators' age and education level are also found to be important determinants of adoption decisions. Therefore, suggestions regarding the application of various preventive measures should be tailored to the farmers' situations and then provided to the targeted farmer groups.

As regards to farmers' knowledge about the available treatments, the better the farmers' knowledge about a particular practice the stronger their biosecurity behavior. Therefore, increasing farmers' access to biosecurity information can be a great way to achieve behavioral change. Since veterinarians are frequently consulted by pig farmers and are usually perceived as trusted advisors, they may play a significant role in information dissemination and measure adoption. However, there exist some disconnections between farmers' knowledge about and the actual uptake of preventive measure. For example, the majority of the surveyed farmers reported they knew a lot about depopulation-repopulation and nursery depopulation, but not many of them did actually apply these two methods on their farms due to cost considerations. In addition, it is detected that unaffordability was deemed as a barrier to the adoption of disease treatments. Our findings suggest government should not only offer training programs to let pig farmers be very familiar with more preventive measures, they should also provide financial supports to make the treatments practicable. For farmers who have positive attitudes (e.g., effectiveness, animal welfare friendly) towards the available preventive treatments, they are found to be more likely to take more measures into practice.

One imperfection of the present study is in-depth quantitative analyses cannot be conducted due to the small sample size. Given this imperfection, the current results we have are somewhat preliminary, and re-evaluation of these results with a larger sample size would be needed. Since the empirical results obtained from the previous chapter showed pig diseases had played a significant role in the eastern provinces like Ontario, and hadn't been important in the western provinces such as Alberta, it is reasonable to expect pig farmers in different provinces would make very different decisions regarding the control and prevention of diseases. Further study would focus on the provinces of Alberta and Ontario to compare how farmers' decisions regarding the uptake of disease preventive measures might vary and to investigate what other factors (i.e., in addition to disease incidence) might lead to the variation in adoption decisions.

Due to farmers' considerations over the additional production costs resulting from disease outbreaks and the uptake of preventive measures, pig farmers might also simultaneously adapt their farm structures (e.g., expansion or shrinkage activities) with the aim to minimize the per unit production costs. Since different regions might experience different types of farm structure changes (as shown in Chapter 3), it might be necessary to conduct the quantitative analyses with the differentiation of regions that experienced different types of structural change.

Although having good knowledge about a preventive measure might facilitate farmers' application, many studies suggest farmers' assessment of the measure's effectiveness and practicability is much more important. Further research is thus encouraged to investigate the association between farmers' attitude toward each practice and the resulting application. Given area spread, farmers may be less likely to apply more preventive measures if they are surrounded by neighbors who have poor biosecurity levels. As a result, neighborhood effect should also be included in the analyses. As aforementioned, pig farmers might also simultaneously make farm structure adjustments to minimize per unit production costs, so future study could be carried out to look at both farm structure changes and preventive measure adoptions.

Figures

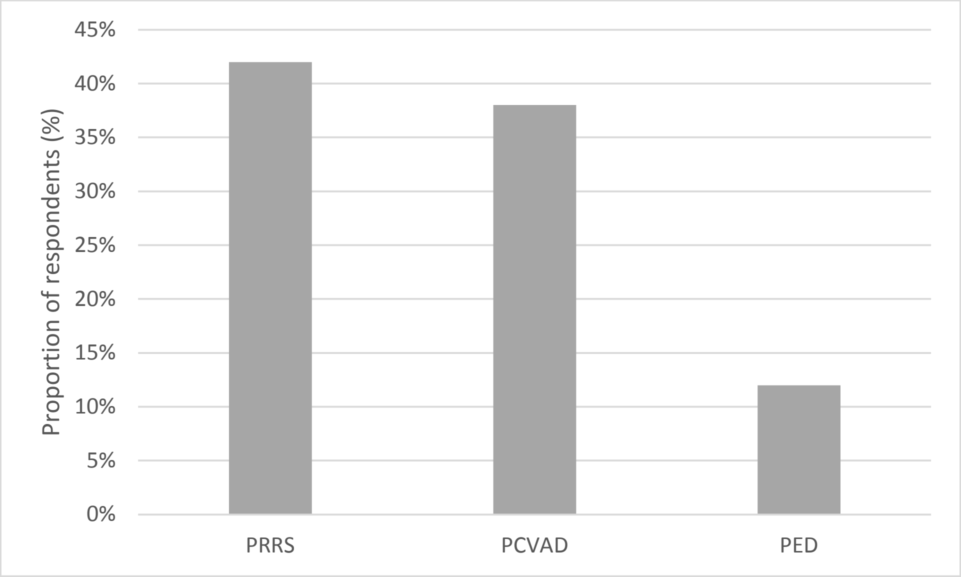

Figure 4.1. Distribution of Herds Reporting PRRS, PCVAD, and PED (Separately) as the Top Three Causes of Pig Mortality in terms of Their Frequency of Occurrence.

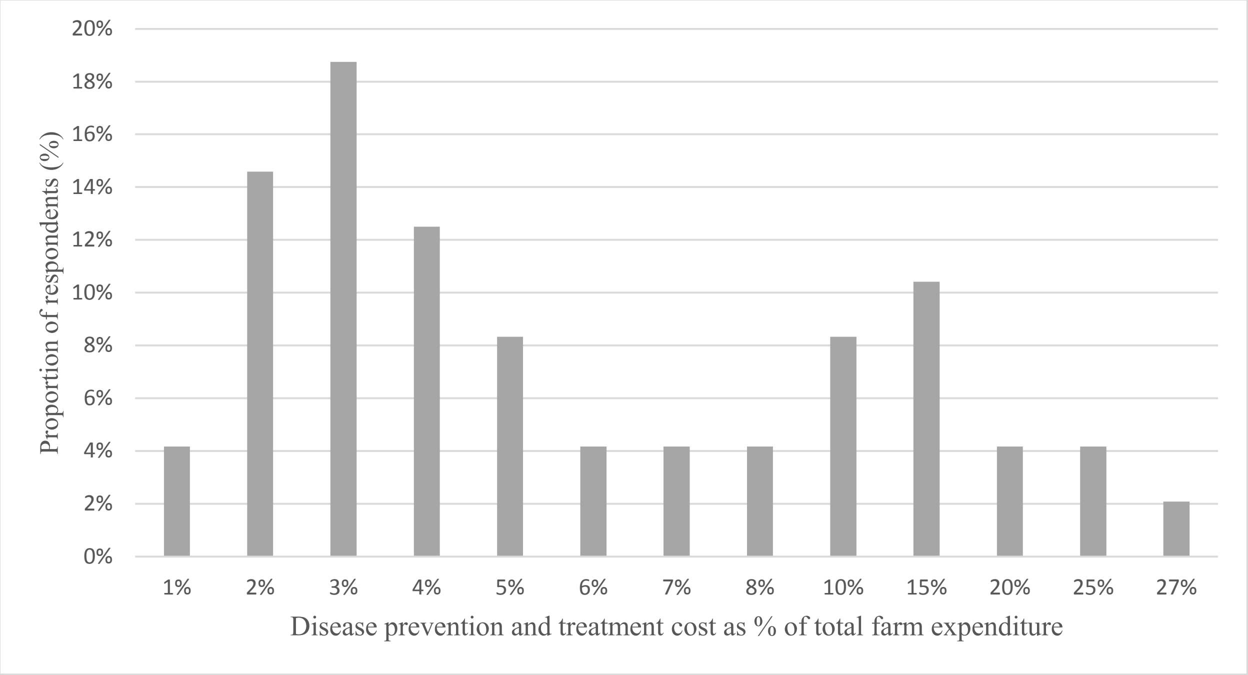

Figure 4.2. Distribution of Disease Prevention and Treatment Costs.

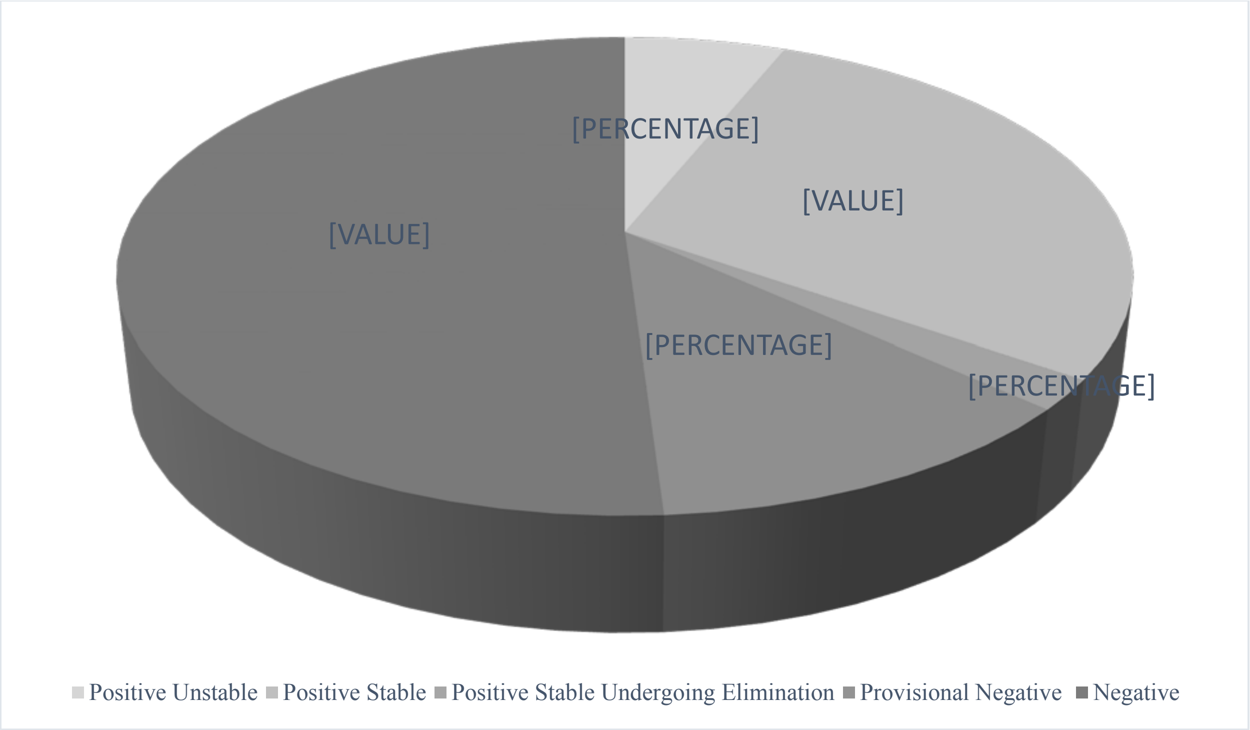

Figure 4.3. PRRS Prevalence in Breeding Herds.

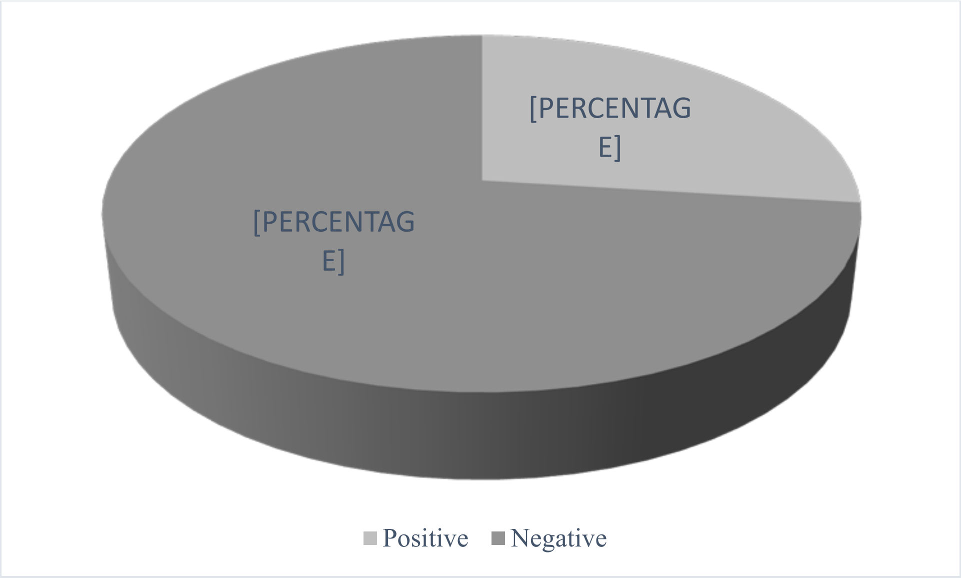

Figure 4.4. PRRS Prevalence in Growing Herds.

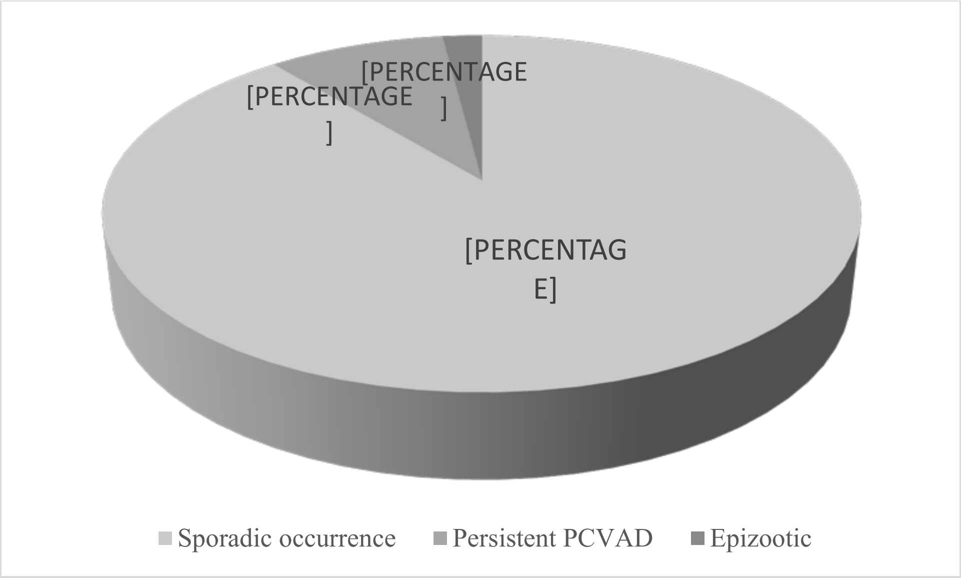

Figure 4.5. PCVAD Prevalence in Breeding Herds.

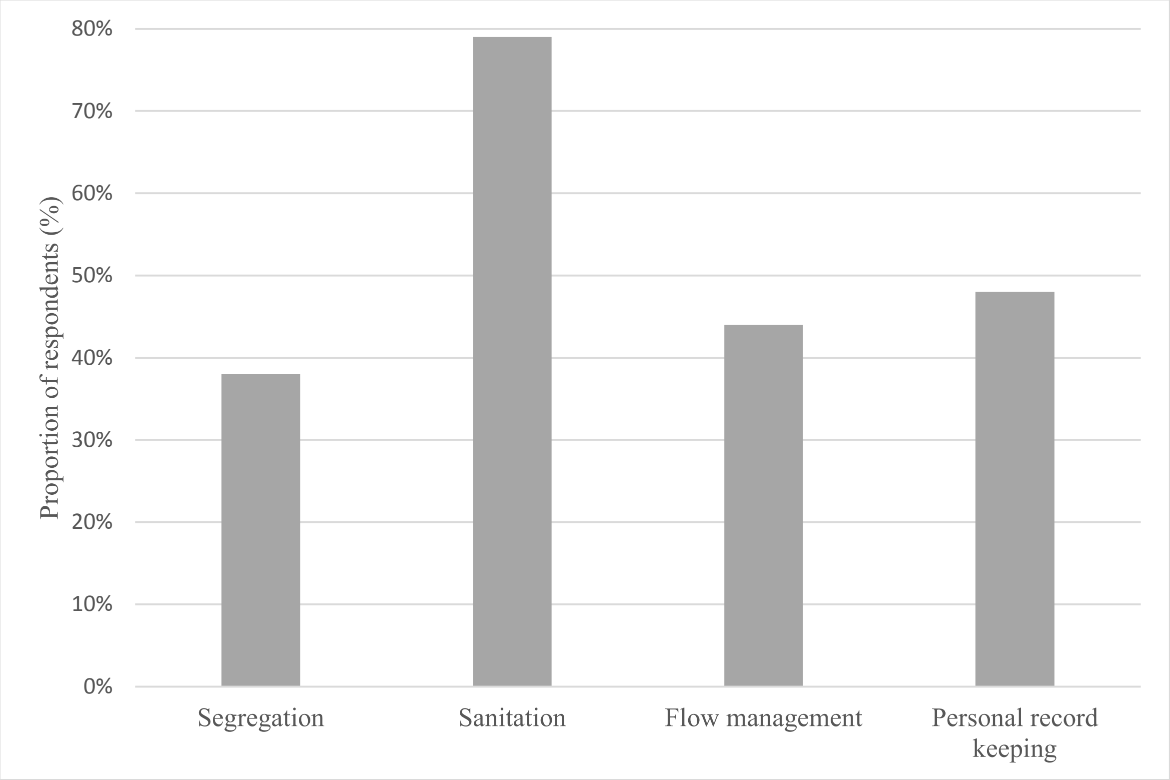

Figure 4.6. Distribution of the Practice of Basic Biosecurity Measures.

