Canada's Beef Cattle Industry: Exchange Rates, Price Pass-Through and Feedlot Profitability Under Different Production Systems

by

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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

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Abstract

This thesis examines two issues from different perspectives of Canada's beef cattle industry. The first study undertakes the analysis of the exogenous variable's threshold effect on the domestic price pass-through across the different market levels. The study employs a 3-step analysis: first, a threshold test to detect threshold effect of variable, in this case, exchange rate, on domestic price transmission pattern; second, the threshold autoregression (TAR) model to find the threshold value; and third, the threshold ECM to estimate the short-run adjustments of the farm level price and the wholesale level price regarding to any deviation from the long-run relationship. The results suggest that the trade-oriented variable, exchange rate, exerts threshold effect inducing two regimes. Furthermore, in each regime, farm level producer and wholesale level producer coordinate with each other regarding prices in different patterns.

The second study examines the impact of production systems on cattle carcass quality and determinants of cattle feeding profitability. It assigns a unit price to each cattle based on its carcass characteristics with the guidance of Canadian Beef Grading System and calculates profit with the grid-based price. The study applies a three-part analysis. First, ordered logit model is built to investigate the probability of cattle carcass falling into different grades. Second, ordinary least square (OLS) regression model is estimated to examine the effect of production variables on the cattle feeding profitability. Third, simulation methodology is applied to generate expected profit; then break-even analysis is conducted. This study also takes price risks into account by conducting the last two analyses in typical input and output price scenarios. The results indicate that cattle’s breed composition, hormone growth promotants, ractopamine treatment, and diet exert impacts on cattle carcass’ grade outcome and cattle feeding profitability in different price scenarios.

Acknowledgments

My sincere gratitude goes to my supervisors, Dr. Sven Anders and Dr. Feng Qiu for your enormous support, professional instruction, insightful comments and suggestions on this thesis throughout the process. Your dedication and patient mentorship not only helped me finish this thesis but also aroused strong interest from me in doing research, and for that, I will always be grateful.

I would also express my genuine appreciation for Dr. Manuel Juárez and Dr. Jordan Roberts, the animal science experts from Lacombe Research and Development Center, AAFC, not only for your provision of the cattle production data but also for your invaluable guidance on data adjustment and pertinent comments from the perspective of animal science. I would not be able to achieve this without your patient instruction and professional comments.

I would like to acknowledge Meat Education and Training Network (MEaTnet) for funding this study.

A special thanks to Brenna Grant and Huiting Huang, the researchers of Canfax Research Services, for your provision of invaluable data on input and output prices of cattle feeding industry and your professional suggestions on data adjustment.

I extend sincere thanks to the staff and students of the Department of Resource Economics and Environmental Sociology. I appreciate the enduring encouragement and unwavering support from my dear friends and family over the past two years.

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Chapter 1. Introduction to the Thesis

1.1. Introduction

The Canadian beef cattle industry plays an increasingly important role in agriculture and makes a significant contribution to national economy. Moreover, the Canadian beef industry has built a worldwide reputation for high quality. In 2014, the farm cash receipt of cattle and calves in Canada accounted for $9.77 billion, taking up about 38.15% of the total livestock cash receipt, and 17% of the total cash receipts (Canfax Research Services 2016). In 2015, Canada's beef industry contributed $33 billion worth of sales of goods and services to the economy (Agriculture and Agri-Food Canada 2016). At the farm level, the cattle feeding industry is becoming increasingly competitive facing challenges stemming from the increasing farm input cost, fluctuating beef prices, consumers' perceptions relative to animal health and food safety, and export market access (López-Campos et al. 2013; Lawrence et al. 1999; Schroeder et al. 1993). At the wholesale level, the beef processing market is a highly concentrated industry and has a highly dependent trade relationship with the U.S. beef cattle market (Miljkovic 2009).

In recent decades, the Canadian beef cattle industry has experienced several disruptive events including the outbreak of bovine spongiform encephalopathy (BSE), the implementation of the mandatory country of origin labeling (COOL), the exchange rate appreciations, and the feed grain price swings (Zhen, Rude and Qiu 2017). These events have caused shocks in the prices at various market levels. The pattern in which price changes are passed through the supply chain reveals how efficiently the economic agents in the market coordinate with one another. The business participants along the beef supply chain, who experienced price fluctuations, competition for production efficiencies, and uncertainties over trade access, found it is necessary to study further on the price linkage between different market levels (Saha and Mitura 2008; Goodwin and Holt 1999). The investigation on the price linkage across each market level could help the industry to manage the risks better and improve the efficiency of market operation.

To address the production challenges posted to the cattle feeding industry, the beef cattle industry has developed numerous cattle production systems and management strategies to improve efficiency, to reduce input cost, and to enable producers to obtain more accurate information on consumers' demand for beef production (López-Campos et al. 2013). One of the chief industry-wide management strategies noted in the past research is the grid-based pricing system, known as the Canadian Beef Grading system in the Canadian beef cattle industry. The grid pricing at its core assigns different prices to individual animals based on their carcass characteristics. This assignment, in turn, improves information efficiency along the supply chain, alleviates the risk that producers face when making production and marketing decisions (López-Campos et al. 2013 and Retallick et al. 2013), and better allows producers to invest on the beef attributes that consumers look for (Johnson and Ward 2005).

1.2. Background on the Canadian beef cattle industry

The Canadian beef cattle production system is similar to that of the U.S. comprising three main types of operations: (1) cow/calf operations, (2) backgrounding operations, and (3) feedlot/ finishing operations (Athwal 2002; Zhen, Rude and Qiu 2017). Cow-calf operations are enterprises where a cowherd is maintained; calves are raised and ultimately sold after weaned from their mother cows. Weaned calves, steers and heifers are the principal products of the cow-calf sector. Depending on breed and production system, some weaned animals undergo a pre-finishing phase, called backgrounding, before they are shipped to a feedlot for finishing until slaughter. The backgrounding is a process of taking calves, usually in the fall, over-wintering them on silage or forage-based ration and pasture them for growth to heavier weight in the spring. The feedlot/finishing operation is the final stage of the beef production system. Western Canada and eastern Canada are different in that the feedlots are integrated with other operations in the east. In general, feedlot/finishing operations typically buy feeder animals from backgrounding operations or cow/calf producers and finish them to slaughter weight. At this stage, feeder animals (calves) are fed with a grain-based diet to put on needed fat (Athwal 2002; Zhen, Rude and Qiu 2017; Filley 2011).

Twine (2014) pointed out that there exists some evidence of vertical integration between different production levels. While the backgrounding process is commonly carried out by cow-calf producers (Athwal 2002), some beef processors also own feedlot operations. Schroeder (2003) and Twine (2014) noted that Canadian beef packers tend to own more feeder cattle than their U.S. counterparts to account for the seasonality of fed cattle supply in Canada relative to the U.S. market.

The Canadian beef cattle industry is highly dependent on its export markets. Around 50% of the Canadian beef and live cattle production ends up being exported to international markets. Prior to the BSE crisis, which had its onset in May 2003, Canadian beef was exported to over 100 markets (Haney 2010). However, only about 70 markets are currently fully or partially open to Canadian beef and cattle (Twine 2014). The U.S. has historically been the largest market for Canadian beef and cattle. Before the BSE crisis, over 70% of beef and almost all live cattle were exported to the U.S. (Miljkovic 2009; Athwal 2002; Twine et al. 2016).

1.3. Economic problem

The economic problem that the first essay aims at investigating is how exogenous and trade-related market shocks impact the vertical price transmission mechanism in the Canadian (domestic) beef cattle supply chain. Price is the primary mechanism that links the different market levels in a supply chain (Abdulai 2002). The extent and speed of adjustment at which price changes are transmitted through the chain can reveal both the efficiency of the market and the extent to which market participants coordinate with one another. Even though different price series may show no signs of moving together in the short-run, they could follow an equilibrium relationship in the long run, which means that a price that “runs away” from the “stable point” (equilibrium) will be pushed back to the equilibrium. The two variables that keep a long-run equilibrium relationship are said to be cointegrated. The theory of neo-classical economics assumes that the market is perfectly competitive. This theory implies that price transmission along the supply chain is immediate and complete. Saha and Mitura (2008) noted that, in competitive markets, the wholesale level price is equal to the farm level price plus the marginal cost of processing the primary product. Thus, the effect of a supply shock on farm prices is likely to be passed through proportionately to the wholesale level; similarly, the effect of a demand shock on wholesale price is expected to be transmitted proportionately to the farm level. In relation to a pair of cointegrated price series, perfect competitiveness means that the price adjusts to any deviation from the long-run equilibrium in a linear pattern. However, the violation of this assumption is prevalent in real world markets where we find price transmission is incomplete and delayed, thus price adjustment is deemed non-linear.

Market prices at different market levels may be affected by the domestic market structure and international trade, particularly in relation to the U.S. Increasing market concentration at the processor market level and the presence of adjustment costs may lead to asymmetric price transmissions or non-linear price adjustments (Bailey and Brorsen 1989; Peltzman 2000; Meyer and Cramon-Taubadel 2004; Zapata and Gauthier 2003). One of the typical non-linear price adjustments found in research is the threshold effect on price cointegration. In this context, changes in the international market may also affect the domestic supply chain. For example, as Saha and Mitura (2008) noted, the U.S. is the largest importer of Canadian beef cattle, and a considerable portion of Canadian beef cattle production exports to the U.S. markets. Thus, any fluctuation of Canadian cattle exports to the U.S. may directly affect vertical price relationships along the domestic supply chain. Therefore, the first essay investigates how a trade-related variable may affect the coordination between farm and wholesale market levels along the domestic supply chain. The result of this research should be of value to stakeholders in the Canadian beef market and policy makers engaged in domestic risk management capacity and policy decision-making aimed at alleviating Canadian beef producers' vulnerability to trade-related shocks.

The economic problem that the second essay aims to address is the profitability (economics) outcomes of producers' production (feeding) decisions. The risks for feedlot operators, associated with raising fed cattle, have two main components: general production risk and price risk (Fausti and Feuz, 1995; Thompson et al. 2016). The production risks examined in this study are associated with herd management, and, the selection of different production systems and other feeding strategies. Since production decisions are made prior to slaughter, at which point carcass traits (yield grade, quality grade, and hot-carcass weight) are unknown, information on profitability outcomes can help fed cattle producers make better decisions both to improve carcass quality and further improve profitability. The price risks examined in this study are related to input and output price fluctuations. The price risks are incorporated by constructing four market price scenarios with the maximum and minimum values affiliated with input and output prices. The grid-based pricing system will only work as the tool to assign a price to each animal. The intuition behind it is to improve the information efficiency along the supply chain (Johnson and Ward 2005). Producers could know which carcass traits consumers are looking for from the price signal, while at the same time, they are incentivized to invest on high quality beef, as they would earn more money by achieving the high quality.

Different production systems and feeding strategies are available in the cattle raising industry, including implant treatment and RAC treatment. However, a producer would only be expected to use this technology if its benefits outweigh the costs. The second essay investigates the linkage between fed cattle producers' production decisions and the profitability of different production systems under different market price scenarios. The results of this study provide fed cattle producers with helpful information on selecting production systems and other feeding strategies that have the potential to improve carcass quality and cattle feeding profitability outcomes under different fluctuating market prices.

1.4. Research objectives

This thesis aims to assess the market efficiency of transmitting price movements along the beef supply chain and to investigate the effect of production systems and other raising strategies on cattle feeding profitability. Price series of farm level market (fed cattle producer) and wholesale level (beef packer) will be analyzed in the first essay. By analyzing the price linkage between different market levels with threshold cointegration model, we can potentially predict the effect of exogenous shocks on the domestic vertical price transmission to improve the efficiency of Canadian beef market and alleviate the vulnerability of Canadian beef cattle market from exogenous shocks. The second essay investigates the effect of production systems and the determinants of cattle feeding profitability under different production systems. The following three analyses will be conducted: (1) to investigate the effect of production systems and other factors on the probability of cattle carcass' grade assignment; (2) to examine the effect of production factors on cattle feeding profitability; and (3) to generate expected profit with simulated critical variables, to find break-even dressed carcass weight in the simulated profit distribution and to calculate the probability of positive profit. To account for price risks, these analyses will be performed under the extreme input price and output price scenarios. The second essay will provide interesting insight into the determinants of cattle feeding profitability under different production systems and propose a recommendation to producers on production decisions concerning the production systems, cattle breed composition, and growth treatment (i.e., experimental diet, hormonal growth promotant implant, and adoption of β-adrenergic agonists).

1.5. Thesis structure

The rest of this thesis contains following three chapters. Chapter 2 and Chapter 3 present two different essays investigating Canadian beef cattle industry from two perspectives. Chapter 4 concludes the thesis with an integration discussion of Chapter 2 and Chapter 3 with the discussion of limitations and suggestions for future research.

Chapter 2 investigates the threshold effect of an exogenous variable (in this case, exchange rate) on domestic vertical price pass-through and different price reactions to any deviation from the long-run equilibrium in the above-threshold regime and the below-threshold regime. The Engle-Granger methodology (Engle and Granger 1987) is applied to test the long-run relationship between farm level fed cattle price and wholesale level beef price. Threshold test developed by Hansen (1996) is conducted to test the existence of threshold effect of exchange rate on the price pass-through across farm level price and wholesale level price. Self-exciting threshold autoregressive (SETAR) model (Chan 1993; Zapata and Gauthier 2003;

Enders 2008) is established to find the threshold value of exchange rate which induces two regimes. 2-regime threshold error correction model (ECM) (Engle and Granger 1987) is estimated to obtain the short-run farm price and wholesale price adjustments with respect to price deviations from the long-run relationship in each regime.

The objective of Chapter 3 is twofold. The first objective is to investigate the effect of production systems, breed composition, and growth treatment on cattle carcass characteristics. The second objective is to examine the linkage of the above factors to the cattle feeding profitability in different input and output price scenarios. The empirical analyses include three parts. (1) Ordered logit model is applied to estimate the probability that cattle carcass falls into each grade category. (2) Ordinary least square (OLS) model is set up to investigate the effect of critical production variables on cattle feeding profitability. Moreover, (3) expected profit is generated based on simulated production variables, then the break-even dressed carcass weight and the probability of positive profit are found in the obtained profit distribution. With necessary meat science knowledge, this essay provides recommendations to fed cattle producers on production and marketing decisions.

Chapter 2. Exchange rate Effects on Price Pass-through in the Canadian Beef Industry

2.1. Introduction

In recent decades, the Canadian beef cattle industry has experienced several significant fluctuations due to market and policy shocks, such as the outbreak of bovine spongiform encephalopathy (BSE), the implementation of the mandatory country of origin labeling (COOL), the exchange rate appreciations, and heightened volatility in feed grain prices. These market events experienced by the Canadian beef cattle industry raised concerns with respect to the volatile trade flows of Canadian cattle and beef product to the U.S. market (Twine et al. 2016) and the price pass-through mechanism along the domestic supply chain (Saha and Mitura 2008). Such concerns were further amplified due to the Canadian beef cattle industry's high degree of dependence on export markets. It is worthy to note that around 50% of the Canadian beef and live cattle production ends up exporting to international markets, and the U.S. has been the largest market for Canadian beef and cattle. Prior to the BSE crisis, which had its onset in May 2003, Canadian beef was exported to over 100 markets; however, only about 70 markets are currently fully or partially open to Canadian beef and cattle (Twine 2014).

An example in fact to illustrate this decline in open market acceptability of Canadian beef and cattle would be in relation to the U.S. Prior to the BSE crisis, over 70% of beef and almost all cattle exports went to the U.S. (Miljkovic 2009; Athwal 2002; Twine et al. 2016). However, in the aftermath of the BSE crisis, the U.S. border closure resulted in a structural transformation of the Canadian beef cattle industry, with direct implications for domestic vertical price transmission. The structural transformation included changes in the structural characteristics of the beef industry induced by a trade-oriented factor (Twine 2014). Indeed, chief concerns surrounding the U.S. border closure were related to the Canadian beef cattle industry's high dependence on trade with the U.S. market. Canada produces live cattle and beef more than its stock capacity and domestic consumption (Athwal 2002; Mutuc et al. 2011; Schulz et al. 2017), thus the contraction of cattle and beef exports led to an increased vulnerability to exogenous shocks (Miljkovic 2009).

Since the trade relationship with the U.S. can potentially influence the way domestic farm level and wholesale level prices coordinate with each other, it is reasonable to hypothesize that trade-oriented variables, such as exchange rate, can play a role in the domestic price pass-through patterns from the farm level to wholesale level along the beef supply chain. An ample amount of literature found that exchange rate and commodity trade flow are significantly and negatively correlated (Athwal 2002; Molina et al. 2013; Arize 1995; Campa and Goldberg 1999). Studies by Mutuc et al. (2011), Schulz et al. (2017) and Grier (2005) argued that the exchange rates affect the relative price of a tradable commodity across different regions, an importing country with appreciated currency can import more foreign commodities. These cheaper imports compete with similar goods produced domestically. Conversely, an exporting country with appreciated currency will have difficulty exporting domestically produced goods, which could lead to domestic product excess. Several literature indicate that under perfect competitive market, in the absence of trade barriers, transactions and transportation costs, and market power, exchange rate changes will be completely "pass through" to import and export prices and the adjustment will be uniformly allocated to domestic prices through the beef cattle supply chain (Feinberg 1986; Peltzman 2000; Meyer and Cramon-Taubadel 2004; Mann 2012). However, Schulz et al. (2017) and Grier (2005) found that farm level price and wholesale level price coordinate with one another in a different way from that under perfect competitive market when there are excess of live cattle and beef production in the domestic market. This effect could be amplified in the countries that have a high degree of trade dependence, i.e., Canada and U.S.

The evidence is also found that exchange rate movements are likely to induce asymmetric domestic price transmission and non-linear adjustment to any deviation from long-run relationship in Canadian beef cattle industry. The study by Grier (2005) suggested that the excess of fed cattle and cow in Canadian market caused by trade policy or exchange rate fluctuation could give Canadian beef packers the negotiating leverage resulting in a substantial decrease in Canadian fed cattle prices, which could be an indication of asymmetric price adjustment along the domestic supply chain. Schulz et al. (2017) noted that Canadian cattle producers and Canadian and U.S. beef packers closely monitor prices in both Canada and the U.S. to determine relative market opportunities. When fed cattle prices in Canada are higher relative to the U.S., Canadian cattle producers sell cattle to Canadian beef packers. Conversely, when the prices of fed cattle in Canada are lower relative to the U.S., Canadian cattle producers would choose to sell to U.S. beef packers. As a result, Canadian fed cattle producers have the choice to sell their cattle to domestic or U.S. beef packers depending on relative fed cattle prices. Moreover, the exchange rate is one of the most critical factors that influence the relative prices between two countries. CAD/USD exchange rate movements can induce the price changes of fed cattle or beef in Canada. As several studies indicate, given the close trade relationship between the Canadian and U.S. beef and cattle markets, the domestic price adjustment is not like that under perfect competitive markets. Therefore, it is a researchable question that exchange rate can induce asymmetric domestic price transmission.

The objective of this study is to investigate the threshold effect on asymmetric price transmission along the Canadian beef cattle supply chain, taking the CAD/USD exchange rate impact into account. This study achieves the objective by way of three steps. First, to test whether Canadian farm and wholesale prices are cointegrated, and to estimate the long-run relationship between two price series using the two-step Engle-Granger approach. Second, to test whether the farm to wholesale price linkage is affected by CAD/USD exchange rate; furthermore, if there is an effect, subsequently to test whether exchange rate can act as a threshold variable in Canadian farm to wholesale price transmission mechanisms by specifying the self-exciting threshold autoregressive (SETAR) model. Finally, to estimate short-run price adjustment patterns under different regimes by applying the threshold ECM.

The research question of the threshold effect of exchange rate on asymmetric price transmission along the domestic supply chain is motivated by the current literature. Sufficient literature investigates asymmetric price transmission using ECM (Goodwin and Holt 1999; Saha and Mitura 2008; Bailey and Brorsen 1989; Goetz and Cramon-Taubadel 2008; Miller and Hayenga 2001; Peltzman 2000; Meyer and Cramon-Taubadel 2004; Zapata and Gauthier 2003). Threshold ECM has been increasingly popular as an approach for analyzing asymmetric price transmission accounting for the possibility of nonlinear and threshold-type adjustment in price series (Awokuse and Wang 2009; Alam and Begum 2012; Greb et al. 2011; Goetz and Taubadel 2008; Goodwin and Holt 1999; Goodwin and Piggott 2001; Mann and Sephton 2016). The reason why we chose exchange rate as the regime-switching variable is twofold. First, exchange rate has been regarded as an important factor impacting trade flows especially on commodities that are heavily traded between two countries (Mutuc et al. 2011). Second, with prices closely linked to increasing trade, the relative importance of the exchange rate in the price transmission mechanism has been amplified (Mihaljek and Klau 2001). And the reasons why we think exchange rate can potentially induce a nonlinear price adjustment to any deviation from the long-run relationship are as follows. First, the domestic fed cattle excess caused by exchange rate fluctuation may offer negotiating leverage to beef packers and cause the decrease in price of fed cattle (Grier 2005). Second, Canadian fed cattle producers will monitor relative prices to determine whether to sell their cattle to domestic beef packers or to U.S. beef packers (Schulz et al. 2017). As Balke and Fombe (1997) noted, the presence of adjustment costs may prevent economic agents from adjusting prices continuously, only when the exchange rate movement exceeds a critical threshold do the benefits of adjustment outweigh the costs, and then economic agents respond to move towards the long-run equilibrium relationship between the two price series.

The contributions of this paper to the literature are twofold. The first contribution is the new application of threshold ECM approach. There are some important studies investigating asymmetric price transmission and the nonlinear price adjustments to restore the long-run equilibrium applying the method of threshold ECM in the oil and gasoline industry (Mann 2012 and Hammoudeh et al. 2008). Moreover, there is an increasing body of literature applying the threshold ECM model in the area of agriculture (Alam and Begum 2012, Goetz and Taubadel 2008; Goetz et al. 2016). However, to our best knowledge, this is the first study that builds threshold ECM to investigate the effect of exogenous variables on price transmission along the Canadian beef cattle supply chain. Second, this study fills a gap in the empirical price pass-through literature by investigating the threshold effect of an exogenous variable, in this case, the exchange rate, on the vertical price transmission mechanism specifically in a domestic supply chain setting, rather than that on spatial price pass-through mechanisms across regions. Most threshold error-correction literature focuses on issues of spatial transmission. Examples of this would be the degree of the exchange rate and world prices pass-through into domestic prices (Mutuc et al. 2011), or, the role exchange rates play in the asymmetric transmission of price shocks across regions (Alam and Begum 2012). There is adequate literature applying exchange rate in spatial price transmission analysis since exchange rate directly affects the price in term of the world currency. Even though the exchange rate is not commonly applied to the vertical price transmission studies, we argue that it is worthy to investigate the potential effects of trade-related variables on vertical price pass-through within the domestic supply chain.

The remainder of this chapter is organized as follows: Section 2.2. provides a brief literature review on the threshold ECM in the area of agricultural economics. Section 2.3 describes data. Section 2.4. sets up the conceptual framework of Canadian and the U.S. beef cattle supply chain to provide an overview of the mechanism of a trade-oriented variable affecting the domestic price pass-through pattern. Section 2.5 provides a broad overview of methodology literature and outlines the empirical methods utilized. Section 2.6 outlines the empirical procedures. Section 2.7 presents the empirical results and the discussions. While Section 2.8 puts forth concluding remarks.

2.2. Literature review

The error-correction model (ECM) is commonly used for investigating price transmission patterns in agriculture. Because the price is important in signaling the functioning of markets, price transmission analysis is increasingly recognized to help the better understanding of the efficiency of market coordination along supply chains. Studies on the price linkage between Canadian cattle producers and their beef packing clients has attracted increasing attention, especially after the Canadian beef cattle industry experienced extreme events (such as BSE) in recent decades. ECM can provide deep insight into business participants along the beef supply chain, particularly when suffering from fierce price volatilities and production uncertainties to different degrees.

The threshold ECM extends the standard form of error-correction by allowing for nonlinear adjustments of the price series to deviations from the long-run equilibrium. Threshold ECM has been used to investigate spatial integration for many different commodities (Alam and Begum 2012; Greb et al. 2011; Goetz and Taubadel 2008) and vertical price transmission across different levels of the supply chain (Goodwin and Holt 1999). This model is applied to determine whether pairs of price series, either spatially separated spot or various market levels, are tied together by a long-run relationship. Further, this model seeks to determine which of the series moves to restore the long-run relationship (Mann 2012). When we consider the potential threshold effect of the exchange rate, it is evident that threshold ECM can provide valuable insight on how the price adjustment patterns are different when the exchange rate change is above or below the threshold value.

Threshold ECM has been broadly studied in the area of agricultural economics. An analysis of cointegrated prices at different market levels describes the relationship of co-movement across the spectrum of different price series.

The vertical price transmission across various levels of the market is an important characteristic describing the overall operation of the market (Goodwin and Harper 2000). The analysis of vertically cointegrated price series often investigates the extent and speed of adjustment with which exogenous shocks pass through across the supply chain; this investigation can serve to reflect how efficient participants along the supply chain coordinates with one another (Goodwin and Holt 1999; Goodwin and Harper 2000; Mann 2016; Awokuse and Wang 2009; Hahn et al. 2016).

Analyses of spatially cointegrated prices, however, are often used to evaluate the trade policy implications (Götz et al. 2016; Myers and Jayne 2011) or the transportation costs (Meyer 2004; Alam and Begum 2012; Goetz and Taubadel 2008; Alam and Begum 2012) between two locations. Due to globalization and increasing interdependence between countries, more and more studies have been focusing on the effect of trade-oriented variables, i.e., exchange rate, trade flow (Mutuc, Pan and Hudson 2011; Molina et al. 2003). An example of this would be the study by Mutuc, Pan and Hudson (2011) which examines the effect of the exchange rate of

RMB to USD on price transmission of soybean, corn, wheat, and cotton from Chinese market to the U.S. market. In such instance, one would consider whether exchange rate can act as a threshold variable in the domestic price pass-through. This study reviewed literature specific to both the trade orientated variable, particularly exchange rate, and the threshold ECMs.

The literature on effect of exchange rate in relation to spatial price pass-through has predominantly focused on exporters' and importers' pricing behavior in response to four aspects: 1) currency shocks (Hosseini et al. 2012), 2) the effect of exchange rate shocks on commodity trade flows (Mutuc et al. 2011), 3) the potential regime switching behaviour of price pass-through resulted from of trade policies (Goetz et al. 2016), and 4) the role exchange rates or market power play in asymmetric pass-through of price shocks across different regions (Alam and Begum 2012).

The empirical evidence to date suggests that exchange rate shocks, and other trade-related factors, have the capacity to induce shifts in the direction and speed in which bilateral trade flow adjusts to exogenous market shocks. Huda (2014) analyzed how the exchange rate movements and global commodity market factors affect exogenous shocks transmission from international markets to the Bangladesh domestic market with respect to the commodity of rice. The results of this study suggested that price pass-through acts like "stabilizers" for rice, which means domestic prices move less volatile than international prices. Molina et al. (2013) analyzed the dynamic relationship between Thailand's export volume of rice and exchange rate volatility using a multivariate error-correction model. The conclusion was that real exchange rate volatility had a significant negative effect on Thai rice exports.

While other words concentrated on the effects of trade policies on domestic vertical price transmission patterns, the study by Goetz et al. (2016) focused on the spatial price transmission analysis of wheat in Ukraine to identify implications of export controls on domestic price pass-through. The model Goetz et al. (2016) used allowed for a smooth transition between free trade price transmission regime and those under export restriction regimes. The results showed that export restriction induced a change in price transmission patterns, which are caused by a change in the trader's pricing behavior.

