Benefit-Cost Analysis of NIRS Feeding Initiative for the Alberta Dairy and Beef Cattle Industry

by

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Abstract

Near-Infrared Reflectance Spectroscopy (NIRS) is considered a promising technique for feed analysis. The main advantages of NIRS are the speed and efficiency with which feeds may be analyzed for nutrient content and the fact that NIRS can accomplish this without destroying the test samples, meaning that they can be tested repeatedly. However, the economic benefits associated with farmer adoption of NIRS have not been studied to any significant extent. This study conducted a benefit-cost analysis for the dairy and beef cattle backgrounding and finishing sectors in Alberta and western Canada. A least-cost ration model was developed to evaluate feed cost savings associated with the adoption of NIRS. This was compared with the costs of adoption to quantify net benefits. Estimates of net benefits were then converted to an animal unit ($ per head) to allow aggregation to an industry level for Alberta and for western Canada. Sensitivity analyses were also performed to examine the effects of changes in feed ingredient prices, NIRS adoption costs, and discount rate. The final results suggested that it would be economically feasible to commercially introduce NIRS technology on dairy and beef cattle farms in Alberta and western Canada.

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Chapter 1: Introduction

1.1 Background

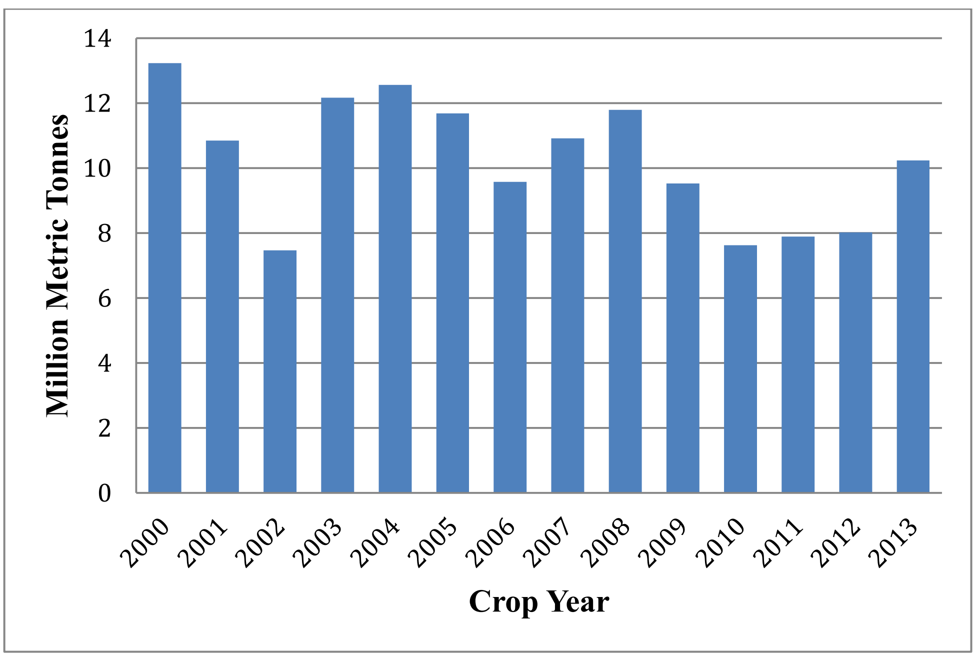
The dairy and beef cattle industries are two major agricultural industries in Canada. The development of both has had a significant economic impact on the Canadian economy, especially in Alberta and western Canada. Dairy products were the second largest component of manufactured shipments[1] in Canada in 2012, after meat products. Dairy products reached $14.70 billion in total, and accounted for 15.1% of the total value of manufactured shipments in Canada in 2012 (CDIC, 2013b). On the other hand, the beef industry has been the largest component of the animal production industry in Canada, involving over 54% of Canadian livestock producers (Statistics Canada, 2012b). Total beef cash receipts, including products from calves, reached $6.53 billion in 2012. In 2012, beef products accounted for the second largest source of cash receipts after canola (Statistics Canada, 2013c). Although both the dairy and beef industries have been generating a substantial value of production, operator profitability has been constrained by operating costs. In particular, feed cost is one of the largest components of operating costs for Canadian dairy and beef cattle operators. Feed cost accounts for 40% to 60% of the total cost in North American dairy farms (Amaral-Phillips, 2011), and is estimated to be about 69% of total costs for beef cattle farms (Saskatchewan Forage Council, 2011). Therefore, managing feed cost is critical to the profitability of both dairy and beef cattle operations.