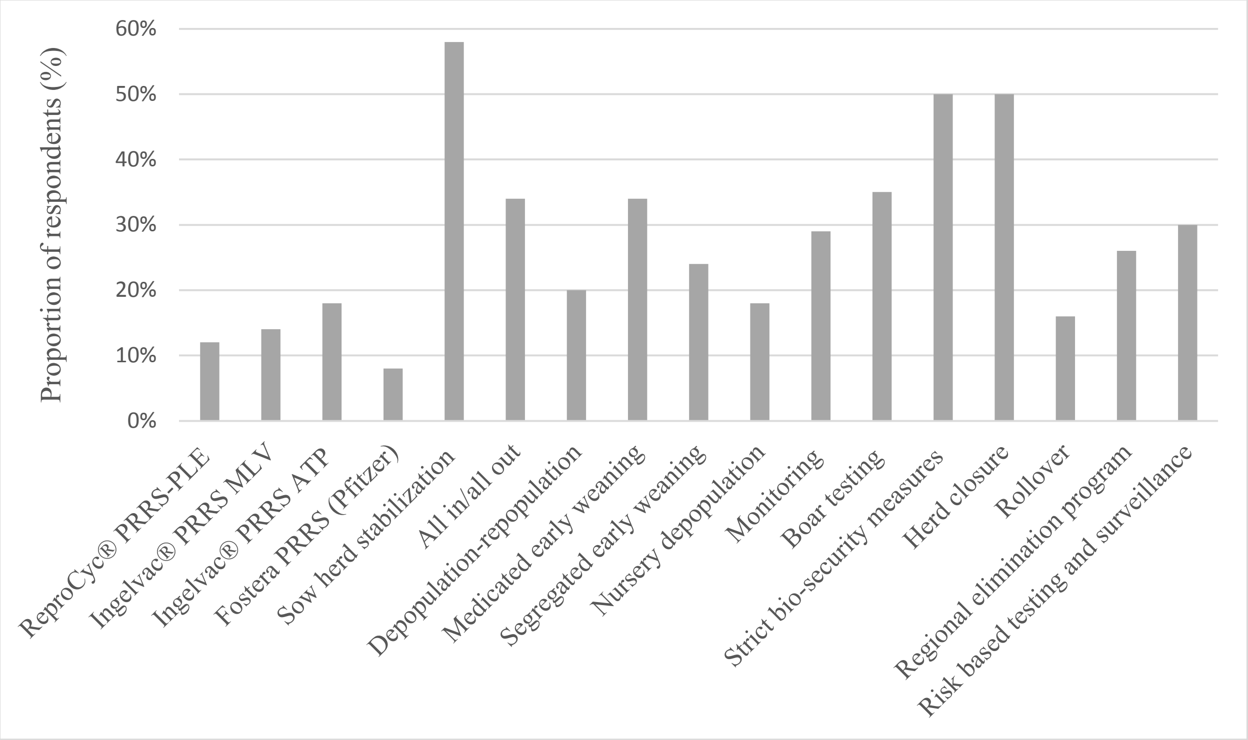

Figure 4.7. Distribution of the Application of PRRS Treatments.

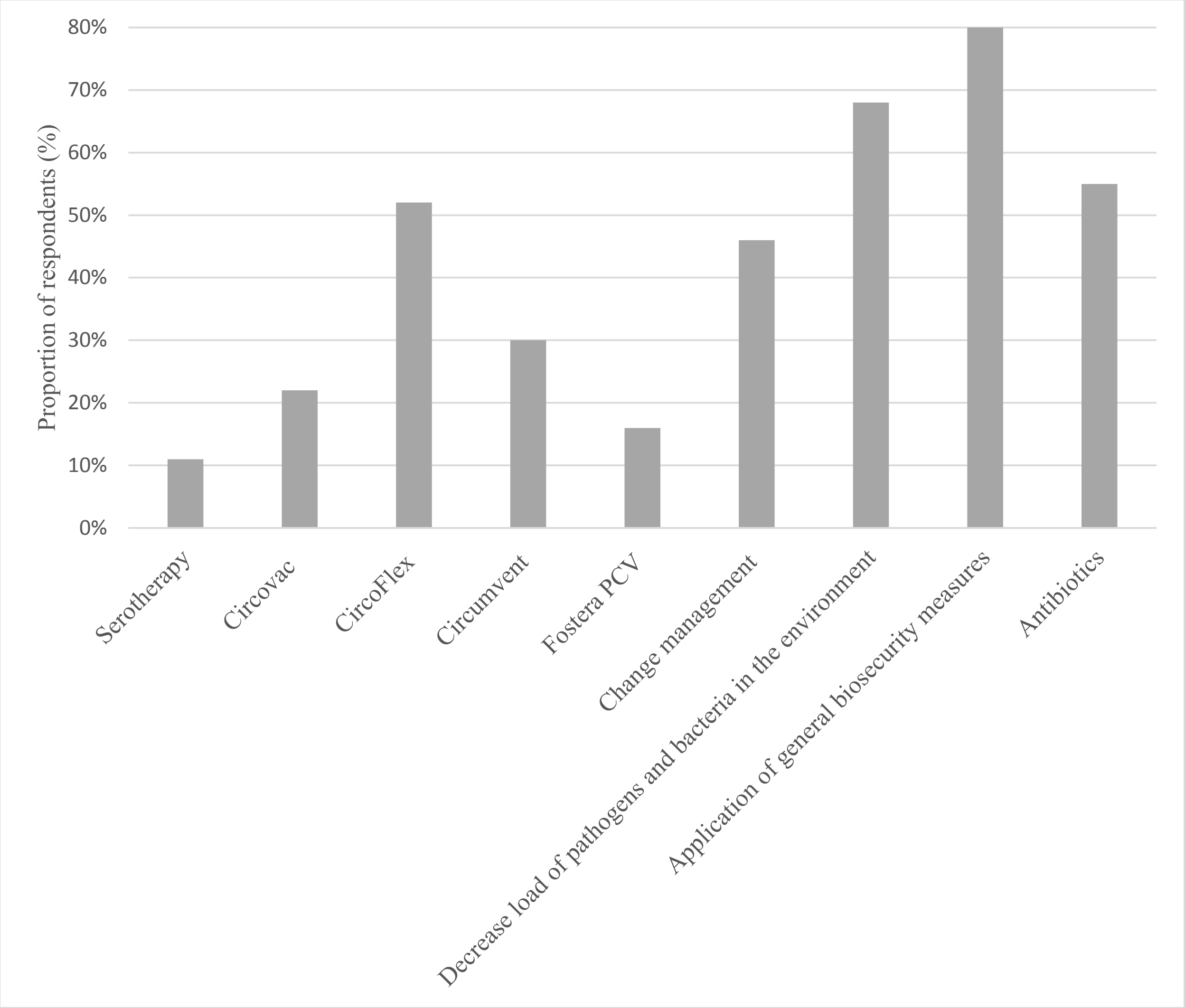

Figure 4.8. Distribution of the Application of PCVAD Treatments.

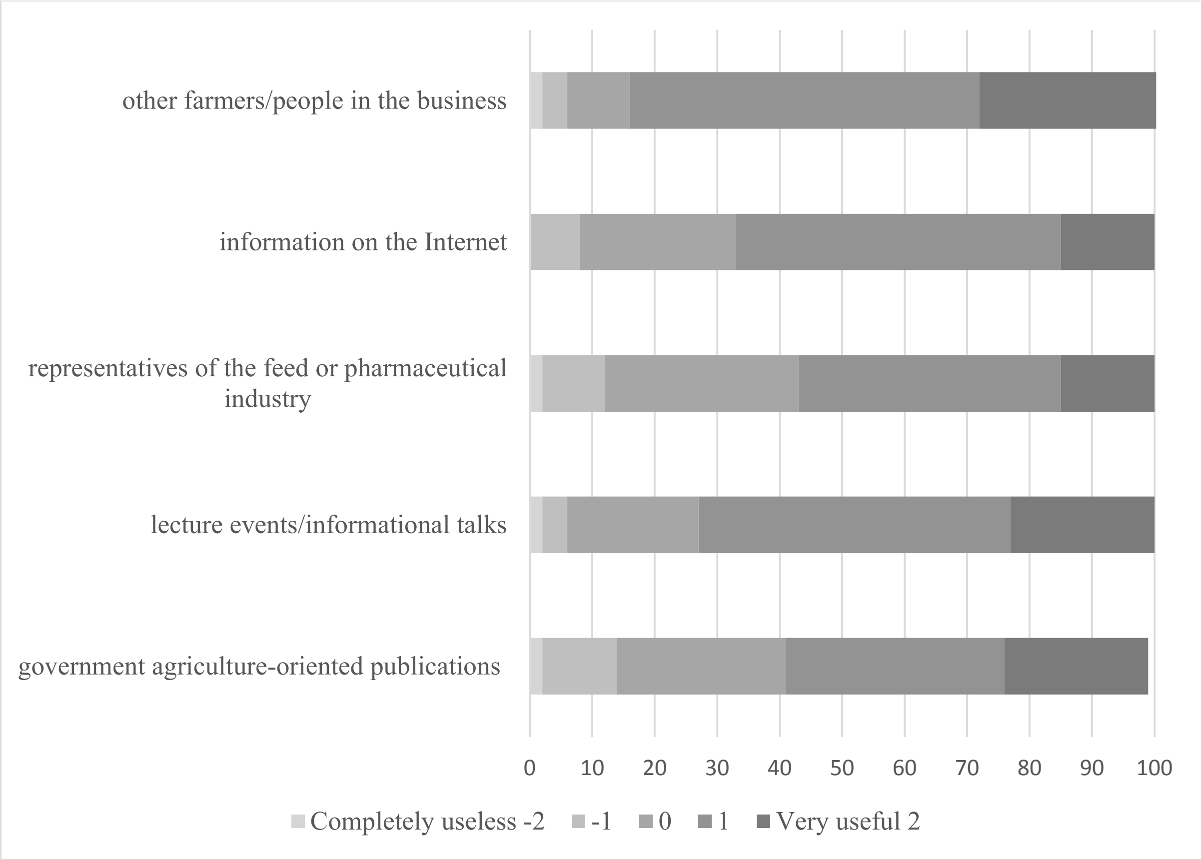

Figure 4.9. Farmers’ Perceptions over the Usefulness of Hog Health Resources.

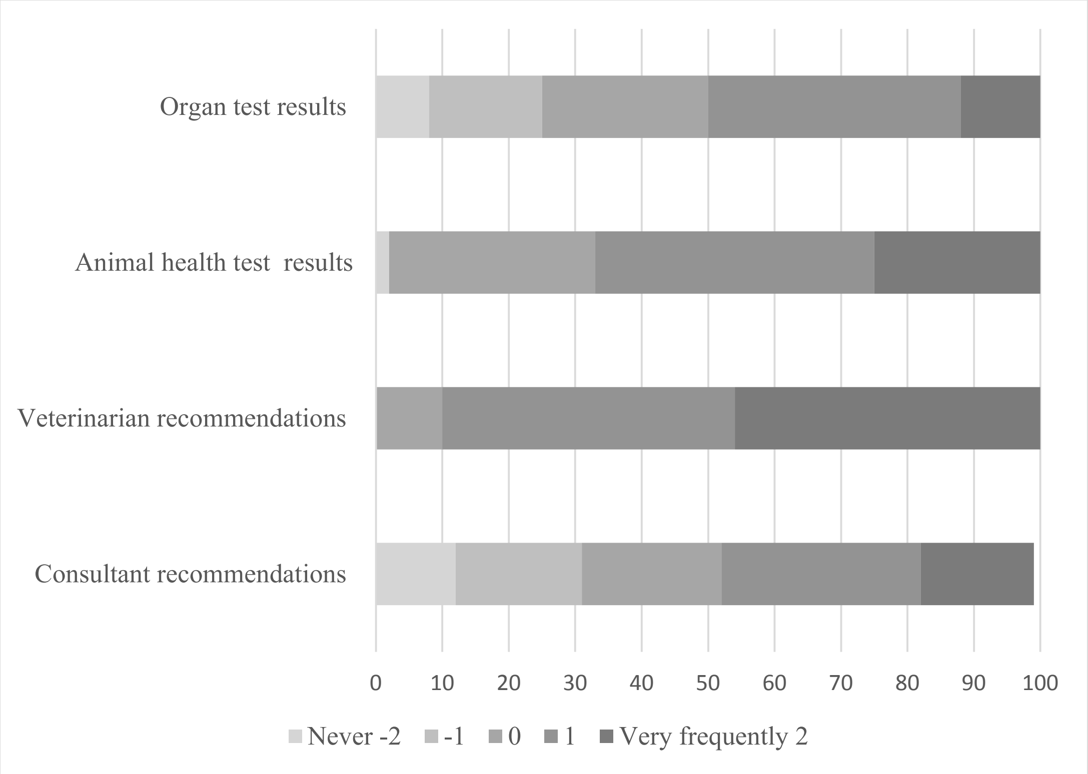

Figure 4.10. Frequency of Information Source Usage.

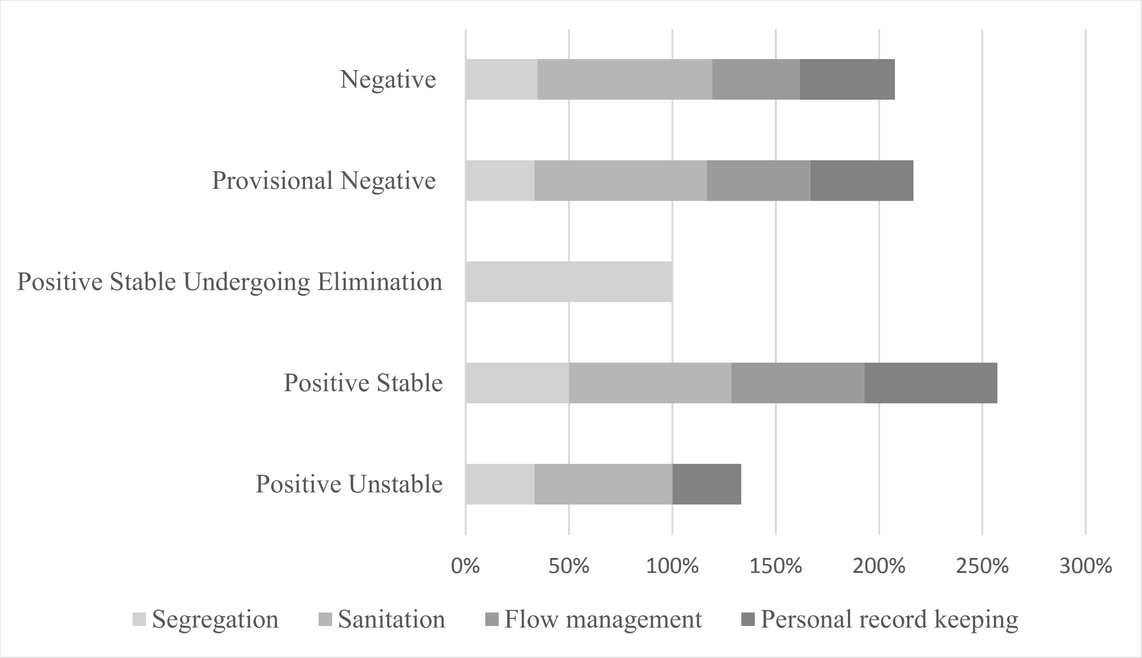

Figure 4.11. Distribution of the Application of Basic Biosecurity Measures, Segregated by PRRS Status.

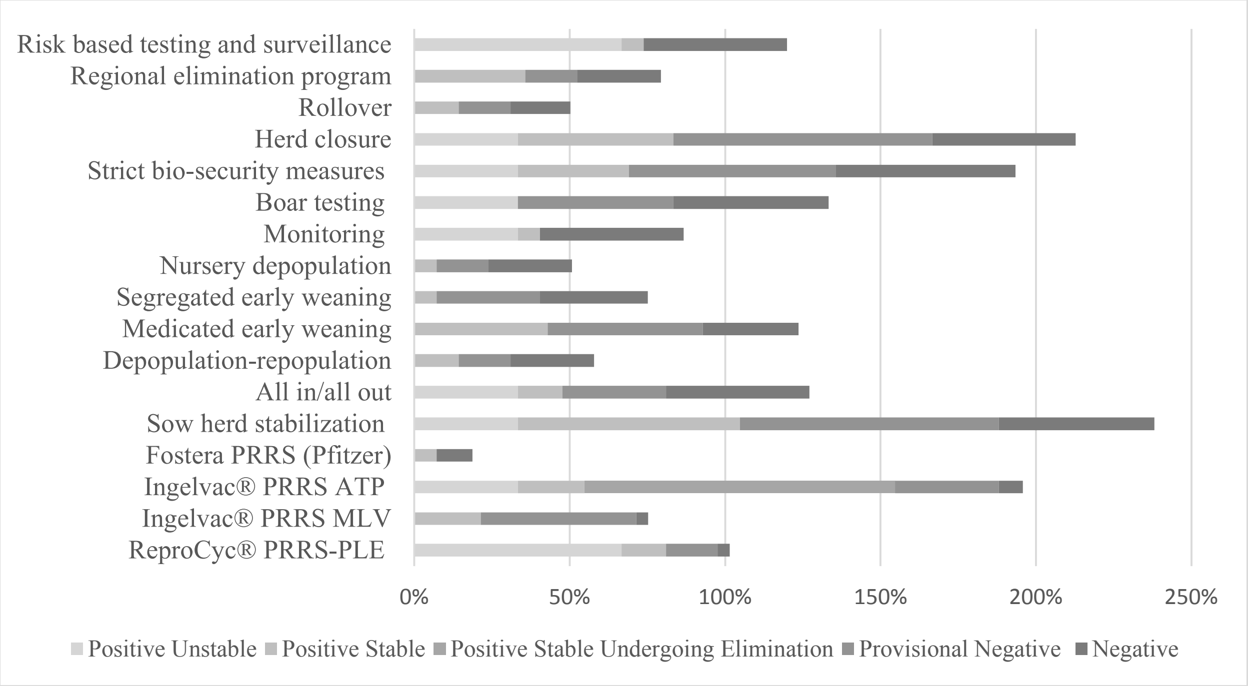

Figure 4.12. Distribution of the Application of PRRS Treatments, Segregated by PRRS Status.