Another aspect that plenty of literature addressed was on detecting asymmetry of price shock transmission across different regions caused by transaction cost or market power (Goodwin and Holt 1999; Saha and Mitura 2008). Saha and Mitura (2008) analyzed different effects of BSE on the various market levels of the Canadian beef industry. Their study showed that market factors and exogenous shocks might influence the prices for agri-food products along the supply chain. Both market power and adjustment costs at retail and processing levels can lead to asymmetric price adjustments at different market levels.

Adequate literature examined the effect of exchange rate on domestic commodity prices. Schulz et al. (2011) found that during the border-open period, relative prices between Canadian and U.S. beef cattle products could have exerted a significant effect on where the cattle are slaughtered. They further found that the resultant effects of this dynamics could further influence Canadian vertical price transmission patterns. A researchable question would be around how exactly movements in exchange rates make the business participants, at different levels along the supply chain, respond differently to price deviations. This study aims at investigating the threshold effect of exchange rate on the domestic price transmission across farm level and wholesale level of Canadian beef cattle supply chain.

2.3. Data

This chapter employs four data series: (1) weekly Canadian fed cattle prices at farm level, (2) weekly Canadian beef prices at wholesale level, (3) weekly CAD/USD exchange rates, as well as (4) weekly Canadian cattle export from January 2001 to September 2014 (with a total of 715 weekly observations). Weekly Alberta Fed steers price and AAA boxed beef price are used to represent the farm level live cattle price and the wholesale level beef price, respectively; and are obtained from Canfax (2001-2014). Prices are in dollar[1] per hundredweight and are transformed into logarithms. All price series are deflated to real levels using the Consumer Price Index (CPI) from 2001 to 2014 (2012 price as the base) to remove the impacts of inflation. The data on CPI are obtained from Statistics Canada (2016). The exchange rate data comes from Global Financial Data (2016). The data on Canadian cattle export to the U.S. is derived from the USDA (2016), prepared by AAFC/ Market Information section. The dataset provides the amount of cattle export to the U.S. including feeder cattle, breeding cattle, other cattle (dairy), slaughter cattle (dead animal) and total cattle. In May 2003, the largest importer of Canadian cattle, the U.S, imposed a complete ban on imports of live cattle and beef from Canada. The border re-opened in July 2005. To examine exchange rate effects during non-BSE periods, this study separates the available price data series (2001-2014) into three parts: a pre-

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[1] Dollars ($s) are assumed to be Canadian dollars, unless otherwise stated

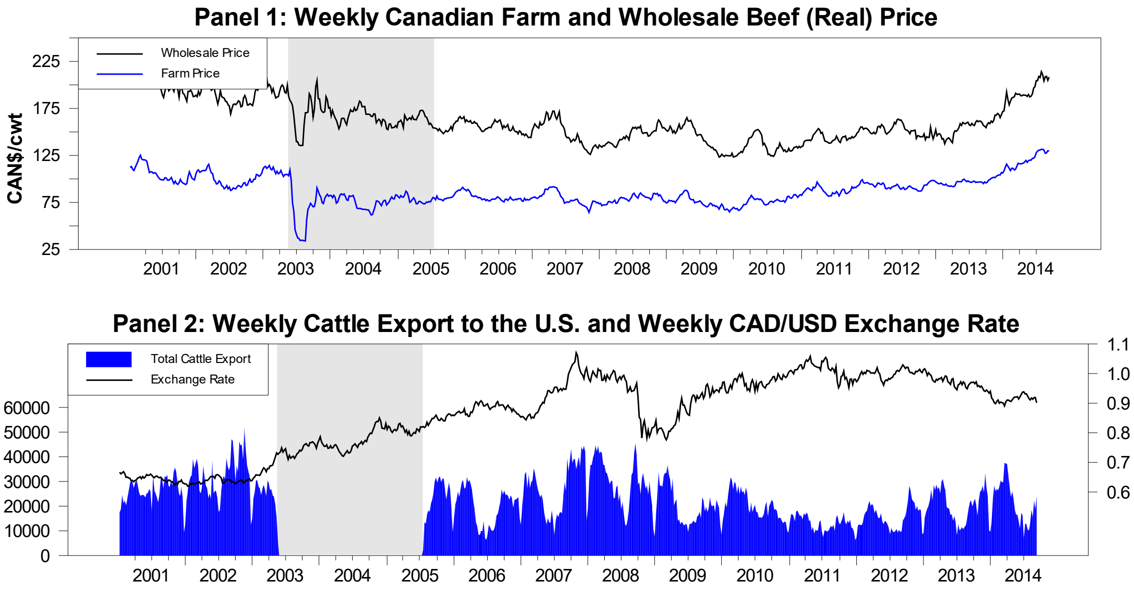
BSE period (January 2001-May 2003), a border closure period (May 2003-July 2005), and a post-BSE period (July 2005-September 2014).

Table 1. Summary Statistics for Real Prices, Exchange rate, Cattle Export and Cattle Slaughtered

Price	Mean	Std. Dev.	Skew	Min	Max
Before Border Closure (January 05, 2001 - May 20, 2003), N=125					
Wholesale price (Real)	196.46	17.59	4.13	169.19	333.79
Farm price (Real)	103.52	9.78	1.60	87.73	159.10
Log Wholesale Price	5.28	0.08	2.76	5.13	5.81
Log Farm Price	4.64	0.09	0.94	4.47	5.07
Exchange rate	0.65	0.02	1.85	0.62	0.73
Total Cattle Export to U.S.	28390.86	7676.91	0.19	6194.00	51746.00
During Border Closure (May 31, 2003 - July 16, 2005), N=114					
Wholesale price (Real)	166.39	12.00	-0.01	135.57	204.41
Farm price (Real)	73.94	13.14	-1.45	34.07	109.35
Log Wholesale Price	5.11	0.07	-0.36	4.91	5.32
Log Farm Price	4.28	0.22	-2.27	3.53	4.70
Exchange rate	0.77	0.04	0.24	0.71	0.85
Total Cattle Export to U.S.	74.06	615.39	9.26	0.00	6194.00
After Border Re-opened (July 18, 2005 - September 12, 2014), N=479					
Wholesale price (Real)	151.49	16.65	1.21	123.19	213.99
Farm price (Real)	86.26	13.13	1.35	64.46	131.49
Log Wholesale Price	5.02	0.11	0.77	4.81	5.37
Log Farm Price	4.45	0.14	0.92	4.17	4.88
Exchange rate	0.94	0.06	-0.50	0.78	1.07
Total Cattle Export to U.S.	20916.15	8638.55	0.60	2248.00	45469.00

Table 1 presents the summary statistics of farm and wholesale prices, exchange rate, and total cattle export to the U.S. in three time periods. Though the mean value of real wholesale price and farm price of cattle after border re-opened, was lower than that before border closure, the CAD to USD exchange rate has progressively increased from $0.684 to $0.94 over the three time-periods. The weekly quantity of slaughtered cattle exported to the U.S. declined from 20,215 heads before border closure to about 14,425 head after border re-opened. As for exports to the U.S., the number of feeder cattle increased but the number of breeding cattle dropped when we compare over two time periods. The total cattle export to the U.S. declined from 28,304 heads before border closure to 20,916 heads after border re-opened. An analysis of the total number of cattle slaughtered domestically in Canada we see a decline as well, such drop indicates that the beef cattle industry shrank a bit, both before and after the border closure, due to the BSE.

Figure 1. Weekly Canadian Farm and Wholesale Beef (Real) Price, Cattle Export to the U.S. and Weekly CAD/USD Exchange Rate



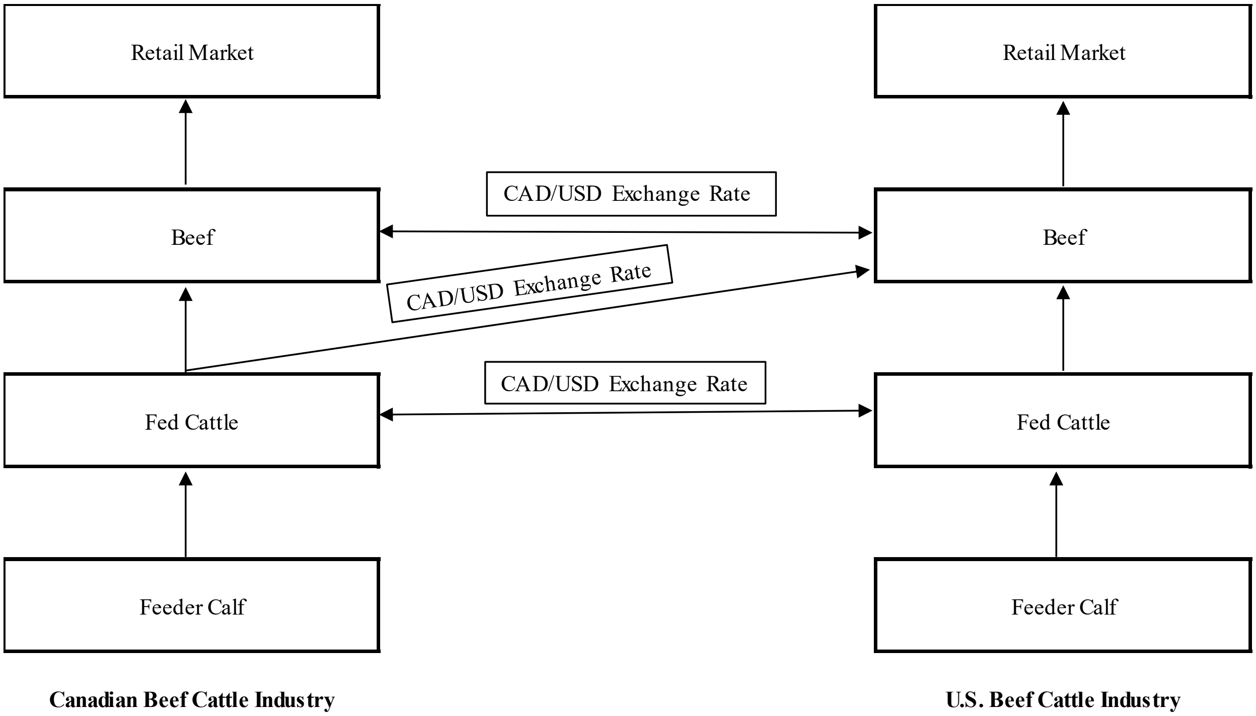
The four data series are presented in Figure 1. In the long run, the farm level and the wholesale level price series generally exhibit a co-movement trend. An exception would have been in the year 2003, which reports a sharp decrease of farm prices but a gentler decline of wholesale prices. From 2004 to 2010, the two price-series seems to keep relatively stable, and the gap between farm and wholesale level prices was consistent as well. From 2010 to 2014, both farm price and wholesale price series exhibited an uprising trend with an 85.95% and 69.30% increase respectively.

The U.S. government mandated country of origin labeling (COOL) in March 2009. This policy has been viewed as having negative effects on the Canadian live cattle exports to the U.S. (Twine et al. 2016). The data series analyzed in this study covers the COOL period. However, the cointegration model employed in this chapter cannot capture the influence of policy variables on the price transmission and the relationship between the Canadian and U.S. beef markets. Therefore, this study does not specifically incorporate the impacts of COOL on U.S.-Canada trade relationship into the empirical model.

2.4. Conceptual framework

This section outlines the general relationship between different markets levels along the Canadian beef cattle supply chain and the trade dependence between the Canadian and U.S. beef cattle industries at each market level. Canadian and the U.S. cattle and beef industries have a significant impact on their national economy and play a significant role in the agriculture of both countries (Athwal 2002; Zhen, Rude and Qiu 2017). The implementation of the trade policies [i.e., the Canada-U.S. Free Trade Agreement (CUSTA) 1989 and the North American Free Trade Agreement (NAFTA) 1992] resulted in the high integration of the Canadian and U.S. beef cattle markets into a single market with the supply and demand determining a single price (Athwal 2002). The U.S. produces almost ten times as much live cattle and beef than Canada and is less dependent on trade. The U.S. imports and exports are less than 10% of its production, Canada, on the other hand, trades a quarter of the amount it produces. As a result, Canada is more dependent on trade, especially with U.S. and Canadian price structure is dominated by the U.S. market conditions. (Fairbairn and Gustafson 2005; Athwal 2002; Schulz, Schroeder and Clement 2011). On top of these facts, this study seeks to investigate the effect of a trade-oriented variable, in this case, the CAD/USD exchange rate, on the domestic farm to wholesale level price transmission. This investigation can provide insight into the impacts of exchange rate on the U.S. market availability to the Canadian fed cattle; further, the impacts of U.S. market availability to Canadian fed cattle on the relative bargaining power between the Canadian fed cattle producers and beef packers.

Figure 2. Flow Chart of Fed Cattle and Beef Products along Domestic Supply Chain and Trade with the U.S.



Note: Arrows indicate the direction of the flow of fed cattle and beef products; double arrows denote bi-directional trade flows.

Figure 2 shows the dynamics of flow of fed cattle and beef products along the Canadian domestic supply chain and the trade between the Canadian and U.S. beef cattle markets. The Canadian fed cattle producers can choose to sell their fed cattle to either domestic beef packers or the U.S. beef packers depending on the market conditions and trade policy.

For the trade of the fed cattle sector (farm level), Canada expanded its size and output dramatically over the past two decades and became more dependent on its export markets. The U.S. has been the largest market for Canadian beef and cattle. Prior to the BSE crisis, over 70% of beef and almost all cattle exports went to the U.S. (Miljkovic 2009; Athwal 2002; Twine et al. 2016).

The exchange rate is one of the most critical factors Canadian beef cattle producers consider when making decisions on whether to sell their product to the domestic buyers or the U.S. buyers. Knowing how the CAD/USD exchange rate affect the trade dependence between Canadian fed cattle farmers and U.S. beef packers and further affect the Canadian domestic price transmission is essential to Canadian fed cattle producers when negotiating and discovering fed cattle sale prices and in making decision about whether sell cattle to U.S. beef packers (Schulz, Schroeder and Clement 2011).

2.5. Literature review on methodology

This section outlines the methodology used to investigate the vertical price pass-through between the farm level and wholesale level in the Canadian cattle market. The methodology incorporates the threshold cointegration analysis and threshold ECM to test if the farm-to-wholesale price series keeps a long-run relationship, and to estimate the magnitude and direction of any adjustments to any deviation from the long-run relationship in the above- and below-threshold regimes. The purpose of this section is to provide a broad overview of how the threshold ECM evolved; to review the methods needed to test for cointegration and threshold effect, and to set up steps for building threshold ECM using Canadian beef prices at the farm and wholesale levels.

2.5.1. Cointegration and threshold cointegration

The concept of cointegration was proposed by Granger (1983), and Engle and Granger (1987). Price series are said to be cointegrated pairwise if they exhibit a long-run equilibrium. Even though two series do not necessarily move in parallel each time, they generally do not move too far away from each other. The two-step Engel-Granger method first estimates the long-run relationship, and then test unit root in the residuals. The result is what indicates whether the two price series are cointegrated. Results as well show the long-run relationship if they are cointegrated.

Lots of studies investigate whether the adjustment to deviation from the long-run equilibrium is linear or not. It is assumed in the neo-classical economics that the market is perfectly competitive, which implies that the speed at which cointegrated series move toward their long-run equilibrium relationship is linear and symmetry for increasing and decreasing price (Peltzman 2000; Meyer and Cramon-Taubadel 2004; Mann 2012). However, the prevalence of nonlinear (i.e., asymmetric and threshold effect, etc.) price transmission in real world economic has attracted increasing attention in recent decades (Bailey and Brorsen 1989; Goetz and Cramon-Taubadel 2008; Kinnucan and Forker 1987; Miller and Hayenga 2001; Peri and Baldi 2010; Peltzman 2000; Meyer and Cramon-Taubadel 2004; Zapata and Gauthier 2003). This nonlinear price adjustment could be a signal of a different distribution of welfare than would obtain under symmetry and could be further associated with net welfare losses (Meyer and Cramon-taubadel 2004). From perspective of methodology, under the assumption of perfect competitiveness, in the standard form of ECM, time series adjusts to departure from long-run equilibrium linearly. The nonlinearity specification of any adjustment is found to be a more realistic representation of data generation process. Some time series variables exhibit nonlinear behavior, such as asymmetric price transmission for increasing or decreasing prices (Goodwin and Holt 1999; Saha and Mitura 2008; Saha and Mitura 2008) and threshold effects (Awokuse and Wang 2009; Meyer 2004; Goodwin and Piggott 2001; Mann 2016).

The threshold autoregressive (TAR) is one of the nonlinear time-series models introduced by Tong (1983), and Tong and Lim (2009); it is discussed extensively by Tong (2012). Since being brought in, the TAR model has been regularly adopted in agricultural economics literature (Zapata and Gauthier 2003). The original motivation of the TAR model was chiefly concerned with limit cycles of a cyclical time series; indeed, the model is capable of producing asymmetric limit cycles (Tsay 1989). As Tsay noted in 1989, the most important aspects of the TAR model are (a) searching of suitable modeling procedures and (b) determining the threshold variable, threshold values, and, as added by Mann (2012), the number of thresholds.

The concept of "threshold" was first introduced by Howell Tong (1978) to account for nonlinear adjustments of time series variables with respect to the deviation from the long-run equilibrium (Tong and Lim 2009; Tong 2012; Hansen 2011; Mann 2012). Based on the foundation laid by Tong (2012), Balke and Fomby (1997), a method known as the "Engle-Granger" method became widely utilized for testing and estimating cointegration by partitioning the lagged long-run residuals ($\widehat{e_{t-1}}$) using an indicator function (I_t). Following this generalization of Engle-Granger model, Enders and Siklos (2001) generalized the Engle and Granger test for cointegration to allow for nonlinear adjustments; this gave rise to the popular threshold cointegration test known as the threshold autoregressive (TAR) test. For the reason that the most basic form of the TAR test allows for only one threshold, hence two regimes, the null hypothesis for the TAR test is no cointegration.

Balke and Fomby (1997) developed the methods of testing the linearity and cointegration of the time series variables. The threshold cointegration was introduced by Balke and Fomby (1997) as a feasible means to combine non-linearity and cointegration. In particular, the model allows for non-linear adjustments to the long-run equilibrium. Due to the complexity of parametrically characterizing stationarity for the threshold model, these researchers conducted a two-step method to test cointegration and linearity behavior separately. Besides merely testing, Balke and Fomby (1997) presented a model in which the cointegrating relationship between variables turns on and off. The on and off behavior is modeled as the threshold model in which the series are cointegrated if they move too far away from the equilibrium relationship, but are not cointegrated as long as they are relatively close to the equilibrium. Balke and Fomby (1997) pointed out that the nonlinear adjustment method could be used in many economic phenomena including the behavior of inventories, money balances, consumer durable, prices, employment, and policy intervention. Similar threshold analysis can also be applied to the spatial market integration; in this case, due to the transaction costs, threshold behavior may play a role that leads to the equilibrium in spatially separated markets.

Enders and Siklos (2001) introduced and developed an explicit test for cointegration with asymmetric error-correction. In particular, they generalized the Enders and Granger (1998) threshold autoregressive (TAR) model for unit roots to multivariate test. The basic form of the TAR model developed by Tong (2012) allowed the degree of autoregressive decay to depend on the state of the variable of interest.

When we estimate threshold ECM, the location and number of thresholds are seldom known beforehand in life. This model, however, has attracted extensive attention towards developing methods to detect the location of thresholds by various researchers including Tsay (1989), Chan (1993), Hansen (1999), Gonzalo and Pitarakis (2002), Strikholm and Terasvirta (2006), Chen, Chong, and Bai (2012).

In this study, we apply a two-regime threshold ECM proposed by Enders and Granger (1998) and Enders and Siklos (2001). The two-regime ECM has been applied to several studies investigating asymmetric price adjustment in agricultural markets (Meyer and Cramon-Taubadel 2004; Awokuse and Wang 2009; Abdulai 2002). Other studies also estimate the multiple-threshold model, especially two thresholds to form three regimes, to analyze asymmetric price adjustment with the presence of adjustment cost or market power (Goodwin and Holt 1999; Mann and Sephton 2016; Mann 2016).

2.5.2. Estimation of the threshold value

Tsay (1989) developed a simple method of testing for threshold nonlinearity and for building the TAR model by using linear regression techniques combined with scatterplots of several statistics versus the threshold indicator variable to determine the location of thresholds and number of thresholds. It is assumed in Tsay's (1989) method that each sample point can possibly be the threshold. This method can help in determining the location of thresholds (τ) and the number of thresholds by computing the recursive least squares estimates based on an arranged autoregression which is ordered based on the magnitude of the threshold indicator (Tsay 1989; Mann 2012). After conducting a threshold test developed by Hansen (1996), with several delays in both the direct and reverse direction, the expected results are that the price difference should be stationary in the two tails and nonstationary in the middle portion; in this study we will use the standard Dickey-Fuller ("D-F") test on price difference (Tsay 1989).

Chan (1993) proposed a way to obtain a super-consistent estimate of the threshold τ for the case where the threshold is unknown. Chan's method determines the threshold value as that which has the smallest sum of squared residual for the fitted model across all possible threshold values (Mann 2012; Enders 2008). In practice, the threshold values are searched within the middle 80 or 70 % of the possible threshold values by excluding the largest and smallest 10 or 15% of the possible threshold values, respectively (Mann 2012; Enders 2008). In our study, the largest and smallest 15% of potential threshold values are discarded. The sum of squared residual (SSR) from the TAR model is considered as a function of the particular threshold used in the estimation. By assuming any value of point in the 70% mark of the all observations can be thresholds, we can estimate the TAR model using each potential threshold value and use the acquired the sum of squared residuals; from there we can then create a scatter plot of the sum of squared residuals against the potential threshold values. The closer we get to the true value of the threshold τ, the smaller the SSR should be. As SSR should be minimized at the true value of the threshold. The SSR will have several local minima if there are more than one thresholds (Enders 2008).

The focus of the method by Hansen (1999) is to determine the number of thresholds rather than the threshold values. The methodology used by Hansen (1999) combined the linear regression technique and a sequential testing approach. The null hypothesis of the sequential testing approach is the linear model; namely, the number of thresholds is zero, against a single threshold model. This testing process continues until one fails to reject the null hypothesis. The critical values are obtained from a bootstrapping procedure developed by Hansen (1997). Overall, the method attributed to Hansen (1999) is more precise than that of Tsay's (1989). This bootstrap procedure (Hansen 1999) is built into several programming packages of software Regression Analysis of Time Series (RATS). The threshold test program applied in this study is developed from the generalization of those packages.

2.5.3. Estimate of threshold error-correction model

With the threshold value estimated from last step, we can build the two-regime error-correction model proposed by Engle-Granger (1987). The coefficients of the threshold ECM show how price series adjust to the departure from the long-run equilibrium in each regime.

2.6. Empirical procedures

The empirical analysis applied in this study is a 3-step procedure. First, cointegration of farm and wholesale prices are tested, and the long-run relationship between two price series is estimated by the Engle-Granger approach. Second, the threshold effect of the exchange rate is tested, and the threshold value is estimated, specifically with the self-exciting threshold autoregressive (SETAR) model. Finally, the two-regime threshold (ECM) is estimated to investigate the direction and speed of price adjustments to price deviations from the long-run relationships.

2.6.1. Long-run price relationship

Before applying the Engle-Granger methodology for testing cointegration, we must first pretest the farm and wholesale prices to determine their order of integration. This initial step is necessary because the definition of cointegrated indicates that two I(d) series are cointegrated if they are tied together by a long-run relationship where e_t is I(d-1). If the series are determined not to be integrated by the same order, then, by definition, they are not cointegrated, and thus there is no need to estimate a TAR model (Mann 2012). Conversely, if the series were found to be integrated of the same order, the next step would be to estimate the cointegrating regression found in equation (2.1) (Mann 2012). Further to this, the unit-root test on residual is performed to determine the order of integration of the established two price series. Given the assurance of residual sequence is stationary, we can conclude that farm and wholesale price series are cointegrated. The long-run relationship between farm and wholesale prices is then estimated using a simple ordinary least squares (OLS) regression.

The resultant significant change in trade flow, due to the BSE, is likely to have an impact on long-term relationship between farm and wholesale prices overall. In order to differentiate the Canadian-U.S. border closure and border open periods, the long-run relationship is estimated herein in three time periods: 1) before BSE (May 20th, 2003), 2) during U.S. border closure (May 20, 2003 – July 18th, 2005), and after BSE. In each period, the long-run relationship between farm and wholesale prices can be specified as:

$$p_t^w = \alpha + \beta\, p_t^f + e_t \tag{2.1}$$

where p_t^j represents the logged price at market level j; α is constant; and β can be interpreted as the transmission elasticity since all prices are transformed to logarithm form. The saved residuals $\widehat{e_{t-1}} = p_{t-1}^w - \beta\, p_{t-1}^f$ from the equilibrium regression is called an error-correction term and can be used to estimate the error-correction model (ECM).

2.6.2. Test the existence of threshold effect and estimate of the threshold value

In the two-regime ECM, prices make different adjustments to the deviation from the long-run equilibrium when the regime-inducing variable is above and below the threshold value. We will use the exchange rate as the regime-switching variable (or threshold-indicating variable). The intuition behind this is, as previously mentioned, the exchange rate is potential to induce asymmetric price transmission and nonlinear price adjustments to any deviation from long-run equilibrium. Furthermore, the presence of adjustment costs may prevent economic agents from adjusting prices continuously. Only when the exchange rate movement exceeds a critical threshold, do the benefits of adjustment outweigh the costs, and then economic agents respond to move towards the long-run equilibrium (Balke and Fombe 1997). Such usage indicates how prices adjust to the deviation depends on the value of the exchange rate from a previous period; namely, when the exchange rate falls into a different regime, the price series adjusts to any deviation from the last period in a different way.

The threshold test developed by Hansen (1996) is applied to test whether the exchange rate exhibits the threshold effect on the price transmission from farm level to wholesale level. Hansen's method not only tests the threshold behavior of a variable but also selects the lag length of the threshold indicator variable.

When we combine the linear regression on TAR model with scatterplots of statistics (sum of squared residuals versus the threshold indicator variable), we can determine the location of thresholds (Chan 1993). The self-exciting threshold autoregressive (SETAR) model is a convenient way to specify a TAR model because the threshold variable (in this case, exchange rate) is defined simply as the dependent variable (Zapata and Gauthier 2003 and Enders 2008). The two-regime SETAR model can be written in the form of equation (2.2):

$$E_t = I_t\,(\alpha_0 + \alpha_1 E_{t-1} + \alpha_2 E_{t-2} + \alpha_3 E_{t-3}) + (1 - I_t)(\beta_0 + \beta_1 E_{t-1} + \beta_2 E_{t-2} + \beta_3 E_{t-3}) + \varepsilon_t \qquad (2.2)$$

where

I_t is the Heaviside indicator function represented by

$$I_t = \begin{cases} 1 \ \ if\ E_{t-1} \geq \tau \\ 0\ if\ E_{t-1} < \tau \end{cases}$$

In this equation, E_{t-1} is the exchange rate (close) in the period (t-1), which is the threshold indicator variable; I_t is Heaviside indicator function; the Heaviside indicator function is based on the level value of the threshold indicator variable; τ is threshold value; α_1, α_2 and α_3 measure the effect of the exchange rate from the last three periods: t-1, t-2 and t-3, while $\mathrm{E}_{\mathrm{t-1}}^{1} \geq \tau$; β_1, β_2 and β_3 measure the effect of the exchange rate from the last three periods when $\mathrm{E}_{\mathrm{t-1}}^{1} < \tau$.