In North America, corn is the most common feed grain for dairy and beef cattle rations. However, in western Canada, due to limits imposed by weather, barley is the main feed grain in both dairy and beef cattle operations (ARD, 2009b). Additionally, barley provides greater ruminal starch digestion than other feed grains, and barley-based rations normally can supply sufficient energy to meet the

[1] Manufactured Shipments is defined as a trade term to report “the production of goods produced by Canadians”. It measures the monetary value of goods (Industry Canada, 2013).

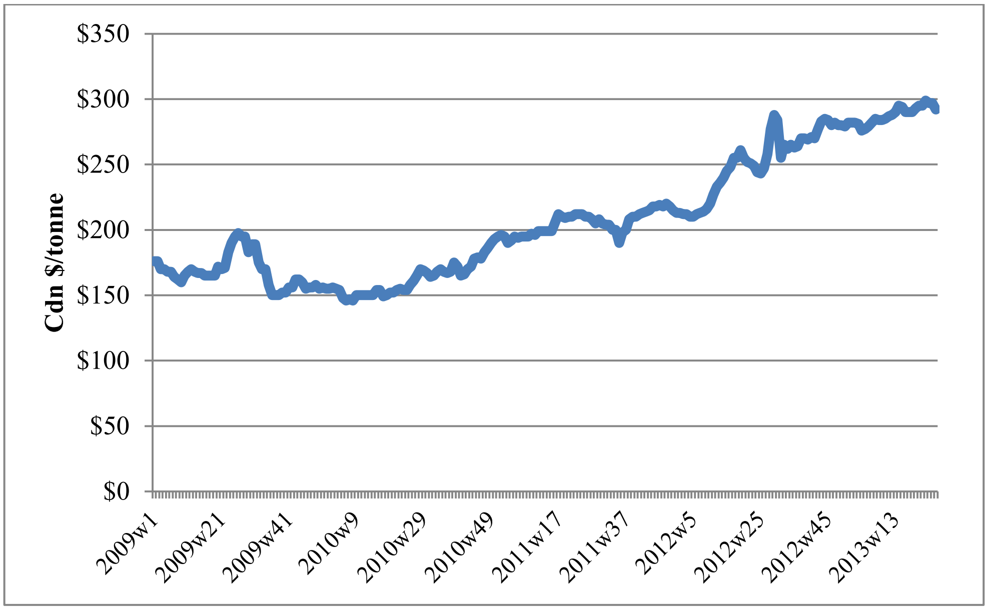
requirement of cattle growth and performance (ARD, 2012b). However, the price of barley has been increasing since late 2009, mostly because of reduced supply. In recent years the barley supply has been significantly lower than the ten-year average due to weather problems (Canfax, 2012b). Barley production and prices in the past years are presented in figures 1.1 and 1.2. After a 28% increase, the Canadian barley production was 10.2 million metric tonnes in 2013, which was still almost one million metric tonnes lower than the ten-year average from 2000 to 2009 (Statistics Canada, 2014a). According to Canfax (2013a), the western Canadian livestock feeding industry needs at least a 12% increase in barley production to meet the demand of livestock feeding operations. In the meantime, the average of the annual Lethbridge barley price reached $254/tonne in 2012, which was almost a historical high. Compared with the previous year, the price increased by 23% (Canfax, 2013a). The decreasing feed grain production and increasing feed grain prices mean that dairy and beef cattle operators are facing much higher feed costs than in the past.

Figure 1.1 Canadian annual barley production (2000-2013)



Source: Statistics Canada (2014a), CANSIM Table 001-0010. Ottawa, Ontario.

Figure 1.2 Alberta weekly nominal barley prices (Week 1, 2009 to Week 25, 2013)



Source: Canfax (2013b), Calgary, Alberta.