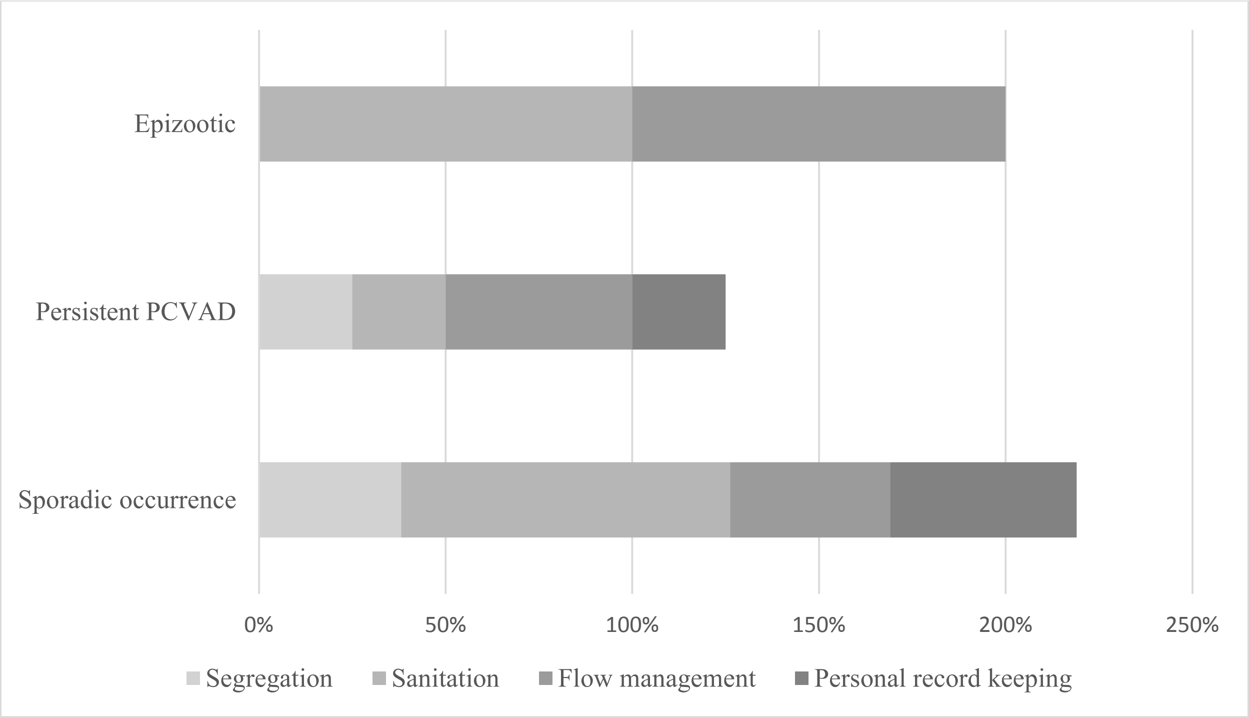

Figure 4.13. Distribution of the Application of Basic Biosecurity Measures, Segregated by PCVAD Status.

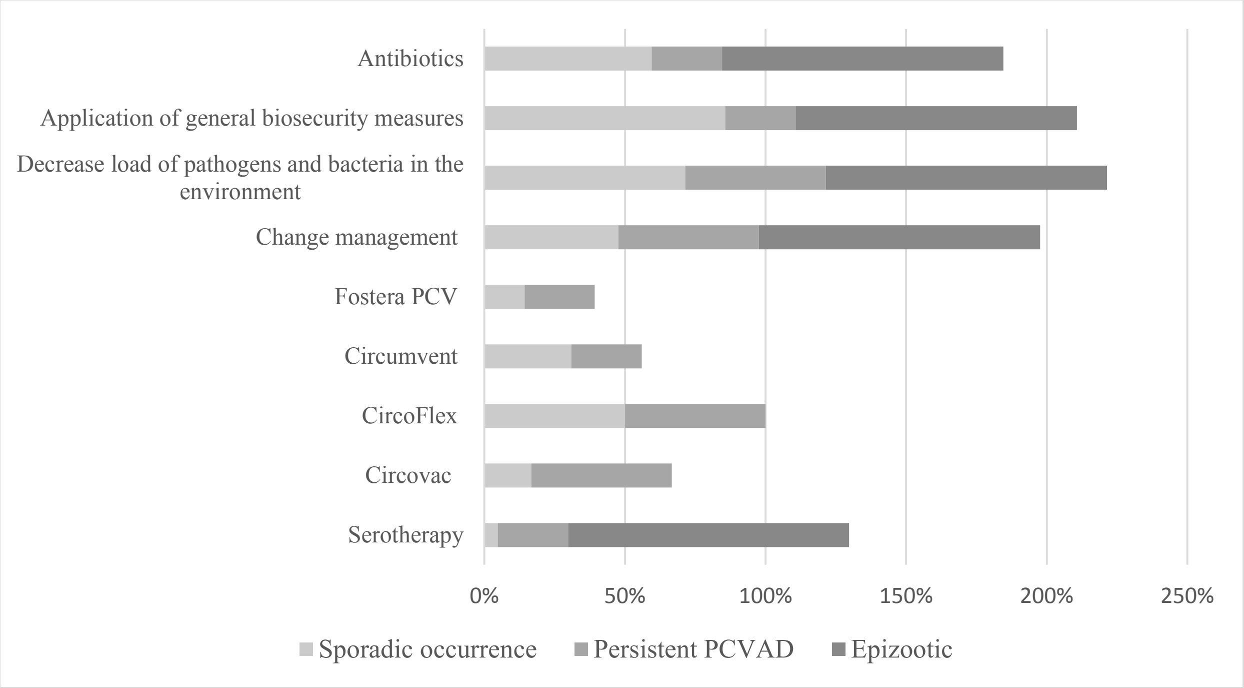

Figure 4.14. Distribution of the Application of PCVAD Treatments, Segregated by PCVAD Status.

Tables

Table 4.1. Tetrachoric Correlation between the Uptake of PRRS Treatments and Farm Type being Farrow-to-wean.

Treatments	**Coefficient**
All-in-all-out	0.5043*
Depopulation-repopulation	0.6107**
Segregated early weaning	0.5161*
Nursey depopulation	0.4708*
Herd closure	0.6327**

Note: Asterisks denote levels of significance (*for 10 percent, and **for 5 percent).

Table 4.2. Point-biserial Correlation between the Uptake of PRRS Treatments and Farm Size.

Treatments	**Coefficient**
Depopulation-repopulation	0.2172
Monitoring	0.1557
Segregated early weaning	0.1528
Medicated early weaning	0.1319
Vaccine Ingelvac® PRRS ATP	0.1285
Nursery depopulation	0.1151
All-in-all-out	-0.1086
Sow herd stabilization	-0.0966

Note: All coefficients are statistically significant at 5 percent level.

Table 4.3. Point-biserial Correlation between the Uptake of PRRS Treatments and Farm Operators' Age.

Treatments	**Coefficient**
Vaccine Ingelvac® PRRS ATP	0.2000
Vaccine Fostera PRRS (Pfitzer)	0.1405
All-in-all-out	0.0614
Monitoring	0.0205
Regional elimination programs	0.0205
Herd closure	-0.2109
Rollover	-0.1775
Nursey depopulation	-0.1294
Medicated early weaning	-0.1238
Boar testing	-0.0896
Sow herd stabilization	-0.0669
Risk based testing and surveillance	-0.0543
Vaccine Ingelvac® PRRS MLV	-0.0369
Depopulation-repopulation	-0.0297

Note: All coefficients are statistically significant at 5 percent level.

Table 4.4. Point-biserial Correlation between the Uptake of PCVAD Treatments and Farm Operators' Age.

Treatments	**Coefficient**
Management changing practices	0.0659
Serotherapy	0.0102
General biosecurity measures	-0.1411
Antibiotics	-0.1032
Decrease load of pathogens and bacteria in the environment	-0.0992
Vaccination	-0.0140

Note: All coefficients are statistically significant at 5 percent level.

Table 4.5. Point-biserial Correlation between the Uptake of PRRS Treatments and Farm Operators' Education Level.

Treatments	**Coefficient**
Sow herd stabilization	0.2894
Nursery depopulation	0.2469
Medicated early weaning	0.1740
Segregated early weaning	0.1047
Vaccine Ingelvac® PRRS MLV	0.1046
All-in-all-out	0.1016
Boar testing	-0.1432
Risk based testing and surveillance	-0.1393
Vaccine Fostera PRRS (Pfitzer)	-0.1146
Vaccine ReproCyc® PRRS-PLE	-0.1140

Note: All coefficients are statistically significant at 5 percent level.

Table 4.6. Point-biserial Correlation between the Uptake of PCVAD Treatments and Farm Operators' Education Level.

Treatments	**Coefficient**
Antibiotics	0.3323
Biosecurity	0.1754
Vaccine Fostera PCV (Pfizer)	0.1613
Decrease	0.1514
management changing practices	0.0974
Vaccine Circumvent (Intervet / Schering - Plough)	-0.2242

Note: All coefficients are statistically significant at 5 percent level.

Table 4.7. Point-biserial Correlation between the Uptake of PRRS Treatments and Farm Operators' Experience.

Treatments	**Coefficient**
Vaccine Ingelvac® PRRS ATP	0.2809
Regional elimination program	0.1779
Vaccine Ingelvac® PRRS MLV	-0.1813
Herd closure	-0.1444
Boar testing	-0.1240
Vaccine ReproCyc® PRRS-PLE	-0.1150

Note: All coefficients are statistically significant at 5 percent level.

Table 4.8. Tetrachoric Correlation between the Uptake of PRRS Treatments and Farmers being very Familiar with the Treatments.

Treatments	**Coefficient**
Vaccine ReproCyc® PRRS-PLE	0.8182***
Vaccine Ingelvac® PRRS MLV	0.7913***
Vaccine Ingelvac® PRRS ATP	0.6153**
Sow herd stabilization	0.4533**
Medicated early weaning	0.5295**
Segregated early weaning	0.6172***
Monitoring	0.7095***
Boar testing	0.6100***
Strict biosecurity measures	0.6216***
Herd closure	0.5814***
Rollover	0.7320***
Regional elimination program	0.6007**
Risk based testing and surveillance	0.6895***

Note: Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Table 4.9. Tetrachoric Correlation between the Uptake of PCVAD Treatments and Farmers being very Familiar with the Treatments.

Treatments	**Coefficient**
Vaccine Circovac (Merial)	0.5508**
Vaccine CircoFlex (Boehringer Ingelheim)	0.5932***
Vaccine Circumvent (Intervet / Schering - Plough)	0.7405***
Vaccine Fostera PCV (Pfizer)	0.8216***
Change management practices	0.6714***
Decreasing load of pathogens and bacteria in the environment	0.5814***
Application of general biosecurity measures	0.6775***
Antibiotics	0.4681**

Note: Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).

Chapter 5: Summary and Conclusions

5.1 Overall Discussion

Since their first discoveries in the early 1990s in Canada, pig diseases, especially porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD), have plagued the Canadian pig industry, and the problem became more severe with the onset of porcine epidemic diarrhea (PED) in 2014. In the meantime, the industry has seen dramatic structural change with a decrease in pig farm numbers and an increase in total pig numbers. Using the census division (CD) level data obtained from the Census of Agriculture Questionnaires, it is found that not every region in Canada went through the same type of structural change over the period from 1981 to 2016. In particular, we find only 31% of the CDs followed the national trend by going through type 1 structural change with a decrease in pig farm numbers and an increase in total pig numbers, while the rest (69% of the CDs) experienced another type of structural change with decreases in both pig farm numbers and total pig numbers (defined as type 2 structural change).

One of the causes of such different patterns of structural change could be pig disease outbreaks, which have affected pig farmers in different regions to different extents. For example, the eastern provinces (e.g., Ontario) have more affected by pig diseases than the western provinces, and southern Ontario has been more affected by PED than the rest of the regions in Ontario. In addition to disease outbreaks, other challenges including price variation and weather fluctuations faced by Canadian pig farmers, are also very heterogeneous. The factors that play a role in the industry's structural change are summarized by the conceptual framework shown in Chapter 2.

Research objectives are addressed here:

Objective #1: To assess how pig diseases (PRRS, PCVAD and PED) have affected structural change in the Canadian pig industry at the individual census division level while controlling for the effect of other key economic explanatory variables.

Given the determinants provided in the conceptual framework, the first objective of this study is to examine how various factors (especially pig diseases) have played a role in the industry's structural change. In our study, farm structure is defined by farm size (i.e., average number of pigs per farm), and the impacts of various economic determinants on the industry's structural change are empirically assessed using random effects generalized least squares models. The heterogeneous challenges faced by farm operators include determinants that are both internal and external to pig farming operations. In particular, internal factors include farm and farmer characteristics, while external factors consist of market factor (e.g., input price), institutional factor (e.g., government policy), biophysical factor (e.g., disease outbreaks) and technology innovation (e.g., the use of computer for farm operation). Empirical analyses are conducted at the individual census division (CD) level to account for the heterogeneities in the types of structural change in different regions. Moreover, since the impact a certain independent variable has on the structural change depends not only on the value of the variable itself, but also on the level of other explanatory variables, we separately conduct the analyses for each province.

The empirical results suggest disease outbreaks did negatively affect the pig industry's structural change in some provinces. Regions that experienced a decrease in pig farm numbers and an increase in pig numbers (type 1 structural change) seemed to be affected more by porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) outbreaks, while the regions that went through decreases in both pig farm numbers and pig numbers (type 2 structural change) seemed to be affected more by porcine epidemic outbreaks diarrhea (PED) outbreaks. One thing to note is CDs that experienced type 1 structural change are dominated by large farms, and CDs that went through type 2 structural change are dominated by small farms. The reason that CDs experiencing type 1 structural change are severely affected by PRRS and PCVAD is there's a strong connection between farm size and these two pig diseases. Particularly, large farms with higher pig densities are at high risks of getting infected with PRRS and PCVAD. Rather than farm size, it is the intermediary (especially birds) that plays a more significant role in the spread of PED. With small pig farms lacking biosecurity measures (e.g., no screens installed), CDs undergoing type 2 structural change are more influenced by PED.

During the period with dramatic increases in PRRS and PCAVD cases (2003-2006), pig farms located in CDs that are categorized into type 1 structural change in Ontario raised on average 511 fewer head of pigs per farm. The average farm size decrease for farms located in the CDs that are categorized into type 1 structural change in Quebec was 257 head. In the province of British Columbia, the average farm size decrease was 205 head per farm. From 1981 to 2016, the changes in farm size for provinces of Ontario, Quebec, and British Columbia are 2241 head per farm, 1869 head per farm, and 3 head per farm, respectively. If PRRS and PCVAD did not play a role in farm structure adjustment, we would expect the farm size changes to be 2752 head per farm for Ontario, 2126 head per farm for Quebec, and 208 head per farm for British Columbia. The marginal effect of "PRRS and PCVAD" variable on farm size and the total change in farm size covering the period from 1981 to 2016 are presented in Table 5.1.

Speaking of the impact of PED outbreaks (2014-2016), farms located in CDs that are categorized into type 2 structural change in Ontario raised on average 87 fewer head per farm, while farms located in CDs that are categorized into type 2 structural change in Quebec raised on average 815 fewer head per farm. Over the past eight census years, change in the average farm size in Ontario was 345 head per farm, and change in the average farm size in Quebec was 1032 head per farm. If PED did not have a significantly negative impacts on farm structure, we would anticipate the changes to be 432 head per farm for Ontario and 1847 head per farm for Quebec. The marginal effect of "PED" variable on farm size and the total change in farm size covering the period from 1981 to 2016 are shown in Table 5.2.

For other determinants that have played a role in the pig industry's structural change, we also find evidence showing these factors do affect the structure of farms that experienced different types of structural change very differently. In particular, our empirical results suggest technology, the implementation of country of origin labelling (COOL) in U.S., and the availability of agricultural universities and veterinary services were the top three external factors that had great impacts on the structure of farms located in CDs that experienced type 1 structural change. Moreover, all three factors are found to have positively and statistically significant effects on the structure of farms (i.e., farm size) in all provinces. The internal factors that had played a more significant role in the determination of farm structure include human population density, farm operators' gender and farm operational arrangement. Among these three internal factors, human population density is found to have statistically significant and negative effect on farm structure in all provinces, but the directions regarding the impacts of farm operators' gender and farm operational arrangement are different across the provinces. In the province of Quebec, male operators are found to be more likely to expand their production, while it is the opposite for the provinces of Alberta and Saskatchewan, and operators' gender is found to have no impact on the size of farms in the provinces of Manitoba and Ontario. For the effect of farm operational arrangement, family farms in Ontario are more likely to expand productions, but no connection between farms size and operational arrangement is detected for the rest of the provinces. Table 5.3 further presents the signs of marginal effects in the analyses of CDs that experienced type 1 structural change.

Regarding the CDs that underwent type 2 structural changes, the external factor that had biggest impact on farm size is technology, and this impact is positive and statistically significant. For internal factors, farm operators' age and the availability of slaughter plants are found to have greatest influences on the structure of farms. We detect the availability of slaughter plants has positively influenced the size of farms in all provinces, but the directions of the impact of farm operators' age vary. Particularly, older farm operators in the provinces of Alberta, British Columbia, Ontario, and Quebec were less likely to expand farm operations. For farm operators in Saskatchewan, as compared to operators aged less than 45, farmers aged between 45 and 50 are found to be less likely to expand farm operations, while farmers aged over 50 were more likely to expand farms. The signs of marginal effects in the analyses of CDs that experienced type 2 structural change is shown in Table 5.4.