Applying the approach developed by Chan (1993) to estimate the TAR model, we need to first order the observations from smallest to largest; for each value of exchange rate, set τ equals potential threshold value of exchange rate. After having done so, we then need to estimate a TAR model. The regression equation with the smallest residual sum of squares generates the real threshold value. The highest and lowest 15% of the exchange rate values are excluded from the grid search in order to ensure there are adequate observations on each side of the threshold.

2.6.3. Short-run price adjustments in different regimes

Given the two series are cointegrated as Equation (2.1) specified, we can proceed to estimate an error-correction model using the saved residuals $\widehat{e_{t-1}}$ from the estimation of the long-run equilibrium relationship in (2.1) and the exchange rate from the period (*t-1*). The error-correction model with no regime switching effect is written in the form of equation (2.3):

$$\Delta p_t^w = \gamma_{10} + \gamma_{11} E_{t-1} + \gamma_{12}\widehat{e_{t-1}} + \sum_{i=1} \delta_{11}(i)\Delta p_{t-i}^w + \sum_{i=1} \delta_{12}(i)\Delta p_{t-i}^f + e_{wt} \tag{2.3}$$

$$\Delta p_t^f = \gamma_{20} + \gamma_{21} E_{t-1} + \gamma_{22}\widehat{e_{t-1}} + \sum_{i=1} \delta_{21}(i)\Delta p_{t-i}^w + \sum_{i=1} \delta_{22}(i)\Delta p_{t-i}^f + e_{ft}$$

In the equations, p_t^w and p_t^f are the dependent variable from the cointegration regression, E_{t-1} is the exchange rate in the period (t-1), $\widehat{e_{t-1}}$ is the error-correction term. While γ_w and γ_f are the speed-of-adjustment coefficients. The absolute value of the error-correction term represents a deviation from the long-run equilibrium in period (t-1), the speed-of-adjustment coefficients indicate the direction and speed at which the prices adjust when there is a deviation from the long-run relationship. If either γ_w or γ_f are not significantly different from zero the variable p_t^w or p_t^f respectively, is weakly exogenous and does not make an adjustment when there is a deviation from the long-run relationship (Mann 2012).

The two-regime threshold error-correction model is specified as follows.

$$\mathit{\Delta} p_t^w = I_t\left(\alpha_{10} + \alpha_{11}\, E_{t-1} + \alpha_{12}\, \widehat{e_{t-1}} + \sum_{i=1} \delta_{11}^{(1)}\,(i)\, \mathit{\Delta} p_{t-i}^w + \sum_{i=1} \delta_{12}^{(1)}(i) \mathit{\Delta} p_{t-i}^f \right) +$$

$$(1 - I_t) * \left(\beta_{10} + \beta_{11} E_{t-1} + \beta_{12}\, \widehat{e_{t-1}} + \sum_{i=1} \delta_{11}^{(2)}\,(i)\, \mathit{\Delta} p_{t-i}^w + \sum_{i=1} \delta_{12}^{(2)}(i) \mathit{\Delta} p_{t-i}^f \right) + e_{wt} \qquad (2.4)$$

$$\mathit{\Delta} p_t^f = I_t\left(\alpha_{20} + \alpha_{21}\, E_{t-1} + \alpha_{22}\, \widehat{e_{t-1}} + \sum_{i=1} \delta_{21}^{(1)}\,(i)\, \mathit{\Delta} p_{t-i}^w + \sum_{i=1} \delta_{22}^{(1)}(i) \mathit{\Delta} p_{t-i}^f \right) +$$

$$(1 - I_t) * \left(\beta_{20} + \beta_{21}\, E_{t-1} + \beta_{22}\, \widehat{e_{t-1}} + \textstyle\sum_{i=1} \delta_{21}^{(2)}\,(i)\, \mathit{\Delta} p_{t-i}^w + \sum_{i=1} \delta_{22}^{(2)}(i) \mathit{\Delta} p_{t-i}^f + \right) + e_{ft}$$

where

$$TAR\colon\ I_t = \begin{cases} 1 \;\; if\ E_{t-1} \geq \tau \\ 0\ if\ E_{t-1} < \tau \end{cases}$$

In equation (2.4), the farm and wholesale prices make adjustments to price deviation, and the exchange rate from last period is shown differently in two regimes. With threshold value τ estimated in SETAR model, two regimes are generated, above and below τ. The adjustment coefficients in any regime of exchange rate above the threshold value are different from those in the other regime.

2.7. Empirical results and discussions

This section discusses the results of the three empirical procedures. First, the estimated results of the long-run relationship between farm prices and wholesale prices in three itemized time periods (before BSE, during the U.S. border closure, and post-BSE) after testing the two price-series are cointegrated. Second, there is a presentation of the results of both the threshold test and the estimation of the SETAR model specifying the value of exchange rate threshold. Third, there is an estimation of results pertinent to the two-regime threshold error-correction model incorporating the threshold value from the SETAR model.

2.7.1. Long-run price equilibrium

Residual-based unit root tests are performed on logged prices at both the farm and wholesale levels; these are noted in the former equation as *I(1)*. The analysis proving that farm and wholesale price series are cointegrated in the three itemized periods indicates that there exists a long-run relationship between farm and wholesale prices. The estimate results of the long-run equilibrium relationship are shown in Table 2.

All coefficient estimates are statistically significant at 1%. As expected, the magnitude of price transmission coefficient during the border closure period was smaller than that in the other two periods.

Table 2. Results of Long-run Relationship

	Farm-Wholesale Model	
Dependent Variable	Wholesale Price	
	Coefficient	Std. Error
	Before Border Closure on May 20th, 2003	
Constant	1.937***	0.465
Farm Prices	0.721***	0.101
	During Border Closure from May 20th, 2003 to July 18th, 2005	
Constant	4.369***	0.152
Farm Prices	0.173***	0.035
	After Border Re-opened on July 18th, 2005	
Constant	2.360***	0.081
Farm Prices	0.597***	0.018

Note: Coefficients are significant at $\alpha = 0.01$, 0.05 and 0.10 denoted by *, ** and ***, respectively.

During border closure period, the transmission elasticity was 0.173, meaning that a 1% decline in the farm level price, on average, can lead to 0.173% drop in wholesale price. By contrast, transmission elasticities during border open periods are much larger, which are 0.721 and 0.597 in pre- and post- BSE period respectively; this suggests that a 1% decrease in the farm level price can induce a respective 0.721% and 0.597% drop in wholesale prices over two periods. The transmission elasticity for the post-BSE period is much lower than that of the pre-BSE period. A possible explanation lies in the effect of the BSE crisis on the Canadian beef cattle sector regarding both a sustained negative impact on the farm level prices and structural breaks in Canada-U.S. feeder and fed cattle trade (Saha and Mitura 2008; Twine et al. 2016). In such environment, powerful Canadian beef processors are less likely to adjust to the decreasing input prices, which leads to an overall lower transmission elasticity estimate for the post-BSE period.

The finding of a lower transmission elasticity during the border closure period can be explained by the increase in domestic cattle supply caused by the U.S. import ban on Canadian beef cattle, which was the main driver behind the decrease in beef cattle prices (Saha and Mitura 2008; Athwal 2002). The excess of live cattle production may have given additional bargaining power to Canadian beef packers, making them are less likely to respond to farm-level price movements.

2.7.2. Test of the threshold effect and estimate of the threshold value (results for SETAR specification)

The threshold test developed by Hansen (1996) was performed on the exchange rate. The results from this test were twofold: 1) threshold effects of exchange rate on domestic vertical price transmission was detected; and 2) the lag length of the threshold variable was selected. Proven was that in the periods before and after BSE crisis, the exchange rate exhibited a threshold behavior on the price transmission pattern from the farm level to the wholesale level of the beef cattle markets. As expected, the exchange rate did not exhibit any threshold effect during the U.S. border closure period.

By combining the SETAR model and Chan's (1993) approach, we first ran the regression of SETAR model repetitively using each exchange rate value as the potential threshold variable; then we compared the sum of squared residuals (SSR) of the equation. The regression that produced the smallest SSR generated the real threshold (τ) of exchange rate value. The scatter plot of the sum of squared residual against the potential threshold value, found in figures 3 and 4 visually shows the mechanism of searching for the threshold value.

Figure 3. Threshold Values versus Sum of Squared Residuals (Before BSE Crisis)

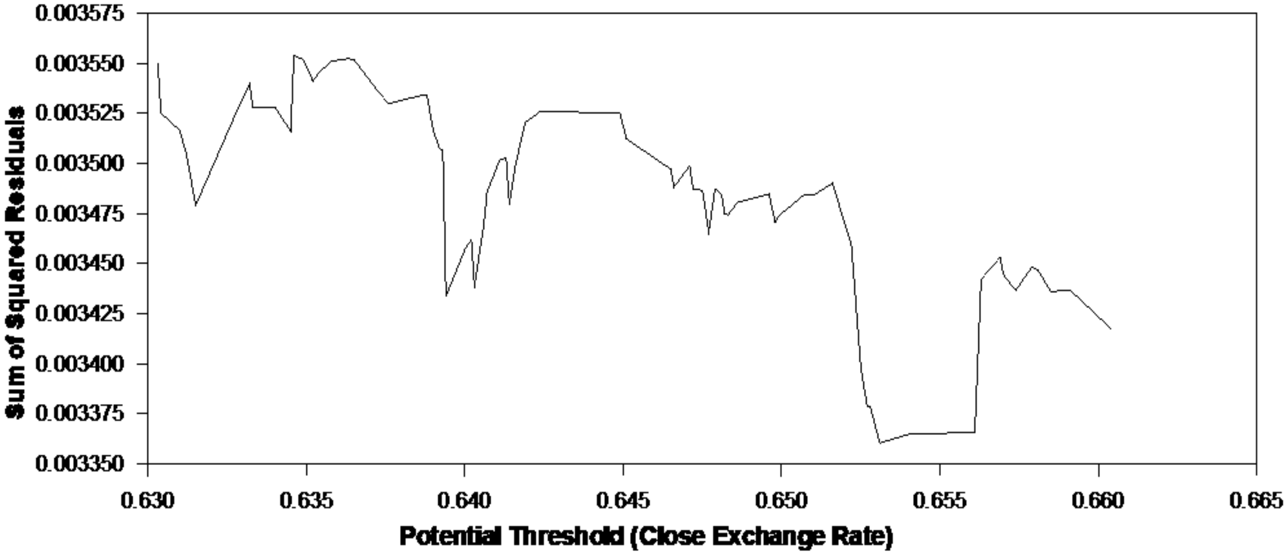
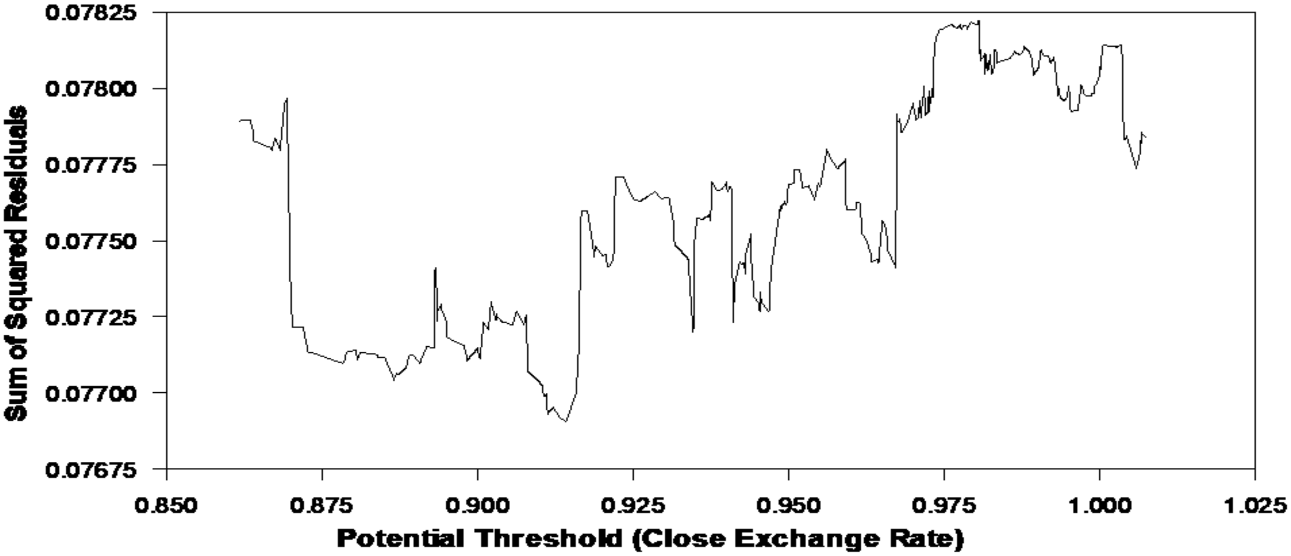


Figure 4. Threshold Values versus Sum of Squared Residuals (After BSE Crisis)



As shown in Figure 3 and Figure 4, the lowest point in the scatter plots indicates the value of exchange rate that produces the smallest SSR. With the aid of the programming package of software: Regression analysis of Time Series (RATS), there is no need to estimate the equation hundreds of times using each exchange rate value as a potential threshold, for the estimations are embedded in the "Do-End loop". It is estimated that the real threshold value of exchange rate were 0.6531 and 0.9142 respectively for the periods before and after the BSE crisis. The existence of the threshold effect and the estimation of the threshold value indicates that farm and wholesale level prices adjust to the deviation from last period in different patterns depending on whether the exchange rate is above or below the threshold value. After finding the real threshold value, we can incorporate it into SETAR model; coefficient estimates are presented in Table 3. The threshold value of exchange rate for before and after BSE are very different, the reason behind that is the appreciation of currency over time. The results are meaningful because they are consistent in the two periods.

Table 3. Results of SETAR Model

Dependent Variable	Exchange Rate			
	Coefficient	Standard Error	Coefficient	Standard Error
	Before Border Closure in May 2004		After Border Re-opened in July 2005	
	Regime 1: Exchange rate > Threshold Value			
Constant	-0.056	0.049	0.049**	0.021
E_{t-1}	1.206***	0.168	1.034***	0.055
E_{t-2}	-0.132	0.214	-0.230***	0.081
E_{t-3}	0.009	0.008	0.147***	0.058
	Regime 2: Exchange rate < Threshold Value			
Constant	0.068	0.045	0.042	0.027
E_{t-1}	0.897***	0.116	0.882***	0.082
E_{t-2}	0.110	0.161	0.074	0.085
E_{t-3}	-0.113	0.117	-0.002	0.015
Threshold Value	0.6531		0.9142	

NOTE: Coefficients are significant at α = 0.01, 0.05 and 0.10 denoted by *, ** and ***, respectively.

2.7.3. Results for two-regime threshold error-correction model

Incorporating threshold value into the error-correction model for two periods, before and after BSE, two-regime threshold ECM are specified. With two different threshold values obtained from SETAR model, threshold ECM is estimated differently in the two periods. The estimation results are shown in Table 4.

Table 4. Error-Correction Model Estimates of Farm-Wholesale Model

Var.	Δp_t^w		Δp_t^f		Δp_t^w		Δp_t^f	
	Before Border Closure in May 2003				**After Border Re-opened in July 200the**			
	Estimates	S.D.	Estimates	S.D.	Estimates	S.D.	Estimates	S.D.
	Regime 1: Exchange rate > Threshold Value							
Constant	0.162	0.148	-0.013	0.160	0.055*	0.032	0.045	0.034
E_{t-1}	-0.249	0.219	0.008	0.238	-0.059*	0.033	-0.046	0.035
e_{t-1}	-0.262**	0.119	0.007	0.129	-0.089***	0.024	-0.040	0.025
Δp_{t-1}^w	-0.077	0.153	-0.184	0.166	0.038	0.057	0.181***	0.06
Δp_{t-2}^w	-0.300**	0.145	-0.178	0.157	-0.022	0.057	0.098*	0.06
Δp_{t-3}^w	0.248*	0.141	-0.214	0.153	0.146***	0.056	0.061	0.06
Δp_{t-1}^f	0.235	0.253	-0.199	0.275	0.211***	0.059	0.201***	0.06
Δp_{t-2}^f	0.613***	0.240	-0.140	0.260	-0.032	0.058	-0.231***	0.06
Δp_{t-3}^f	0.046	0.147	0.256	0.159	0.044	0.058	-0.065	0.06
	Regime 2: Exchange rate < Threshold Value							
Constant	-0.163	0.184	0.361*	0.199	0.049	0.037	0.028	0.04
E_{t-1}	0.255	0.287	-0.565*	0.312	-0.044	0.042	-0.034	0.04
e_{t-1}	-0.274***	0.097	0.066	0.105	-0.165***	0.067	0.019	0.07
Δp_{t-1}^w	0.103	0.132	-0.199	0.143	0.033	0.097	0.094	0.10
Δp_{t-2}^w	-0.204*	0.121	-0.130	0.131	-0.243	0.088	0.038	0.09
Δp_{t-3}^w	0.083	0.120	0.068	0.130	-0.061	0.086	-0.210**	0.09
Δp_{t-1}^f	0.232**	0.118	0.423***	0.128	0.191**	0.088	0.186**	0.09
Δp_{t-2}^f	-0.078	0.121	-0.193	0.131	0.092	0.085	-0.002	0.09
Δp_{t-3}^f	-0.141	0.120	0.089	0.130	-0.009	0.082	0.042	0.09

Note: Coefficients are significant at $\alpha = 0.01$, 0.05 and 0.10 denoted by *, ** and ***, respectively

Table 4 contains the estimated results of the threshold ECM for the two non-BSE periods. Consistent in two periods, comparing between two regimes vertically, coefficients we are most interested in are the error correction terms in both regimes. The signs and magnitudes of the four significant coefficients refer to the direction and speed of prices' adjustments to the price departure from the long-run relationship. The results of threshold ECM are consistent in two periods because in both periods, the signs if the significant coefficients of error correction terms are all negative. The magnitude of the coefficient in above threshold regime is lower than that in the below threshold regime. Though comparing the magnitudes of coefficients between the regimes above and below the threshold value, the results suggest that wholesale price adjusts to price deviations faster in lower-exchange-rate regime than in higher-exchange-rate regimes. For instance, during the period in which the border was re-opened (after July 2005), the regime of exchange rate was above threshold value of 0.9142; further, the magnitude of adjustment coefficients of wholesale price with regard to error-correction term was 0.089 [lower than the magnitude of adjustment coefficient of wholesale price (0.165) in regime of exchange rate below threshold value]. Consistently, before the border closure, the magnitude of adjustment coefficients of wholesale prices with regards to the error-correction term (0.089) in the above-threshold regime was also lower than the magnitude of adjustment coefficient of the wholesale price (0.165) in the below-threshold regime.

By contrast, farm price does not react to price deviations from the long-run relationship in neither regime. The possible explanation for this discrepancy is that, in the higher exchange-rate regime, the price of Canadian fed cattle was higher relative to the U.S., which made it less competitive in U.S. wholesale market. Canadian fed cattle producers were thus more likely to sell cattle to domestic beef packers, which puts Canadian beef packers into a stronger market position, or we can say they can exert stronger bargaining power. Thus, with weaker incentives, beef packers were more likely to adjust to price deviations at a lower speed. In the lower exchange-rate regime, Canadian cattle were relatively cheaper than U.S. cattle, which made it more competitive in the U.S. wholesale market. Canadian fed cattle farmers were more willing to sell their cattle to the U.S. market, which makes Canadian packers being in a weaker market position; therefore, they were more accommodating or open to negotiation in price adjustments. Even though both the farm level producers and the wholesale level processors can export their product to the U.S. market, Canadian fed cattle farmers can choose to sell their cattle to either U.S. fed cattle feedlot or U.S. beef packing plants. Thus, being in a position of deciding whether to sell cattle to domestic beef packers or U.S. beef packers, the Canadian cattle producers could remain inactive in responding to price departures from long-run relationships.

2.8. Concluding remark

This research sought to investigate the threshold effect of exchange rates on the domestic vertical price transmission mechanism across the farm to wholesale prices of Canadian beef cattle markets. Specifically, this investigation focused on three periods in relative to the BSE crisis: before BSE, during U.S. border closure, and post-BSE crisis. The self-exciting threshold autoregressive (SETAR) model and threshold error-correction model (ECM) were applied to test threshold effect, to detect threshold value, and to estimate the short-run price adjustment different regimes induced by threshold variables.

First, our results suggested that farm price and wholesale price are tied together by a long-run relationship in both the non-BSE and the border closure periods. Price transmission elasticity during the border open period was significantly higher than that in border closure period. This disparity indicates that trade-related shocks can render great impacts on the coordination spectrum across different levels along Canadian beef cattle supply chain.

Second, our results indicate that CAD/USD exchange rate can act as a threshold variable in the domestic vertical price transmission patterns; meaning threshold value of exchange rate can trigger two regimes, within which farm and wholesale prices make adjustments to price deviations to restore the long-run relationship. Our results are supported by the evidence that the Canadian and U.S. fed cattle farmers closely monitored the relative prices of cattle in two countries to determine whether it was best to slaughter cattle domestically or to do so in the other country.

Third, our results of the two-regime threshold ECM model showed that wholesale prices made adjustments to price deviation faster in lower-exchange-rate-regimes than in high-exchange-rate-regimes. This difference of rate suggests that Canadian beef packers are more negotiable in prices when Canadian cattle farmers are more willing to sell cattle to the U.S. market, and they are more negotiable in prices when Canadian cattle farmers are more willing to sell cattle to the Canadian market. This suggestion on our part is supported by the evidence that the Canadian beef cattle industry is highly dependent on export markets, especially that of the U.S. The relative market position between Canadian cattle farmers and beef packers is, to some degree, determined by U.S. market availability to the Canadian cattle; namely, the trade relationship between Canadian and U.S. beef markets.

Finally, the results of this chapter provide interesting insights into new applications of threshold ECM. The previous empirical practice on the threshold ECM either investigated vertical price transmission pattern using price devotions from the long-run relationship as the threshold-inducing variable or, evaluated the exchange rate threshold effect on the spatial price transmission across different regimes. Our study, in contrast, explored the regime-inducing behavior of an exogenous variable: exchange rate, in the vertical price transmission. This new application of threshold ECM was motivated by the heavily trade-dependent relationship between the Canadian and U.S. beef cattle markets. The overall results shed some light on how export-oriented variable can induce structural adjustments of the domestic supply chain.

Chapter 3. Effects of Cattle Production System on Carcass Quality and Determinants of Cattle Feeding Profitability under Different Production Systems

3.1. Introduction

Cattle feeding is a high-risk industry stemming from the facts that it is intensively competitive, it has a narrow margin, and it is prone to severe volatility originating from many aspects. The profitability of cattle, from calf placement to finishing, is subject to massive fluctuations (Lawrence et al. 1999). Cattle feeders compete both in input markets for purchase feeder cattle and feedstuffs and in the output market to sell perishable products (Lawrence et al. 1999; Schroeder et al. 1993). The output beef cattle market is a highly concentrated processing industry with a relatively fixed weekly capacity. Cattle feeding is also a significant value-added business on farms and ranches in North America (Lawrence et al. 1999). Increasing price risk (including volatile input costs and beef prices) and an increase in production risk (including animal health and food safety) have driven up the challenge of operations for beef cattle industry (Lawrence et al. 1999 and Schroeder et al. 1993). Furthermore, it is of importance to note that the increasing adoption of grid-based pricing systems reveals consumers' perceptions relative to animal health and food quality (Lusk et al. 2001).

To address the challenges, the cattle feeding industry has developed numerous cattle production systems and management strategies to improve efficiency, to reduce input cost and to enable producers to obtain more accurate information on consumer beef demand (López-Campos et al. 2013). Improving information efficiency along the supply chain can alleviate the risk that producers face when making marketing decisions and can better allow producers to invest on the attributes of beef products that conform with what consumers are looking for (Johnson and Ward 2005). One of the chief management strategies noted in research is the grid-based pricing system, also known as Canadian beef grading system in the Canadian beef cattle industry. The grid pricing system at its core assigns different prices to individual animals based on three factors: their carcass weight (dressed), lean yield percentage, and marbling score. Premium or discount will be assigned to each category of attributes (Canadian Beef Grading Agency 2015). This assignment, in turn, helps cattle producers make production and marketing decisions as they face the trade-offs between beef carcass quality and production economics (López-Campos et al. 2013; Retallick et al. 2013). Under the grid-based pricing system, it is essential for producers to get the information on which raising strategy can specifically produce the cattle that can receive a high quality grade, a high yield grade, or a high dressed carcass weight.

The earlier research (i.e., Schroeder et al. 1993; Lawrence et al. 1999; Pyatt et al. 2005) dictate that cattle feeding profitability be largely determined by feeder calf price, fed cattle price, and animal performance. Therefore, making production decisions on improving animal growth performance and carcass characteristics plays a vital role in determining the economic status of the operation. When examining animal growth performance that will affect profitability of a feedlot, recent studies identified the following factors: breed composition, implant treatment, initial birth weight, diet treatment, days on feed in feedlots, growth performance and the specific assignment rule of grid pricing system (Schroeder et al. 1993; Lawrence et al. 1999; Retallick et al. 2013; López-Campos et al. 2013). Results from Pyatt et al.'s 2005 study, which was around the impacts of growth performance and carcass characteristics on feedlot economics, supported that hot carcass weight, marbling score, and yield grade accounted for nearly 80% of the variation in carcass value. Similarly, the study by Retallick et al. (2013) further investigated economic performance variation, growth performance, and carcass quality by examining components such as the effect of breed composition, different treatments including diet experiment, the implant of hormonal growth promotants and ractopamine (RAC) treatment. The study by Schroeder et al. (1993), Lawrence et al. (1999) and Retallick et al. (2013) are all done in the context of U.S. cattle beef industry. López-Campos et al. (2013) conducted an experiment on cattle production at the Lacombe Research Centre, Agriculture and Agri-Food Canada. The data collected from this experiment were used to do covariance analysis to determine the effect of reduced age at slaughter using calf-fed versus yearling-fed production systems with and without growth implants on production characteristics and economics. This study aims at providing empirical evidence of the effect of cattle growth performance and carcass characteristics on the profitability and extending the López-Campos et al.'s 2013 study by conducting more economic analysis on the effect of production systems and growth treatments on profitability. As discussed above, grid pricing is an important tool that assigns differentiated prices to individual cattle based on underlying quality criteria given by the Canadian beef grading system. In this study, a pricing grid will be used to investigate how carcass quality characteristics affect the final profitability of different production systems.

The objective of this chapter is in three parts: first, to find which animal production strategies can increase the probability of cattle carcass being in each category of quality grade, yield grade and dressed carcass weight grade; second, to investigate which production strategies can contribute to the final profit or economic value that cattle producers receive; and third, to generate expected profit through simulation of critical production variables and to calculate break-even dressed carcass weight and probability of earning profit. Our approach in achieving the objectives can be divided into two parts: the first part examines how production strategy and growth performance affect the carcass characteristics. The second part reviews how the profit of feedlots varied across individual animals with different carcass characteristics, the profit herein being market driven based on specific premium given for certain characteristics. To account for price risks, the analyses on profit will be conducted under different scenarios classified based on the maximum and minimum value of input price (feeder calf purchase price) and maximum and minimum value of output price (fed cattle price).

The remainder of this chapter is organized into six additional sections: Section 3.2 provides a brief literature review. Section 3.3 provides descriptions of the data that will be used in this chapter. Section 3.4 provides an overview of three methodologies with regards to the three objectives raised in the introduction. Section 3.5 presents the empirical results. While Section 3.6 puts forth implications and limitations of this research as well as the potential for future research.