Feed cost is the most significant cost saving that can be achieved in livestock operations (Saskatchewan Forage Council, 2011). However, lowering feed cost does not simply mean using cheaper feed ingredients or reducing the quantity of rations. A minimum feed cost should be realized while nutrient requirements of livestock are fulfilled, which means it is necessary to know the feed ingredients' prices and nutrient contents, and the livestock nutrient requirements. A tool with the potential to facilitate this is Near-Infrared Reflectance Spectroscopy (NIRS). NIRS is a technology that can rapidly analyze and predict nutrient content information for single or multiple ingredient rations. NIRS can observe multiple nutrient content characteristics including fat, protein, fibre, minerals, and moisture, which are vital for livestock health and growth. By knowing the nutrient contents of feed ingredients and the nutrient requirements of livestock, livestock operators can potentially use smaller amounts of ration ingredients with an associated reduction in ration cost.

1.2 Economic Problem

Most of the current literature about NIRS technology is from a scientific perspective with discussions about the accuracy for various test objectives, such as grains, forage, and animal products. Given the wide range of possible tests and the accuracy of results (Ben-Gera and Norris, 1968; Clark et al., 1987; Tkachuk, 1987; Thiex and Erem, 1999; Xiccato et al., 1999; Garnsworthy et al., 2000), NIRS technology has potential for both livestock and crop operators. Operators can obtain direct or indirect benefits from adopting NIRS technology into their business operations. For livestock operators, NIRS can quickly analyze the nutrient content of feed ingredients for livestock rations. It enables livestock operators to make purchase decisions based on the results of the analysis. Crop operators may receive indirect benefits, such as additional information about their product's value. NIRS can also be widely used in purchasing and selling activities, to enhance feed mills' bargaining power by improving accuracy in grading feeds. However, there is not a lot of information about the economic value of NIRS technology. It is necessary to identify potential benefits of adopting the technology in the agricultural industry, and to assess the economic value to stakeholders.

Although NIRS technology can potentially benefit operators, there is an economic barrier to commercial introduction. An initial investment cost of around $30,000 to $60,000 is required to purchase the NIRS machine. There are also follow-up costs after adoption, such as for calibration and maintenance. It is unclear whether it is economically feasible to adopt NIRS technology for commercial use. Therefore, it is essential to conduct an economic evaluation of NIRS technology in the agricultural industry to assess whether the benefits outweigh the associated costs, and to provide decision-making information for stakeholders.

1.3 Research Problem and Objectives

This study focuses on the dairy and beef cattle industries in Alberta. The results are extended to western Canada. In performing an economic evaluation of adopting NIRS technology in the research area, the following research questions are addressed:

- Is it economically feasible to commercially introduce NIRS technology on dairy and beef cattle farms in Alberta and western Canada?
- Is there any difference in net benefit for different sectors by adopting NIRS technology? If so, what causes the difference?
- How sensitive are the results of economic feasibility of NIRS adoption to changes in parameters (i.e., feed ingredient price, adoption cost, and discount rate) in this study?

In this study, the main objective is to examine the economic feasibility of NIRS technology in livestock industries. It is necessary to estimate the private benefits and costs for livestock operators adopting NIRS technology in their feeding operations. More specifically, there are three objectives. Firstly, representative farms and animal characteristics for dairy and beef cattle operations in Alberta are defined. It is important to note that this study uses a livestock operator perspective. All the impacts, including benefits and costs, are estimated for specific livestock farms that are represented in the research region. The objective is to identify related livestock sectors, as well as operation phases, on which the NIRS technology can have an impact, and for which the differences in assessment results can also be observed. It is expected that adopting NIRS can benefit those identified livestock operators in a number of ways including costs. Those benefits and costs may vary between industries and/or operation phases.

Secondly, the impacts of adopting NIRS are quantified. The objective is to define and estimate related benefits and costs, which can lead to the net benefits of adopting NIRS.

Thirdly, the benefits and costs are quantified into monetary values, and then compared between a baseline case (without adopting NIRS in feeding operations) and a comparison case (adopting NIRS in feeding operations) for each industry.

Since NIRS technology is a tool for predicting nutrients, the benefits are estimated from the value of rations that are formulated based on nutrient content information. The costs of adopting NIRS are determined based on the number of NIRS tests, while initial capital costs and other costs incurred during the adoption process (i.e., calibration and maintenance costs) are included. In this manner, net benefits can eventually be estimated and used to examine the economic feasibility of adopting NIRS in the research region. Additionally, the benefits and costs in this study are considered over a twenty-year time period to examine whether it is worthwhile to invest in the technology. Therefore, a net present value (NPV) analysis is employed in this study to evaluate long-term benefits and costs associated with adopting NIRS in the research region.