Objective #2: To explore the role of pig diseases in farm operations and identify the factors that impact or might impact pig producers' decisions on the adoption of various diseases treatments.

Recall that the results obtained from the analyses addressing the first objective reveals pig diseases had played a significant role in pig farming operations in some geographical regions in Canada. When diseases are introduced to the country or the regions where pig producers farm, pig farmers would make operational decisions that are either ex ante or ex post to disease occurrences in order to prevent disease introduction and control their spread. To facilitate a better understanding on how various factors (especially pig diseases) play a role in pig farmers' decision making process, we then analyzed how on-farm disease status, management variables, farmers' knowledge about and attitudes towards various treatment methods affect the actual application of these preventive measures. Overall the results from the analyses indicates the following:

1) Farmers who had experienced pig disease outbreaks are more incentivized to apply more preventive measures to control and prevent diseases, while those who had no experience are less motivated to do so. Such a finding necessitates the participation of risk based surveillance program which can provide early warnings about disease outbreaks and let farmers be more aware of local and national situations.
2) Farm and farmer characteristics do affect the application of disease control and prevention strategies. Therefore, suggestions regarding the application of various preventive measures should be tailored to the farmers' situations and then provided to the targeted farmer groups.
3) The better the farmers' knowledge about a particular practice the stronger their biosecurity behavior. Thus, increasing farmers' access to biosecurity information can be a great way to achieve behavioral change.
4) Many farmers deem unaffordability as a barrier to the adoption of disease treatments, which suggests government should not only offer training programs to let pig farmers be very familiar with more preventive measures, they should also provide financial supports to make the treatments practicable.

5.2 Implications

The objective of this research is to understand how pig diseases have affected the Canadian industry, and the results of this research provide insights into the role of pig diseases in farm structure change and farmers' adoption decisions and have several implications for pig farming in Canada. The evidence shows that pig disease outbreaks do negatively affect farm structure in some parts of Canada, and pig diseases have played a more significant role in eastern Canada. In addition, different regions are found to be plagued by certain pig diseases differently. For example, the regions that experienced a decrease in pig farm numbers and an increase in total pig numbers (type 1 structural change) seemed to be affected more by porcine reproductive respiratory syndrome (PRRS) and porcine circovirus associated disease (PCVAD) outbreaks. Our findings demonstrate the necessity of government programs to assuage the negative impacts of pig diseases on farm structure. Instead of promoting a national program, which neglects the heterogeneities in the situations faced by the pig farmers in different regions, regional programs are highly recommended with the incorporation of regional specific characteristics into policy development to prevent and control the spread of pig diseases.

Take the implementation of vaccine subsidy program as an example. Instead of proposing a program that subsidizes only a fixed percentage of expenses incurred through diagnostic testing and vaccination, as what Control of Diseases in the Hog Industry (CDHI) programming did claiming the applicants can only receive up to 50 percent of eligible expenses for PCVAD diagnostics and vaccination, policy makers should allow for variations in the percentage amount that would meet the needs of farmers from different regions, especially for farmers from the eastern provinces that are severely affected by pig disease outbreaks. The rational for such a suggestion is that for regions or farms that are severely affected by pig diseases, it is possible that the subsidy, which is provided based on the fixed percentage standard, would not be a relief for farmers as too many pigs in their farms are affected. Even though the per unit cost of disease control and treatment decreases, the total costs are still too high and burdensome for these farmers, and they might finally give up treating pig diseases and quit the business. Therefore, we would suggest policy makers developing a subsidy program that sets different percentage amounts based on the total disease control and treatment costs incurred. As the total cost increases to a certain threshold, the percentage amount would also increase. Given that not all regions were affected by the same type of pig disease, subsidy programs should be offered for all pig diseases, not just for one type of pig disease. In addition, we encourage the implementation of programs that aim to help the improvement of biosecurity levels, especially in the regions that experienced type 2 structural change, as those regions are dominated by small pig farms and our results suggest they are more likely to get infected with PED.

Heterogeneity in structural change across different regions does exist, and the comparison of the scenarios referring to the different types of structural change shows a strong difference in the determinants of farm size changes. If the empirical analyses were conducted at the national level, there would exist over-and under-estimations of the impacts of different factors on farm structures. The findings of this study confirmed the necessity of investigating the industry’s structural change with the differentiation of types of structural change and regions to have a better understanding on how various factors affect farm structure changes. In our case, such analyses easily help us identify the regions where pig diseases have been important and could assist both governments and pig producers to make policies and decisions that are pertinent to their situations.

Given our empirical results suggest that farm and farmer characteristics do affect farm structure changes and farmers' decisions in relation to the application of disease control and prevention strategies, farm transition policies and assistance programs should be developed to align with the values and needs of different farm and/or farmer groups. For example, in the regions where younger pig farmers (e.g., aged below 45 in the Quebec case) are less likely to expand their farms and to apply more disease preventive measures, policies such as investment subsidies for younger farmers could be conducted in these regions to facilitate farm size growth. In addition, our analyses also detect regions that experienced type 1 structural change are typically dominated by large farms and regions that experienced type 2 structural change (decreases in both pig farm numbers and pig numbers) are mainly dominated by small farms. For local governments that want to promote large hog farming business or aim to help small farm operators adapt out of business in certain regions, our study provides them with a guideline on what they can do to achieve their goals. For example, if Ontario government wants to encourage large farm business in the regions that experienced type 1 structural change, they might be able to achieve this by providing more government land for hog farming.

Although many surveyed pig farmers reported they were familiar with various disease treatment methods, the application rates for many treatments were far from satisfactory. One possible reason is PRRS, PCVAD, and PED are not reportable or immediately notifiable diseases in Canada. These three diseases are managed at the provincial level, and different provinces set different standards and codes of practice. Even within the same province, different agencies or organizations may have different standards. Some pig farmers are reluctant to take actions because they are not clear which standards they should adhere to. The management of pig diseases would be especially challenging when interprovincial trade is involved. For example, different provinces may have different requirements for trailer testing and different restrictions for trading hogs that are infected with pig diseases. Clearly, we need a national entity to set the standards for interprovincial hog trade, to facilitate communication among veterinarians, pork agencies and other organizations, and to define what our national and provincial governments should do. Also, the national entity could help coordinate regional agencies with international organizations as some countries refuse to import pigs infected with diseases.

Many different disease treatment methods including vaccines and antibiotics are currently available for the control of pig diseases, but the benefits of these treatments will erode with the appearance of parasite and microbial resistance (Raszek et al., 2016; Stromberg and Gasbarre, 2006). One of the most promising alternatives is genomic selection, which has been widely used in the dairy and cattle industry. If genomic selection can be successfully implemented, it would not only address parasite resistance, but also improve the overall health of animals and reduce the impact of infection by different disease agents (Plastow, 2016). With such a tool available, reproduction efficiency could also be enhanced. Therefore, government may need to provide more funding to support activities related to genomic selection to introduce such a technique to pig farmers as soon as possible.

5.3 Limitations and Future Research

There are several limitations regarding our analyses of role of various factors on farm structure changes. The first is in utilizing time dummies to examine the impact of pig disease outbreaks. Given this situation, we could only gauge farm size changes during the periods of dramatic increases in disease incidences, not the rest of the time. More detailed data on disease evolution might improve estimation of the effects. In addition, the timing of development of vaccines and the timing of government support for vaccines delivery could also be included for further study. Second, due to the data protection rules from Statistics Canada, empirical analyses were conducted with the utilization of aggregated level data (Census Division level in our case), which reduced estimation efficiency and failed to account for farm specific differences. If farm accountancy level data is available, future study could be conducted using this dataset with improved estimation efficiency. Third, it needs to be recognized that government payment is not considered in our study as a determinant of farm structure change. Previous literature suggests farmers who received commodity payment would be more likely to expand their production by buying out the farmland of other farm operators (e.g. Ahearn et al., 2004). Combing government payments (e.g., through AgriStability) into the analysis might be meaningful to provide insights into how efficiently the programs are to help farm operators make structural adjustments. Fourth, other factors such as pig disease outbreaks in U.S. should also be included as determinants as Canada and the U.S. share borders and have extensive trade relationships. At last, future study could also consider the addition of dynamic elements and further neighborhood effects, which might help improve the estimates of disease impacts.

The major limitation of the present study regarding the role of pig diseases in farmers' decision making process is in-depth quantitative analyses were not conducted due to the small sample size. Further study should reevaluate the results empirically with a larger sample. With large enough sample size, empirical analyses might be conducted for the regions where pig diseases have played a significant role and those where diseases haven't been important to compare how pig farmers in different regions with different experiences make very different adoption decisions. Provided by farmers' considerations over the additional production costs resulting from disease outbreaks and the uptake of preventive measures, pig farmers might simultaneously apply preventive measures with the adaptation their farm structures (e.g., expansion or shrinkage activities) to minimize the per unit production costs. Possible extension of this research is simultaneously examining how various factors affect both farm structure changes and preventive measure adoptions. Instead of using application index to evaluate how farmer's perceptions over all available treatment methods affect the overall application of the treatments, future study is encouraged to investigate the association between farmers' attitude toward each practice and its resulting application. Given area spread, farmers may less likely to apply more preventive measures if they are surrounded by neighbors who have poor biosecurity levels. Further study should also include neighborhood effects into the analyses. Another possibility is to examine how farmers' social networks with feed companies, veterinarians, and transport companies might influence pig producers' decisions about the adoption of various disease treatments.

Tables

Table 5.1. The Marginal Effect of "PRRS & PCVAD" Variable on Farm Size and The Total Changes in Farm Size Covering the Period over 1981-2016.

	Type 1 Structural Change		**Type 2 Structural Change**	
	Changes in Farm Size, Attributable to Disease	**Changes in Farm Size, 1981-2016**	**Changes in Farm Size, Attributable to Disease**	**Changes in Farm Size, 1981-2016**
British Columbia			-511 head per farm	3 head/farm
Ontario	-511 head/farm	2241 head/farm		
Quebec	-257 head/farm	1869 head/farm		

Table 5.2. The Marginal Effect of "PED" Variable on Farm Size and The Total Changes in Farm Size Covering the Period over 1981-2016.

	Type 2 Structural Change	
	Changes in Farm Size, Attributable to Disease	**Changes in Farm Size, 1981-2016**
Ontario	-87 head/farm	345 head/farm
Quebec	-815 head/ farm	1032 head/ farm

Table 5.3. The Signs of Marginal Effects in the Analyses of CDs that Experienced Type 1 Structural Change.

	Alberta	Saskatchewan	Manitoba	Ontario	Quebec
Provincial level data					
COOL implementation (D)	+	+	+	+	+
Disease variables					
Dramatic increase in pig disease outbreak (D)	/	/	/	-	-
PED outbreak (D)			/	/	/
Hog-feed price ratio (C)	/	/	/	+	+
Census Division level data					
Distance to Slaughter plant (C)	/	+	/	-	/
Distance to Research institutions (C)	-	-	-	+	/
Family farm (C)	/	/	/	+	/
Gender (% of male operators) (C)	-	-	/	/	+
Human population density (C)	-	-	-	+	/
Land tenure (C)	/	/	-	+	/
Number of pig farms (C)	/	/	+	-	+
Off-farm work (C)	-	-	/	+	+
Operator's average age (C)	+	+	+	-	+
Operator living on farm (C)	/	/	/	/	/
Production type (C)	/	/	/	-	/
Technology (C)	+	+	+	/	+
Temperature	-	-	/	/	+

Note: “+” denotes positive effect, “-” denotes negative effect, “/” denotes no effect.

Table 5.4. The Signs of Marginal Effects in the Analyses of CDs that Experienced Type 1 Structural Change.

	Alberta	Saskatchewan	British Columbia	Ontario	Quebec
Provincial level data					
COOL implementation (D)	+	+	/	/	+
Disease variables					
Dramatic increase in pig disease outbreak (D)	/	/	-	/	/
PED outbreak (D)				-	-
Hog-feed price ratio (C)	+	/	/	/	+
Census Division level data					
Distance to Slaughter plant (C)	-	-	/	-	/
Distance to Research institutions	-	+	-	/	-
Family farm (C)	/	-	+	/	+
Gender (% of male operators) (C)	-	/	/	/	/
Human population density (C)	-	-	-	-	+
Land tenure (C)	-	/	+	/	+
Number of pig farms (C)	/	/	-	-	+
Off-farm work (C)	/	-	/	/	+
Operator's average age (C)	-		-	-	-
Operator's average age (45≤ age <50) (D)		-	-		
Operator's average age (age ≥50) (D)		+			
Operator living on farm (C)	+	/	/	/	/
Production type (C)	/	/	/	-	-
Technology (C)	+	+	/	/	+
Temperature	-	/	+	+	/

Note: “+” denotes positive effect, “-” denotes negative effect, “/” denotes no effect.

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Appendices

Appendix 1. Descriptive Statistics of Variables Specified in the Model, British Columbia, 1986 and 1991[14].

	1986				1991			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	44.15	0	44.15	44.15	48.97	0	48.97	48.97
Census Division level data								
Dependent variable								
Farm size (C)	80	126	6	501	91	141	7	576
Independent variable								
Distance to Slaughter plant (C)	3.13	2.12	0.14	9.32	3.11	2.12	0.14	9.32
Distance to Research institutions (0≤ d <0.5km) (D)	0.22	0.43	0	1	0.22	0.43	0	1
Distance to Research institutions (0.5≤ d <1km) (D)	0.06	0.24	0	1	0.06	0.24	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0	0	0	0	0	0	0	0
Distance to Research institutions (1.5≤ d <2km) (D)	0.11	0.32	0	1	0.11	0.32	0	1
Distance to Research institutions (2≤ d <3km) (D)	0.11	0.32	0	1	0.11	0.32	0	1
Distance to Research institutions (3≤ d <4km) (D)	0.33	0.49	0	1	0.33	0.49	0	1
Distance to Research institutions (d ≥4km) (D)	0.17	0.38	0	1	0.17	0.38	0	1
Family farm (C)	4.28	8.50	0	31	0.33	0.97	0	3
Gender (% of male operators) (C)	83.67	21.90	33	100	36.22	28.99	0	100
Human population density (C)	6.74	13.44	0.23	58.6	46.99	133.78	0.45	568.16
Land tenure (C)	17.00	11.13	0	40	15.06	11.37	0	40
No Off-farm work (C)	53.39	35.97	0	100	51.89	28.89	0	100
Number of pig farms (C)	73.67	67.80	15	295	70.89	54.31	20	244
Operator's average age (age ≤45) (D)	0.56	0.51	0	1	0.67	0.49	0	1
Operator's average age (45≤ age <50) (D)	0.39	0.50	0	1	0.22	0.43	0	1
Operator's average age (age ≥50) (D)	0.06	0.24	0	1	0.11	0.32	0	1
Operator living on farm (C)	79.65	23.86	0	99	62.44	26.84	68	100
Production type (C)	31.22	26.37	0	100	30.72	23.42	0	89
Technology (C)	2.333	5.0176	0	20	14.83	11.68	0	40
Temperature (C)	12.56	1.75	9.27	14.47	13.29	1.49	10.72	15.69

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[14] Number of observations would not be listed here to avoid redundancy.

Appendix 2. Descriptive Statistics of Variables Specified in the Model, British Columbia, 1996 and 2001.

	1996				**2001**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	37.41	0	37.41	37.41	43.84	0	43.84	43.84
Census Division level data								
Dependent variable								
Farm size (C)	84	172	6	692	88	254	7	1099
Independent variable								
Distance to Slaughter plant (C)	3.37	2.11	0.14	9.32	2.97	2.11	0.14	9.32
Distance to Research institutions (0≤ d <0.5km) (D)	0.19	0.40	0	1	0.22	0.43	0	1
Distance to Research institutions (0.5≤ d <1km) (D)	0	0	0	0	0.06	0.24	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0	0	0	0	0	0	0	0
Distance to Research institutions (1.5≤ d <2km) (D)	0.13	0.34	0	1	0.11	0.32	0	1
Distance to Research institutions (2≤ d <3km) (D)	0.13	0.34	0	1	0.11	0.32	0	1
Distance to Research institutions (3≤ d <4km) (D)	0.38	0.50	0	1	0.33	0.49	0	1
Distance to Research institutions (d ≥4km) (D)	0.19	0.40	0	1	0.17	0.38	0	1
Family farm (C)	17.13	25.49	0	100	7.17	10.55	0	35
Gender (% of male operators) (C)	49.87	26.79	0	100	67.39	27.07	0	100
Human population density (C)	50.26	160.69	0.47	649.4	57.13	165.29	0.44	704.43
Land tenure (C)	7.94	10.44	0	29	8.67	9.39	0	25
No Off-farm work (C)	47.75	39.87	0	100	35.94	35.48	0	100
Number of pig farms (C)	72.44	46.25	22	178	56.94	30.34	17	126
Operator's average age (age ≤45) (D)	0.56	0.51	0	1	0.50	0.51	0	1
Operator's average age (45≤ age <50) (D)	0.38	0.50	0	1	0.39	0.50	0	1
Operator's average age (age ≥50) (D)	0	0	0	0	0.11	0.32	0	1
Operator living on farm (C)	87.31	22.94	30	100	88.50	26.06	68	100
Production type (C)	27.94	28.50	0	100	20.44	23.48	0	80
Technology (C)	19.13	19.5205	0	52	39.39	18.03	0	69
Temperature (C)	12.32	2.00	8.99	15.23	13.08	2.00	9.33	15.85

Appendix 3. Descriptive Statistics of Variables Specified in the Model, British Columbia, 2006 and 2011.