3.2. Literature review

3.2.1. Determinants of cattle feeding profitability

Many studies investigate potential factors that can affect profitability in feedlots (i.e., Schroeder et al. 1993; Lawrence et al. 1999; McDonald and Schroeder 2003; Mark, Schroeder and Jones 2000; Swanson and West 1963; Trapp and Cleveland 1989). However, the focus and emphasis of cattle feeding profitability studies varied across several categories. Some studies examine the effect of economic variables (i.e., feeder calf cost, feed cost, fed cattle prices, etc.) on profit (Schroeder et al. 1992; Lawrence et al. 1999; McDonald and Schroeder 2003; Trapp and Cleveland 1989; Mark, Schroeder and Jones 2000). Whereas other studies investigate the effect of production variables [i.e., feed efficiency, average daily gain, hormonal growth promotants, ractopamine (RAC) treatment, marbling score, lean yield percentage, hot carcass weight, etc.] on profit (Retallick et al. 2013; Lusk J. 2007; Thompson et al. 2016)

Schroeder et al.‘s 1993 study analyzed data from 1980 to 1991 on the profitability of feedlots in Kansas, U.S. These researchers identified six factors that explained more than 90% of the variability of steer feeding profits, which are fed cattle prices, feeder calf prices, corn price, feed efficiency, average daily gain, and interest rate. The methodology they applied is the ordinary least square (OLS) linear regression of profitability on the six factors. Results from their study indicated that 70 to 80% of profit variability was due to the feeder and fed cattle prices; 6 to 16% of profit variability was due to corn prices, while 5 to 10% was contributed to animal performance.

Lawrence et al. (1999) extended Schroeder et al.'s 1993 research by analyzing the cross-sectional data of Midwest cattle feeders from multiple feedlots in different geographical regions, instead of just two regions. Lawrence and his cohorts as well took into consideration the effect of climate conditions and lot conditions on cattle performance when evaluating profitability. They applied OLS methods to build the basic model of cattle feeding profitability on the same explanatory variables as used in Schroeder et al.'s 1993 study, namely, fed cattle prices, feeder calf prices, corn price, feed efficiency, average daily gain, and interest rate. Besides the basic model, they estimated separate models for steers and heifers in four placement weight categories. Their results showed that on an all other things equal basis, the placement weight had a significant negative effect on performance and thus on profit. Profit variation across pens of cattle largely stems from fed cattle price and feeder calf prices. Of key emphasis in their study was the breadth of information since the data was collected from more geographically varied feedlots. Other studies of this category also concurred that feeder calf price and fed cattle price play important roles in the feedlot profitability, largely because these two factors holding the largest proportion of cost, in turn, contribute most to profit variability (i.e., Trapp and Cleveland 1989; Mark, Schroeder and Jones 2000). Mark, Schroeder and Jones 's 2000 study more specifically confirmed that feeder price plays a more important role in profit variability, especially for spring and fall placements.

Retallick et al. (2013) evaluated the economic value of feed efficiency and identify performance, carcass, and feed efficiency characteristics that predict carcass value, profit and cost of gain. They estimated OLS regression of carcass value, profit and cost of gain as a function of performance (i.e., average daily gain, dry matter intake, feed efficiency, etc.) and carcass characteristics (hot carcass weight, marbling score, yield grade). Their results showed that average daily gain, marbling score, yield grade, dry matter intake, hot carcass weight, and year born explained 81% of the variation for profit. Average daily gain, dry matter intake, hot carcass weight and year born explained 85% of the variation in the cost of gain.

There is another category of literature that investigated the dynamic multivariate relationship between yield variables of cattle production and profit (Belasco et al. 2009; Anderson and Trapp 2000). The methodology applied by Belasco et al. (2009) is to specify profit function on the critical production variables and simulated profit based on random draws from these production variables. Their study constructed a model of overall fed cattle profit risks, providing conditional forecasts of expected profits and other random variables to assign a measure of variability to the feedlot profit.

3.2.2. Feedlot profitability under different production and grid-pricing systems

The second part of the related literature review was relative to the evaluation of the factors that can affect the cattle feedlot profitability (i.e., Lusk 2007; Thompson et al. 2016). These studies calculate the profit of each animal using the price assigned by the USDA grid pricing system. As Johnson and ward (2006) noted, the beef grid pricing system can act as an incentive to improve the quality and quantity of the marketed carcass. Knowing the relative importance of each grid component should be of interest for cattle producers who want to earn profits by investing on the carcass quality that can receive highest premiums. The study by Lusk (2007) determined the economic value of using information on leptin genotype to select and manage beef cattle. He conducted conditional analysis across different genotypes, where per head profit and revenue is regressed on production variables (i.e., placement weight, frame score at placement, days on feed, percent steer, genotypic dummy variables, etc.). His results revealed that the value of using leptin information to choose days on feed is relatively small. However, the value of using leptin information to optimize the selection of cattle is relatively high. The results showed that the value of genetic information lies in allowing cattle producers to select animals of specific genotypes with superior economic performance. The study by Thompson et al. (2016) evaluated the value of genetic information for improving fed cattle marketing decisions and timing to market. They estimate regression equations for average daily gain, dressing percentage, yield grade, and quality grade as a function of live-animal characteristics and genetic information. Both studies by Lusk (2007) and Thompson et al. (2016) calculate the price of fed cattle using the base price and premium and discounts on each grade category. The grid pricing only works as a tool to link the carcass characteristics and final profitability of each cattle carcass.

Insufficient economic research has examined the variation of feedlot profitability across different production systems, treatments and breed compositions. López-Campos et al. (2013), typically from the perspective of animal science, assessed the impact of production systems (calf-fed; yearling-fed), aggressive growth implant (not implanted; implanted), β-adrenergic agonist (RAC; no-bag) and breed type on production characteristics and economics. The only economic evaluation of this study was an economic value calculation and covariance analysis.

The authors calculated the profit of raising cattle with the per-head grid-based prices and detailed production cost. The price is assigned to each fed cattle based on their dressed carcass weight, lean yield percentage, and marbling score. The costs of raising cattle were calculated based on the different diet of calf-fed and yearling-fed production systems with and without growth implant and β-adrenergic agonist. As López-Campos et al. (2013) showed, the price per cattle varied by production systems and implant regimes, and non-implanted yearling-fed cattle was least profitable. Their results also concurred that reducing the age at slaughter can increase profitability when combined with growth promotants.

3.2.3. Contribution to the literature

This chapter builds on previous feedlot profitability studies that investigated on the U.S. beef cattle market. This chapter will focus on estimating the effect of different production variables on the feedlot-level profitability by jointly analyzing three dimensions of this question that were addressed separately in previous: regressing profitability on production factors; simulation of critical production factors on profitability; and calculation of animal-based profitability measures under grid pricing.

First, this chapter builds on the studies on the feedlot profitability by Lusk (2007), Thompson et al. (2016), and López-Campos et al. (2013) and investigates the profit variation stemming from production variables (i.e., days on feed, pre-feedlot days after weaned, birth weight, weaning weight, placement weight, slaughter weight, breed composition, and growth treatment). Ordinary least square (OLS) regression model of the feedlot profitability will be estimated using the production variables as explanatory variables. The price of fed cattle is assigned based on Canadian Beef Grading Grid (Canadian Beef Grading Agency 2015). The profit is the difference between total revenue and total cost, where the total revenue is obtained by grid-based fed cattle price multiplied by dressed carcass weight, and the total cost is the sum of all variable costs and fixed cost. This chapter contributes to the previous literature by (1) running regression model of profit under the two production systems; (2) building ordered logit model to examine effect of production variables (i.e., weaning age, days on feed, pre-feedlot days after weaned, birth weight, weaning weight, placement weight, breed composition, growth treatment, etc.) on the probability that cattle carcasses fall into each grade category; and (3) considering the price risk with the incorporation of the maximum and minimum value of fed cattle base rail prices and feeder calf prices. The analysis on the effect of production variable on profit will be conducted under each of the four scenarios. The particular difference of the present study from López-Campos et al. (2013) is that variations in profitability across production systems and implant regimes are assessed with a joint economic analysis that will provide comprehensive recommendations for feedlot operators on management and production decisions. For instance, the effect of different treatments on the probability of each quality grade and the shift of expected profit distribution with the intervention of removing each treatment. Overall, the results of this analysis are of particular interests to the fed cattle producers in feedlots who need more pertinent information on breed type selection, growth treatment and other production strategies to increase the probability that they can receive high price for cattle carcasses, which in turn increases the probability of earning profit.

Second, this chapter builds on research by Belasco et al. (2009) and Anderson and Trapp (2000) which generated expected profit conditional on simulated production factors (production systems, cattle performance, carcass characteristics). This chapter also adopts the methodology of simulation to first specify profit function on the critical production variables, and then to generate expected profit based on random draws from the distributions of the production variables. Furthermore, this chapter contributes to the current literature by investigating the variation of distribution characteristics of expected profit across (1) the two production systems, (2) the four price scenarios as previously mentioned, and (3) the scenarios with the intervention of removing each of the three types of growth treatments. Besides, this chapter also extends the existing literature by calculating break-even dressed carcass weight and the probability of positive profit under each scenario.

The results of this chapter should be of particular interest to producers in the fed cattle industry whose objective is to optimize their prediction of animal performance and related economic profitability. Moreover, information about cattle production system performance regarding how individual production factors affect carcass quality and economic returns is important to many sectors when they make marketing and production decisions.

3.3. Data

This section addresses the sources and construction of the three parts of the data that will be used in the analysis in this chapter. Each part of the data will be introduced in three dimensions: (1) the raw data; (2) data adjustment and methods of model variable generation; and (3) the presentation of summary statistics for the different datasets used.

3.3.1. Price of each animal in the grid-pricing system

3.3.1.1. Raw data

To calculate revenue per head, it is necessary to assign a differentiated price to each cattle based on its carcass characteristics. There are three dimensions of the Canadian Beef Grading System; these are shown in Table 5. Four categories of quality grade are A, AA, AAA, and Prime. Three categories of yield grade exist, namely: Y1, Y2, and Y3. While the four categories of dressed carcass weight are <249.5kg, 249.5 to 430.9kg, 430.9 to 453.6kg and >453.6kg. The evaluation of grade is as follows: 1) quality grade is evaluated based on marbling score, 2) yield grade is evaluated based on lean yield percentage, and 3) dressed carcass grade is divided into different ranges. The market decides the premium or discount for different levels of each standard; some grade categories that receive no premium or discount are equivalent to the market price. The equivalent market price is the benchmark price without adjustment of premium or discount from the pricing grid (see Table 5). In this chapter, Alberta fed steer rail price ($\$ \text{ kg}^{-1}$) is adopted as the equivalent market price. Unlike the data of fed steer live price, the data of fed steer rail price is not available. However, fed steer live price can convert into fed steer rail price with the dressing percentage[1]. The data series of monthly Alberta fed steer live price from 2002 to 2016 with 180 observations were obtained from Canfax (2017).

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[1] Fed cattle base rail price = fed cattle live price / dressing percentage
Typical dressing percentage of fed steer is 60.0% (Canfax 2013)

It should be noted that the grid structure and the premium and discount on each grade vary across different beef packers and change over time. The standard of assignment of each grade category were obtained from Canadian Beef Grading Grid (Canadian Beef Grading Agency 2015). The data with respect to premiums and discounts on different grade categories were obtained from personal communication with experts from Cargill Foods (High River 2017). Therefore, the grid-pricing structure used here only reveal the market condition in Western Canada in 2017 as implemented by a single (yet major) industry player. Possible price variations that might stem from movements of both premiums (and discounts) over time and across different beef packers were not captured in the analysis. The data on premiums or discounts of each category of quality grade, yield grade, and dressed carcass weight class were presented in Table 5.

Table 5. Canadian Beef Grading Grid

Quality Grade	Marbling score	Premium(+$/kg)
Prime	800+	0.295
AAA	500 to 799	Par
AA	400 to 499	-0.079
A	300 to 399	-0.236
Yield Grade	Estimated Yield (%)	($/kg)
Y1	59 or more	0.039
Y2	54 to 58	Par
Y3	53 or less	-0.197
Carcass weight(kg)	Carcass weight(lbs)	($/kg)
<249.5	<550 lb	-0.394
249.5 to 430.9	550-950	Par
430.9 to 453.6	950-1000	0.165
453.6	1000	-0.591

Note: The Canadian Beef Grading Grid is obtained from Canadian Beef Grading Agency (CBGA). The data on premium is obtained through personal communication with experts from High River, Cargill (2017).

[a] Use applicable market price without any premium or discount.

As Table 5 shows, for quality grade, there is a premium of \$0.295kg^{-1} for the Prime beef, while the price of AAA beef does not receive any premium or discount but is equivalent to the market price. AA and A beef producers will receive a discount of \$0.079 kg^{-1} and \$0.236 kg^{-1} respectively. Beef of yield grade Y2 is equivalent to market price and does not receive any premium or discount. Y1 beef producers will receive \$0.039 kg^{-1} premium, while Y3 beef producers will generate a discount of \$0.197 kg^{-1}. Dressed carcass weight category, deemed the third standard of the grid-pricing system, accounts that some cattle that are either too light or too heavy will receive a discount. Any cattle that is lighter than 249.5 kg will receive a discount of \$0.394 kg^{-1} and any cattle that is heavier than 453.6 kg will receive a discount of \$0.59 kg^{-1}.

3.3.1.2. Data adjustment

Fed cattle rail price was converted from dividing fed cattle live price by carcass dressing percentage using the following formula:

$$BASEP = LIVEP/\,DREPERCT \tag{3.5}$$

where *BASEP* is the rail price (\$ kg^{-1}) of fed steer, *LIVEP* is the live price (\$ kg^{-1}) of fed steer and *DREPERCT* is the dressing percentage of each carcass. The typical dressing percentage (60 %) of fed steers will be used (Canfax 2017).

The price of each animal is calculated by applying the following formula:

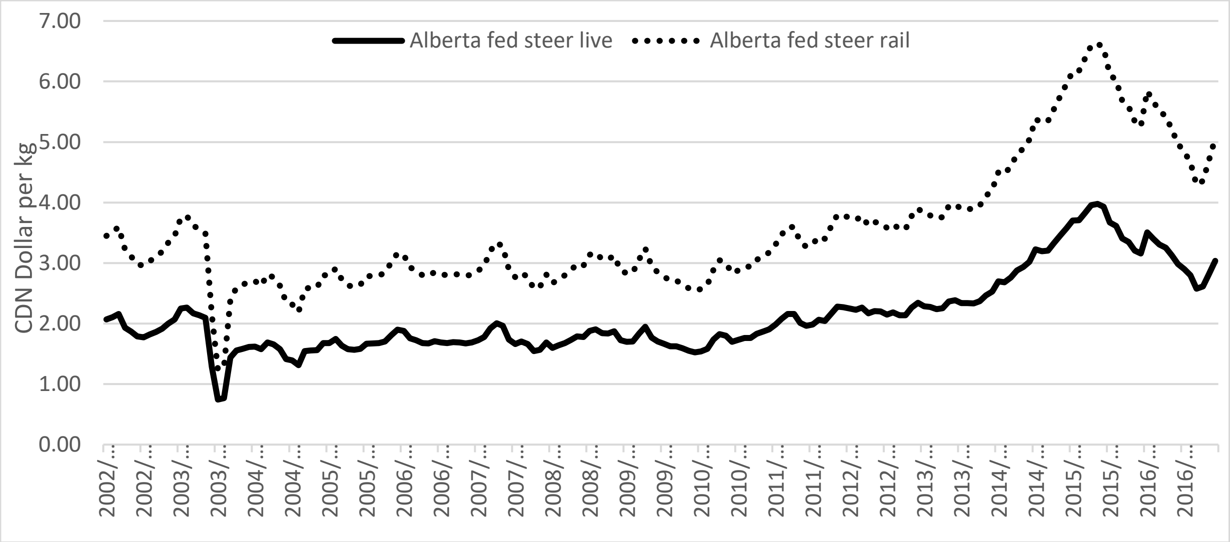
$$FEDP = (BASEP + PREMQLT + PREMYLD + PREMDREWT) * DREWT \qquad (3.6)$$

where *FEDP* is the fed cattle price per head, and $BASEP$ is the rail price (\$ kg^{-1}) of fed steer. Additionally, *PREMQLT, PREMYLD,* and $PREMDREWT$ refer in relative terms to premium (\$ kg^{-1}) for each quality grade, premium (\$ kg^{-1}) for each yield grade and premium (\$ kg^{-1}) for each dressed carcass weight class. A negative premium denotes a discount in that category. $DREWT$ is the dressed carcass weight of each carcass. The price for each cattle will be assigned using equation (3.6) given the fed cattle base rail price and the premium and discount for each category of grades. In this way, the economic value of a carcass will be related to its specific carcass characteristics.

3.3.1.3. Descriptive statistics of the data

Figure 5The monthly Alberta fed steer live price and rail price data series from January 2002 to December 2016 with 180 observations are shown in Figure 5. Generally, the fed rail price fluctuated between \$2.00 kg^{-1} and \$4.00 kg^{-1} from years 2002 to 2013 despite the sharp decrease in 2003. The huge shock depicted on the prices in 2003 was due to the break-out of bovine spongiform encephalopathy (BSE) crisis. From 2014 to the middle of 2015, fed rail price rose abruptly and reached a high in July 2015. After this time, the price started to drop, but gently rebounded in January 2016 and July 2016.

Figure 5. Monthly Alberta Fed Steer Live Price and Rail Price



It shows that both fed steer live price and fed steer rail price experienced substantial turmoil in 2003 due to the BSE crisis. A stream of studies have investigated that exogenous shocks like BSE raised concerns regarding the volatile trade flows of Canadian cattle and beef product to the U.S. market (Twine 2016; Miljkovic 2009), beef production and price pass-through patterns along the domestic supply chain (Rude, Carlberg and Pellow 2007; Saha and Mitura 2008), domestic beef cattle price volatility (Miljkovic 2009; Zhen, Rude and Qiu 2017) and potential interdependence between cattle and feed grain markets (Goodwin et al 2011). There was a substantial difference in pre- and post-BSE beef cattle price series. To remove the price variation from the exogenous shocks and avoid biasness of results, this chapter only adopted the price series of the post-BSE period (January 2004 to December 2016) to investigate the impacts of price risk on the profitability of cattle feeding.

The mean value and standard deviation of fed steer rail price are 3.63 and 1.10 for post-BSE period (January 2004 to July 2016), as opposed to 3.54 and 1.07 for entire data series

(January 2002 to July 2016). The descriptive statistics of both price series are reported in Appendix 1. As mentioned in the introduction section, one of the objectives is to investigate how price risks influence profitability. The maximum and minimum fed cattle selling prices over 2004 to 2016 were selected to comprise the typical price scenarios. Therefore, the fed cattle selling price is calculated using equation (3.6) with both the maximum and minimum value of the monthly fed steer rail price over 2004 and 2016 to generate two extreme scenarios.

Table 6. Frequency Statistics of Each Grid Grade

Quality Grade	Frequency	Percent
A	75	9.28
AA	426	52.72
AAA	305	37.75
Prime	2	0.25
Yield Grade	Frequency	Percent
Y1	352	43.56
Y2	356	44.06
Y3	100	12.38
Dressed Carcass Weight Grade	Frequency	Percent
Smaller than 249.5kg	27	3.34
249.5 to 430.9 kg	717	88.74
430.9 to 453.6 kg	37	4.58
Greater than 453.6 kg	27	3.34
Total	808	100

Note: All cattle carcasses in the data are A-grade beef. A, AA and AAA grades together represented 97.1% of all graded beef derived from fed slaughter cattle in Canada (Beef Cattle Research Council 2012).

Grade AA takes the largest percentage at 52.72%, followed by grade AAA at 37.75%, grade A at 9.28%, and lastly Prime beef at 0.25%. Relative to classification of yield grade score, 44.56% of the carcass sample scored as Y2, followed by 44.06% as Y1, and 12.38% as Y3. When considering the dressed carcass class, the data shows that 88.74% of observations fall in the range of 249.5 kg - 430.9 kg. And 4.58% fall in the range of 430.9 kg - kg 453.6 kg, 3.34% fall in the range of greater than 453.6 kg, 3.34% fall below 249.5 kg.

3.3.2. Fed cattle growth performance and carcass characteristics data

3.3.2.1. Raw data

Dr. Manuel Juárez and Dr. Jordan Roberts collected cattle growth production data pertinent to the breed composition, treatment on cattle, growth performance and carcass quality from their experiments on cattle conducted in Lacombe Research and Development Centre, Agriculture and Agri-Feed Canada (located in Lacombe, Alberta). The necessary animal science knowledge for other parts of the economic analyses was obtained from consulting Dr. Juárez and Dr. Roberts as well as from researching the study by López-Campos et al. (2013) whose experiment on cattle was also conducted at the side of Lacombe Research and Development Center.

The cattle production data set contains pertinent information on the cattle breed composition, performance, various treatments on growth, and carcass characteristics with a total of 2,087 cattle observations experimented from birth to slaughter. Tables of the complete summary statistics for continuous variables and frequency statistics of categorical variables in the raw data set are presented in Appendix 2 (see Appendix 2, Table 22 and Table 23). As mentioned in Section 3.2.1, studies investigating the effect of production variables on the profitability of cattle chose the following explanatory variables: feed conversion ratio, average daily gain, implant of hormonal growth promotants, ractopamine (RAC) treatment, marbling score, lean yield percentage, placement weight, days on feed and hot carcass weight (Retallick et al. 2013; Lusk J. 2007; Thompson et al. 2016). From the available variables in the data set, this analysis only employs a selection of variables found to be relevant to determining profitability outcomes of interest, which include: breed composition, weaning age, slaughter age, birth weight, weaning weight, dressed carcass weight, estimated lean yield percentage, marbling score, diet experiment, implant of hormonal growth promotants, ractopamine (RAC) treatment. Breed composition, diet experiment, implant of hormonal growth promotants and RAC treatment were provided in the form of indicator variables, observations with missing information for any of the above selected variables were excluded from the dataset. Therefore, this study may neglect some observations that may contain useful but incomplete data.

The time spans of the data collection processes are different for factors such as birth date, weaning date and slaughter date. The birth date time spans 2002-03-04 to 2002-04-25 and from 2005-09-01 to 2015-05-08; the weaning date time span is from 2006-10-22 to 2015-10-13; while the slaughter date time span is from 1999-04-27 to 2016-06-24.

3.3.2.2. Data adjustment

This chapter divides cattle observations into two groups, denoted as two production systems, calf-fed and yearling-fed groups. These two production systems are defined based on the days of slaughter after cattle are weaned. The calf-fed production requires an earlier placement of weaned calves on high concentrate following a 1-2 month dietary adjustment period. While in the yearling-fed production system, calves are grown on backgrounding diets for varying periods before entering feedlots. Placement into feedlots is the starting point of feeding calves a finishing diet. It also represents the starting point for the economic analysis. Both the nominal components and the percentages of each component in the finishing diets are differentiated between calf-fed and yearling-fed production systems. Integrated into these two production systems is the utilization of three feeding treatments in the data: growth promoting implants, β-adrenergic agonists (B-ag) and experimental adjustments to an otherwise standard finishing diet. Animals implanted with growth promotants are noted as *Implanted* with a control group being noted as *Non-implanted*. Animals that are fed with B-ag are noted as having *RAC* treatment with a control group being noted as *No B-ag*. Animals fed with an experimental diet are noted as *Experimental-diet* observations with a control group of *Routine-diet*. The dataset contains both steer and heifer observations; however, only six heifers possess complete information of the variables that will be examined in the analysis of this chapter. The heifer observations were excluded from the data set, and analyses will only be conducted on steer observations.

The Canadian beef production system is similar to that of the U.S. comprising of three main types of operations: (1) cow/calf operations, (2) backgrounding operations, and (3) feedlot/ finishing operations (Athwal 2002; Zhen, Rude and Qiu 2017). Cow-calf operations are enterprises where a cowherd is maintained; calves are raised and ultimately sold after weaned from the mother cows. The weaned calves, steers and heifers are the principal products that are produced by cow/calf operator[1] and they are the primary inputs of the meat supply process. Depending on breeds and production systems, the calves will enter one of the two following activities: a backgrounding operation or a feedlot/finishing operation.

Typically, during every fall, the beef calves in the herd go through the weaning process wherein they are separated from their mothers (Whittier 1995; Filley 2011). After finishing the

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[1] Also known as a rancher.

weaning process, calf producers usually have three choices to prepare the weaned calves for the feedlot feeding process. These choices include: (1) to sell the calves at weaning; (2) to precondition the calves for about one month prior to shipment to feedlots; and (3) to initiate the process of backgrounding operation, which requires feeding the calves for a few months before selling. A 45-day post-weaning period before shipping has been shown to be beneficial in comparison to shipping calves immediately after weaned (Lalman and Smith 2001; Filley 2011). In this study, both calf-fed and yearling-fed calves will have the process described in choice two prior, but yearling-fed calves will additionally have the backgrounding treatment described in choice three prior. After being weaned, both calf-fed and yearling-fed calves go through an adjustment period. During this period, they spend several weeks either eating grass or being fed with an adjustment diet. After the adjustment period, calf-fed calves are sent to a feedlot and start a finishing diet. Yearling-fed calves, however, go through a backgrounding process for 3-4 months and are fed with a backgrounding diet. After the backgrounding process is completed, they are sent to feedlots and start finishing diet (López-Campos et al. 2013).

Due to the lack of several important variables in the dataset presented, this section will adjust the data by making the following assumptions:

1. Calf-fed and yearling-fed calves are fed with an adjustment diet for 50 days; apart from this, yearling-fed animals also have a backgrounding diet for an additional 200 days.
2. Animals with post-weaned days to slaughter greater than 340 days are identified as yearling-fed cattle. Animals with post-weaned days to slaughter less than 309 days are identified as calf-fed cattle. Since there could be overlapping parts of the yearling-fed and

calf-fed observations, the observations with post-weaned days to slaughter between 309 and 340 days are excluded from the dataset. Anomalies may occur in that yearling-fed calves could end the backgrounding process earlier, while calf-fed calves could enter the backgrounding process; or the latter could be kept for a longer time because calf producers may need to monitor market conditions to determine when to sell their calves to feedlots.

3. The days on feed is constrained between 90 to 120 days. According to López-Campos et al. (2013) and experts from the Lacombe Research and Development Center, the days on feed in a feedlot (for both calf-fed and yearling-fed cattle) are between 90-120 days. Since there is no placement date data, our study conducted random generation of the data on days animals spent in feedlots by assuming the days on feed follows a uniform distribution. Uniform distribution indicates there is an equal probability that the days on feed fall into the intervals: 90-95 days, 95-100 days, 100-105 days, 105-110 days, 110-105 days and 115-120 days. The reason behind this random generation process of data on days on feed is that days on feed in feedlots is necessary for the calculation of the total feed cost during the period cattle spent in feedlots from placement date to slaughter date.

4. Given the weaning age, weaning weight, slaughter age and slaughter weight, we can assume that from the weaning to slaughtering process, the animal's body weight would increase linearly. Since it is also important to calculate placement weight of calves, the weight of calves when they enter feedlots, to further calculate the purchase price of feeder calves given the purchase price of feeder calves is one of the primary costs for feedlots. The method of calculating the placement weight is shown in following three equations:

$$PA = SA - DOF \tag{3.7}$$

where PA is the placement age (days), SA is the slaughter age (days), and DOF is the days on feed (which is the time length animals spent in the feedlot).

$$SW = WW + \beta * (SA - WA) \tag{3.8}$$

where SW and WW represent the slaughter weight (kg) and the weaning weight (kg) respectively, SA and WA are the slaughter age (days) and the weaning age (days), respectively. To calculate coefficient β, then placement weight can be calculated as:

$$PW = WW + \beta * (PA - WA) \tag{3.9}$$

Excluding observations with missing data for production variables and important dates of interest and heifer observations left 808 observations from the total of 2,087 observations in the raw data.