1.4 Organization of the Study

The remainder of the thesis is divided into five chapters. Chapter 2 provides more detailed background information, including overviews, operating structure, and important nutrient considerations for feeding operations in the dairy and beef cattle industries. A literature review of NIRS technology and its development process is also provided in Chapter 2. Chapter 3 includes a conceptual discussion of benefit-cost analysis (BCA). A critical evaluation of BCA, NPV analysis, and the measurement of welfare changes is also presented.

Chapter 4 presents the empirical methods for modeling. Following the discussion of NIRS adoption, the modeling steps are outlined and explained. Seven scenarios regarding the feeding operations in the dairy and beef cattle industries are set up for further discussion. A further discussion of the estimation details in BCA is presented, including NPV analysis and the choice of discount rate. The results for the seven scenarios are reported and discussed in Chapter 5, along with the aggregate results for western Canada and the results of sensitivity analyses. Finally, Chapter 6 presents conclusions and implications of the study results, and a summary of and explanation about the study's limitations. Chapter 6 ends with an introduction to and discussion about possible further research.

Chapter 2: Background and Literature Review

This chapter provides the background information and literature review that are relevant to this study's research objectives. An overview of the dairy and beef cattle industries in the study region is presented, as well as a description of the production phases, and a short discussion of cattle feed and nutrition. Next, a literature review of Near-Infrared Reflectance Spectroscopy (NIRS) is provided, which includes a discussion on the history of NIRS technology and its application and studies in grain and forage analysis. By the end of the chapter, it is clear that NIRS technology has the ability to provide a quick analysis for the nutrient content of feed ingredients, and can potentially benefit dairy and beef cattle businesses.

2.1 Dairy and Beef Cattle Industry

2.1.1 Overview of the Dairy Industry in Alberta and Western Canada

In the Canadian dairy industry, Québec and Ontario are the two leading provinces. More than 69% of dairy cash receipts come from these two provinces (CDIC, 2013b). Western Canada is a relatively minor player in the dairy industry compared with Québec and Ontario. In 2012, 12.61% of Canadian dairy farms were located in western Canada, representing about 1,580 dairy farms. However, more than one-third of them - 585 dairy farms - were in Alberta. Alberta has the greatest number of dairy farms among the western Canadian provinces, including British Columbia, Manitoba, and Saskatchewan (CDIC, 2013b). Alberta also has more dairy cows than other western Canadian provinces, coming in third nationally behind Québec and Ontario (Statistics Canada, 2014b). Although the size of the dairy industry in Alberta and western Canada is smaller than those in Québec and Ontario, dairy farms in western Canada have a larger herd size than farms in Québec and Ontario. For example, the average size of herds in Alberta was 139 head in 2012, while the average size of herds in Québec and Ontario was 60 head and 78 head, respectively. Meanwhile, the average size of herds in western Canada was greater than 130 head (CDIC, 2013b).

Dairy products generated $5.92 billion in farm cash receipts in Canada in 2012. Although only 12.6% of dairy farms were located in western Canada, dairy cash receipts reached $1.47 billion in western Canada in 2012, which was about 25% of the national total (CDIC, 2013b). British Columbia and Alberta each contributed nearly 36% of the dairy cash receipts in western Canada in 2012. Alberta generated $521 million in dairy cash receipts, ranking it fourth in that category, after Québec, Ontario, and British Columbia (CDIC, 2013b). Dairy products were also the fourth largest single source of farm cash receipts in Alberta in 2012, after beef cattle, canola, and wheat. In addition, dairy cash receipts in Alberta have steadily grown at approximately 3% per year, and with a peak of 5% in 2011(Statistics Canada, 2013c).

Figure 2.1 shows that the average annual net operating income[2] of dairy farms in Alberta has been increasing for more than ten years, except for 2004 and 2011, when it decreased. This is similar to what happened throughout Canada (Statistics Canada, 2013b). The average net operating income in Alberta was also higher than for western Canada and the Canadian average. This figure reached $239,681 in 2012, well above the Canadian average of $139,386 and western Canadian average of $210,638. In 2012, Alberta's net operating income was higher than the average in Québec ($114,430) and Ontario ($153,097) (Statistics Canada, 2013b). Since more than 80% of dairy farms are located in Québec and Ontario (CDIC, 2013b), their average net operating incomes more closely reflect the Canadian average.