	2006				2011			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	35.04	0	35.04	35.04	20.1	0	20.1	20.1
Census Division level data								
Dependent variable								
Farm size (C)	87	275	6	1150	96	306	5	1272
Independent variable								
Distance to Slaughter plant (C)	2.27	2.21	0.32	9.32	1.89	1.28	0.32	5.66
Distance to Research institutions (0≤ d <0.5km) (D)	0.24	0.44	0	1	0.24	0.44	0	1
Distance to Research institutions (0.5≤ d <1km) (D)	0.059	0.24254	0	1	0.06	0.24	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0	0	0	0	0	0	0	0
Distance to Research institutions (1.5≤ d <2km) (D)	0.12	0.33	0	1	0.11	0.32	0	1
Distance to Research institutions (2≤ d <3km) (D)	0.12	0.33	0	1	0.11	0.32	0	1
Distance to Research institutions (3≤ d <4km) (D)	0.35	0.49	0	1	0.33	0.49	0	1
Distance to Research institutions (d ≥4km) (D)	0.12	0.33	0	1	0.17	0.38	0	1
Family farm (C)	6.76	12.67	0	41	7.06	14.76	0	50
Gender (% of male operators) (C)	66.65	25.40	0	100	68.18	33.37	0	100
Human population density (C)	64.48	180.83	0.41	750.4	69.49	197.37	0.52	820.14
No Off-farm work (C)	42.82	43.19	0	100	32.00	39.57	0	100
Land tenure (C)	2.53	6.37	0	24	8.24	14.85	0	50
Number of pig farms (C)	40.76	22.11	10	88	32.35	21.49	9	79
Operator's average age (age ≤45) (D)	0.29	0.47	0	1	0.24	0.44	0	1
Operator's average age (45≤ age <50) (D)	0.35	0.49	0	1	0.29	0.47	0	1
Operator's average age (age ≥50) (D)	0.35	0.49	0	1	0.41	0.51	0	1
Operator living on farm (C)	93.71	13.61	50	100	99.35	2.67	89	100
Production type (C)	26.41	31.88	0	100	18.94	27.96	0	100
Technology (C)	42.59	29.778	0	100	65.18	32.38	0	100
Temperature (C)	14.30	1.84	10.92	16.78	13.02	1.89	9.50	15.76

Appendix 4. Descriptive Statistics of Variables Specified in the Model, British Columbia, 2016.

	Mean	Std. Dev	Min	Max
Provincial level data				
Hog-feed price ratio (C)	14.39	0	14.39	14.39
Census Division level data				
Dependent variable				
Farm size (C)	71	224	4	956
Independent variable				
Distance to Slaughter plant (C)	3.66	2.41	0.32	9.87
Distance to Research institutions (0≤ d <0.5km) (D)	0.28	0.46	0	1
Distance to Research institutions (0.5≤ d <1km) (D)	0.11	0.32	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.11	0.32	0	1
Distance to Research institutions (1.5≤ d <2km) (D)	0.06	0.24	0	1
Distance to Research institutions (2≤ d <3km) (D)	0.17	0.38	0	1
Distance to Research institutions (3≤ d <4km) (D)	0.11	0.32	0	1
Distance to Research institutions (d ≥4km) (D)	0.17	0.38	0	1
Family farm (C)	9.61	15.37	0	50
Gender (% of male operators) (C)	54.89	33.39	0	100
Human population density (C)	69.76	204.66	0.52	873.4
Land tenure (C)	9.39	15.15	0	50
No Off-farm work (C)	17.06	28.97	0	100
Number of pig farms (C)	46.00	24.08	7	84
Operator's average age (age ≤45) (D)	0.28	0.46	0	1
Operator's average age (45≤ age <50) (D)	0.22	0.43	0	1
Operator's average age (age ≥50) (D)	0.39	0.50	0	1
Operator living on farm (C)	97.61	7.83	68	100
Production type (C)	17.39	20.47	0	50
Technology (C)	44.50	33.05	0	100
Temperature (C)	14.75	1.80	11.89	17.21

Appendix 5. Descriptive Statistics of Variables Specified in the Model, Alberta, 1986.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	49.37	0	49.37	49.37	49.37	0	49.37	49.37
Census Division level data								
Dependent variable								
Farm size (C)	336.14	167.33	71	533	191.57	104.03	60	375
Independent variable								
Distance to Slaughter plant (C)	2.72	0.73	1.58	3.96				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.37	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.14	0.37	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.286	0.48	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0	0	0	0
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.143	0.37	0	1
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.143	0.37	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.143	0.37	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	4.71	3.64	0	11	4.00	2.45	0	7
Gender (% of male operators) (C)	98	3	92	100	97.71	1.70	96	100
Human population density (C)					15.67	21.51	1.67	47.81
Human population density (0< p ≤1) (D)	0.57	0.53	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	1				
Human population density (2< p ≤4) (D)	0.14	0.38	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	40.14	9.26	23	50	44.14	5.76	34	52
No Off-farm work (C)	62.43	12.71	50	79	74.29	11.54	67	100
Number of pig farms (C)	324.29	241.62	97	782	609.71	311.10	106	1026
Operator's average age (C)	41.85	1.81	39.40	44.40	44.47	2.84	42	49.70
Operator living on farm (C)	89.14	9.55	73	98	97.57	2.44	93	100
Production type (C)	62.86	11.77	50	79	60.29	8.73	47	73
Technology (C)	4.71	2.36	2	9	73.14	20.72	50	100
Temperature (C)	11.98	1.16	9.92	13.49	10.76	0.62	9.90	11.52

Appendix 6. Descriptive Statistics of Variables Specified in the Model, Alberta, 1991.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	48.87	0	48.87	48.87	48.87	0	48.87	48.87
Census Division level data								
Dependent variable								
Farm size (C)	412.86	192.47	89	616	227.29	118.44	64	454
Independent variable								
Distance to Slaughter plant (C)	1.73	0.77	0.69	2.52				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0	0	0	0
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.14	0.38	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	65.57	10.55	49	78	0.29	0.49	0	1
Gender (% of male operators) (C)	19.14	8.99	0	26	28.71	2.98	24	33
Human population density (C)					19.36	27.94	0.97	64.78
Human population density (0< p ≤1) (D)	0.29	0.49	0	1				
Human population density (1< p ≤2) (D)	0.00	0.00	0	0				
Human population density (2< p ≤4) (D)	0.57	0.53	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	36.14	10.07	24	52	40.43	11.59	17	52
No Off-farm work (C)	68.43	14.75	50	86	76.71	10.56	69	100
Number of pig farms (C)	315.00	226.11	101	739	563.29	283.73	71	946
Operator's average age (C)	42.00	2.05	40.00	46.40	42.99	1.48	40.5	45.20
Operator living on farm (C)	78.57	10.01	67	95	65.71	8.32	48	74
Production type (C)	65.57	10.55	49	78	57.29	19.15	17	76
Technology (C)	22.42857	12.11	11	44	16.57	6.05	8	100
Temperature (C)	13.07	1.11	11.49	14.34	12.10	0.90	10.98	13.22

Appendix 7. Descriptive Statistics of Variables Specified in the Model, Alberta, 1996.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	30.6	0	30.6	30.6	30.6	0	30.6	30.6
Census Division level data								
Dependent variable								
Farm size (C)	665.71	319.41	123	973	299.71	198.47	73	694
Independent variable								
Distance to Slaughter plant (C)	1.56	0.77	0.69	2.52				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0	0	0	0
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.14	0.38	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	21.29	11.63	11	44	11.86	6.23	0	19
Gender (% of male operators) (C)	70.29	7.23	60	79	70.14	8.97	50	76
Human population density (C)					20.56	29.85	1.03	70.91
Human population density (0< p ≤1) (D)	0.14	0.38	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	0				
Human population density (2< p ≤4) (D)	0.57	0.53	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	42.43	21.40	25	89	39.29	9.12	25	54
No Off-farm work (C)	74.14	18.08	50	100	76.00	6.06	70	88
Number of pig farms (C)	203.57	134.00	64	440	392.43	196.05	69	623
Operator's average age (C)	43.84	1.96	42.00	47.20	44.56	1.38	43.2	47.40
Operator living on farm (C)	91.86	8.86	75	100	90.71	7.80	74	98
Production type (C)	64.43	16.81	42	89	57.43	10.71	42	70
Technology (C)	34.14	11.0216	20	52	25.14	13.09	0	41
Temperature (C)	12.10	1.26	9.89	13.46	10.61	0.56	9.68	11.31

Appendix 8. Descriptive Statistics of Variables Specified in the Model, Alberta, 2001.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	39.01	0	39.01	39.01	39.01	0	39.01	39.01
Census Division level data								
Dependent variable								
Farm size (C)	1350.71	669.27	134	2215	461.43	358.44	64	1169
Independent variable								
Distance to Slaughter plant (C)	1.54	0.75	0.69	2.44				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0	0	0	0
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.14	0.38	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	17.43	8.60	8	32	15.43	8.38	0	26
Gender (% of male operators) (C)	76.86	4.91	69	83	71.71	5.91	64	82
Human population density (C)					23.04	33.92	1.01	82.19
Human population density (0< p ≤1) (D)	0.14	0.38	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	0				
Human population density (2< p ≤4) (D)	0.57	0.53	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	42.43	20.78	18	80	34.00	17.94	0	54
No Off-farm work (C)	66.71	11.32	50	81	63.86	8.76	50	79
Number of pig farms (C)	146.57	98.28	43	329	235.57	119.99	37	343
Operator's average age (C)	47.23	4.93	43.10	57.20	45.99	1.87	43.2	49.40
Operator living on farm (C)	92.86	7.63	83	100	93.57	4.96	88	100
Production type (C)	55.57	6.19	45	63	57.71	6.58	48	65
Technology (C)	59	13.2665	31	71	47.57	15.86	17	69
Temperature (C)	13.35	1.55	10.60	15.31	11.79	0.83	10.40	12.58

Appendix 9. Descriptive Statistics of Variables Specified in the Model, Alberta, 2006.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	30.47	0	30.47	30.47	30.47	0	30.47	30.47
Census Division level data								
Dependent variable								
Farm size (C)	2223.57	1028.42	402	3664	692.29	588.80	77	1885
Independent variable								
Distance to Slaughter plant (C)	1.56	0.77	0.69	2.52				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.00	0.00	0	0
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.00	0.00	0	0
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	28.43	8.66	17	39	22.14	16.29	0	42
Gender (% of male operators) (C)	81.29	10.57	67	100	57.29	26.74	0	100
Human population density (C)					25.77	38.27	1.04	93.45
Human population density (0< p ≤1) (D)	0.14	0.38	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	0				
Human population density (2< p ≤4) (D)	0.57	0.53	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	46.00	15.06	27	70	44.14	11.75	33	67
No Off-farm work (C)	73.57	15.44	55	100	69.43	16.86	50	100
Number of pig farms (C)	102.71	73.05	25	235	122.29	62.82	27	196
Operator's average age (C)	48.16	4.36	40.30	53.60	46.20	3.06	41.8	49.30
Operator living on farm (C)	94.29	5.94	86	100	81.14	36.18	0	100
Production type (C)	55.43	11.21	41	75	44.71	9.78	33	55
Technology (C)	66.43	13.697	41	80	57.86	18.89	33	79
Temperature (C)	13.97	0.85	12.83	15.16	12.58	1.08	10.32	13.52

Appendix 10. Descriptive Statistics of Variables Specified in the Model, Alberta, 2011.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	16.95	0	16.95	16.95	16.95	0	16.95	16.95
Census Division level data								
Dependent variable								
Farm size (C)	3578.14	2599.78	408	8993	862.14	925.50	4	2687
Independent variable								
Distance to Slaughter plant (C)	1.56	0.77	0.69	2.52				
Distance to Slaughter plant (0< d <0 .5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (0 .5≤d <1km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (1≤ d < 1.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1.5≤ d <2km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2≤ d <2.5km) (D)					0.00	0.00	0	0
Distance to Slaughter plant (2.5≤ d < 3km) (D)					0.29	0.49	0	1
Distance to Slaughter plant (d ≥3km) (D)					0.00	0.00	0	0
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	38.00	19.09	0	60	23.86	22.35	0	59
Gender (% of male operators) (C)	81.71	15.22	60	100	63.71	21.48	25	88
Human population density (C)					28.82	43.19	1.07	105.5
Human population density (0< p ≤1) (D)	0.14	0.38	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	0				
Human population density (2< p ≤4) (D)	0.57	0.53	0	1				
Human population density (p ≥4) (D)	0.14	0.38	0	1				
Land tenure (C)	45.71	26.98	23	100	38.43	24.94	0	83
No Off-farm work (C)	48.86	40.22	0	100	74.14	19.83	50	100
Number of pig farms (C)	58.86	50.46	8	158	63.57	33.74	15	96
Operator's average age (C)	50.19	7.06	43.60	65.00	39.82	17.71	41.8	49.60
Operator living on farm (C)	94.86	9.67	75	100	71.14	35.23	0	100
Production type (C)	48.71	31.12	0	100	28.00	15.23	0	45
Technology (C)	90.86	11.6394	69	100	67.71	33.55	0	96
Temperature (C)	12.39	0.80	11.40	13.62	11.32	0.86	9.78	12.05

Appendix 11. Descriptive Statistics of Variables Specified in the Model, Alberta, 2016.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	12	0	12	12	12	0	12	12
Census Division level data								
Dependent variable								
Farm size (C)	2312	998	462	3651	509	443	19	1290
Independent variable								
Distance to Slaughter plant (C)	1.57	0.80	0.69	2.65				
Distance to Slaughter plant (0< d <0 .5km) (D)								
Distance to Slaughter plant (0 .5< d <1km) (D)					0.29	0.49	0	0
Distance to Slaughter plant (1< d < 1.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (1.5< d <2km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2< d <2.5km) (D)					0.14	0.38	0	1
Distance to Slaughter plant (2.5< d < 3km) (D)					0	0	0	0
Distance to Slaughter plant (d ≥3km) (D)					0.29	0.49	0	1
Distance to Research institutions (0< d <1km) (D)	0.43	0.53	0	1	0.57	0.53	0	1
Distance to Research institutions (1< d <2km) (D)	0.43	0.53	0	1	0.29	0.49	0	1
Distance to Research institutions (d ≥2km) (D)	0.14	0.38	0	1	0.14	0.38	0	1
Family farm (C)	45.43	30.56	0	100	28.14	27.36	0	100
Gender (% of male operators) (C)	70.71	15.89	50	100	66.14	17.75	50	100
Human population density (C)					32.65	49.40	1.1	120.65
Human population density (0< p ≤1) (D)	0.14	0.38	0	1				
Human population density (1< p ≤2) (D)	0.14	0.38	0	1				
Human population density (2< p ≤4) (D)	0.43	0.53	0	1				
Human population density (p ≥4) (D)	0.29	0.49	0	1				
Land tenure (C)	32.71	17.38	13	50	37.14	30.95	0	100
No Off-farm work (C)	69.29	31.25	25	100	38	29.56	0	67
Number of pig farms (C)	82.71	76.79	19	242	90.29	44.90	25	141
Operator's average age (C)	49.56	5.41	40.1	56	51.87	7.10	46	67
Operator living on farm (C)	94.86	9.67	75	100	71.14	35.23	0	100
Production type (C)	34.43	19.92	0	58	32.86	31.51	0	100
Technology (C)	67	21.39	38	95	73.14	20.72	50	100
Temperature (C)	13.27	0.68	12.50	14.28	12.36	0.84	10.74	13.18

Appendix 12. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 1986.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	60.9	0	60.9	60.9	60.9	0	60.9	60.9
Census Division level data								
Dependent variable								
Farm size (C)	117	58	60	242	104	48	34	169
Independent variable								
Distance to Slaughter plant (C)					1.14	0.80	0.36	2.81
Distance to Slaughter plant (1≤ d <2km) (D)	0.63	0.52	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.13	0.35	0	1				
Distance to Research institutions (C)	1.40	0.51	0.75	2.02				
Distance to Research institutions (0≤ d <0.5km) (D)					0.38	0.52	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.38	0.52	0	1
Distance to Research institutions (d ≥1km) (D)					0.25	0.46	0	1
Family farm (C)	3.375	3.42	0	10	5.25	5.15	0	16
Gender (% of male operators) (C)	92.75	17.50	50	100	97.25	5.34	86	100
Human population density (0≤ p <1) (D)	0	0	0	0				
Human population density (1≤ p <1.5) (D)	0	0	0	0				
Human population density (1.5≤ p <2) (D)	0	0	0	0	0	0	0	0
Human population density (2≤ p <2.5) (D)	1	0	1	1	0.13	0.35	0	1
Human population density (2.5≤ p <5) (D)					0.13	0.35	0	1
Human population density (5≤ p <10) (D)					0.38	0.52	0	1
Human population density (10≤ p <15) (D)					0	0	0	0
Human population density (p ≥15) (D)					0.38	0.52	0	1
Land tenure (C)	52.75	8.08	44	65	61.50	8.02	47	74
No Off-farm work (C)	80.5	14.25	64	100	68.75	8.65	60	86
Number of pig farms (C)	300.88	120.25	144	490	401.9	216.32	190	880
Operator's average age (age ≤45) (D)	0.75	0.46	0	1	0.88	0.35	0	1
Operator's average age (45≤ age <50) (D)	0.13	0.35	0	1	0.13	0.35	0	1
Operator's average age (age ≥50) (D)	0.125	0.3535	0	1	0	0	0	0
Operator living on farm (C)	88.5	16.40	50	100	92.38	5.83	81	100
Production type (C)	56.75	10.36	44	70	57.38	12.40	42	81
Technology (C)	7.875	6.51	0	20	5.5	3.55	2	12
Temperature (C)	12.34	0.60	11.44	13.13	12.41	0.60	11.22	12.94