3.3.2.3. Descriptive statistics of the data

The 808 observations that will be used in the analysis of this chapter is divided into the calf-fed and yearling-fed group, the frequency statistics of the two production systems are shown in the following table.

Table 7. Frequency Statistics of Two Production Systems

Production Systems	Frequency	Percent
Calf-fed Group	450	55.69
Yearling-fed Group	358	44.31
Total	808	100

As Table 7 shows, among the entire sample dataset, there are 450 observations in the calf-fed production group, comprising 55.69% of the total observations; there are 358 observations in the yearling-fed production group, comprising 44.31% of the total observations.

The table of frequency statistics of categorical variables in the cattle production data set is presented in Appendix 2 (see Appendix 2, Table 23). Table 23 shows that there are six types of breed composition, which are assigned based on pedigree or genomically determined breed composition. The breed compositions include *anguscross, continentalcross, herefordanguscross, herefordcross, highangus* and *highhereford*. The unknown breed composition refers to the observation that misses the breed information, the analyses in the following part does not include the unknown phenotype. The proportions of the same breed types are generally similar in two production systems. In calf-fed group, both *anguscross* and *highangus* take the highest percentage at 30.67%; and in yearling-fed group, *anguscross* takes the largest percentage at 38.55%.

The majority of animals in both production groups are without implant treatment. The percentage of implanted animals in the calf-fed group is 31.11%. While the percentage of animals with implant treatment in the yearling-fed group is 21.51%, Part of animals also have RAC treatment, possible values are RAC for animals receiving RAC treatment, and *no-bag* otherwise. 12.44% of observations in the calf-fed group are B-ag treated. Whereas 15.36% of observations in the yearling-fed group are B-ag treated.

There is a significant difference on the percentage of observations that are fed with experimental diet. In calf-fed group, only 3.56% of animals are fed with experimental diet and the rest 96.44% of animals are fed with routine finishing diet. Whereas in yearling-fed group, 43.58% of the animals are in experimental finishing diet group, the other 56.42% are fed with routine finishing diet which is controlled group.

Table 8. Summary Statistics of Growth Performance and Carcass Characteristics Variables in Two Production Systems

	Calf-fed Group					Yearling-fed Group				
VARIABLES	N	Mean	S.D.	Min	Max	N	Mean	S.D.	Min	Max
Weaning age	450	192.32	18.86	144.00	250.00	358	186.20	17.44	138.00	230.00
Slaughter age	450	437.60	38.67	330.00	529.00	358	595.04	39.54	494.00	691.00
Birth weight	450	41.44	5.07	28.12	61.82	358	41.38	4.88	23.59	62.60
Weaning weight	450	271.40	32.01	165.11	339.29	358	255.14	28.95	162.39	329.31
Slaughter weight	450	557.59	58.01	392.50	714.00	358	616.48	96.47	411.00	849.00
Dressed carcass weight	450	322.50	36.93	208.80	401.80	358	356.33	64.48	229.20	510.60
Days on feed	450	104.47	8.38	90.14	119.90	358	105.27	8.68	90.09	119.93
Pre-feedlot days after weaned	450	140.81	36.52	37.79	215.79	358	303.56	39.66	226.09	397.94
Placement age	450	333.13	39.49	217.96	432.09	358	489.77	40.39	382.78	595.94
Placement weight	450	433.79	45.31	301.47	543.98	358	524.02	79.70	355.21	717.91

As Table 8 shows, the average weaning age of cattle in calf-fed group is 193 days, which is higher than in yearling-fed group at 187 days. Cattle in calf-fed group are slaughtered at the average age of 438 days while cattle in yearling-fed group are slaughtered at the average age of 596 days. Since the days on feed in feedlots is generated randomly, there is not much difference between the mean values of days on feed of calf-fed and yearling-fed groups. Whereas pre-feedlot days after weaned of yearling-fed cattle are more than twice as that of calf-fed cattle (304 days versus 141 days). Average placement age of yearling-fed cattle is also much larger than that of calf-fed cattle (490 days versus 334 days). The average birth weight of cattle in calf-fed and yearling-fed groups are almost equal (41.44 kg versus 41.38 kg). It worth noticing that calf-fed cattle tend to have a larger weaning weight than yearling-fed cattle with an average value of 271.40 kg versus 255.14 kg. The average slaughter weight in calf-fed group is reasonably lower than that of yearling-fed group (557.59 kg versus 616.48 kg). The average weight of cattle when they are sent to feedlots in calf-fed group is lower than that of yearling-fed group (433.79 kg versus 524.02 kg).

3.3.3. Cost of raising fed cattle for feedlot

3.3.3.1. Raw data

According to López-Campos et al.'s 2013 study, which is also concurred by Lawrence et al.'s 1999 study and McDonald et al.'s 2003 study, feeder calves purchase cost and feed cost comprise two significant parts of the total cost. As explained in Section 3.3.2.2, the analysis of this chapter is conducted only on steer data. Concerning feeder calf purchase cost, the average prices ($\$\ \mathrm{kg}^{-1}$) of Alberta feeder steers of different weight classes (500-600 lbs., 600-700 lbs., 700-800 lbs., and 800-900 lbs.) are selected, and the monthly data from 2002 to 2016 are obtained from CanFax (2002-2016). As stated in Section 3.3.1.3, only the data after BSE crisis, namely, feeder steer prices from January 2004 to July 2016 will be used in building models in the Section 3.4. Methodology.

This chapter will utilize the same finishing diet as the previously mentioned study by López-Campos et al. (2013). The feed cost for both calf-fed and yearling-fed steers will be calculated based on the ingredient and percentage of each ingredient of the diet in the study by López-Campos et al. (2013). The following table presents the detailed ingredients of the finishing diet.

Table 9. Average Ingredient of the Finishing Diet of Both Production Systems (As Dry Matter Basis)

	Ingredient	% of each component (as dry matter basis)	Unit cost per component ($ kg^{-1})
Calf-fed group	Barley grain protein mix A	81.40%	0.19
	Alfalfa grass silage	9.70%	0.08
	Barley silage	8.90%	0.05
Yearling-fed group	Barley grain protein mix B	79.00%	0.19
	Barley silage	21.00%	0.05

Source: López-Campos et al. 2013

As Table 9 shows, the average ingredient of the diet [as dry matter (DM) basis] of calf-fed steers during the finishing phase is composed of 81.4% barley grain protein mix A, 9.70% alfalfa grass silage and 8.90% barley silage. The barley grain protein mix A contained 89.2% dry matter and consisted of 88.4% rolled barley and 11.60% beef supplement (López-Campos et al. 2013). The average ingredient of the finishing diet of yearling-fed cattle is made up of 79.00% barley grain protein mix B and 21.00% barley silage. Moreover, the barley grain protein mix B contained 89.20% dry matter and consisted of 93.28% rolled barley and 6.72% beef supplement (López-Campos et al. 2013). The data on the monthly average of weekly high prices ($ kg^{-1}) of the rolled barley are obtained from Canfax (2002-2016). The data of monthly beef supplement are obtained from Canfax (2006-2016). The cost ($ kg^{-1}) data of alfalfa grass silage is obtained from the advertisements from Alberta Agriculture and Forestry (2018).

Other variable costs besides feed cost and feeder steer purchase cost include the cost of transportation, veterinary and medicine, death loss, marketing, implant, and RAC. The data are found from Canfax (2017) as the typical variable costs.

Annual data of the number of beef cattle farms in Alberta, average total general operational expense per farm, and the total number of beef heifers and steers that are produced in Alberta from 2002 to 2014 are obtained from Statistics Canada. The average value of the data across 2002 to 2014 were applied to calculate general operational cost per animal ($\$ \text{head}^{-1}\text{year}^{-1}$). The average general operational cost per animal was used as a proxy of the fixed cost ($\$ \text{head}^{-1}\text{year}^{-1}$) for a typical beef cattle farm in Alberta. General operational costs contain the total machinery expenses (i.e., small tool expenses, net fuel expenses, machinery, truck, etc.), salaries, rent expenses and insurance expenses.

3.3.3.2. Data adjustment

The average price of the Alberta feeder steers of 500-600 lbs., 600-700 lbs., 700-800 lbs., and 800-900 lbs. was used as the unit price of feeder steer ($\$ \text{kg}^{-1}$) in this chapter. The feeder steer purchase cost ($\$ \text{head}^{-1}$) was calculated as:

$$FDRC = PW * PFDR \tag{3.10}$$

where *FDRC* is the feeder calf cost ($\$ \text{head}^{-1}$), PW is the placement weight (kg) of feeder steers when they are sent to feedlots, *PFDR* is the unit price of feeder steer ($\$ \text{kg}^{-1}$). The feed cost of a steer during the entire period in the feedlot is calculated as follows:

$$FDC = DMI * DOF * CDM \tag{3.11}$$

where *FDC* is the feed cost ($\$\ \mathrm{kg}^{-1}$), *DMI* is the dry matter intake (kg) per animal per day, *DOF* is the days on feed in the feedlot where cattle are fed with finishing diet, *CDM* is unit dry matter cost ($\$\ \mathrm{kg}^{-1}$). Data of the dry matter intake ($\mathrm{kg\ head}^{-1}\ \mathrm{day}^{-1}$) of both calf-fed and yearling-fed production systems are obtained from the study by López-Campos et al. (2013).

Unit dry matter cost ($\$\ \mathrm{kg}^{-1}$) is calculated with quantity (kg) of each component that is needed to provide 1 kg dry matter and unit cost of each component ($\$\ \mathrm{kg}^{-1}$). The quantity (kg) of each component that is needed for 1 kg dry matter is obtained by dividing the percentage of each component by the dry matter percentage of each component.

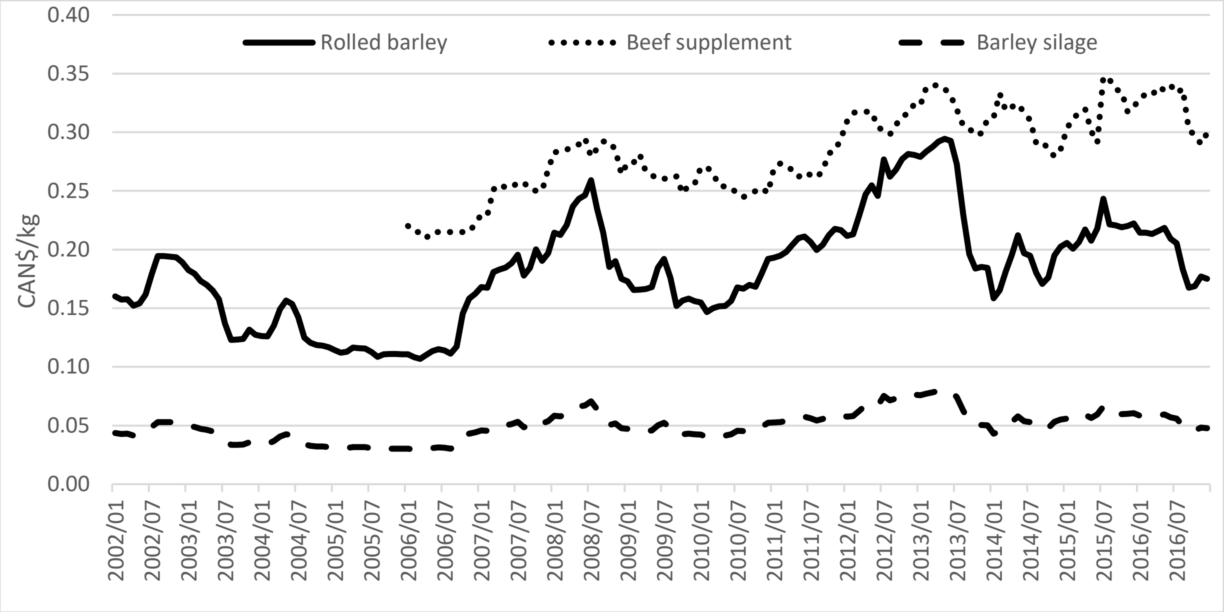
Table 9 shows that both the finishing diet of the calf-fed and yearling-fed steers contain barley silage. Barley silage price ($\$\ \mathrm{kg}^{-1}$) is converted from rolled barley price ($\$\ \mathrm{kg}^{-1}$) with the following two equations, in which the conversion ratio is obtained from Canfax Research Services (2016).

$$Barley\ Price\ (\$\ bushel^{-1}) = Rolled\ barley\ price\ (\$\ kg^{-1})\ /\ 45.93 \qquad (3.12)$$

$$Barley\ silage\ price\ (\$\ kg^{-1}) = Barley\ price\ (\$\ bushel^{-1}) * 12.5 \qquad (3.13)$$

Figure 6 presents the price trend of different diet components from January 2002 to July 2016. The price data of beef supplement was only available from January 2006 to July 2016.

Figure 6. Monthly Price Series of Feed Components



Barley silage price was the lowest compared with other diet components. From year January 2006 to July 2016, price series of rolled barley and beef supplement generally showed similar trends. All price series rose from August 2006 to April 2008 reaching a high in April 2008; thereafter, they started to drop until January 2010 except rolled barley price rebounded a bit in July 2009. From May 2010 to April 2013, the three prices showed a general increasing trend followed by a sharp decrease until July 2013 for beef supplement and January 2014 for rolled barley. Since January 2014 both rolled barley and beef supplement prices had been somewhat volatile, and both prices showed a decreasing trend until July 2016. To simplify the analyses, this study adopts the average value of the three price series from January 2006 to July 2016 in the feed cost calculation. Table 10 presents the summary of unit dry matter cost ($\$ \text{kg}^{-1}$) of the finishing diet fed to both calf-fed and yearling-fed steers.

Table 10. The Unit Feed Cost as Dry Matter Basis of the Finishing Diet Fed to Calf-fed and Yearling-fed Steers

	Component	% of each component	DM %	Quantity (kg) of each component needed for 1 kg DM[a]	Unit cost of each component ($ kg^{-1})	Unit DM cost ($ kg^{-1})[c]
Calf-fed group	Barley grain protein mix A	81.40%	89.20%	0.91[b]	0.19	0.19[d]
	Alfalfa grass silage	9.70%	87.40%	0.11[b]	0.08	
	Barley silage	8.90%	36.80%	0.24[b]	0.05	
Yearling-fed group	Barley grain protein mix B	79.00%	89.20%	0.89[b]	0.19	0.20[d]
	Barley silage	21.00%	36.80%	0.57[b]	0.05	

Note: The method of calculation of unit dry matter cost follows López-Campos et al. (2013) (Quantity (kg) of each component that is needed to provide 1 kg DM = 1 kg * percentage of DM of Each Component/ DM percentage).

Using the calculation method from previously mentioned studies by Schroeder et al. (1993), McDonald and Schroeder (2003), and Lawrence, Wang and Loy (1999), the profit of fed cattle in this chapter is calculated as follows:

$$PROFIT = TR - FDRC - FDC - OVC - FC \tag{3.14}$$

where *PROFIT* is the profit ($ head^{-1}), *TR* is the total revenue ($ head^{-1}) the feedlot receive by raising cattle, *FDRC* is the cost of purchase feeder steers ($ head^{-1}), *FDC* is the cost of feedstuff ($ head^{-1}), *OVC* represents other variable costs ($ head^{-1}), i.e., cost of transportation, veterinary and medicines, marketing, death loss, implant and RAC treatment. *FC* represents the fixed cost ($ head^{-1}) which is the total general operational cost ($ head^{-1}). *TR* is defined as follows:

$$TR = DREWT * PFED \tag{3.15}$$

where *DREWT* is the dressed carcass weight (kg), *PFED* is the selling price ($\$\ \mathrm{kg}^{-1}$) of fed cattle, which has been calculated in 3.3.1.2 using equation (3.6)

3.3.3.3. Descriptive statistics of the data

The following table shows the summary of the total costs of raising cattle from the perspective of the feedlot manager. The variable costs including feeder calf purchase cost, feed cost and other variable costs (i.e., cost of transportation, veterinary and medicines, marketing, death loss, etc.) are calculated as dollars per head. The fixed cost including general operational cost of a typical farm in Alberta is the average value of annual operational cost of beef cattle farm across 2002 to 2014, and it is also calculated as the dollar per head.

Table 11. Summary Statistics of Feedlot Cost of Raising Fed Cattle

Cost ($\$\ \mathrm{head}^{-1}$)	N	Mean	S.D.	Min	Max
General operational cost[a]	808	486.14	0.00	486.14	486.14
Max feeder calf cost[c]	808	2,722.82	443.81	1,732.59	4,125.95
Min feeder calf cost[c]	808	702.24	114.46	446.85	1,064.12
Transportation	808	11.50	0.00	11.50	11.50
Veterinary/med.	808		2.75% of feeder cost		
Death loss	808		1.675% of feeder cost		
Marketing costs	808	5.00	0.00	5.00	5.00
Implant cost	808	1.50	0.00	1.50	1.50
RAC	808	8.50	0.00	8.50	8.50
Feed cost (Calf-fed)	450	166.15	14.09	140.68	197.44
Feed cost (Yearling-fed)	358	266.21	24.98	222.16	331.04

Source: Statistics Canada 2018; Canfax Trends West 2017.
Notes: General operational expense includes total machinery expenses (small tool expenses, net fuel expenses, machinery, truck, etc.) and salaries, rent expenses and insurance expenses, and it is calculated using the following formula: general operational expense ($\$\ \mathrm{head}^{-1}$) = average general expense per farm * number of beef cattle farm in Alberta / number of beef cattle raised in Alberta. [c] Maximum monthly feeder calf purchase price between the year 2002 and 2016. Minimum monthly feeder calf purchase price between year the 2002 and 2016.

From Table 11 we can see that feeder steer purchase cost and feed cost are the most significant costs of raising cattle for a feedlot. The mean value of feeder calf costs ($\$\ \mathrm{head}^{-1}$) that are calculated with the maximum and the minimum value feeder steer unit price ($\$\ \mathrm{kg}^{-1}$) are \$1,064.12 head^{-1} and \$702.24 head^{-1} respectively. As Equation (3.10) shows, per head feeder calf cost is calculated with feeder steers' weight (kg) at placement and unit price of feeder steer ($\$\ \mathrm{kg}^{-1}$). Using the maximum and the minimum value of feeder steer unit price ($\$\ \mathrm{kg}^{-1}$) over time this study examined were selected, and the placement weights are differentiated among animals. Therefore, feeder calf costs ($\$\ \mathrm{head}^{-1}$) that are calculated with the maximum (minimum) value of feeder steer unit price varied between \$1,732.59 head^{-1} (\$446.85 head^{-1}) and \$4,125.95 head^{-1} (\$1,064.12 head^{-1}) with a mean value of \$2722.82 head^{-1}(\$702.24 head^{-1}). The feed cost of calf-fed and yearling-fed group are \$166.15 head^{-1} and \$266.21 head^{-1} respectively. General operational expense per head is calculated from average operational expense per farm multiplied by the number of farms in Alberta and then divide the obtained number by the total number of beef cattle raised in Alberta. The calculated general operational expense (\$486.14 head^{-1}) is used as the fixed cost of a typical across all Alberta farms.

Table 11 also shows that feeder calf purchase cost is the largest part of a feedlot's total cost. In order to account for the price risk stemming from both input and output prices, the analyses of revenue and profitability is conducted under four market price scenario based on the maximum and minimum value of feeder calf purchase prices and fed steer selling prices (see Section 3.3.1.2). Systems profitability is then calculated for both production systems, which comprises eight scenarios in total. The outcomes of the eight scenarios and summary statistics of related revenues and profits are presented in Table 12.

Table 12. Summary Statistics of Economic Variable in Different Scenarios of Two Production Systems

	VARIABLES	N	Mean	S.D.	Min	Max
	Revenue with maximum fed rail price	808	2,204.31	344.77	1,291.10	3,094.41
	Revenue with minimum fed rail price	808	705.44	120.17	341.56	1,083.40
	Profit of Calf-fed Group					
Scenario	(1) Max fed rail price, max feeder calf price	450	-1,059.93	149.93	-1,417.00	-614.82
	(2) Max fed rail price, min feeder calf price	450	790.35	199.63	114.44	1,200.45
	(3) Min fed rail price, max feeder calf price	450	-2,492.22	192.11	-2,998.04	-2,010.41
	(4) Min fed rail price, min feeder calf price	450	-641.94	53.52	-859.62	-493.66
	Profit of Yearling-fed Group					
Scenario	(5) Max fed rail price, max feeder calf price	358	-1,470.61	150.24	-2,079.39	-1,076.08
	(6) Max fed rail price, min feeder calf price	358	764.47	288.39	92.49	1,395.38
	(7) Min fed rail price, max feeder calf price	358	-3,053.18	373.63	-4,169.87	-2,380.21
	(8) Min fed rail price, min feeder calf price	358	-818.11	100.58	-1,250.25	-615.62

As Table 12 shows, there is a significant difference between the mean value of revenue calculated with maximum and minimum fed cattle rail prices (\$2204.31 head^{-1} versus \$705.44 head^{-1}). For both production systems, scenarios with maximum fed cattle rail price and minimum feeder calf price [(2) for calf-fed group and (6) for yearling-fed group] generate the profit distribution with the highest mean value. Scenarios with minimum fed cattle price and minimum feeder calf price [(4) for calf-fed group and (8) for yearling-fed group] generate the profit distribution with the second highest mean value; and scenarios with minimum fed cattle price and minimum feeder calf price [(3) for calf-fed group and (7) for yearling-fed group] generate the profit distribution with the smallest mean value.

The data adjustment process generates the following limitations of the results. The first limitation pertains to the generation of days on feed. As previously mentioned, we assumed that days on feed the cattle spent in feedlot follows uniform distribution and is constrained between 90 to 120 days. This randomly generated days on feed could prevent examining the growth gains through feed a high energy diet for a long period. Besides, it also prevents us from examining if longer days on feed can lead to heavier dressed carcass weight and therefore more revenue. The assumption is strong given that the relationship between post-weaned days to slaughter and feed duration in the feedlot is not clear. The possible relationships could be: (1) the animal that was kept longer was probably fed longer, days on feed would be heavily skewed towards 120 days; (2) older animals would be heavier already and would spend less time on feed to not overshoot weight targets. However, there are likely circumstances where either case is true, so we finally decided to stick to the assumption to assign days on feed randomly between 90-120 days.

The second limitation also pertains to the cattle production data set. We assumed that animals with post-weaned days to slaughter greater than 340 days are identified as yearling-fed group; animals with post-weaned days to slaughter less than 309 days are identified as calf-fed group. There is still a pre-feedlot period time when the calves are fed with grass or cheap feed before the final diet. Producers adjust this timing depending on the market; however, after data adjustment, the average value of these pre-feedlot days of feed with grass is very large. This shortfall would be hard to address since cattle production experiment focused more on animal science information and did not collect specific information that is necessary for economic analysis.

Similar to the first two limitations, the third limitation is also due to the lack of information from the cattle production data set. We calculated the placement weight based on the assumption that cattle's body weight grows in a linear relationship with age. From an animal science perspective, cattle's body weight growth and age may not follow an exact linear relationship; however, given that only weaning weight (age) and slaughter weight (age) are available in the data set, the linear relationship would be a fair assumption.

3.4. Methodology

This section introduces the three methodological approaches used to investigate the three objectives of this chapter. The first part of the methodology is to adopt ordered logit model to analyze the effect of cattle's breed composition and production systems on carcass characteristics. The second part is to estimate ordinary least squares (OLS) regression model to examine the effect of cattle's performance and carcass characteristics on producers' profitability. The third part is to generate expected profit through simulation, to do scenario analyses on the break-even dressed carcass weight, and to calculate the probability of positive profit.

3.4.1. Ordered logit model on the probability of quality grade, yield grade, and dressed carcass weight class

Given the fact that the quality grade is classified as four categories (A, AA, AAA, and Prime), yield grade is classified as three categories (Y3, Y2, and Y1) and dressed carcass weight is classified as four categories (smaller than or equal to 249.5kg, 249.5 to 430.9kg, 430.9 to

453.6kg, and greater than or equal to 453.6kg), the ordered multiresponse model would be the best fitted method to be applied. Multiresponse models are developed to describe the probability of each of the possible outcomes as a function of alternative specific characteristics. This model aims at describing the probabilities with a limited number of unknown parameters and in a logically consistent way. Namely, the probability of each outcome should lie between 0 and 1, and all alternatives should add up to 1 (Verbeek 2012).

The intuition behind the ordered multiresponse model is that there is assumed to exist one underlying latent variable that drives the choice between the alternatives. That being said, the results will be sensitive to the ordering of the alternatives, so there must exist a logical ordering of the alternatives (Verbeek 2012). In our analyses, three ordered response models are constructed with respect to quality grade, yield grade and dressed carcass weight class. The categories of the three dependent variables indeed have a logical ordering, since quality grade is evaluated based on marbling score, yield grade is evaluated based on lean yield percentage, and dressed carcass grade is divided into different classes. Specifically, the three ordered logit models are developed to investigate the effect of breed composition and production systems on the probability that carcass falls into each category of the quality grade, yield grade and dressed carcass weight class. We chose the quality grade, yield grade and dressed carcass weight class, instead of the underlying variables (i.e., marbling score, lean yield percentage and dressed carcass weight), as dependent variables in the three models. The reason is that the cattle producers receive premium and discounts based on the grade rather than the specific carcass characteristics. It is more relevant to provide fed cattle producers with information on improving probability on achieving higher grades since the incentive and penalty are given for the grades.

According to Verbeek (2012), the ordered response model is based on one underlying latent variable but with a different match from the latent variable, y_i^*, to the observed one ($y_i = 1,2, \dots . M$). There is a logical ordering in the M alternatives, numbered from 1 to M, and it can be described as follows:

$$y_i^* = x_i\beta + \varepsilon_i \tag{3.16}$$

$$y_i = j \; if \; \gamma_{j-1} < y_i^* \leq \gamma_j \tag{3.17}$$

For unknown γ_js with $\gamma_0 = -\infty$, $\gamma_1 = 0$ and $\gamma_M = \infty$. Consequently, the probability that alternative j is chosen is the probability that the latent variable $y_i^*$is between two boundaries γ_{j-1} and γ_j, assuming that ε_i is i.i.d. standard normal results in ordered probit model. The logistic distribution gives the ordered logit model. Estimating ordered logit model uses maximum likelihood estimation, which is an iterative procedure. At the first iteration (called iteration 0) is the log likelihood of the “null” or “empty” model; that is a model with no predictors. At the next iteration, the predictors are included in the model. At each iteration, the log likelihood increases because the overall goal is to maximize the log likelihood. The model is noted as “converged” when the difference between successive iterations is very small (Long and Freese 2006).