The gross margin[3] on dairy farms in Alberta has also been increasing (Heikkila and Biert, 2011). The margin was $26.51 per hectolitre sold in 2009. The figure

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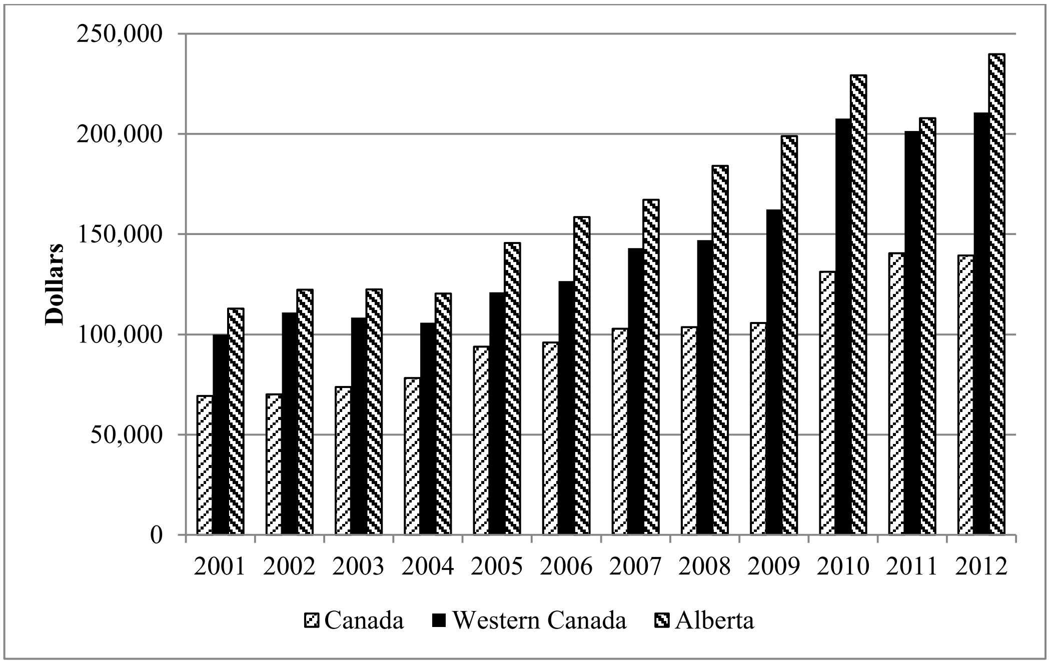
[2] Net operating income: "the profit or loss of the farm operation measured by total operating revenues minus total operating expenses, excluding capital cost allowance, the value of inventory adjustments and other adjustments for tax purposes. In these summary tables, net operating income is also equal to the sum of net market income and net program payments." (Statistics Canada, 2005)

[3] Gross margin: gross income minus variable costs.

went up to $29.10 per hectolitre sold in 2010 when total cash costs also saw a slight increase.

Figure 2.1 Average annual net operating income of dairy farms (2001-2012)



Source: Statistics Canada (2013b), CANSIM Table 002-0044. Ottawa, Ontario.

2.1.1.1 Dairy Operations

Dairy producers in Canada had more than 960,000 dairy cows and 472,600 dairy heifers in 2013. They owned 12,529 dairy farms across Canada. About 98% of dairy farms are family-owned (CDIC, 2013b). The average herd size of a Canadian dairy farm is about 77 head of dairy cows. As described above, the herd size in eastern Canada is slightly smaller than the Canadian average, while the herd size in western Canada is bigger than the Canadian average.

A variety of breeds is present on Canadian dairy farms (i.e., Jersey, Ayrshire, Brown Swiss). The most common, at 94%, is Holstein (Dairy Farmers of Ontario, 2013). A typical Holstein can produce 9,000 to 10,000 litres of milk per year, which means it can produce more than 30 litres of milk daily (CDIC, 2013a; Dairy Farmers of Ontario, 2013). According to Dairy Farmers of Ontario (2013), a mature dairy cow can give milk for about ten months after having a calf. Before giving birth, a dairy cow has a dry period, which usually lasts for two months. The dry period "allows the cow's udder an opportunity to regenerate secretory tissue and to allow the digestive system to recover from the stress of high levels of feed intake." (Waldner, 2007, pg. 1). After giving birth, dairy cows enter another ten-month milk cycle (Dairy Farmers of Ontario, 2013). Although dairy cows can give birth and enter the milk cycle many times, they are frequently replaced or culled. According to CDIC (2013b), 49.93% of dairy cows enrolled in a milk recording program in Canada were replaced or culled in 2012. Since 2008 the annual replacement rate has been higher than 40% (CDIC, 2013b).