Appendix 13. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 1991.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	55.65	0	55.65	55.65	55.65	0	55.65	55.65
Census Division level data								
Dependent variable								
Farm size (C)	264	89	145	410	145	72	45	234
Independent variable								
Distance to Slaughter plant (C)					1.14	0.80	0.36	2.81
Distance to Slaughter plant (1≤ d <2km) (D)	0.63	0.52	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.13	0.35	0	1				
Distance to Research institutions (C)	1.40	0.51	0.75	2.02				
Distance to Research institutions (0≤ d <0.5km) (D)					0.38	0.52	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.38	0.52	0	1
Distance to Research institutions (d ≥1km) (D)					0.25	0.46291	0	1
Family farm (C)	0.75	1.16	0	3	0.625	1.19	0	3
Gender (% of male operators) (C)	22.88	8.76	14	43	24.50	7.37	13	38
Human population density (0≤ p <1) (D)	0.25	0.46291	0	1				
Human population density (1≤ p <1.5) (D)	0.375	0.51755	0	1				
Human population density (1.5≤ p <2) (D)	0.375	0.51755	0	1	0.125	0.353553	0	1
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.125	0.353553	0	1
Human population density (2.5≤ p <5) (D)					0.50	0.53	0	1
Human population density (5≤ p <10) (D)					0.00	0.00	0	0
Human population density (10≤ p <15) (D)					0.25	0.52	0	1
Human population density (p ≥15) (D)					0.00	0.00	0	0
Land tenure (C)	47.375	7.44	36	55	54.13	12.80	37	71
No Off-farm work (C)	79.625	12.97	62	100	68.00	5.83	56	73
Number of pig farms (C)	264.38	88.66	145	410	338	210.38	173	844
Operator's average age (age ≤45) (D)	1.00	0.00	1	1	0.88	0.35	0	1
Operator's average age (45≤ age <50) (D)	0.00	0.00	0	0	0.13	0.35	0	1
Operator's average age (age ≥50) (D)	0	0	0	0	0	0	0	0
Operator living on farm (C)	78.375	12.87	56	93	80.25	8.14	70	95
Production type (C)	61.5	13.05	47	86	61.00	9.26	73	71
Technology (C)	17.875	9.15638	5	30	17.5	9.4112	4	35
Temperature (C)	13.89	0.43	13.43	14.54	13.91	0.61	13.01	14.59

Appendix 14. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 1996.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	31.77	0	31.77	31.77	31.77	0	31.77	31.77
Census Division level data								
Dependent variable								
Farm size (C)	321	140	168	549	248	136	76	443
Independent variable								
Distance to Slaughter plant (C)					1.14	0.80	0.36	2.81
Distance to Slaughter plant (1≤ d <2km) (D)	0.63	0.52	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.13	0.35	0	1				
Distance to Research institutions (C)	1.40	0.51	0.75	2.02				
Distance to Research institutions (0≤ d <0.5km) (D)					0.38	0.52	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.38	0.52	0	1
Distance to Research institutions (d ≥1km) (D)					0.25	0.46291	0	1
Family farm (C)	12.125	9.09	0	25	10.375	5.80	0	20
Gender (% of male operators) (C)	79.13	13.95	63	100	79.25	15.18	60	100
Human population density (0≤ p <1) (D)	0.25	0.46291	0	1				
Human population density (1≤ p <1.5) (D)	0.375	0.51755	0	1				
Human population density (1.5≤ p <2) (D)	0.375	0.51755	0	1	0.125	0.353553	0	1
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.25	0.46291	0	1
Human population density (2.5≤ p <5) (D)					0.38	0.52	0	1
Human population density (5≤ p <10) (D)					0.00	0.00	0	0
Human population density (10≤ p <15) (D)					0.25	0.46	0	1
Human population density (p ≥15) (D)					0.00	0.00	0	0
Land tenure (C)	48.375	12.36	25	64	46.88	13.30	30	72
No Off-farm work (C)	78.5	16.89	57	100	67.50	10.00	50	80
Number of pig farms (C)	151.88	53.26	99	241	195	137.02	83	524
Operator's average age (age ≤45) (D)	0.50	0.53	1	1	0.75	0.46	0	1
Operator's average age (45≤ age <50) (D)	0.50	0.53	0	0	0.25	0.46	0	1
Operator's average age (age ≥50) (D)	0	0	0	0	0	0	0	0
Operator living on farm (C)	88.875	9.14	75	100	88.13	10.30	71	100
Production type (C)	61.375	12.32	45	76	61.88	11.87	44	77
Technology (C)	30.25	11.901	15	47	29.375	7.3082	20	44
Temperature (C)	12.24	0.64	11.33	13.14	12.14	0.65	11.01	12.95

Appendix 15. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 2001.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	40.78	0	40.78	40.78	40.78	0	40.78	40.78
Census Division level data								
Dependent variable								
Farm size (C)	966	849	232	2878	404	293	119	976
Independent variable								
Distance to Slaughter plant (C)					1.14	0.80	0.36	2.81
Distance to Slaughter plant (1≤ d <2km) (D)	0.63	0.52	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.13	0.35	0	1				
Distance to Research institutions (C)	1.40	0.51	0.75	2.02				
Distance to Research institutions (0≤ d <0.5km) (D)					0.38	0.52	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.38	0.52	0	1
Distance to Research institutions (d ≥1km) (D)					0.25	0.46291	0	1
Family farm (C)	21.875	15.47	0	50	9.25	6.32	0	15
Gender (% of male operators) (C)	81.38	12.50	67	100	81.88	22.35	50	100
Human population density (0≤ p <1) (D)	0.25	0.46291	0	1				
Human population density (1≤ p <1.5) (D)	0.375	0.51755	0	1				
Human population density (1.5≤ p <2) (D)	0.375	0.51755	0	1	0.125	0.353553	0	1
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.5	0.534522	0	1
Human population density (2.5≤ p <5) (D)					0.13	0.35	0	1
Human population density (5≤ p <10) (D)					0.00	0.00	0	0
Human population density (10≤ p <15) (D)					0.25	0.46	0	1
Human population density (p ≥15) (D)					0.00	0.00	0	0
Number of pig farms (C)	85.25	25.01	58	133	118	72.87	47	283
No Off-farm work (C)	76.75	53.34	40	100	74.25	22.28	50	100
Land tenure (C)	35.25	8.38	25	50	47.13	20.52	21	88
Operator's average age (age ≤45) (D)	0.00	0.00	0	0	0.50	0.53	0	1
Operator's average age (45≤ age <50) (D)	0.75	0.46	0	1	0.25	0.46	0	1
Operator's average age (age ≥50) (D)	0.25	0.46291	0	1	0.25	0.46	0	1
Operator living on farm (C)	94.25	8.24	80	100	80.25	16.74	50	100
Production type (C)	70.75	17.09	50	100	52.63	18.44	25	88
Technology (C)	61.75	24.317	26	100	50.5	19.3095	29	88
Temperature (C)	13.84	0.70	13.09	15.04	13.76	0.70	12.47	14.74

Appendix 16. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 2006.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	35.72	0	35.72	35.72	35.72	0	35.72	35.72
Census Division level data								
Dependent variable								
Farm size (C)	2086	1995	387	6158	590	412	46	1168
Independent variable								
Distance to Slaughter plant (C)					0.90	0.47	0.36	1.71
Distance to Slaughter plant (1≤ d <2km) (D)	0.57	0.53	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.29	0.49	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.14	0.38	0	1				
Distance to Research institutions (C)	1.31	0.48	0.75	1.98				
Distance to Research institutions (0≤ d <0.5km) (D)					0.43	0.53	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.29	0.49	0	1
Distance to Research institutions (d ≥1km) (D)					0.29	0.49	0	1
Family farm (C)	27.714	19.27	6	63	12.571	10.29	0	28
Gender (% of male operators) (C)	97.14	7.56	80	100	78.86	17.72	50	100
Human population density (0≤ p <1) (D)	0.1429	0.37796	0	1				
Human population density (1≤ p <1.5) (D)	0.5714	0.53452	0	1				
Human population density (1.5≤ p <2) (D)	0.2857	0.48795	0	1	0.14286	0.37796	0	1
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.42857	0.534522	0	1
Human population density (2.5≤ p <5) (D)					0.14	0.38	0	1
Human population density (5≤ p <10) (D)					0.00	0.00	0	0
Human population density (10≤ p <15) (D)					0.29	0.49	0	1
Human population density (p ≥15) (D)					0.00	0.00	0	0
Land tenure (C)	43.714	27.04	7	75	48.86	7.10	38	56
No Off-farm work (C)	88.571	34.85	50	100	77.71	21.61	50	100
Number of pig farms (C)	48.71	15.50	31	76	68.5714	35.77	33	144
Operator's average age (age ≤45) (D)	0.00	0.00	0	0	0.29	0.49	0	1
Operator's average age (45≤ age <50) (D)	0.71	0.49	0	1	0.57	0.53	0	1
Operator's average age (age ≥50) (D)	0.2857	0.48795	0	1	0.14	0.38	0	1
Operator living on farm (C)	95.286	12.47	67	100	90.86	13.93	67	100
Production type (C)	67.286	14.58	46	88	48.71	14.87	23	67
Technology (C)	56.714	17.153	31	75	55.4285	19.755	33	92
Temperature (C)	14.06	0.70	13.29	15.06	14.43	0.49	13.78	15.00

Appendix 17. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 2011.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	18.14	0	18.14	18.14	18.14	0	18.14	18.14
Census Division level data								
Dependent variable								
Farm size (C)	2976	1520	1234	5772	695	580	13	1253
Independent variable								
Distance to Slaughter plant (C)					1.54	0.66	1.08	2.51
Distance to Slaughter plant (1≤ d <2km) (D)	0.14	0.38	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.14	0.38	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.71	0.49	0	1				
Distance to Research institutions (C)	0.95	0.21	0.69	1.24				
Distance to Research institutions (0≤ d <0.5km) (D)					0.50	0.58	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.25	0.50	0	1
Distance to Research institutions (d ≥1km) (D)					0.25	0.50	0	1
Family farm (C)	18.2857	28.19	0	67	19.75	22.98	0	43
Gender (% of male operators) (C)	95.86	7.22	83	100	88.75	13.15	75	100
Human population density (0≤ p <1) (D)	0.14285	0.37796	0	1				
Human population density (1≤ p <1.5) (D)	0.57142	0.53452	0	1				
Human population density (1.5≤ p <2) (D)	0.285714	0.48795	0	1	0	0	0	0
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.25	0.5	0	1
Human population density (2.5≤ p <5) (D)					0.25	0.5	0	1
Human population density (5≤ p <10) (D)					0.00	0.00	0	0
Human population density (10≤ p <15) (D)					0.25	0.5	0	1
Human population density (p ≥15) (D)					0.25	0.5	0	0
Land tenure (C)	34.428	31.31	0	83	18.50	22.34	0	45
No Off-farm work (C)	82.857	29.84	30	100	79.25	24.94	50	100
Number of pig farms (C)	28.57	8.60	22	45	46	21.56	22	73
Operator's average age (age ≤45) (D)	0.00	0.00	0	0	0.00	0.00	0	0
Operator's average age (45≤ age <50) (D)	0.14	0.38	0	1	0.25	0.50	0	1
Operator's average age (age ≥50) (D)	0.8571	0.37796	0	1	0.75	0.50	0	1
Operator living on farm (C)	91.57	12.46	67	100	78.50	15.59	67	100
Production type (C)	64.428	20.36	33	100	31.50	36.95	0	71
Technology (C)	78.285	21.7923	50	100	64.75	44.55	0	100
Temperature (C)	12.64	0.43	12.24	13.46	13.21	0.45	12.68	13.75

Appendix 18. Descriptive Statistics of Variables Specified in the Model, Saskatchewan, 2016.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	11.8	0	11.8	11.8	11.8	0	11.8	11.8
Census Division level data								
Dependent variable								
Farm size (C)	2336	1068	772	3978	284	271	10	629
Independent variable								
Distance to Slaughter plant (C)					1.76	0.76	1.08	2.65
Distance to Slaughter plant (1≤ d <2km) (D)	0.25	0.46	0	1				
Distance to Slaughter plant (2≤ d <3km) (D)	0.13	0.13	0	1				
Distance to Slaughter plant (d ≥2km) (D)	0.63	0.52	0	1				
Distance to Research institutions (C)	1.03	0.29	0.69	1.58				
Distance to Research institutions (0≤ d <0.5km) (D)					0.40	0.55	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.40	0.55	0	1
Distance to Research institutions (d ≥1km) (D)					0.20	0.45	0	1
Family farm (C)	15.63	22.90	0	50	41.60	37.29	0	100
Gender (% of male operators) (C)	81.88	35.06	0	100	75.00	25.00	50	100
Human population density (0≤ p <1) (D)	0.25	0.46	0	1				
Human population density (1≤ p <1.5) (D)	0.50	0.53	0	1				
Human population density (1.5≤ p <2) (D)	0.25	0.46	0	1	0	0	0	0
Human population density (2≤ p <2.5) (D)	0	0	0	0	0.40	0.55	0	1
Human population density (2.5≤ p <5) (D)					0.20	0.45	0	1
Human population density (5≤ p <10) (D)					0	0	0	0
Human population density (10≤ p <15) (D)					0	0	0	0
Human population density (p ≥15) (D)					0.40	0.55	0	1
Land tenure (C)	15.63	22.90	0	100	0.00	0.00	0	0
No Off-farm work (C)	53.75	47.49	0	100	63.40	24.84	33	100
Number of pig farms (C)	33.50	7.39	22	47	51.20	14.67	33	73
Operator's average age (age ≤45) (D)	0.25	0.46	0	1	0.20	0.45	0	1
Operator's average age (45≤ age <50) (D)	0.13	0.13	0	1	0.20	0.45	0	1
Operator's average age (age ≥50) (D)	0.50	0.53	0	1	0.60	0.55	0	1
Operator living on farm (C)	91.57	12.46	67	100	85.00	14.56	67	100
Production type (C)	52.13	38.27	0	100	56.60	43.51	0	100
Technology (C)	78.13	36.44	0	100	55	44.7213	0	100
Temperature (C)	13.56	0.61	12.59	14.25	13.76	0.32	13.27	14.16

Appendix 19. Descriptive Statistics of Variables Specified in the Model, Manitoba, 1986 and 1991.

	1986				**1991**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	49.30	0.00	49.30	49.30	49.55	0.00	49.55	49.55
Census Division level data								
Dependent variable								
Farm size (C)	397	313	139	1387	557	366	159	1651
Independent variable								
Distance to Slaughter plant (C)	0.78	0.43	0.17	1.54	0.74	0.45	0.12	1.54
Distance to Research institutions (0≤ d <1km) (D)	0.36	0.50	0.00	1.00	0.40	0.51	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.21	0.43	0.00	1.00	0.20	0.41	0	1
Distance to Research institutions (d ≥1.5km) (D)	0.43	0.51	0.00	1.00	0.40	0.51	0	1
Family farm (C)	5.29	5.51	0	22	0.73	1.03	0	3
Gender (% of male operators) (C)	94.07	7.01	80.00	100.00	21.67	8.14	0	33
Human population density (C)	6.62	6.09	1.46	20.64	77.54	277.11	1.09	1079.06
Land tenure (C)	41.07	8.22	27	58	48.53	12.81	26	76
No Off-farm work (C)	65.71	10.96	44.00	86.00	66.20	9.88	43	80
Number of pig farms (C)	208.29	133.79	47	459	162.07	118.65	5	383
Operator's average age (C)	42.26	1.95	39.90	45.70	42.81	2.61	39.6	50.4
Operator living on farm (C)	92.00	6.84	71.00	99.00	74.07	6.63	60	90
Production type (C)	51.21	10.89	36	71	54.47	10.93	41	74
Technology (C)	3.00	2.35	0	9	21.67	15.19	5	67
Temperature (C)	13.37	0.58	11.91	14.18	14.98	0.57	14	16

Appendix 20. Descriptive Statistics of Variables Specified in the Model, Manitoba, 1996 and 2001.

	1996				2001			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	32.96	0.00	32.96	13.73	48.77	0.00	48.77	48.77
Census Division level data								
Dependent variable								
Farm size (C)	971	483	380	2100	1664	805	841	3849
Independent variable								
Distance to Slaughter plant (C)	0.73	0.45	0.12	1.54	0.63	0.38	0.10	1.30
Distance to Research institutions (0≤ d <1km) (D)	0.40	0.51	0	1	0.40	0.51	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.20	0.41	0	1	0.20	0.41	0	1
Distance to Research institutions (d ≥1.5km) (D)	0.40	0.51	0	1	0.40	0.51	0	1
Family farm (C)	11.53	6.89	0	24	15.93	7.65	5	33
Gender (% of male operators) (C)	81.20	8.81	67	100	82.40	11.21	63	100
Human population density (C)	78.17	278.54	1.10	1084.79	78.51	279.12	1.12	1087.21
Land tenure (C)	45.87	14.55	30	88	44.40	17.81	0	73
No Off-farm work (C)	74.13	13.79	50	100	63.40	9.31	50	80
Number of pig farms (C)	118.27	102.35	5	370	96.47	89.81	8	337
Operator's average age (C)	43.13	2.95	37.0	49.0	44.87	2.29	41.0	48.0
Operator living on farm (C)	90.13	8.74	67	100	88.13	14.08	50	100
Production type (C)	48.07	13.83	27	69	41.93	14.05	17	67
Technology (C)	41.47	9.96	28	68	62.67	8.40	48	77
Temperature (C)	12.78	0.49	12	16	14.43	0.65	13.24	15.90

Appendix 21. Descriptive Statistics of Variables Specified in the Model, Manitoba, 2006 and 2011.