The three ordered logit models of quality grade, yield grade and dressed carcass weight class will be built based on the same set of explanatory variables, and are specified as follows:

$$MARBLE \tag{3.18}$$

$$LEANYIELD \qquad = \qquad X\beta + \varepsilon \tag{3.19}$$

$$DCW \tag{3.20}$$

where latent variable $MARBLE$, $LEANYIELD$, and DCW are the marbling score, lean yield percentage and dressed carcass weight range of each animal; X refers to the vector of the cattle carcass characteristics and growth treatment that can affect cattle's marbling score, lean yield percentage, and dressed carcass weight. βs are the parameters to be estimated;Xs that are examined in this model include: weaning age, days on feed in feedlots, pre-feedlot days after weaned, birth weight, weaning weight, placement weight, dummy variables for five breed composition with anguscross cattle being the reference group, dummy variables for three growth treatment (diet experiment, implant treatment, and RAC treatment); and ε are error terms. Estimation is based upon the maximum likelihood, where the below probabilities enter the likelihood function. A positive β means that the corresponding cattle's carcass marbling score increases as certain characteristics increases. The match of the underlying latent variables and the observed dependent variables of the three models are as follows:

$$Quality\ Grade = \begin{cases} 1\ if\ 300 \leq MARBLE \leq 399 \\ 2\ if\ 400 \leq\ MARBLE \leq 499 \\ 3\ if\ 500 \leq MARBLE \leq 799 \\ 4\ \ if\ MARBLE \geq 0800 \end{cases} \tag{3.21}$$

$$Yield\ Grade = \begin{cases} 1\ \ if\ LEANYIELD \leq 53 \\ 2\ \ if\ 54 \leq\ LEANYIELD \leq 58 \\ 3\ if\ LEANYIELD \geq 58 \end{cases} \tag{3.22}$$

$$DREWT = \begin{cases} 1\ \ if\ \ DCW \leq\ \ 249.5\ kg \\ 2\ if\ 249.5 \leq\ \ DCW \leq 430.9\ kg \\ 3\ if\ 430.9 < DCW \leq 453.9\ kg \\ 4\ if\ DCW \geq 453.9\ kg \end{cases} \tag{3.23}$$

where $Quality\ Grade$ refers to the quality grade of cattle carcass. $Quality\ Grade$ equals to 1 when the cattle carcass is graded as A; $Quality\ Grade$ equals to 2 when the cattle carcass is graded as AA; and $Quality\ Grade$ equals to 3 when the cattle carcass is regarded as AAA; and $Quality\ Grade$ equals to 4 when the cattle carcass is graded as Prime. $Yield\ Grade$ is the yield grade of cattle carcass. $Yield\ Grade$ equals to 1 when cattle carcass is graded as Y1; $Yield\ Grade$ equals to 2 when cattle carcass is graded as Y2; $Yield\ Grade$ equals to 3 when cattle carcass is graded as Y3. $DREWT$ is the dressed carcass weight class. $DREWT$ equals to 1 when the dressed carcass weight is less than 249.5 kg; $DREWT$ equals to 2 when the dressed carcass weight is between 249.5 and 430.9 kg; $DREWT$ equals to 3 when the dress carcass weight is between 430.9 to 453.9 kg grade; $DREWT$ equals to 4 when dressed carcass weight is greater than 453.9 kg.

3.4.2. Ordinary least square (OLS) regression model on the determinants of net return

This part of analyses applies ordinary least square (OLS) model to investigate the effect of cattle's breed composition, production systems and treatment on the cattle feeding profitability of both calf-fed and yearling-fed cattle. OLS regression model on cattle raising profit is as well applied by several other research of economic analyses on the cattle feeding profitability (Schroeder et al. 1993, Lawrence et al. 1999 and Lusk 2007). In Schroeder et al.'s 1993 study and Lawrence et al.'s 1999 study, the explanatory variables of profit model are economic variables, such as base rail price of fed cattle, feeder calf price, feed price and dummy variables of different grade categories. Whereas Lusk's study regressed profit of raising cattle on the cattle production variables, i.e., cattle's growth performance and carcass characteristics. The OLS analyses of our study will be similar to the latter one. Particularly, the basic variables of our OLS regression can be divided into four groups: time of different production phases, i.e., weaning age, days on feed in feedlots, pre-feedlot days after weaned; animal's body weight at different production phases (i.e., birth weight, weaning weight, placement weight and slaughter weight); dummy variable for each breed composition (i.e., *continentalcross, herefordanguscross, herefordcross, highangus,* and *highhereford,* with *anguscross* being the reference category); and dummy variable for each treatment (i.e., diet experiment, implant treatment and RAC treatment).

Being emphasized by Dr. Juárez and Dr. Roberts and the previously mentioned studies by López-Campos et al. (2013) and Retallick et al. (2013), interaction terms (i.e., interactions between breed composition and implant; interactions between breed composition and RAC treatment) will be of great importance from perspective of animal science. This analysis adds the multiple interactions as regressors in the OLS regression model through a stepwise process. For the sake of parsimony of the regression model, the OLS model only incorporates significant interaction terms through a stepwise process. The stepwise process is as follows. The first step is to run a model with the basic variables including continuous variables and categorical variables, as well as interactions between dummy variables for breed compositions and dummy variables for implant treatment. After running the regression, the model only keeps the significant interaction terms. The second step is to add the interactions between dummy variables for breed compositions and dummy variables for RAC treatment to the model from last step. The insignificant interaction terms are dropped from the model. The last step is to run the model with basic variables and the significant interaction terms from last two steps and obtained the final estimate results.

The regression model of profit is specified as equation (3.24). Compared with the regression specification, equation (3.25) that is defined in Section 3.3.1.2 is an accounting identity that calculates the net profit per head based on actual price and quantity.

$$PROFIT = \beta_0 + + \beta_1 BREED + \beta_2 TRT + \beta_3 GROWTH + \beta_4 CARCASS + + \beta_5 BREED * TRT \tag{3.24}$$

$$PROFIT = TR - FDRC - FDC - OVC - FC \tag{3.25}$$

In equation (3.24), $PROFIT$ denotes profit ($\$\ \text{head}^{-1}$) of raising cattle; β_0 to β_5 are the parameters to be estimated. $BREED$ denotes the dummy variable for breed composition of each cattle including *continentalcross, herefordanguscross, herefordcross, highangus* and *highhereford,* which takes the value of 1 when the cattle belong to that breed composition and 0 otherwise with $anguscross$ being the reference category. TRT refers to the dummy variable for different growth treatments, i.e., diet experiment, implant treatment and RAC treatment which takes the value of 1 if the treatment is imposed and 0 otherwise. $GROWTH$ denotes the vector of growth performance variables (i.e., weaning age, birth weight, weaning weight, days on feed, etc.). CARCASS is the vector of carcass characteristics variables (i.e., dressed carcass weight, lean yield percentage, marbling score, etc.). $BREED * TRT$ are the interaction terms between different breed composition and treatments.

3.4.3. Simulating data based on sample distribution

The process of profit simulation in this section characterizes production risk in fed cattle production by accounting for characteristics that affect the cattle production yield factors. The objectives of this section are (1) to find the distribution of cattle production yield variables of sample data, simulate for 10,000 times based on the sample distribution; (2) generate revenue with the 10,000 simulated cattle dressed carcass variables; (3) calculate profit with the revenue and cost; and (4) find the break-even dressed carcass weight and calculate the probability of positive profit from the distribution of 10,000 simulated data. The simulation steps are specified as follows:

3.4.3.1. Step 1: Run OLS regression on dressed carcass weight

The ordinary least-square (OLS) model on dressed carcass weight is specified as follows:

$$DREWT = \alpha + \beta X + \gamma Z + \varepsilon \qquad (3.26)$$

where *DREWT* denotes dressed carcass weight; *X* refers to a vector of continuous explanatory variables (i.e., cattle performance and carcass characteristics) that affect dressed carcass weight; *Z* refers to a vector of categorical variables (i.e., breed composition, diet experiment, implant treatment, or RAC treatment) that affect dressed carcass weight. After running the regression in equation (3.26), coefficient estimates for α, β, γ are recorded for later use.

3.4.3.2. Step 2: Find the best fitted distributions of explanatory variables

Test the distribution of continuous variables, find the best fitted distribution of each variable and obtain the coefficient of the specific distribution; test frequency of the presence of categorical variables. The best fitted distributions of continuous variables are detected using PROC SEVERITY (SAS Institute, Inc.2009). This command of SAS software provides several different distributions of the variables with AIC of each distribution; the distribution with smallest AIC is selected. Simulation of categorical variables (i.e., breed composition, growth treatment, etc.) depends on the frequency of presence of each category. The frequency of simulated data is the same as that of sample data.

3.4.3.3. Step 3: Random draw data generation based on best fitted distributions and calculate the break-even dressed carcass weight

Simulate continuous explanatory variables, $\hat{X}$ (i.e., cattle performance and carcass characteristics), through random draw process based on best fitted distributions; simulate categorical explanatory variables, $\hat{Z}$ (i.e., breed composition, diet experiment, implant treatment, or RAC treatment), based on their frequencies in sample data. Simulate error term assuming it follows normal distribution with mean equal to zero and standard deviation of error term $\hat{\varepsilon}$ obtained from regression results in equation (3.26). $\widehat{\mathrm{DREWT}}$ can be calculated with the following formula:

$$\widehat{DREWT} = \alpha + \beta\hat{X} + \gamma\,\hat{Z} + \varepsilon \tag{3.27}$$

where $\widehat{\mathrm{DREWT}}$ denotes the generated dressed carcass weight, $\hat{X}$ stands for the simulated continuous cattle production variables, $\hat{Z}$ represents the simulated categorical variables, and estimated coefficients α, βs and γs are obtained from regression estimates from Step 1.

3.4.3.4. Step 4: Calculate profit with simulated data

Calculate the profit per head using the formula (3.25) with simulated variables so that there are 10,000 observations of PROFIT. Equation (3.25) can also be converted as follows:

$$PROFIT = \widehat{DREWT} * \widehat{PFED} - \widehat{FDRC} - \widehat{FDC} - OVC - FC \tag{3.28}$$

where $\widehat{DREWT}$ refers to the simulated dressed carcass weight, $\widehat{PFED}$ refers to the simulated fed cattle prices ($\$\ \mathrm{kg}^{-1}$), which is assigned based on the simulated marbling score, lean yield percentage and dressed carcass weight. $\widehat{FDRC}$ refers to simulated feeder calf cost ($\$\ \mathrm{head}^{-1}$), which is obtained by multiplying simulated placement weight (kg) by unit feeder calf price ($\$\ \mathrm{kg}^{-1}$); $\widehat{FDC}$ refers to simulated feed cost ($\$\ \mathrm{head}^{-1}$), and is obtained using the following formula:

$$\widehat{FDC} = DMI * \widehat{DOF} * CDM \tag{3.29}$$

where $\widehat{\text{DOF}}$ is the simulated days on feed, DMI and CDM are the dry matter intake (kg $\text{head}^{-1}\ \text{day}^{-1}$) and the cost of dry matter cost (\$ kg^{-1}) which are obtained from the paper by López-Campos et al. (2013). After obtaining the distribution of profit with 10,000 observations, the break-even dressed carcass weight is calculated by setting profit equal to zero, which is the point that a feedlot starts to make profits. The probability of positive profit is calculated by dividing the number of positive profit observations by 10,000. Both break-even dressed carcass weight and probability of profitability are calculated under the four baseline price scenarios of both calf-fed and yearling-fed production systems that are classified based on the maximum and the minimum value of fed cattle rail price and the maximum and the minimum value of feeder calf cost over 2004 to 2016 (see Section 3.3.3.3).

In addition, the probabilities of positive profit in these baseline scenarios are compared with alternative scenarios where the probabilities of positive profit are calculated with the interventions of removing each of the treatments. That is, the probabilities of positive of scenarios without implant treatment, the scenario with routine diet, and the scenario without RAC treatment under both production systems. The comparison would provide the indication on the effect of growth treatment on the probability that the feedlot earns profits.

3.5. Results

The first part of the result is of particular interest to the producers who intend to produce the beef of the specific grade with premium. The ordered logit models on quality grade, yield grade, and dressed carcass weight classes show the effect of cattle performance, carcass characteristics, growth treatment, and production systems on the probability that cattle carcass falls into each grade category. The second part of result provides insights into the different effect of production factors on the profitability under four price scenarios. And the third part of result presents the calculation of the break-even dressed carcass weight and probability of positive profit under different price scenarios, and the variation of the probability of positive profit in the scenarios with the interventions of removing each of the three growth treatments (including diet experiment, implant treatment, and RAC treatment) removed.

To interpret the results clearly, this section categorizes the explanatory variables in the first two parts of result into four groups: the timing of different production phases (including weaning age, days on feed, and pre-feedlot days after weaned); the affiliated animal's body weight at each production phase (including birth weight, weaning weight, and placement weight); cattle's breed composition (including *continentalcross, herefordanguscross, herefordcross, highangus* and *highhereford*); and growth treatment (including experimental diet, implant treatment, and RAC treatment).

3.5.1. Results of ordered logit models

This section will present the marginal effects at the means (MEMS) of the explanatory variables in the three ordered logit models. Marginal effects are interpreted differently for discrete (i.e., categorical) and continuous variables. Particularly, on the basis of all other categorical variables being equal and all continuous variables being at their mean values, the marginal effects for discrete variables measure the predicted probabilities change as the binary independent variable changes from 0 to 1; the marginal effect for continuous variables measure the instantaneous rate of change. The marginal effect of each category of the ordered logit model would sum up to zero, for if the cattle carcass is more likely to fall in one category, it would be less likely to fall in other categories.

3.5.1.1. Ordered logit model on quality grade

Table 13 presents the marginal effects at means (MEMS) of the explanatory variables on the probability of cattle carcass that fall into each quality grade category for the calf-fed production system and the yearling-fed production system. In both production systems, the model of Prime grade carcass is dropped because there are too few observations. Growth treatment has the most critical impact on the quality grade assignment for both calf-fed and yearling-fed cattle followed by the breed composition and cattle's weight at different production phases.

First, Table 13 shows that among all the production factors (including cattle performance, carcass characteristics, growth treatment, and production systems), two of the growth treatments evaluated in this study, diet experiment and implant treatment, have the most substantial impact on the quality grade assignment for both calf-fed and yearling-fed groups. Both growth treatments have more significant impacts on the quality grade assignment of yearling-fed cattle than that of calf-fed cattle. For instance, the calf-fed and yearling-fed cattle that are fed with experimental diet, on average, have a higher probability (17.8% and 21% respectively) of achieving a grade A and AA. Meanwhile, such cattle have a lower probability (17.8% and 20.9% respectively) of achieving a grade AAA than cattle fed with routine diet, keeping other categorical variables equal and continuous variables at their mean values. Correspondingly, the calf-fed and yearling-fed cattle with implant treatment are associated with a higher likelihood (22.9% and 42% respectively) of achieving a grade A and AA and a lower likelihood (22.8% and 41.8% respectively) of achieving a grade AAA. Therefore, the implant treatment and experimental diet negatively affect the probability of achieving a high quality grade (AAA) beef. This result is consistent with the previous studies which found that even though growth implant can boost the feed efficiency, weight gain and muscle growth, it negatively affects meat quality traits through decreased marbling scores and quality grade (Roeber et al. 2000; Reiling and Johnson 2003). Given that there is sufficient literature have already proved that hormonal growth promotants can improve beef production while at a price of lower marbling score (Beef Cattle Research Council 2013), this study concurs the finding from an economic perspective. RAC treatment is proved to have no significant impact on quality grade, which is consistent with the finding by Winterholler et al. (2007).

Table 13. Marginal Effects of Explanatory Variables on the Probability of the Carcass being in Each Category of the Quality Grade under Both Production Systems

	Calf-fed Group			Yearling-fed Group		
VARIABLES	Marginal Effect (A)	Marginal Effect (AA)	Marginal Effect (AAA)	Marginal Effect (A)	Marginal Effect (AA)	Marginal Effect (AAA)
	Timing of production phases					
Weaning age	-0.001*	-0.002*	0.003*	-0.000	-0.001	0.002
	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Days on feed	-0.001	-0.007***	0.008***	-0.000	-0.005**	0.007**
	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)	(0.003)
Pre-feedlot days after weaned	0.001***			0.001***		
	(0.000)			(0.000)		
	Animal weights at different production phases					
Birth weight	0.006***	0.022***	-0.028***	0.007***	0.023***	-0.030***
	(0.001)	(0.004)	(0.005)	(0.002)	(0.006)	(0.007)
Weaning weight	0.001***	0.003***	-0.004***	0.001***	0.004***	-0.005***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Placement weight	-0.001***	-0.005***	0.007***	-0.001***	-0.003***	0.004***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
	Breed composition					
Dummy for Continentalcross	0.075**	0.124***	-0.198***	0.029	0.067	-0.095
	(0.033)	(0.025)	(0.050)	(0.031)	(0.052)	(0.083)
Dummy for Herefordanguscross	-0.020*	-0.109	0.128	0.002	0.007	-0.010
	(0.012)	(0.082)	(0.092)	(0.023)	(0.067)	(0.089)
Dummy for Herefordcross	-0.021*	-0.113	0.133	0.000	0.001	-0.001
	(0.012)	(0.086)	(0.097)	(0.022)	(0.067)	(0.089)

Table 13. Cont.

	Calf-fed Group			Yearling-fed Group		
	Marginal Effect (A)	Marginal Effect (AA)	Marginal Effect (AAA)	Marginal Effect (A)	Marginal Effect (AA)	Marginal Effect (AAA)
Dummy for Highangus	0.000	0.001	-0.002	-0.029**	-0.105*	0.132*
	(0.011)	(0.042)	(0.053)	(0.014)	(0.061)	(0.074)
Dummy for Highhereford	-0.010	-0.047	0.057	-0.035*	-0.179	0.213
	(0.027)	(0.151)	(0.176)	(0.019)	(0.151)	(0.167)
Treatments						
Dummy for Diet Experiment	0.070*	0.108***	-0.178***	0.057***	0.153***	-0.209***
	(0.041)	(0.023)	(0.057)	(0.022)	(0.051)	(0.069)
Dummy for Implant Treatment	0.065***	0.164***	-0.228***	0.274***	0.146***	-0.418***
	(0.024)	(0.037)	(0.055)	(0.069)	(0.049)	(0.047)
Dummy for RAC	0.004	0.014	-0.017	0.011	0.030	-0.040
	(0.016)	(0.057)	(0.073)	(0.023)	(0.059)	(0.081)
Observations	450	450	450	358	358	358
	Weaning age = 192.3178 (mean) Days on feed = 104.4745 (mean) Pre-feedlot days after weaned = 140.81 (mean) Birth weight = 41.43691 (mean) Weaning weight = 271.3985 (mean) Placement weight = 433.7942 (mean)			Weaning age = 186.2039 (mean) Days on feed = 408.8352 (mean) Pre-feedlot days after weaned = 105.271 (mean) Birth weight = 41.38304 (mean) Weaning weight = 255.1441 (mean) Placement weight = 524.0168 (mean)		

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; NOTE: All predictors at their mean value

The second most influential production factor on the quality grade outcome is the cattle's breed composition for both production systems. Calf-fed *continentalcross, herefordanguscross,* and *herefordcross* cattle show significantly different impacts on quality grade outcome from *anguscross* cattle, whereas yearling-fed *highangus* and *highhereford* cattle show significantly different impacts from *anguscross* cattle. In calf-fed group, *continentalcross* cattle is about 19.8% less likely to fall into grade AAA in comparison to *anguscross* cattle; holding all other categorical variables equal and continuous variables at their mean values: weaning weight (192.32), days on feed (104.47), pre-feedlot days after weaned (140.81), birth weight (41.44), weaning weight (271.40) and placement weight (433.7942). *Herefordanguscross* and *herefordcross* calf-fed cattle both have about a 2.0 % lower probability of being classified as grade A than *anguscross* cattle but do not show a significantly different probability of being AA or AAA than *anguscross* cattle. In the yearling-fed production system, *highangus* cattle are about 13.2% more likely to fall into grade AAA in comparison to *anguscross* cattle. These results imply that calf-fed *anguscross* cattle are associated with higher potentialities of producing AAA beef. Correspondingly yearling-fed *highangus* cattle is shown to have a higher likelihood to receive high quality grades than *anguscross* cattle. Overall, the results are in line with previous studies, which found that there is a considerable economic value of breed composition selection for the feedlot industry (Thompson et al. 2016; DeVuyst et al. 2007; Lusk 2007).

The timing of different production phases and the affiliated cattle's body weights exert minor impacts on the cattle carcasses' quality grade assignment. Generally, the two factors have larger impacts on yearling-fed cattle than on calf-fed cattle, and the results could provide some information with respect to the herd management. The marginal effect of timing of the different production phases indicates that for calf-fed cattle, weaning the animal later will raise the probability of getting AAA beef. However, this result is qualified by the coefficient estimate for weaning weight of calf-fed cattle. With an additional kg bodyweight at weaning the likelihood of AAA marbling at slaughter is reduced by 0.4%. This could be an indication of the balance between the timing of weaning and the calves' weaning weight, for weaning the calves later could relieve their pressure and further raise the probability of achieving high quality grade; however, the potential higher weaning weight could reduce the possibility of high quality grade. Overall, the results are consistent with the results of (Schoonmaker et al. 2002), who reported that early weaned, non-implanted cattle tended to have greater marbling score. Longer days on feed for both calf-fed and yearling-fed cattle could have a higher probability of producing AAA beef. For instance, the producers who feed cattle for one more day would raise the probability of producing AAA beef by 0.8% and 0.7% for calf-fed and yearling-fed cattle, respectively, keeping all categorical variables equal and all other continuous variables at their mean.

Placement weight shows a positive impact on the probability of achieving AAA beef. The cattle with one more kg of body weight when they enter the feedlot are associated with 0.7% and 0.4% higher potentiality to be graded as AAA. Birth weight and weaning weight show negative impacts on the probability of achieving AAA beef. For instance, the calves of calf-fed (yearling-fed) system with one kg higher body weight at weaning are associated with a

0.4% (0.5%) lower likelihood to be graded as AAA. Cow calf producers of both production systems who are good at managing cow calf herd and controlling calves' body weight at each production phase could improve the potentiality of producing AAA carcass. Therefore, the results regarding the timing of different production phases and the cattle's body weight are essential since producers could directly control these factors of herd management to raise the likelihood of producing AAA carcass and further improve the profitability of cattle.

Table 14 presents the marginal effects of explanatory variables on the probability of cattle carcasses' yield grade assignment for the calf-fed group and the yearling-fed group. Breed composition of cattle exerts the most important impact on the yield grade assignment for both calf-fed and yearling-fed groups, followed by growth treatment and cattle's body weight at different production phases.

Breed composition shows the most significant impact on the cattle carcasses' yield grade outcome for both calf-fed and yearling-fed groups. In comparison to anguscross cattle, both calf-fed and yearling-fed continentalcross cattle are associated with higher potentiality (35.2% and 26.9% respectively) of achieving high yield grade (Y1), and calf-fed anguscross cattle show a higher probability (27.7% and 19.5%) of achieving Y1 than herefordanguscross and highhereford cattle, respectively, holding other categorical variables equal and all continuous variables at their mean. Overall, the results that breed composition could affect the yield grade outcome are consistent with the finding reported by Lusk (2007) who suggested that genotype was associated with variations in lean yield and tenderness in beef cattle.

3.5.1.2. Ordered logit model on yield grade

Table 14. Marginal Effects of Explanatory Variables on the Probability of the Carcass being in Each Category of the Yield Grade under Both Production Systems

	Calf-fed Group			Yearling-fed Group		
VARIABLES	Marginal Effect (Y3)	Marginal Effect (Y2)	Marginal Effect (Y1)	Marginal Effect (Y3)	Marginal Effect (Y2)	Marginal Effect (Y1)
			Timing of production phases			
Weaning age	-0.000	-0.000	0.000	-0.001	-0.001	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Days-on-feed	-0.002	-0.002	0.003	0.003*	0.002*	-0.005*
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.003)
Pre-feedlot days after weaned	-0.002***	-0.002***	0.004***	-0.001**	-0.001**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
			Animal weights at different production phases			
Birth weight	-0.009***	-0.009***	0.018***	-0.009***	-0.008***	0.016***
	(0.003)	(0.002)	(0.005)	(0.003)	(0.003)	(0.005)
Weaning weight	-0.002***	-0.002***	0.004***	-0.000	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Placement weight	0.002***	0.002***	-0.004***	0.002***	0.002***	-0.004***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
			Breed composition			
Dummy for Continentalcross	-0.102***	-0.250***	0.352***	-0.102***	-0.167***	0.269***
	(0.019)	(0.069)	(0.083)	(0.023)	(0.053)	(0.071)
Dummy for Herefordanguscross	0.252***	0.025	-0.277***	0.029	0.021	-0.050
	(0.073)	(0.036)	(0.044)	(0.052)	(0.034)	(0.086)
Dummy for Herefordcross	0.046	0.035	-0.081	-0.015	-0.014	0.030
	(0.045)	(0.024)	(0.069)	(0.035)	(0.036)	(0.071)

Table 14. Cont.

	Calf-fed Group			Yearling-fed Group		
Variable	Marginal Effect (Y3)	Marginal Effect (Y2)	Marginal Effect (Y1)	Marginal Effect (Y3)	Marginal Effect (Y2)	Marginal Effect (Y1)
Dummy for Highangus	-0.004	-0.004	0.007	0.043	0.033	-0.076
	(0.022)	(0.023)	(0.044)	(0.028)	(0.021)	(0.049)
Dummy for Highhereford	0.152	0.043*	-0.195**	-0.010	-0.009	0.019
	(0.116)	(0.025)	(0.096)	(0.066)	(0.064)	(0.130)
	Treatments					
Dummy for Diet Experiment	0.146**	0.047***	-0.192***	0.119***	0.084***	-0.203***
	(0.070)	(0.016)	(0.062)	(0.034)	(0.023)	(0.053)
Dummy for Implant Treatment	-0.009	-0.010	0.019	-0.063**	-0.063**	0.126**
	(0.027)	(0.029)	(0.056)	(0.029)	(0.031)	(0.058)
Dummy for RAC	0.063	0.044**	-0.107*	0.037	0.028	-0.066
	(0.046)	(0.020)	(0.064)	(0.042)	(0.027)	(0.069)
Observations	450	450	450	358	358	358
			Weaning age = 192.3178 (mean)			Weaning age = 186.2039 (mean)
			Days on feed = 104.4745 (mean)			Days on feed = 408.8352 (mean)
			Pre-feedlot days after weaned = 140.81 (mean)			Pre-feedlot days after weaned = 105.271 (mean)
			Birth weight = 41.43691 (mean)			Birth weight = 41.38304 (mean)
			Weaning weight = 271.3985 (mean)			Weaning weight = 255.1441 (mean)
			Placement weight = 433.7942 (mean)			Placement weight = 524.0168 (mean)

Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$; NOTE: All predictors at their mean value

After breed composition, growth treatments play the second most important role in affecting yield grade assignments for both calf-fed and yearling-fed cattle. Compared against the experimental diet, the routine diet shows a positive effect on improving the probability of achieving Y1 by 19.2% and 20.3% for calf-fed and yearling-fed cattle, respectively. Calf-fed cattle treated with RAC are about 10.7% less likely to achieve Y1 than those without RAC treatment. This result confirms the previous study which concluded that adoption of β-adrenergic agonist (RAC treatment) had a negative impact on yield grades (Winterholler et al. 2007). Therefore, in line with other studies, this analysis emphasizes that RAC treatment of calf-fed cattle may stand against many producers' objective to produce high yield grade beef animals.

Both the timing of different production phases and the affiliated cattle's body weight have a minor impact on yield grade assignments for both production systems. Different from quality grade outcomes, a higher placement weight is associated with a lower potentiality of Y1 beef. The cattle with one kg higher placement weight is about 0.4% less likely to be graded as Y1 for both calf-fed and yearling-fed production systems. Such result could be an indication that operators a feedlot face a trade-off between raising the probability of a high quality grade at the expense of a declined probability of a high yield grade when they select feeder calves, as a calf with higher body weight when it enters a feedlot has opposite effects on the probability of achieving a high quality grade and a high yield grade.

3.5.1.3. Ordered logit model on dressed carcass weight class

As mentioned in Section 3.4.1, the convergence of logit model is required through an iteration process. The dressed carcass weight model for the calf-fed and yearling-fed cattle groups can not converge, this section will present the logit model of dressed carcass weight category with the calf-fed and yearling-fed groups combined. The revamped model combining the data will allow for a convergence to occur.