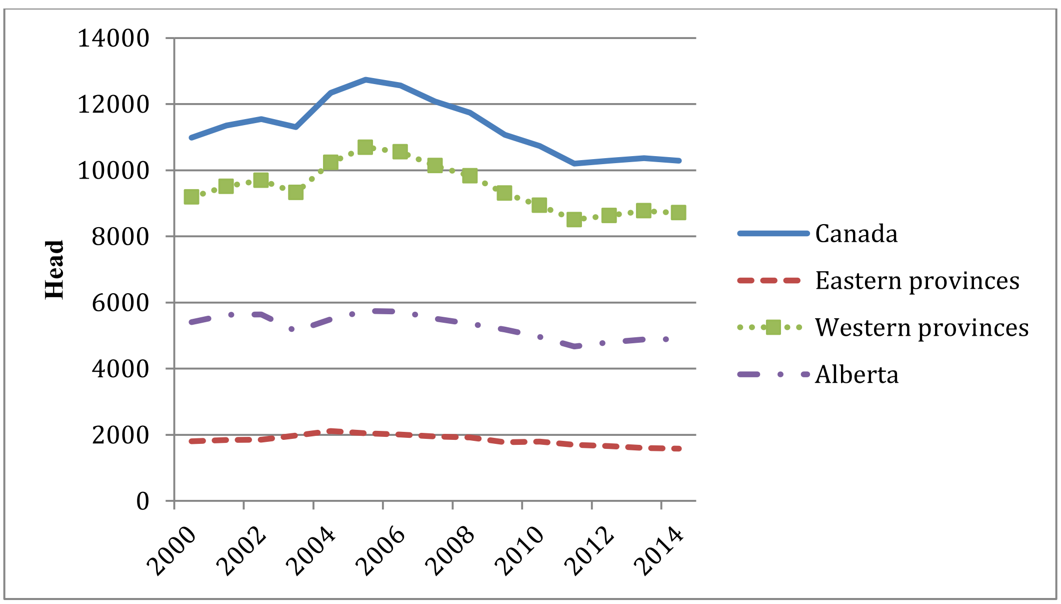
A dairy cow can consume approximately 11 kg of hay and 16 kg of silage and grain per day (Dairy Farmers of Ontario, 2013), which is normally more than a beef cow's daily diet (Gibb, 2013). However, unlike beef cattle feedlots, dairy farms usually purchase formulated rations from feed mills and/or crop farms in western Canada (Swift, 2012). Feed costs for dairy operations are usually higher than for beef operations. Careful management of feed cost is critical to a dairy operation.

2.1.2 Overview of the Beef Cattle Industry in Alberta and Western Canada

Alberta's beef cattle industry started in the late 1800s. Alberta has been and continues to be the most important province for the Canadian beef cattle industry (ABP, 2012a). In fact, of the 25% of farms in Canada operating beef cattle businesses, approximately 38% were located in Alberta (Statistics Canada, 2012a). As of January 1st, 2014, 4.89 million head of beef cattle were on Alberta farms, which is more than any other province and almost half of the total number in Canada. It is also higher than the total beef cattle inventory in eastern Canada (1.59 million head) (Statistics Canada, 2014b). In 2012, 25,965 farms in Alberta were feeding more than 42% of Canadian calves. More than 50% of the calves were fed on farms located in western Canada (Canfax, 2012a). The average herd size in Alberta is 192 cows per farm. This is higher than the Canadian average (132 head) and western Canadian average (161 head) (Statistics Canada, 2012b). Canadian beef cattle inventory has generally been decreasing since 2000, but has shown a small upward trend since 2011 (figure 2.2). The situation in Alberta is similar to that of the rest of the Canadian beef cattle industry.