	2006				2011			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	37.19	0.00	37.19	37.19	20.20	0.00	20.20	20.20
Census Division level data								
Dependent variable								
Farm size (C)	2787	1637	1577	7620	4082	2122	1469	9424
Independent variable								
Distance to Slaughter plant (C)	0.69	0.36	0.10	1.30	0.91	0.54	0.10	2.15
Distance to Research institutions (0≤ d <1km) (D)	0.36	0.50	0	1	0.38	0.51	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.21	0.43	0	1	0.23	0.44	0	1
Distance to Research institutions (d ≥1.5km) (D)	0.43	0.51	0	1	0.38	0.51	0	1
Family farm (C)	28.14	11.28	5	54	36.15	17.86	5	67
Gender (% of male operators) (C)	83.79	11.38	67	100	88.54	11.98	67	100
Human population density (C)	60.73	267.01	1.19	1027.27	72.59	287.70	1.18	1028.52
Land tenure (C)	46.29	12.67	32	79	41.15	13.26	20	67
No Off-farm work (C)	72.07	10.23	56	91	69.92	21.27	33	100
Number of pig farms (C)	74.00	69.58	23	267	38.00	34.79	12	137
Operator's average age (C)	48.64	3.13	45.0	54.0	52.46	2.90	48.0	58.0
Operator living on farm (C)	85.79	9.00	93	100	79.62	11.62	67	100
Production type (C)	40.50	14.92	16	67	42.85	19.64	15	75
Technology (C)	71.21	8.55	56	85	86.00	10.30	75	100
Temperature (C)	15.17	0.63	13.69	16.08	13.10	1.64	9.54	15.65

Appendix 22. Descriptive Statistics of Variables Specified in the Model, Manitoba, 2016.

	2016			
	Mean	Std. Dev	Min	Max
Provincial level data				
Hog-feed price ratio (C)	15.26	0	15.26	15.26
Census Division level data				
Dependent variable				
Farm size (C)	4224	3078	1519	13483
Independent variable				
Distance to Slaughter plant (C)	0.97	0.54	0.1	2.15
Distance to Research institutions (0≤ d <1km) (D)	0.13	0.35	0	1
Distance to Research institutions (1≤ d <1.5km) (D)	0.40	0.51	0	1
Distance to Research institutions (d ≥1.5km) (D)	0.47	0.52	0	1
Family farm (C)	38.53	15.82	8	64
Gender (% of male operators) (C)	84.93	15.00	65	100
Human population density (C)	89.82	318.30	1.26	1240.1
Land tenure (C)	35.13	17.16	13	78
No Off-farm work (C)	66.87	27.80	0	100
Number of pig farms (C)	40.20	32.93	6	135
Operator's average age (C)	50.29	5.80	37	60.8
Operator living on farm (C)	65.60	18.67	0	76
Production type (C)	24.00	17.39	0	57
Technology (C)	84.60	15.81	45	100
Temperature (C)	14.13	0.87	11.72	15.62

Appendix 23. Descriptive Statistics of Variables Specified in the Model, Ontario, 1986.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	36.94	0	36.94	36.94	36.94	0	36.94	36.94
Census Division level data								
Dependent variable								
Farm size (C)	323	103	125	459	136	97	4	351
Independent variable								
Distance to Slaughter plant (C)	1.16	0.52	0.53	2.03				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.27	0.45	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.20	0.41	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.27	0.45	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.17	0.38	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.10	0.31	0	1
Distance to Research institutions (C)	0.3844	0.17458	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.27	0.45	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.27	0.45	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.20	0.41	0	1
Distance to Research institutions (d ≥1km) (D)					0.27	0.45	0	1
Family farm (C)	6.89	2.32	3	11	3.67	4.29	0	17
Gender (% of male operators) (C)	96.44	2.55	92	100	90.13	21.37	0	100
Human population density (C)	33.70	11.36	17.36	55.71	91.56	124.49	0.67	476.63
Land tenure (C)	37.56	7.52	25	50	34.33	16.47	0	61
No Off-farm work (C)	65.11	6.81	50	72	42.73	24.89	0	67
Number of pig farms (C)	596.89	367.89	229	1256	237.73	260.65	24	967
Operator's average age (C)	43.59	2.10	40.9	46.7	44.62	3.52	39.2	54.8
Operator living on farm (C)	96.11	2.76	90	99	87.83	19.03	0	100
Production type (C)	61.89	9.53	39	72	49.97	15.30	0	71
Technology (C)	5.22	2.11	2	9	3.33	6.16	0	33
Temperature (C)	15.76	0.50028	14.95	16.63	14.66	1.27	11.40	17.56

Appendix 24. Descriptive Statistics of Variables Specified in the Model, Ontario, 1991.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	31.73	0	31.73	31.73	31.73	0	31.73	31.73
Census Division level data								
Dependent variable								
Farm size (C)	419	122	196	576	166	119	16	474
Independent variable								
Distance to Slaughter plant (C)	1.16	0.52	0.53	2.03				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.27	0.45	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.20	0.41	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.27	0.45	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.17	0.38	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.10	0.31	0	1
Distance to Research institutions (C)	0.38	0.17	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.27	0.45	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.27	0.45	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.20	0.41	0	1
Distance to Research institutions (d ≥1km) (D)					0.27	0.45	0	1
Family farm (C)	1.22	0.83	0	3	0.47	1.70	0	8
Gender (% of male operators) (C)	30.11	3.48	24	34	32.50	26.53	0	100
Human population density (C)	44.40	26.40	17.36	110.88	109.00	146.84	1.37	598.17
Land tenure (C)	41.11	7.01	27	51	36.27	20.33	0	78
No Off-farm work (C)	68.78	8.63	50	77	44.17	20.79	0	80
Number of pig farms (C)	458.44	307.06	155	1041	166.87	195.80	18	744
Operator's average age (C)	43.83	2.14	41.8	48.6	45.84	6.04	38	71.5
Operator living on farm (C)	68.66	4.66	62	75	64.86	24.02	0	100
Production type (C)	63.33	5.70	52	69	57.07	22.02	0	100
Technology (C)	21.11	5.13	16	30	15.50	18.16	0	100
Temperature	16.9944	0.46	16.22	17.72	15.92	1.36	12.56	18.95

Appendix 25. Descriptive Statistics of Variables Specified in the Model, Ontario, 1996.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	21.11	0	21.11	21.11	21.11	0	21.11	21.11
Census Division level data								
Dependent variable								
Farm size (C)	578	195	182	798	186	138	6	517
Independent variable								
Distance to Slaughter plant (C)	1.07	0.55	0.53	2.03				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.32	0.48	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.25	0.44	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.29	0.46	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.07	0.26	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.07	0.26	0	1
Distance to Research institutions (C)	0.38	0.17	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.32	0.48	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.29	0.46	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.21	0.42	0	1
Distance to Research institutions (d ≥1km) (D)					0.18	0.39	0	1
Family farm (C)	18.56	6.37	4	24	8.68	9.10	0	36
Gender (% of male operators) (C)	68.00	4.97	56	72	68.25	23.49	0	100
Human population density (C)	45.83	27.79	17.7	116.06	127.20	167.11	1.44	695.91
Land tenure (C)	46.11	7.69	33	56	38.61	22.68	0	76
No Off-farm work (C)	72.67	11.29	50	88	69.75	30.05	0	100
Number of pig farms (C)	338.22	231.84	104	772	124.96	148.47	12	592
Operator's average age (C)	43.66	1.66	42	46	46.21	6.46	29	70
Operator living on farm (C)	94.00	4.21	88	100	92.89	19.69	0	100
Production type (C)	58.22	7.55	48	73	8.68	9.10	0	36
Technology (C)	37.00	6.18	26	44	25.71	20.00	0	100
Temperature (C)	15.3	0.77	13.87	16.62	14.31	1.29	10.77	17.16

Appendix 26. Descriptive Statistics of Variables Specified in the Model, Ontario, 2001.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	27.06	0	27.06	27.06	27.06	0	27.06	27.06
Census Division level data								
Dependent variable								
Farm size (C)	968	298	306	1286	282	218	6	834
Independent variable								
Distance to Slaughter plant (C)	1.07	0.55	0.53	2.03				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.34	0.48	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.21	0.41	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.31	0.47	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.03	0.19	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.10	0.31	0	1
Distance to Research institutions (C)	0.38	0.17	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.31	0.47	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.28	0.45	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.21	0.41	0	1
Distance to Research institutions (d ≥1km) (D)					0.21	0.41	0	1
Family farm (C)	24.22	6.76	13	36	9.24	9.22	0	30
Gender (% of male operators) (C)	71.67	4.15	67	80	70.86	26.13	0	100
Human population density (C)	46.45	29.05	17.55	120.09	134.57	188.56	1.31	807.27
Land tenure (C)	42.56	4.82	33	50	38.52	25.40	0	90
No Off-farm work (C)	67.33	5.57	60	76	62.45	29.53	0	100
Number of pig farms (C)	260.78	182.10	77	572	83.83	102.65	12	406
Operator's average age (C)	44.78	1.30	43	47	48.48	4.41	39	62
Operator living on farm (C)	94.56	3.61	89	100	95.34	9.14	0	100
Production type (C)	46.11	9.88	31	67	45.83	17.42	0	75
Technology (C)	62.67	4.12	54	67	49.00	23.56	0	100
Temperature (C)	16.66	0.63	15.88	18.12	15.51	1.22	12.48	18.47

Appendix 27. Descriptive Statistics of Variables Specified in the Model, Ontario, 2006.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	22.68	0	22.68	22.68	22.68	0	22.68	22.68
Census Division level data								
Dependent variable								
Farm size (C)	1351	319	741	1749	380	294	9	1130
Independent variable								
Distance to Slaughter plant (C)	0.67	0.38	0.15	1.39				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.26	0.45	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.22	0.42	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.37	0.49	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.11	0.32	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.04	0.19	0	1
Distance to Research institutions (C)	0.384	0.17	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.30	0.47	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.30	0.47	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.22	0.42	0	1
Distance to Research institutions (d ≥1km) (D)					0.19	0.40	0	1
Family farm (C)	34.11	8.08	18	43	13.74	12.20	0	43
Gender (% of male operators) (C)	69.56	3.17	67	75	75.04	22.61	0	100
Human population density (C)	47.76	30.77	17.43	125.8	125.76	157.64	1.28	508.48
Land tenure (C)	45.89	7.01	35	56	36.93	26.08	0	100
No Off-farm work (C)	63.11	3.92	58	68	58.52	32.43	0	100
Number of pig farms (C)	226.44	160.66	62	488	70.11	82.67	4	315
Operator's average age (C)	45.89	1.27	44	48	46.70	4.81	38	58
Operator living on farm (C)	92.89	4.48	83	100	89.00	22.06	0	100
Production type (C)	35.67	7.97	18	43	41.00	23.28	0	100
Technology (C)	66.78	10.84	42	78	58.85	20.24	17	100
Temperature (C)	16.44	0.6786	15.55	17.82	15.58	0.95	13.02	17.79

Appendix 28. Descriptive Statistics of Variables Specified in the Model, Ontario, 2011.

	Type 1 structural change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	13.19	0	13.19	13.19	13.19	0	13.19	13.19
Census Division level data								
Dependent variable								
Farm size (C)	1921	364	1494	2662	404	372	6	1141
Independent variable								
Distance to Slaughter plant (C)	0.66	0.48	0.15	1.36				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.30	0.47	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.17	0.39	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.17	0.39	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.26	0.45	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.09	0.29	0	1
Distance to Research institutions (C)	0.38	0.17	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.22	0.42	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.30	0.47	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.22	0.42	0	1
Distance to Research institutions (d ≥1km) (D)					0.26	0.45	0	1
Family farm (C)	41.88	10.98	20	55	18.74	18.53	0	71
Gender (% of male operators) (C)	73.89	10.75	64	100	70.86	36.08	0	100
Human population density (C)	48.43	32.39	17.37	130.81	129.55	167.15	1.33	588.12
Land tenure (C)	51.78	8.51	36	61	42.52	26.60	0	92
No Off-farm work (C)	63.89	6.75	50	71	62.78	30.86	0	100
Number of pig farms (C)	136.22	97.46	35	305	51.48	56.16	14	210
Operator's average age (C)	49.11	3.52	46	57	49.39	8.21	36	72
Operator living on farm (C)	90.33	6.65	80	100	89.83	24.43	0	100
Production type (C)	33.67	12.63	19	53	35.04	29.09	0	100
Technology (C)	86.44	6.15	74	93	71.65	20.01	41	100
Temperature (C)	16.7	0.69	15.38	17.75	15.60	1.33	12.25	18.42

Appendix 29. Descriptive Statistics of Variables Specified in the Model, Ontario, 2016.

	Type 1 structural change				**Type 2 structural change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	13.56	0	13.56	13.56	13.56	0	13.56	13.56
Census Division level data								
Dependent variable								
Farm size (C)	2100	577	913	2901	449	467	7	1736
Independent variable								
Distance to Slaughter plant (C)	0.69	0.38	0.17	1.36				
Distance to Slaughter plant (0 ≤ d <0.5km) (D)					0.32	0.48	0	1
Distance to Slaughter plant (0 .5≤ d <1km) (D)					0.12	0.33	0	1
Distance to Slaughter plant (1≤ d < 2km) (D)					0.28	0.46	0	1
Distance to Slaughter plant (2≤ d <3km) (D)					0.16	0.37	0	1
Distance to Slaughter plant (d ≥3m) (D)					0.12	0.33	0	1
Distance to Research institutions (C)	0.380	0.180	0.11	0.7				
Distance to Research institutions (0≤ d <0.25km) (D)					0.28	0.46	0	1
Distance to Research institutions (0.25≤ d <0.5km) (D)					0.28	0.46	0	1
Distance to Research institutions (0.5≤ d <1km) (D)					0.24	0.44	0	1
Distance to Research institutions (d ≥1km) (D)					0.20	0.41	0	1
Family farm (C)	53.78	7.87	42	66	33.71	24.97	0	100
Gender (% of male operators) (C)	70.22	3.42	67	78	73.48	34.86	0	100
Human population density (C)	49.46	33.89	17.43	135.69	159.41	258.93	1.33	1127.89
Land tenure (C)	43.44	8.20	33	55	30.00	26.20	0	73
No Off-farm work (C)	63.56	12.34	40	80	54.35	30.77	0	100
Number of pig farms (C)	140.33	97.66	51	318	58.29	52.68	6	185
Operator's average age (C)	48.96	1.98	46	53	48.93	9.67	28	74
Operator living on farm (C)	90.33	6.65	80	100	88.86	25.41	0	100
Production type (C)	27.22	10.12	18	48	27.00	23.54	0	100
Technology (C)	81.89	5.46	73	89	60.19	29.35	0	100
Temperature	16.59	0.64	15.47	17.33	15.89	1.33	12.55	18.54

Appendix 30. Descriptive Statistics of Variables Specified in the Model, Quebec, 1986.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	29.39	0.00	29.39	29.39	29.39	0.00	29.39	29.39
Census Division level data								
Dependent variable								
Farm size (C)	443	272	13	1063	454	366	7	1202
Independent variable								
Distance to Slaughter plant (C)	0.58	0.47	0.12	2.51	0.56	0.36	0.07	1.25
Distance to Research institutions (C)	0.76	0.88	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.08	0.28	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.29	0.46	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.21	0.41	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.29	0.46	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	16.37	12.98	0	67	11.78	10.77	0	50
Gender (% of male operators) (C)	97.54	4.38	80	100	93.77	21.19	0	100
Human population density (0< p <100) (D)	0.06	0.23	0	1	0.13	0.34	0	1
Human population density (10< p <20) (D)	0.37	0.49	0	1	0.21	0.41	0	1
Human population density (20≤ p <30) (D)	0.14	0.36	0	1	0.08	0.28	0	1
Human population density (30≤ p <60) (D)	0.11	0.32	0	1	0.13	0.34	0	1
Human population density (60≤ p <90) (D)	0.09	0.28	0	1	0.17	0.38	0	1
Human population density (90≤ p <180) (D)	0.17	0.38	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.06	0.24	0	1	0.13	0.34	0	1
Land tenure (C)	23.17	12.04	0	48	27.57	21.32	0	100
No Off-farm work (C)	75.46	22.78	0	100	81.62	11.43	69	100
Number of pig farms (C)	88.94	115.21	10	468	45.42	52.84	3	198
Operator's average age (age ≤45) (D)	0.86	0.36	0	1	0.79	0.41	0	1
Operator's average age (45≤ age <50) (D)	0.11	0.32	0	1	0.13	0.34	0	1
Operator's average age (age ≥50) (D)	0.029	0.169	0	1	0.08	0.28	0	1
Operator living on farm (C)	85.14	21.68	0	100	77.83	34.86	0	100
Production type (C)	36.46	21.30	0	86	34.65	27.67	0	100
Technology (C)	1.857	2.5453	0	10	3.125	3.87088	0	11
Temperature (C)	12.76	1.32	10.78	14.67	13.09	1.30	10.8	15.16