Table 15. Marginal Effects of Explanatory Variables on the Probability of the Carcass being in Each Dressed Carcass Weight Class (Calf-fed and Yearling-fed Groups Combined)

Variable	Marginal Effect (less than 249.5 kg)	Marginal Effect (249.5 to 430.9 kg)	Marginal Effect (430.9 to 453.6 kg)	Marginal Effect (greater than 453.6 kg)
Timing of production phases				
Weaning age	-0.000***	0.000	0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Days-on-feed	-0.002***	0.000	0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Pre-feedlot days after weaned	0.000***	-0.000	-0.000*	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Animal weights at different production phases				
Birth weight	0.001	-0.000	-0.000	-0.001
	(0.001)	(0.000)	(0.000)	(0.000)
Weaning weight	0.001***	-0.000	-0.000**	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Placement weight	-0.002***	0.000	0.000*	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Breed composition				
Dummy for Continentalcross	-0.014**	-0.001	0.003	0.012**
	(0.006)	(0.002)	(0.003)	(0.005)
Dummy for Herefordanguscross	0.004	-0.000	-0.001	-0.003
	(0.010)	(0.001)	(0.002)	(0.006)
Dummy for Herefordcross	0.008	-0.001	-0.002	-0.005
	(0.009)	(0.002)	(0.002)	(0.005)
Dummy for Highangus	0.003	-0.000	-0.001	-0.002
	(0.006)	(0.001)	(0.001)	(0.004)
Dummy for Highhereford	0.061***	-0.025**	-0.016***	-0.021***
	(0.017)	(0.010)	(0.005)	(0.004)

Table 15. Cont.

Variable	Marginal Effect (less than 249.5 kg)	Marginal Effect (249.5 to 430.9 kg)	Marginal Effect (430.9 to 453.6 kg)	Marginal Effect (greater than 453.6 kg)
	Treatments			
Dummy for Diet Experiment	0.019	-0.003	-0.005	-0.011
	(0.016)	(0.005)	(0.005)	(0.007)
Dummy for Implant Treatment	-0.004	0.000	0.001	0.003
	(0.005)	(0.000)	(0.001)	(0.004)
Dummy for RAC	-0.010**	-0.001	0.003*	0.009*
	(0.004)	(0.002)	(0.002)	(0.004)
Observations	808	808	808	808

Weaning age = 189.61 (mean)
Days on feed = 104.83 (mean)
Pre-feedlot days after weaned = 212.92 (mean)
Birth weight = 41.41 (mean)
Weaning weight = 264.20 (mean)
Placement weight = 473.77 (mean)

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; NOTE: All predictors at their mean value

Table 15 shows that breed composition has the most significant impact on the probability of cattle dressed carcass-weight class assignment. In comparison to *anguscross* cattle, *continentalcross* cattle are, on average, about 1.2% more likely to fall into the category of greater than 430.9 kg, keeping all other categorical variables equal and with mean values on continuous variables. Whereas comparing with *highhereford* cattle, *anguscross* cattle are about 63.7% more likely to fall into the category of greater than or equal to 430.9 kg. This finding confirms the results of Lusk (2007) who found that the genotype of cattle has a significant impact on their live weight. Given that dressed carcass percentage is assumed to be relatively constant across animals, it could be deduced that genotype also affects the dressed carcass weight.

RAC treatment has the second most significant impact on dressed carcass weight. The cattle treated with RAC treatment are, on average, about 1.2 % more likely to grow over 430.9 kg than the cattle without RAC treatment. This result confirms the finding of Gruber et al. (2007) and Winterholler et al. (2007), who noted that RAC could improve carcass weight and dressing percentage. Therefore, RAC treatment and *anguscross* cattle could be preferable choices for the cattle producers whose objective is to produce heavier cattle. In addition, as previously mentioned, the RAC treatment negatively affects the probability of achieving high yield grade carcass, which could an indication that producers need to balance between reducing the probability of high yield grade and improving the probability of heavier cattle when they adopt RAC treatment.

3.5.2. Results of OLS regression on profit

With respect to the second objective of this chapter, the OLS regression model on profit was established to investigate which cattle breed composition, growth treatment, and production systems could best contribute to the final profit or economic value that cattle producers receive. Four price scenarios were utilized, wherein the profit was calculated with the grid-based price of the cattle. The four price scenarios were classified based on the maximum and minimum value of input (feeder calf) price and output (fed cattle) price. Table 16 and Table 17 present the OLS regression results of the calf-fed cattle profit under the four price scenarios. The explanatory variables of the OLS regression on profit per head contain: the timing of different production stages and the affiliated cattle's body weight (i.e., weaning age, days on feed, slaughter age, birth weight, and slaughter weight); dummy variables for breed composition; and, dummy variables for the three growth treatments (i.e., diet experiment, implant treatment and RAC treatment). Only the significant interaction terms between breed composition and growth treatment were selected in the model through a stepwise process (see Section 3.4.2).

Table 16, which shows the OLS regression on profit, explains a relatively high percentage of the variability (R-squared) in profits. Such outcome indicates that the variables identified are important determinants of cattle feeding profits. The predictive performance of the model was quite good as it explained 64 to 87% in scenarios with high fed cattle prices [scenario (1) and (2)] and explained 44 to 88% in scenarios with low fed cattle prices [scenario (3) and (4)].

Table 16. Estimated Results of the OLS Model on Profit Under the Four Scenarios (Calf-fed Group)

Dependent Variable	Profit Per Head of Calf-fed Group			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Fed cattle price high	Fed cattle price high	Fed cattle price low	Fed cattle price low
Variable	Feeder calf price high	Feeder calf price low	Feeder calf price high	Feeder calf price low
	Timing of different production phases			
Weaning age	0.47*	0.11	0.62***	0.26**
	(0.26)	(0.21)	(0.20)	(0.12)
Days on feed	6.00***	0.99**	5.56***	0.55**
	(0.52)	(0.42)	(0.39)	(0.23)
Slaughter age	-1.73***	-0.19	-1.93***	-0.38***
	(0.15)	(0.12)	(0.11)	(0.07)
	Animal weights at different production phases			
Birth weight	-4.01***	-2.63***	-3.00***	-1.62***
	(1.02)	(0.82)	(0.77)	(0.45)
Slaughter weight	0.17*	3.10***	-2.47***	0.46***
	(0.09)	(0.07)	(0.07)	(0.04)
	Breed composition			
Dummy for Continentalcross	66.72***	54.49***	38.15***	25.93***
	(16.36)	(13.16)	(12.33)	(7.29)
Dummy for Herefordanguscross	-41.32**	-8.33	-51.23***	-18.25**
	(18.10)	(14.56)	(13.64)	(8.07)
Dummy for Herefordcross	-33.28*	-15.92	-24.67*	-7.31
	(17.03)	(13.69)	(12.83)	(7.59)
Dummy for Highangus	-16.65	-10.40	-10.76	-4.51
	(10.40)	(8.36)	(7.84)	(4.64)
Dummy for Highhereford	-44.86	6.19	-62.24**	-11.19
	(38.35)	(30.84)	(28.91)	(17.09)

Table 16. Cont.

Dependent Variable	Profit Per Head of Calf-fed Group			
Variable	Scenario 1 Fed cattle price high Feeder calf price high	Scenario 2 Fed cattle price high Feeder calf price low	Scenario 3 Fed cattle price low Feeder calf price high	Scenario 4 Fed cattle price low Feeder calf price low
	Treatment			
Dummy for Diet Experiment	11.70	-19.77	18.88	-12.59
	(25.02)	(20.12)	(18.85)	(11.15)
Dummy for Implant Treatment	64.26***	25.37***	41.40***	2.51
	(11.47)	(9.22)	(8.65)	(5.11)
Dummy for RAC	108.90***	64.97***	73.50***	29.56***
	(14.90)	(11.98)	(11.23)	(6.64)
	Interactions			
Highhereford*Implant treatment	-86.94	-89.46	-81.65	-84.17*
	(99.17)	(79.74)	(74.74)	(44.19)
Constant	-977.39***	-887.51***	-867.33***	-777.45***
	(103.47)	(83.20)	(77.98)	(46.11)
Observations	450	450	450	450
R-squared	0.64	0.87	0.88	0.44

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

For the OLS model of calf-fed cattle profitability, the coefficient estimates of treatment and breed composition are close in magnitude in the two scenarios having the same fed cattle prices; namely, the scenario (1) [scenario (3)] and in scenario (2) [scenario (4)]. RAC treatment is the most influential factor that determines the profitability in all scenarios; and its impact is relatively more significant in the scenarios where profit is calculated with maximum fed cattle selling price [scenario (1) and (2)]. Specifically, when the fed cattle price is extremely high, producers of calf-fed cattle using RAC treatment, on average, earn about \$64.97 head^{-1} to \$108.90 head^{-1} more profit than those without RAC treatment. Such finding is consistent with the results in Section 3.5.1.3, which indicates that RAC treatment has a positive impact on the probability of producing a heavier cattle carcass. When fed cattle price is extremely high, the impact of RAC treatment exerts an even larger impact as it directly improves the probability of achieving a high dressed carcass weight. Section 3.5.1.2 (see Table 14) indicates that the cattle treated with RAC are associated with a 10.7% lower likelihood of being graded as Y1, which means the RAC treatment negatively affects the probability of achieving high lean yield percentage. However, fed cattle producers do not necessarily have to pursue the high yield grade beef when the cost of achieving a high lean yield percentage outweighs the benefit. The possible reason why the RAC treatment has positive effect on profitability, while it negatively affects the probability of achieving high yield grade, is that the RAC treatment is shown to be about 10.7% more likely to produce Y3 and Y2 beef, and about 1.2% more likely to produce a dressed carcass weight over 430.9 kg. A higher dressed carcass weight could improve the profitability, albeit with a lower lean yield percentage.

The impact of the timing of different production phases and the affiliated cattle's body weight are close in the scenarios having the same feeder calf prices; namely, the impacts of above factors are close in scenario (1) [or scenario (2)] and scenario (3) [or scenario (4)]. Such results indicate that reducing the age at slaughter increased profit in all scenarios; and in scenarios with maximum feeder calf price [scenario (1) and (3)], profit is more sensitive to the age at slaughter than in the scenarios with minimum feeder calf price [scenario (2) and (4)]. This result confirms the finding by Lopez-Campos et al. (2013). Besides, this analysis also reveals the difference in profitability under different input and output price scenarios. For instance, in scenario (1) and (3), cattle that are slaughtered one day earlier, on average, generate about $\$1.34\ \text{head}^{-1}$ to $\$1.44\ \text{head}^{-1}$ more profit. Whereas in the scenario with low feeder calf price, cattle that are slaughtered one day later, on average, generate about $\$0.38\ \text{head}^{-1}$ less profit. The result could be interpreted that it is more profitable for a feedlot to slaughter the cattle earlier, especially when feeder calf price is high. Such result makes sense since the feedlot operators will spend less feedstuff cost and other costs if they slaughter the cattle earlier. The possible reason why profit is more sensitive when feeder calf price is extremely high could be that cost of purchasing feeder calf takes the largest percentage of the total cost. Therefore, a high feeder calf price drives the marginal cost of feeding cattle for one more day go beyond the marginal benefit faster than in the scenarios with low feed calf price.

Cattle's body weight at different production phases (i.e., birth weight and slaughter weight), across the four price scenarios, exert a significant impact on the profitability of calf-fed cattle. The calf-fed cattle's profitability is negatively affected by birth weight in all scenarios. In general, the cattle that are born one kg heavier are associated with \$1.62 head^{-1} to \$4.01 head^{-1} lower profit. One possible reason could be, as reported in Section 3.5.1.1, a higher birth weight could lead to a lower probability of producing AAA beef, which in turn negatively affects profitability. Another possible reason is in relation to the way we adjusted data. As mentioned in Section 3.3.2.2, when calculating placement weight, this study assumes the body weight of cattle increases linearly from birth date to slaughter date. As such, the placement weight would be positively affected by birth weight. Cattle with a higher birth weight will be given a heavier placement weight in the process of data adjustment. As a result, a higher placement weight means a higher feeder calf purchase cost, thus leads to lower profit. This interpretation is concurred by the results that the magnitude of the impact of birth weight on profit is larger in the scenarios with high feeder calf price.

Table 17 presents the results of the OLS regression model of yearling-fed cattle profitability across the four market price scenarios. Overall, the predictive performance of the model is more varied than for the calf-fed model presented in Table 16. Similar to the calf-fed model, the results of the yearling-fed system confirm breed composition and growth treatment as the most significant factors in profitability.

Table 17. Estimated Results of the OLS Model on the Profit Under the Four Scenarios (Yearling-fed Group)

Dependent Variable	Profit Per Head of Yearling-fed Group			
	Scenario 5	Scenario 6	Scenario 7	Scenario 8
	Fed cattle price high	Fed cattle price high	Fed cattle price low	Fed cattle price low
Variable	Feeder calf price high	Feeder calf price low	Feeder calf price high	Feeder calf price low
	Timing of different production phases			
Weaning age	0.51	0.37	0.50	0.36
	(0.41)	(0.39)	(0.35)	(0.33)
Days-on-feed	2.35***	-1.45**	2.40***	-1.41***
	(0.68)	(0.65)	(0.59)	(0.54)
Slaughter weight	-1.34***	-0.53**	-1.44***	-0.62***
	(0.25)	(0.24)	(0.21)	(0.20)
	Animal weights at different production phases			
Birth weight	-7.30***	-5.05***	-6.27***	-4.02***
	(1.33)	(1.25)	(1.14)	(1.05)
Slaughter weight	-0.35***	2.97***	-3.17***	0.15**
	(0.10)	(0.09)	(0.08)	(0.08)
	Breed composition			
Dummy for Continentalcross	94.05**	95.77***	70.72**	72.44**
	(37.19)	(35.19)	(31.95)	(29.38)
Dummy for Herefordanguscross	-22.22	-9.25	-26.80	-13.84
	(23.99)	(22.70)	(20.61)	(18.95)
Dummy for Herefordcross	-64.95***	-54.10***	-33.01*	-22.17
	(21.29)	(20.15)	(18.29)	(16.82)
Dummy for Highangus	0.47	-8.34	6.45	-2.36
	(16.46)	(15.57)	(14.14)	(13.00)
Dummy for Highhereford	-37.96	-13.55	-18.94	5.47
	(37.64)	(35.61)	(32.34)	(29.73)

Table 17. Cont.

Dependent Variable	Profit Per Head of Yearling-fed Group			
Variable	Scenario 5 Fed cattle price high Feeder calf price high	Scenario 6 Fed cattle price high Feeder calf price low	Scenario 7 Fed cattle price low Feeder calf price high	Scenario 8 Fed cattle price low Feeder calf price low
	Treatment			
Dummy for Diet Experiment	-24.74	-10.20	-36.80***	-22.25*
	(16.49)	(15.60)	(14.16)	(13.02)
Dummy for Implant Treatment	-164.40***	-162.12***	-148.13***	-145.85***
	(23.93)	(22.64)	(20.56)	(18.90)
Dummy for RAC	83.11***	89.70***	29.59	36.18*
	(25.43)	(24.06)	(21.85)	(20.09)
	Interactions			
Continentalcross*Implant treatment	94.58**	90.66**	64.52*	60.60*
	(43.71)	(41.36)	(37.55)	(34.52)
Herefordcross*Implant treatment	117.97**	91.18*	147.20***	120.41***
	(56.53)	(53.48)	(48.56)	(44.65)
Highangus*Implant treatment	72.66*	79.45**	50.83	57.62*
	(38.45)	(36.37)	(33.03)	(30.36)
Highhereford*Implant treatment	-205.35*	-233.07**	-210.53**	-238.25**
	(118.73)	(112.34)	(102.00)	(93.77)
Continentalcross*RAC treatment	-84.47*	-99.79**	-65.70*	-81.02**
	(44.05)	(41.68)	(37.84)	(34.79)
Constant	-466.46***	-438.09***	-290.49**	-262.12**
	(160.53)	(151.88)	(137.91)	(126.79)
Observations	358	358	358	358
R-squared	0.49	0.88	0.94	0.29

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

In comparison to calf-fed cattle, weaning age does not affect the profitability of a yearling-fed cattle. Cattle's birth weight is negatively associated with the profitability with a larger magnitude for yearling-fed cattle than for calf-fed cattle. Reducing the age at slaughter is consistently shown to increase the profitability of both production systems, albeit with various magnitudes across different market price scenarios.

For both production systems, *continentalcross* cattle are showed to be more profitable than *anguscross* cattle with a larger magnitude for yearling-fed cattle. While the cattle of other breed compositions are less profitable than *anguscross* cattle. Different from the profitability of calf-fed cattle, which is most affected by RAC treatment, implant treatment exerts the greatest impact on the profitability of yearling-fed cattle.

It is worthy to note that the implant treatment negatively affects the profitability of yearling-fed cattle while it positively affects the profitability of calf-fed cattle. This is against the results of Lopez-Campos et al. (2013), who found that the non-implanted cattle was less profitable than implanted cattle. The possible reasons are both found in this study and supported by previous studies. First, the previous studies (Roeber et al. 2000; Reiling and Johnson 2003) indicated that even though hormonal growth implant could improve the revenue side by boosting the growth of cattle, it can negatively affect the meat quality through a decreased marbling score and quality grade of the carcass. The result in Section 3.5.1.1 (see Table 13) confirms the finding of the previous studies and shows that implant treatment has a negative impact on the probability of achieving a high quality grade compared to non-implanted animals across both production systems, albeit with a larger magnitude in the yearling-fed production system. The larger negative impact on probability of achieving high quality grade for yearling-fed cattle could be one of the reasons why implant treatment has a negative impact on yearling-fed cattle profitability. Another possible reason could be in relation to the way we adjusted the data, where placement weight was calculated through birth weight and slaughter weight (see Section 3.3.2.2). With the assumption that a cattle's body weight increases linearly, a higher slaughter weight leads to a higher placement weight. Implanted animals tend to have higher slaughter weight. Therefore, the average placement weight of implanted cattle is larger than that of non-implanted cattle, which raises the cost of purchasing feeder calves and thus reduces profitability.

3.5.3. Results of break-even analyses with simulated data

3.5.3.1. Comparison of sample data and simulated data

The comparison of descriptive statistics between sample data and simulated data, together with the detected best fit distribution type of continuous variables and the frequency of categorical variables in the sample of both calf-fed group and yearling-fed group are presented in Appendix 3 (see Appendix 3, Table 24).

Table 24 shows that the continuous variables, birth weight, weaning weight, pre-feedlot days after weaned, placement weight for both calf-fed group and yearling-fed group all follow gamma distributions. The scale (noted as Sigma) and shape (noted as alpha) are two essential coefficients to define a gamma distribution. As mentioned in Section 3.3.2.2, days on feed in feedlots for both calf-fed and yearling-fed cattle are assumed to follow uniform distribution between 90 and 120 days. The comparison of distribution coefficient and basic statistics between sample data and simulated data (see Appendix 3, Table 24) proved that the simulated distributions could represent the sample distribution since the coefficients of two distributions are quite close. Moreover, the similar mean value and standard deviation indicate that the simulated data with a sample size of 10,000 can represent the sample data very well. For example, the sample data of weaning weight of yearling-fed cattle follows a gamma distribution with the sigma equal to 3.51 (versus 3.41 for simulated data), and the alpha equal to 71.60 (versus 77.46 for simulated data). The mean value of weaning weight in sample data is 255.14 (versus 251.73 for simulated data), and the standard deviation is 29.74 (versus 30.05 for simulated data).

3.5.3.2. Break-even analyses under different scenarios

The summary statistics of profit calculated from simulated data under all scenarios are shown in Table 18. Similar to profit scenarios calculated with sample data, scenario (2) with maximum fed cattle price and minimum feeder calf price is the most profitable scenario for both calf-fed and yearling-fed cattle. The scenario (3) where fed cattle price is minimum and feeder calf price is maximum earns the least profit. Yearling-fed cattle are generally more profitable than calf-fed cattle except that in scenario (4) calf-fed cattle are more profitable.

Table 18. Comparison of Simulated Profit under Different Scenarios under Two Production Systems

	Variable	N	Mean	SD	Min	Max
	Profit of Calf-fed Group					
Scenario	(1) Max fed rail price, max feeder calf price	10,000	-1137.21	403.14	-2918.97	386.2
	(2) Max fed rail price, min feeder calf price	10,000	691.69	310.32	-344.21	2078.39
	(3) Min fed rail price, max feeder calf price	10,000	-2480.99	285.61	-3985.73	-1497.85
	(4) Min fed rail price, min feeder calf price	10,000	-652.09	122.45	-1239.14	-155.9
	Profit of Yearling-fed Group					
Scenario	(5) Max fed rail price, max feeder calf price	10,000	-1079.2	581.72	-3273.07	1107.74
	(6) Max fed rail price, min feeder calf price	10,000	1106.21	375.78	-273.9	2590.47
	(7) Min fed rail price, max feeder calf price	10,000	-2863.1	480.34	-4921.16	-1450.96
	(8) Min fed rail price, min feeder calf price	10,000	-677.69	185.01	-1451.2	-64.96

With the calculation described above, a distribution of profit with 10,000 observations under each of the scenarios can be obtained. Calculation of break-even dressed carcass weight is to find the zero-profit point of the distribution. Break-even dressed carcass weight represents the starting point of weight that fed cattle producers start to make profits. Table 19 presents the break-even dressed carcass weight in each scenario and Figure 7 shows the histograms of the simulated profit under the four price scenarios for calf-fed and yearling-fed groups.

Table 19. Break-even Dressed Carcass Weight under Different Scenarios

	Variable	Break-even dressed carcass weight
	Calf-fed Group	
Scenario	(1) Max fed rail price, max feeder calf price	362.09
	(2) Max fed rail price, min feeder calf price	179.6
	(3) Min fed rail price, max feeder calf price	
	(4) Min fed rail price, min feeder calf price	
	Yearling-fed Group	
Scenario	(5) Max fed rail price, max feeder calf price	375.35
	(6) Max fed rail price, min feeder calf price	227.07
	(7) Min fed rail price, max feeder calf price	
	(8) Min fed rail price, min feeder calf price	

In some scenarios, there are no exact points where the profit equal to zero. Break-even dressed carcass weight in this section refers to the dressed carcass weight value that makes the minimum positive profit. Table 19 shows that, in some scenarios, there does not exist a break-even point, which means profits are all distributed in the negative part. By detecting in the histograms of the profits shown in Figure 7, it is consistent with Table 19 as the scenarios with no break-even point [scenario (3), (4), and (7)] have the expected profit distributed entirely in negative part.

Figure 7. Histograms of Simulated Profit Under the Four Scenarios of both Production Systems

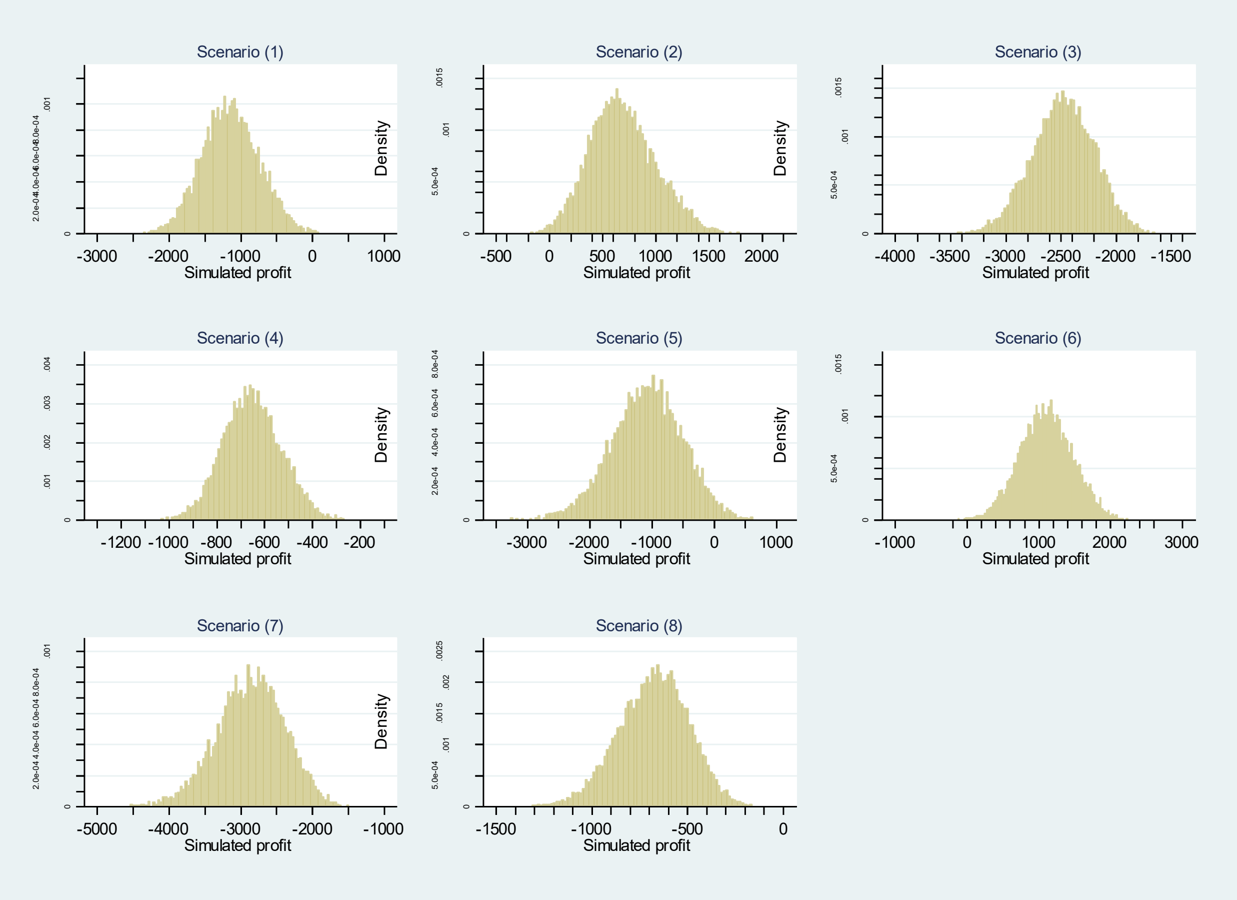


Table 19 shows that in scenario (1) when fed cattle and feeder calf price are both the maximum, break-even dressed carcass weight of calf-fed cattle is 362.09 kg. That means a feedlot starts to make profits when the dressed carcass weight of cattle is 362.09 kg. For both production systems, break-even dressed carcass is the largest in scenarios with high fed cattle price and low feeder calf price [362.09 kg in scenario (1) for calf-fed group and 375.35 kg in scenario (5) for yearling-fed group]. In scenarios with extremely low fed cattle prices [scenario (3) and (4) for calf-fed group and scenario (7) and (8) for yearling-fed group], profits are all negative, so break-even dressed carcass weight does not exist. In scenario (2) when fed cattle price is maximum and feeder calf price is minimum, it starts to be profitable when the cattle's dressed carcass weight reach 179.6 kg. For yearling-fed cattle, break-even dressed carcass weight in scenario (1) and (2) are both greater than that of calf-fed cattle. When fed cattle price and feeder calf price are both high, yearling-fed cattle start to be profitable when the dressed carcass weight is over 375.35 kg. While when fed cattle price is maximum, and feeder calf is minimum, yearling-fed cattle start to be profitable when the dressed carcass weight is over 227.07 kg. The results of this specific analysis could be applied by producers to locate their animals within the above distributions to predict dressed carcass weights at the break-even point. This information should be useful to producers' production and profitability strategies under fluctuating market price scenarios.

3.5.3.3. Scenario analyses on probability of positive profit

The probability of positive profit is the percentage of positive profit observations over the total 10,000 simulated observations under the four price scenarios of both calf-fed and yearling-fed groups. In order to examine the effect of different treatment on cattle profitability, this part adds the scenarios with interventions in which the profit is calculated with one of the three treatments (including implant treatment, diet experiment, and RAC treatment) removed.

Table 20 shows the probability of positive profit under the basic price scenarios and the scenarios with interventions of both calf-fed and yearling-fed groups. In the four basic scenarios, cattle are raised with all three treatments: implant treatment, diet experiment, and RAC treatment. The three scenarios with interventions are (a) probability of positive profit of the cattle that are raised without implant treatment; (b) probability of positive profit of the cattle that are raised without diet experiment; (c) probability of positive profit of the cattle that are raised without RAC treatment.

Consistent with the break-even analyses, the probability of positive profit is zero in the scenarios where profits are entirely distributed in the negative value. The probabilities of gain profit of yearling-fed cattle are generally higher than that of calf-fed cattle. In basic scenarios, the scenarios with maximum fed cattle price and maximum feeder calf price of both calf-fed and yearling-fed groups generate the largest probability of positive profit (99.35% for calf-fed group versus 99.82% for yearling-fed group).

Table 20. Scenarios of Probability of Positive Profit under Different Production Systems

	Price Scenarios	Probability of Positive Profit		Price Scenarios	Probability of Positive Profit
		Calf-fed Group			**Yearling-fed Group**
		Benchmark			
Scenario	(1) Max fed rail price, max feeder calf price	0.27%	Scenario	(5) Max fed rail price, max feeder calf price	2.68%
	(2) Max fed rail price, min feeder calf price	99.35%		(6) Max fed rail price, min feeder calf price	99.82%
	(3) Min fed rail price, max feeder calf price	0.00%		(7) Min fed rail price, max feeder calf price	0.00%
	(4) Min fed rail price, min feeder calf price	0.00%		(8) Min fed rail price, min feeder calf price	0.03%
		Scenarios of Cattle without Implant Treatment			
Scenario	(1a) Max fed rail price, max feeder calf price	0.04%	Scenario	(5a) Max fed rail price, max feeder calf price	1.86%
	(2a) Max fed rail price, min feeder calf price	99.10%		(6a) Max fed rail price, min feeder calf price	99.79%
	(3a) Min fed rail price, max feeder calf price	0.00%		(7a) Min fed rail price, max feeder calf price	0.00%
	(4a) Min fed rail price, min feeder calf price	0.00%		(8a) Min fed rail price, min feeder calf price	0.00%
		Scenarios of Cattle without Diet Experiment			
Scenario	(1b) Max fed rail price, max feeder calf price	0.15%	Scenario	(5b) Max fed rail price, max feeder calf price	3.72%
	(2b) Max fed rail price, min feeder calf price	99.35%		(6b) Max fed rail price, min feeder calf price	99.92%
	(3b) Min fed rail price, max feeder calf price	0.00%		(7b) Min fed rail price, max feeder calf price	0.00%
	(4b) Min fed rail price, min feeder calf price	0.00%		(8b) Min fed rail price, min feeder calf price	0.00%
		Scenarios of Cattle without RAC Treatment			
Scenario	(1c) Max fed rail price, max feeder calf price	0.11%	Scenario	(5c) Max fed rail price, max feeder calf price	2.26%
	(2c) Max fed rail price, min feeder calf price	99.35%		(6c) Max fed rail price, min feeder calf price	99.82%
	(3c) Min fed rail price, max feeder calf price	0.00%		(7c) Min fed rail price, max feeder calf price	0.00%
	(4c) Min fed rail price, min feeder calf price	0.00%		(8c) Min fed rail price, min feeder calf price	0.00%

In the scenarios with the intervention of removing implant treatment, the probability of positive profit of both calf-fed and yearling-fed cattle is lower than that in the scenarios without the intervention. That means, for both production systems, implant treatment can increase the probability of profitability slightly. The probability of positive profitability of calf-fed cattle without implant treatment decreased from 0.27% [scenario (1)] to 0.04% [scenario (1a)]. While the probability of positive profit of yearling-fed cattle without implant treatment [1.86% in scenario (5a)] is lower than that with implant treatment [2.68% in scenario (5)].

In the scenarios with the intervention of feeding cattle with routine diet, there is only a slight change in the probability of profitability in both calf-fed cattle and yearling-fed group. The probability of gain profit for calf-fed cattle fed with the routine diet [0.15% in scenario (1b)] is lower than that fed with experimental diet [0.27% in scenario (1)] when the fed cattle price and feeder calf price are both the maximum. When feeder calf price is minimum, the probability of profitability does not change between experimental diet and routine diet [99.35% in scenario (2b) versus 99.35% in scenario (2)]. Whereas yearling-fed cattle raised with routine diet has a little bit higher probability of profitability [3.72% in scenario (5b) versus 2.68% in scenario (5); 99.92% in scenario (6b) versus 99.82% in scenario (b)] than that fed with experimental diet when the fed cattle price is extremely high. Therefore, feeding yearling-fed cattle with routine diet can be more profitable than that with experimental diet.

The impact of removing RAC treatment is also very weak. The probability of profitability of calf-fed cattle without RAC treatment [0.11% in scenario (1c)] is lower than that with RAC treatment [0.27% in scenario (1)]. Removing RAC treatment does not exert any impact on the probability of positive profit in other scenarios.

3.6. Conclusion, limitations and future research

This study contributes to the current literature by conducting a comprehensive analysis of the economic profitability of alternative production systems and feeding choices and the particular impacts on growth performance and carcass quality in Canadian beef cattle industry. A specialty of this study was the consideration of a grid pricing system as a tool for calculating a differentiated price for each cattle. The overall research question of this chapter was "what are the effects of cattle production systems and production factors on carcass quality outcomes" and "how do these factors affect the profitability of cattle feeding in Canada?" Eng (2006) estimated that the adoption ratio of yearling-fed vs. calf-fed production systems in the U.S. is about 76:24, while Basarab et al. (2009) estimated that this ratio for Canada to be about 55:45. Several studies noted that profitability varies between calf-fed and yearling-fed production systems (Winterholler et al. 2008; Griffin et al. 2007). This study emphasizes the complex relationships between individual production and animal factors in determining the profitability of yearling-fed and calf-fed systems in the Canadian context. Based on the experimental data used in the analyses, the answer to which systems is more profitable cannot be made with confidence. Generally speaking, the results show that breed composition of cattle and the treatments examined in this study have significantly different impacts on carcass characteristics and profitability of both calf-fed and yearling-fed cattle systems. Consistent with the finding by Roeber et al. (2000) and Reiling and Johnson (2003), this study finds that implant treatment negatively affects the probability of achieving a high quality grade, e.g., AAA, and the magnitude of this impact is larger in yearling-fed production systems. This result stands against the previous literature, e.g., Lopez-Campos et al. 2013, which indicates that implant treatments have a significant positive effect on calf-fed cattle profitability and negative impact yearling-fed cattle profitability. This could be caused by the larger negative impact of growth promotants on quality grade of yearling-fed cattle. Another possible reason is that increased placement weight raises feeder calf purchase costs and thus negatively affects their profitability.

RAC treatment is shown to improve the profitability of both calf-fed and yearling-fed cattle and increase the probability of a high dressed carcass weight. Such outcome is consistent with the finding by Gruber et al. (2007) and Winterholler et al. (2007). The results also indicate that it should be of value to fed cattle producers to keep a balance between a high yield grade and a high dressed carcass weight when adopting RAC treatment since it has opposite impacts on the probability of achieving a high lean yield percentage and a high dressed carcass weight. The result also reveals that the profitability is not necessarily associated with a high lean yield percentage, as calf-fed cattle producers who adopt RAC treatment could compensate the negative effect on the yield grade and make profits by raising the probability of a higher dressed carcass weight.

This study agrees with the finding of Lopez-Campos et al. (2013), who noted that reducing the age at slaughter age increased profitability. Besides, this study verifies the results for both production systems and the four market price scenarios. The profitability is more sensitive to age at slaughter in the scenarios with extremely high feeder calf price, as cost of purchasing feeder calf takes the most significant share of the total cost and the high feeder calf price raises marginal cost over marginal benefit of feeding the cattle for one more day faster than in the scenarios with low feeder calf price.

The results of generated profit distribution through simulation method show that, as expected, the profit is the highest in the scenario with maximum fed cattle price and minimum feeder calf price; and the profit is the lowest in the scenario with minimum fed cattle price and maximum feeder calf price. For both production systems, only in scenarios with maximum fed cattle rail prices, there exist break-even dressed carcass weight. When fed rail price is extremely high and feeder calf price is extremely low, the dressed carcass weight achieves the starting point of profitability quickest. Yearling-fed cattle producers choosing routine diet and implant treatment have a higher probability of earning profits

3.6.1. Limitations

Despite a relatively comprehensive analysis on the cattle feeding profitability determinants under Canadian grid pricing system and contributions to the current literature, there are several limitations in this study, some of which have been acknowledged in data adjustment sections and result section.

The most critical limitation is the oversimplification of price risk scenarios analysis. To account for price risks, this study only constructs the four extreme market price scenarios. The results indicate that the effect of production systems and other factors on profitability varies across different price scenarios. However, in the real world, extremely high (low) input and output prices rarely occur at the same time. The magnitude of the results could thus be overestimating the real effects. The results of this analysis and their implications for the industry should, therefore, be interpreted with caution.

Another limitation is related to the source of cattle production data set. The cattle production data set adopted in this study is collected from Lacombe Research and Development Centre, Agriculture and Agri-Feed Canada (Lacombe, Alberta). The cattle in an experiment might not be perfectly representative to those in Canadian beef cattle industry. However, the effects of production systems, breed composition and growth treatments on the cattle's growth performance and carcass characteristics should be consistent from the perspective of animal science regardless the cattle are raised for an experiment or for real beef cattle markets. Moreover, the data on fed cattle rail price, premium (discount) and the cost of raising cattle are real market price data. That means, this limitation of data is relatively minor for our purposes and the analyses on determinants of cattle feeding profitability should not be affected by the difference between experimental cattle growth production data and the real market data.

3.6.2. Future research

Future research could extend this study in the following two aspects. First, more price risk scenarios could be added to the analysis besides the extreme high and low fed cattle rail price and feeder calf price. With more middle price ranges added to scenarios analyses, producers would find a best fitted input price and output price situation to make the most profitable decisions on breed composition selection, growth treatment (i.e., experimental diet, implant treatment and RAC treatment), weaning date, days on feed and slaughter date. Second, if it is possible to collect more data on economic side (i.e., placement weight, placement age, days on feed in feedlots, and feed conversion ratio, average daily gain), the model can be improved a lot in examining relationship between production factors (i.e., production systems, breed composition and growth treatment) and cattle feeding profitability. Third, even though the cattle growth production data from an experiment will not make a fundamental difference on examining the relationship between production factors and profitability, building the model with the real beef cattle production data from the market would provide more pertinent and more convincing results to fed cattle producers in the industry.

Chapter 4. Conclusions, Limitations and Future Research of the Thesis

The Canadian beef cattle industry, similar to that of the U.S., has a significant impact on its national economy and plays a major role in its agriculture sector (Athwal 2002; Zhen, Rude and Qiu 2017). In 2015, Canada's beef industry contributed $33 billion worth of sales of goods and services to its economy (Agriculture and Agri-Food Canada 2016). At the farm level, cattle feeding is a high-risk industry because it is increasingly competitive and it is susceptible to volatility stemming from many aspects. Cattle feeders are subject to substantial fluctuations both from input markets (for purchase feeder cattle and feedstuffs) and from output markets (to sell perishable products) (Lawrence et al. 1999; Schroeder et al. 1993). The output beef processing market, at the wholesale level, is a highly concentrated industry facing challenges both from a domestic fixed weekly capacity and from the highly dependent trade relationship with the U.S. beef cattle market (Miljkovic 2009). In recent decades, both farm level and wholesale level producers of the Canadian beef cattle industry have been confronted with increasing production risks and price risks. The causes of such risks were the exchange rate appreciation; the outbreak of bovine spongiform encephalopathy (BSE); the implementation of the mandatory country of origin labeling (COOL); and, the heightened volatility in feed grain prices. These market events gave rise to concerns with regard to the volatile trade flows of Canadian cattle and beef products to the U.S. market (Twine et al. 2016); the price pass-through mechanism along the domestic supply chain (Saha and Mitura 2008); and, the domestic beef cattle production profitability (López-Campos et al. 2013).

This thesis consisted of two essays investigating the challenges the beef cattle industry is confronted with at both the wholesale level and the farm level. The first essay investigated the effect of the trade-oriented variable, in this case, the CAD/USD exchange rate, on the Canadian farm level to wholesale level price pass-through. The second essay examined the relationship between production factors and cattle carcass characteristics, as well, the determinants of cattle feeding profitability under different production systems.

The first essay started from the following questions: i) Does the CAD/USD exchange rate play a role in the Canadian farm to wholesale price transmission? ii) Is there a threshold effect of exchange rate on domestic price pass-through patterns? Further, if there is a threshold effect, what is the threshold value? iii) How do farm level price and wholesale level price react to the price deviations from the long-run relationship between the two prices in different regimes? The essay contributed to the literature by first building threshold ECM using the exogenous variable as the regime-inducing variable on the domestic vertical price transmission. The analyses in the first essay were conducted in three itemized time periods: before BSE, during the U.S. border closure, and post-BSE.

Three important findings are as follows. First, farm level price (Alberta fed steer price) and wholesale level price (boxed beef AAA cut out price) were tied together by a long-run relationship during the non-BSE and the border closure periods. However, the price transmission elasticities were different between non-BSE periods and the border closure period. This difference could be an indication that trade-related shocks can render impact on the manner in which stakeholders at the farm level and the wholesale level coordinate with each other. Second, the threshold values of CAD/USD exchange rate were found for both pre- and post-BSE periods. Each threshold value triggers two regimes. Within each regime, the price adjustment to any deviation from the long run relationship is different from that in the other regime. In the regimes above and below the threshold value of exchange rate, farm and wholesale prices make adjustments differently to price deviations to restore the long-run relationship. Such findings imply that the exchange rate does affect the domestic supply chain coordination between the farm level price and the wholesale level price. Third, for each period, wholesale prices make faster adjustments to any price deviation in the regime below the threshold values than in the regime above the threshold value. This finding suggests that Canadian beef packers are more willing to negotiate prices under the circumstance where the U.S. market is more attractive to Canadian fed cattle producers and Canadian fed cattle producers are more willing to sell their cattle to the U.S. market, and vice versa.

The implication of the first essay is that it should be of interest to stakeholders at different market levels along the beef cattle supply chain to improve the risk management capacity as to alleviate the vulnerability to the trade-related shocks. On top of the fact that both farm level and wholesale level prices of Canadian beef cattle markets are dominated by the U.S. market conditions (Fairbairn and Gustafson 2005; Athwal 2002; Schulz, Schroeder and Clement 2011), the results of this study indicated that the relative bargaining power of Canadian fed cattle producers and beef packers is, to some degree, determined by the trade relationship between Canadian and the U.S. beef cattle markets.

The second essay started by raising the question: i) What are the effects of cattle production systems and other production factors on carcass quality? ii) How do the above factors further affect the cattle feeding profitability under grid pricing? This essay builds on current literature by conducting more comprehensive analyses in the following three aspects. The first part of analysis extends the methodology of calculating profit depicted in previous research (López-Campos et al. 2013; Lusk 2007; Thompson et al. 2016; and McDonald and Schroeder 2003) by calculating profits under the two cattle production systems and calculating profits in the typical price scenarios to account for price risks. The second part of analysis follows the methodology in previous literature (López-Campos et al. 2013; Retallick et al. 2013; Lusk J. 2007; Thompson et al. 2016) which build OLS model of profit. This analysis extends their methodology by running an OLS model under the two production systems and building an ordered logit model of different grade categories. The third part of the analysis adapts the simulation methodology from the studies by Belasco et al. (2009) and Anderson and Trapp (2000), and extends the methodology by finding the break-even dressed carcass weight from the distribution of generated expected profit and probability of positive profit.

The first key finding indicates that growth treatment and breed composition of cattle are the most influential factors on quality grade and yield grade that cattle carcass receive, therefore, on the cattle feeding profitability. Generally speaking, the profitability of yearling-fed cattle is more sensitive to breed composition and treatments (i.e., growth promotant implant and RAC treatment) than that of calf-fed cattle. Producers who adopt an implant treatment face the trade-off between having an improvement of cattle production at the expense of a reduction in the probability of achieving a high quality grade. Whereas and producers who adopt RAC treatment also face the trade-off between improving the probability of a high dressed carcass weight at the expense of a declined probability of a high yield grade.

The second key finding from the generated profit distribution through simulation suggests that only in scenarios where fed cattle rail price is extremely high, there exists a break-even dressed carcass weight. The intervention of removing each of the three growth treatments (including experimental diet, implant treatment, and RAC treatment) only exerts a minor impact on the probability of positive profit.

The two essays in this thesis not only shed light on the effect of trade-related factors on the coordination of beef cattle supply chain (between the farm level and the wholesale level), they, as well, examine the determinants of farm-level profitability. The first essay concludes that the U.S. market opportunity to Canadian live cattle affects the way in which farm level prices and wholesale level prices adjust to any price deviation from the long-run relationship. The second essay finds that the effect of breed composition and treatment on cattle feeding profitability varies across the two production systems and among different market price scenarios.

The two essays are linked because they both investigate the functioning of the supply chain. The first essay looks at the performance of the supply chain from the perspective of the impact of export marketing on domestic market coordination. However, the second essay directly studies the profitability of the feedlot level cattle production from the perspective of the production system. Key to both analyses is the roles of price and pricing. Essay one investigates the role the CAD/USD exchange plays in the Canadian supply chain, while quality differentiated carcass pricing is an important factor in cattle profitability examined in essay two.

The research presented in both essays needs to be placed in the context of the underlying structure of the North American beef industry. The Canadian beef packing industry is highly integrated and dominated by large US-based multinational beef processing corporations. The Canadian beef packing sector involves only a few large beef packing firms, and many smaller abattoirs (Rude, Harrison and Carlberg 2011). In 2007, the three major packing plants (Cargill, Tyson, and XL) were estimated to account for 77.62% of the total Canadian beef packing market share. Cargill and Tyson alone accounted for 67.43% of Canadian beef packing capacity (NFU 2008). Cargill and Tyson are subsidiaries of US-based multinational corporations that benefit from substantial market infrastructures in multiple meat importing countries. The Canadian plants, as part of a larger network, are required to use Canadian cattle and beef in ways to complement and coordinate with their US-based plants (Rude, Harrison and Carlberg 2011). Even though the cattle and beef produced in the Canadian plants are not used to compete with their US-based plants directly, the fluctuation of exchange rate could affect the relative price of Canadian live cattle; thus affecting the beef packers' management decisions on where to raise and slaughter cattle.

4.1.1. Limitations and future research

There are two main limitations associated with the first essay in spite of its contribution to the current literature by first using an exogenous variable, in this case, exchange rate, as the regime-inducing variable in threshold ECM of domestic farm to the wholesale price pass-through. The first limitation, in essay one, is due to the application of Chan's (1993) method to determine the threshold value of exchange rate. The primary limitation of this method is that it only allows for one threshold (Mann 2012). To address this limitation, future studies could consider more than one thresholds. As several studies have investigated, it is very likely that there exist two threshold values which comprise a "band" (Balke and Fomby 1997; Mann and Septon 2016; Mann 2016). Within this "band", farm and wholesale level prices will not make any reaction to exchange rate changes or deviations from the long-run relationship. Once the exchange rate goes outside the "band", the farm and wholesale prices will be "pulled" back.

The second limitation of the first essay originates from the sample size of data set. The farm level and wholesale level price series are cut into three itemized time periods: before BSE, during the U.S. border closure, and, post-BSE, which have the sample size of 125,114, and 479 respectively. Future studies could analyze a larger sample to obtain more general results of both the threshold effect of the exchange rate; and short-run adjustments of farm and wholesale level prices to any deviation from the long-run relationship.

In respect to the second essay, there are as well several limitations. As mentioned in Section 3.6.1, such shortcomings are mainly due to a lack of information from the cattle production data set. Moreover, the data of premium and discount at one point of time does not capture the variation of the price market across time or among different beef packers.

Some assumptions are made to adjust the data in order to obtain the necessary variables needed to conduct an economic analysis. Such assumptions center around the days on feed in the feedlot, placement age, and, placement weight. The assumptions strongly affect the results, and, prevent us from examining the relationship between feed duration in the feedlot and the affiliated cattle feeding profitability. Moreover, the lack of important economic-related variables (i.e., feed conversion ratio, cost of gain, average daily gain, etc.) in the cattle production data set also impedes any further investigation on the effect of production factors on the profitability.

The final important limitation of essay two is that price risk scenario analyses only account for the maximum and minimum values of the output price (fed cattle rail price) and input price (feeder calf price). Future research might provide additional price ranges to investigate how the effect of production factors on cattle feeding profitability changes across different scenarios. Results from such extended research would be more relevant to fed cattle producers as they could find the best fitted price scenario rather than only the extreme high-price and low-price scenarios.

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Appendix

Appendix 1 Descriptive statistics of Alberta fed steer price series

Table 21 Descriptive Statistics of Alberta Fed Steer Price Series

VARIABLES	N	Mean	S.D.	Min	Max
Alberta Fed Steer Live Price	180.00	2.13	0.64	0.74	3.98
Alberta Fed Steer Rail Price	180.00	3.54	1.07	1.24	6.63
Post-BSE Alberta Fed Steer Live Price	156.00	2.18	0.66	1.31	3.98
Post-BSE Alberta Fed Steer Rail Price	156.00	3.63	1.10	2.19	6.63

Appendix 2 Descriptive statistics of variables of the cattle production data set

Table 22. Summary Statistics of All Continuous Variables of the Cattle Production Data Set

VARIABLES	N	Mean	S.D.	Min	Max
ID number	2,087.00	2.18e+14	2.53e+14	1.24e+14	9.00e+14
Weaning age	1,590.00	189.70	19.44	126.00	263.00
Age at yearling weight	1,061.00	434.06	1,787.98	281.00	42,081.00
Slaughter age	1,072.00	504.77	80.43	330.00	691.00
Birth weight	1,758.00	40.82	5.50	21.77	68.04
Weaning weight	1,592.00	256.08	32.30	136.98	365.14
Unadjusted yearling weight	1,061.00	392.00	66.95	215.91	635.50
Slaughter weight	1,397.00	564.15	76.63	313.00	849.00
Birth weight adjusted by the age of dam	1,755.00	42.46	5.26	25.40	68.04
Weaning weight adjusted by the age of dam	1,590.00	246.25	28.07	135.86	359.48
Adjusted yearling weight	983.00	377.76	61.14	214.38	608.73
Adjusted additional weight from weaning weight to weight at 440 days	892.00	448.66	68.79	255.22	699.39
Slaughter age group (if slaughter age (days) is >= 400 and < 500, age group is 450 days; if slaughter age (days) is >= 500 and <600, slaughter age group is 550 days.)	846.00	490.66	49.15	450.00	550.00
Adjusted slaughter weight	689.00	539.77	66.66	369.30	746.93
Average daily gain between weaning and yearling weight	1,061.00	0.79	0.31	0.05	2.00
Average daily gain between weaning and 440-day weight	1,459.00	0.83	0.27	0.16	1.85
Dressed carcass weight	1,346.00	329.88	47.47	208.80	510.60
Dressing percentage	1,342.00	58.30	2.24	49.94	67.10
Estimated lean yield percentage	1,401.00	57.97	3.25	49.00	65.00
Marbling score	1,401.00	468.38	71.04	220.00	810.00
Age of meat when shear force evaluated	1,086.00	6.13	0.41	6.00	8.00

Table 22. Cont.

VARIABLES	N	Mean	S.D.	Min	Max
Peak shear force required to shear steak	1,063.00	7.02	2.24	3.41	17.62
Age of dam at birth of calf	1,756.00	4.76	2.62	1.82	14.15
Average adjusted birth weights of older siblings	1,257.00	41.93	3.69	27.21	57.70
Average adjusted wean weights of older siblings	1,058.00	239.15	22.89	120.36	312.90
Average adjusted yearling weights of older siblings	810.00	366.43	49.75	225.74	590.07

Table 23. Frequency Statistics of Categorical Variables for Two Production Systems

	Calf-fed Group		**Yearling-fed Group**	
Breed composition	Frequency	Percentage	Frequency	Percentage
Anguscross	138	30.67	138	38.55
Continentalcross	50	11.11	35	9.78
Herefordanguscross	30	6.67	26	7.26
Herefordcross	36	8	43	12.01
Highangus	138	30.67	92	25.7
Highhereford	7	1.56	11	3.07
unknown	51	11.33	13	3.63
Total	450	100	358	100
Diet experiment	Frequency	Percentage	Frequency	Percentage
control	434	96.44	202	56.42
experimental	16	3.56	156	43.58
Total	450	100	358	100
Implanted treatment	Frequency	Percentage	Frequency	Percentage
Implanted	140	31.11	77	21.51
non-implant	310	68.89	281	78.49
Total	450	100	358	100
Ractopamine (RAC) treatment	Frequency	Percentage	Frequency	Percentage
RAC	56	12.44	55	15.36
No-bag	394	87.56	303	84.64
Total	450	100	358	100

Appendix 3 Best fitted distribution of continuous variables and comparison of distribution coefficient between sample and simulated data.

Table 24. Best Fitted Distribution of Continuous Variable and Comparison of Distribution Coefficient between Sample Data and Simulated Data

		Yearling-fed Group		Calf-fed Group	
Best Fitted Distribution		Gamma Distribution		Gamma Distribution	
		Weaning Weight		**Weaning weight**	
Parameter	Symbol	Sample Data	Simulated Data	Sample Data	Simulated Data
N		359	10,000	450	10,000
Scale	Sigma	3.51	3.41	4.03	3.40
Shape	Alpha	71.60	77.46	66.31	94.26
Mean		255.14	251.73	271.40	268.13
S.D.		29.74	30.05	32.84	32.98
Best Fitted Distribution		Gamma Distribution		Gamma Distribution	
		Days of Slaughter after Weaned		**Days of Slaughter after Weaned**	
Parameter	Symbol	Sample Data	Simulated Data	Sample Data	Simulated Data
N		359	10,000	450	10,000
Scale	Sigma	3.61	3.67	5.57	5.05
Shape	Alpha	112.17	109.15	43.05	52.08
Mean		408.84	404.99	245.28	239.96
S.D.		38.26	38.36	36.56	36.46
Best Fitted Distribution		Gamma Distribution		Gamma Distribution	
		Placement Weight		**Placement Weight**	
Parameter	Symbol	Sample Data	Simulated Data	Sample Data	Simulated Data
N		359	10,000	450	10,000
Scale	Sigma	12.39	12.98	4.91	4.61
Shape	Alpha	41.32	37.57	87.36	102.08
Mean		524.02	510.67	433.79	428.82
S.D.		79.63	79.56	45.89	46.57
Best Fitted Distribution				Gamma Distribution	
				Birth Weight	
Parameter	Symbol			Sample Data	Simulated Data
N				450	10,000
Scale	Sigma			0.62	0.69
Shape	Alpha			66.16	53.17
Mean				41.44	40.81
S.D.				5.02	5.02
Best Fitted Distribution		Uniform Distribution		Uniform Distribution	
		Days on feed in feedlots		**Days on feed in feedlots**	
		Sample Data	Simulated Data	Sample Data	Simulated Data
N		359	10,000	450	10,000
Mean		105.14	104.96	106.05	105.10
S.D.		8.86	8.70	8.74	8.67