Appendix 31. Descriptive Statistics of Variables Specified in the Model, Quebec, 1991.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	26.80	0.00	26.80	26.80	26.80	0.00	26.80	26.80
Census Division level data								
Dependent variable								
Farm size (C)	648	320	13	1199	606	404	6	1187
Independent variable								
Distance to Slaughter plant (C)	0.50	0.46	0.12	2.51	0.54	0.34	0.07	1.25
Distance to Research institutions (C)	0.75	0.86	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.08	0.28	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.29	0.46	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.21	0.41	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.29	0.46	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	3.64	4.76	0	17	5.77	21.14	0	100
Gender (% of male operators) (C)	27.11	18.68	0	100	24.45	23.78	0	100
Human population density (0< p <100) (D)	0.19	0.40	0	1	0.25	0.44	0	1
Human population density (10< p <20) (D)	0.32	0.47	0	1	0.13	0.34	0	1
Human population density (20≤ p <30) (D)	0.24	0.43	0	1	0.13	0.34	0	1
Human population density (30≤ p <60) (D)	0.11	0.11	0	1	0.17	0.38	0	1
Human population density (60≤ p <90) (D)	0.00	0.00	0	0	0.00	0.00	0	0
Human population density (90≤ p <180) (D)	0.08	0.28	0	1	0.25	0.44	0	1
Human population density (p ≥180) (D)	0.05	0.23	0	1	0.08	0.28	0	1
Land tenure (C)	16.11	10.03	0	40	18.86	13.71	0	50
No Off-farm work (C)	72.31	20.98	0	100	74.70	10.70	50	100
Number of pig farms (C)	67.30	92.70	6	354	37.00	40.95	5	147
Operator's average age (age ≤45) (D)	0.86	0.36	0	1	0.71	0.46	0	1
Operator's average age (45≤ age <50) (D)	0.05	0.23	0	1	0.21	0.41	0	1
Operator's average age (age ≥50) (D)	0.081	0.27672	0	1	0.08	0.28	0	1
Operator living on farm (C)	68.06	17.91	0	100	64.73	28.91	0	100
Production type (C)	46.00	21.15	0	95	34.45	18.95	0	75
Technology (C)	19.19	14.9719	0	67	19	20.44	0	100
Temperature	14.02	1.29	11.6	16.42	14.45	1.46	11.1	16.42

Appendix 32. Descriptive Statistics of Variables Specified in the Model, Quebec, 1996.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	18.79	0.00	18.79	18.79	18.79	0.00	18.79	18.79
Census Division level data								
Dependent variable								
Farm size (C)	1028	373	63	1836	935	648	50	2484
Independent variable								
Distance to Slaughter plant (C)	0.50	0.44	0.13	2.17	0.49	0.33	0.03	1.25
Distance to Research institutions (C)	0.61	0.57	0.06	2.64				
Distance to Research institutions (0≤ d <0.2km) (D)					0.08	0.28	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.29	0.46	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.21	0.41	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.29	0.46	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	23.68	13.16	0	50	29.63	24.93	0	100
Gender (% of male operators) (C)	69.53	18.00	0	100	66.77	27.56	0	100
Human population density (0< p <100) (D)	0.18	0.39	0	1	0.25	0.44	0	1
Human population density (10< p <20) (D)	0.32	0.47	0	1	0.13	0.34	0	1
Human population density (20≤ p <30) (D)	0.24	0.43	0	1	0.13	0.34	0	1
Human population density (30≤ p <60) (D)	0.12	0.33	0	1	0.13	0.34	0	1
Human population density (60≤ p <90) (D)	0.06	0.24	0	1	0.04	0.20	0	0
Human population density (90≤ p <180) (D)	0.06	0.24	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.03	0.17	0	1	0.17	0.38	0	1
Land tenure (C)	21.97	9.19	0	43	16.29	12.87	0	35
No Off-farm work (C)	86.18	17.28	50	100	70.52	34.50	0	100
Number of pig farms (C)	63.74	83.98	7	314	30.33	37.80	4	121
Operator's average age (age ≤45) (D)	0.86	0.36	0	1	0.67	0.48	0	1
Operator's average age (45≤ age <50) (D)	0.12	0.33	0	1	0.29	0.46	0	1
Operator's average age (age ≥50) (D)	0.029	0.17149	0	1	0.04	0.20	0	1
Operator living on farm (C)	84.97	13.98	50	100	91.14	13.67	50	100
Production type (C)	42.47	18.31	10	80	45.04	29.14	0	100
Technology (C)	38.59	14.21	13	80	35.25	22.12	0	100
Temperature (C)	13.59	1.17	11.48	15.75	13.83	1.33	11.32	15.86

Appendix 33. Descriptive Statistics of Variables Specified in the Model, Quebec, 2001.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	26.02	0.00	26.02	26.02	26.02	0.00	26.02	26.02
Census Division level data								
Dependent variable								
Farm size (C)	1567	432	893	2758	1323	654	519	3410
Independent variable								
Distance to Slaughter plant (C)	0.39	0.30	0.12	1.86	0.45	0.33	0.03	1.25
Distance to Research institutions (C)	0.73	0.85	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.13	0.34	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.33	0.48	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.17	0.38	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.25	0.44	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	29.28	12.39	10	56	36.00	22.40	0	100
Gender (% of male operators) (C)	73.47	18.59	0	100	68.68	23.50	0	100
Human population density (0< p <100) (D)	0.19	0.40	0	1	0.25	0.44	0	1
Human population density (10< p <20) (D)	0.25	0.44	0	1	0.17	0.38	0	1
Human population density (20≤ p <30) (D)	0.19	0.40	0	1	0.08	0.28	0	1
Human population density (30≤ p <60) (D)	0.17	0.38	0	1	0.17	0.38	0	1
Human population density (60≤ p <90) (D)	0.06	0.24	0	1	0.00	0.00	0	0
Human population density (90≤ p <180) (D)	0.11	0.32	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.03	0.17	0	1	0.17	0.38	0	1
Land tenure (C)	32.81	14.46	10	75	28.08	18.51	0	67
No Off-farm work (C)	80.00	16.99	40	100	63.48	32.50	0	100
Number of pig farms (C)	55.17	73.03	4	273	27.42	31.08	3	102
Operator's average age (age ≤45) (D)	0.75	0.44	0	1	0.50	0.51	0	1
Operator's average age (45≤ age <50) (D)	0.22	0.42	0	1	0.42	0.50	0	1
Operator's average age (age ≥50) (D)	0.028	0.16667	0	1	0.08	0.28	0	1
Operator living on farm (C)	83.94	15.46	50	100	71.13	34.58	0	100
Production type (C)	36.89	18.42	0	81	42.25	23.96	0	100
Technology (C)	68.89	13.664	25	100	62.92	24.45	0	100
Temperature (C)	14.36	1.54	10.2	17.08	14.77	1.58	10.20	16.98

Appendix 34. Descriptive Statistics of Variables Specified in the Model, Quebec, 2006.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	22.38	0.00	22.38	22.38	22.38	0.00	22.38	22.38
Census Division level data								
Dependent variable								
Farm size (C)	1767	565	857	3999	1683	913	496	4123
Independent variable								
Distance to Slaughter plant (C)	0.38	0.30	0.07	1.86	0.45	0.34	0.05	1.25
Distance to Research institutions (C)	0.73	0.88	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.13	0.34	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.33	0.48	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.17	0.38	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.25	0.44	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	37.32	14.29	0	69	45.74	27.90	0	100
Gender (% of male operators) (C)	67.29	21.61	0	100	71.95	23.89	0	100
Human population density (0< p <100) (D)	0.18	0.39	0	1	0.25	0.44	0	1
Human population density (10< p <20) (D)	0.26	0.45	0	1	0.17	0.38	0	1
Human population density (20≤ p <30) (D)	0.21	0.41	0	1	0.04	0.20	0	1
Human population density (30≤ p <60) (D)	0.12	0.33	0	1	0.21	0.41	0	1
Human population density (60≤ p <90) (D)	0.09	0.29	0	1	0.00	0.00	0	0
Human population density (90≤ p <180) (D)	0.09	0.29	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.06	0.24	0	1	0.17	0.38	0	1
Land tenure (C)	32.68	17.11	0	73	18.91	16.50	0	71
No Off-farm work (C)	68.62	24.17	0	100	61.26	34.41	0	100
Number of pig farms (C)	53.06	65.63	4	261	22.96	28.26	1	88
Operator's average age (age ≤45) (D)	0.56	0.50	0	1	0.25	0.44	0	1
Operator's average age (45≤ age <50) (D)	0.41	0.50	0	1	0.63	0.49	0	1
Operator's average age (age ≥50) (D)	0.029	0.1715	0	1	0.13	0.34	0	1
Operator living on farm (C)	86.00	11.82	50	100	79.82	24.54	0	100
Production type (C)	30.76	16.77	0	69	35.22	27.74	0	100
Technology (C)	70.79	13.1028	38	100	64.83	24.554	0	100
Temperature (C)	14.32	1.50	9.83	16.8	14.66	1.60	9.83	16.83

Appendix 35. Descriptive Statistics of Variables Specified in the Model, Quebec, 2011.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	12.52	0.00	12.52	12.52	12.52	0.00	12.52	12.52
Census Division level data								
Dependent variable								
Farm size (C)	2329	791	1300	4694	2331	1159	253	5439
Independent variable								
Distance to Slaughter plant (C)	0.42	0.32	0.07	1.62	0.69	0.80	0.05	3.59
Distance to Research institutions (C)	0.74	0.84	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.13	0.34	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.33	0.48	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.17	0.38	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.25	0.44	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	44.47	17.15	0	80	44.05	29.06	0	100
Gender (% of male operators) (C)	72.50	14.57	50	100	78.00	27.75	0	100
Human population density (0< p <100) (D)	0.20	0.41	0	1	0.25	0.44	0	1
Human population density (10< p <20) (D)	0.23	0.43	0	1	0.17	0.38	0	1
Human population density (20≤ p <30) (D)	0.20	0.41	0	1	0.04	0.20	0	1
Human population density (30≤ p <60) (D)	0.13	0.35	0	1	0.13	0.34	0	1
Human population density (60≤ p <90) (D)	0.13	0.35	0	1	0.08	0.28	0	0
Human population density (90≤ p <180) (D)	0.07	0.25	0	1	0.17	0.38	0	1
Human population density (p ≥180) (D)	0.03	0.18	0	1	0.17	0.38	0	1
Land tenure (C)	29.77	16.97	0	75	22.86	19.31	0	67
No Off-farm work (C)	75.53	23.63	33	100	68.43	30.73	0	100
Number of pig farms (C)	47.47	54.06	6	207	19.50	23.30	1	66
Operator's average age (age ≤45) (D)	0.10	0.31	0	1	0.29	0.46	0	1
Operator's average age (45≤ age <50) (D)	0.63	0.49	0	1	0.33	0.48	0	1
Operator's average age (age ≥50) (D)	0.267	0.44977	0	1	0.38	0.49	0	1
Operator living on farm (C)	76.37	15.64	50	100	70.56	25.80	0	100
Production type (C)	30.73	17.28	0	75	31.67	33.39	0	100
Technology (C)	80.17	12.312	57	100	60.38	34.626	0	100
Temperature (C)	14.21	1.71	9.32	16.73	14.06	2.96	2.95	16.68

Appendix 36. Descriptive Statistics of Variables Specified in the Model, Quebec, 2016.

	Type 1 Structural Change				**Type 2 Structural Change**			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Provincial level data								
Hog-feed price ratio (C)	12.32	0.00	12.32	12.32	12.32	0.00	12.32	12.32
Census Division level data								
Dependent variable								
Farm size (C)	2566	1334	860	7582	1420	797	20	2472
Independent variable								
Distance to Slaughter plant (C)	0.43	0.35	0.12	2.2	0.67	0.75	0.05	3.81
Distance to Research institutions (C)	0.73	0.85	0.06	3.66				
Distance to Research institutions (0≤ d <0.2km) (D)					0.13	0.34	0	1
Distance to Research institutions (0.2≤ d <0.4km) (D)					0.35	0.49	0	1
Distance to Research institutions (0.4≤ d <0.6km) (D)					0.13	0.34	0	1
Distance to Research institutions (0.6≤ d <1.2km) (D)					0.26	0.45	0	1
Distance to Research institutions (1.2≤ d <2.4km) (D)					0.13	0.34	0	1
Family farm (C)	45.61	17.76	21	100	47.60	27.10	0	100
Gender (% of male operators) (C)	71.33	20.04	0	100	80.61	26.83	0	100
Human population density (0< p <100) (D)	0.19	0.40	0	1	0.26	0.45	0	1
Human population density (10< p <20) (D)	0.25	0.44	0	1	0.17	0.39	0	1
Human population density (20≤ p <30) (D)	0.17	0.38	0	1	0.04	0.21	0	1
Human population density (30≤ p <60) (D)	0.14	0.35	0	1	0.09	0.29	0	1
Human population density (60≤ p <90) (D)	0.08	0.28	0	1	0.09	0.29	0	1
Human population density (90≤ p <180) (D)	0.08	0.28	0	1	0.17	0.39	0	1
Human population density (p ≥180) (D)	0.08	0.28	0	1	0.17	0.39	0	1
Land tenure (C)	25.67	15.26	0	67	19.80	18.55	0	67
No Off-farm work (C)	64.75	24.31	0	100	72.22	31.55	0	100
Number of pig farms (C)	40.72	48.01	3	210	18.05	19.93	3	70
Operator's average age (age ≤45) (D)	0.11	0.32	0	1	0.30	0.47	0	1
Operator's average age (45≤ age <50) (D)	0.36	0.49	0	1	0.13	0.34	0	1
Operator's average age (age ≥50) (D)	0.53	0.51	0	1	0.57	0.51	0	1
Operator living on farm (C)	74.75	21.31	0	100	63.27	31.29	0	100
Production type (C)	20.28	15.05	0	90	16.10	24.76	0	100
Technology (C)	68.11	16.80	33	100	70.30	31.97	0	100
Temperature (C)	14.01	1.64	9.48	16.56	14.47	1.90	9.48	16.65

Appendix 37. Criteria for Breeding-Herd Classification for PRRS.

	Herd category	**Definition**
1	Positive Unstable (I)	Shedding and exposure status on farm are positive. Any virus detected on the site along with clinical signs consistent with PRRS. Herds that do not meet the criteria for any of the other categories (II through IV) are Category I by default (e.g. if your status is not confirmed, your herd is not tested, your farm is experiencing a clinical outbreak and if shedding of the virus is reoccurring on your farm)
2	Positive Stable (II-A)	Shedding status is uncertain, exposure status is positive. Category II starts after a 90-day period of sustained lack of viremia in weaning-age pigs and no clinical signs of PRRS in the breeding herd. Herd has not initiated an elimination program.
3	Positive Stable Undergoing Elimination (II-B)	Shedding status is uncertain but herd is undergoing elimination, exposure status is positive. Category II starts after a 90-day period of sustained lack of viremia in weaning-age pigs and no clinical signs of PRRS in the breeding herd. Herd has initiated an elimination program and intends to become Negative.
4	Provisional Negative (III)	Shedding status is negative, exposure status is positive. Category III starts 60 days after negative breeding replacements are first introduced during a herd rollover with diagnostic evidence that they remain uninfected. If growing pigs are present at the same premises, a confirmation of negative exposure status in that subpopulation is also required.
5	Negative (IV)	Shedding status is negative, exposure status is negative. For herd rollovers, Category IV starts when all previously infected animals have been removed from the herd. Alternatively, Category IV starts 1 year after the herd was classified as Category III if all animals in the herd are seronegative by ELISA. For herds established Negative as a new startup or by complete depopulation and repopulation. If growing pigs are present at the same premises, confirmation of a negative exposure status in that subpopulation is also required.

Appendix 38. Criteria for Growing-Herd Classification for PRRS.

	Herd category	**Definition**
1	Positive	If either the shedding status or the exposure status are positive. If any virus is detected on the site, along with clinical signs consistent with PRRS the farm has a positive status. Herds that do not meet the criteria for Negative are Positive by default.
2	Negative	If shedding status and exposure status are negative. A test serum from growing pigs by ELISA is required to confirm the status. The test must show no positive results, after ruling out false-positives, and no clinical signs may be observed that are consistent with PRRS in growing pigs.

Appendix 39. Criteria for Breeding-Herd Classification for PCVAD.

	Herd category	**Definition**
1	Level 1	Sporadic occurrence. Minimal effect on farm mortality rates. Mainly a wasting disease, and fits within the PWMS definition.
2	Level 2	Persistent PCVAD. Mortality is elevated, maybe doubled in the affected age group, and there is an increase in the number of culled pigs sold.
3	Level 3	Epizootic, severity varies mainly dependent on presence or absence of concurrent disease, especially PRRS. Mortality ranges between 8 to 25% in 8- to 13-week-old pigs.

Appendix 40. List of the Available PRRS Treatments.

	Vaccine
1.	ReproCyc® PRRS-PLE
2.	Ingelvac® PRRS MLV
3.	Ingelvac® PRRS ATP
4.	Fostera PRRS (Pfitzer
5.	Sow herd stabilization
6.	All-in-all-out
7.	Depopulation-repopulation
8.	Medicated early weaning
9.	Segregated early weaning
10.	Nursery depopulation
11.	Monitoring
12.	Boar testing
13.	Strict biosecurity measures
14.	Herd closure
15.	Rollover
16.	Regional elimination program
17.	Risk based testing and surveillance

Appendix 41. List of the Available PCAVD Treatments.

1.	Serotherapy
	Vaccination
2.	Circovac (Merial)
3.	CircoFlex (Boehringer Ingelheim)
4.	Circumvent (Intervet / Schering - Plough)
5.	Fostera PCV (Pfizer)
6.	Change management practices
7.	Decreasing load of pathogens and bacteria in the environment
8.	Application of general biosecurity measures
9.	Antibiotics