Alberta's leading status in the beef cattle industry also shows up in beef products. The number of cattle slaughtered in Alberta was 2.4 million head in 2009, which was over 71% of the national total (ABP, 2012a). As to the quality, according to the 2012 Grading Report for Canadian Cattle issued by Canadian Beef Grading Agency, the number of cattle graded as "prime" in western Canada was 15,568, while the total number of prime cattle in Canada was 24,504 (Canfax, 2013a). In other words, more than 60% of the highest graded cattle in Canada originated in western Canada. The percentage went up to 76% when the grade "AAA" was included. Within western Canada, Alberta is the main supplier of high quality beef products (Canfax, 2013a).

Figure 2.2 Beef cattle inventory on January 1st (2000-2014)

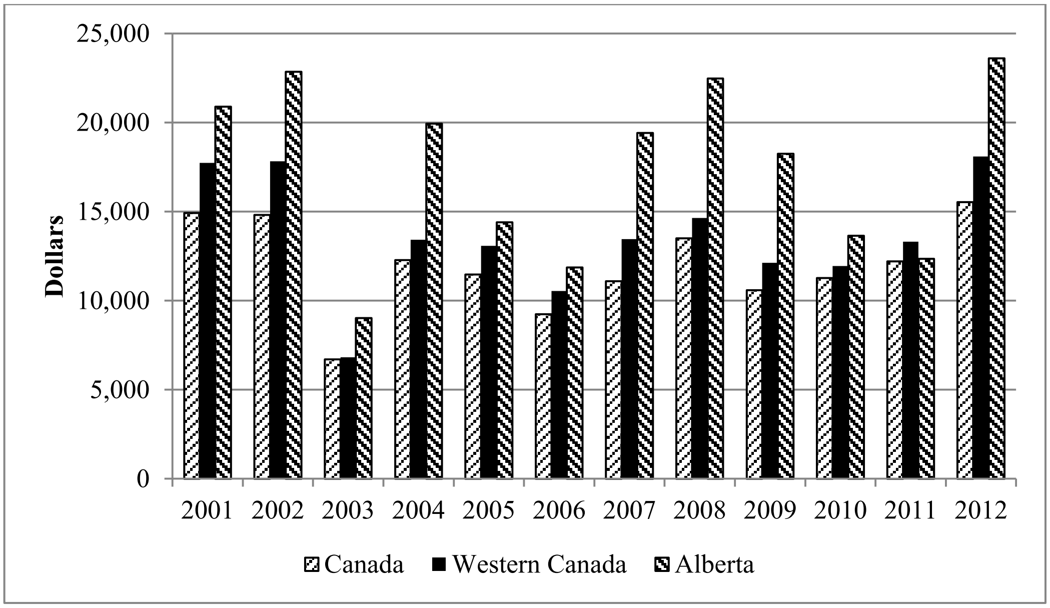


Source: Statistics Canada (2014b), CANSIM Table 003-0032. Ottawa, Ontario.

As mentioned in Chapter 1, beef cattle and calf products have been the second largest source of Canadian farm cash receipts in past years (Statistics Canada, 2013c). According to the latest data from Statistics Canada (2013c), in the second quarter of 2013, beef cattle and calves cash receipts in Alberta totaled $925 million, which was 34.20% of whole farm cash receipts and 72.50% of livestock cash receipts. However, for the same period, the national percentage was just 13.88% of whole farm cash receipts and 31.93% of livestock cash receipts (Statistics Canada, 2013c). This is further evidence that the beef cattle industry is a major contributor to Alberta's agricultural sector.

The average total income and net operating income in the Canadian beef cattle industry were below the mean value of whole livestock industry (Statistics Canada, 2013c). This suggests that beef cattle farm and feedlot owners face challenges in earning a profit. For example, the average total income of beef cattle business in Alberta was $349,799 in 2012 (Statistics Canada, 2013b). It ranked at the bottom compared with the dairy, hog, and poultry sectors in Alberta, in spite of rising beef product prices. This is the case throughout Canada. The average net operating income shows the same situation for the beef cattle industry in Alberta and Canada. However, Alberta has a higher average net operating income than the average for Canada. In 2012, the average net operating income was $23,608 in Alberta while for Canada it was $15,530 (Statistics Canada, 2013b). The average net operating income of beef cattle farms is presented in figure 2.3.

Figure 2.3 Average net operating income of beef cattle farms (2001-2012)



Source: Statistics Canada (2013b), CANSIM Table 002-0044. Ottawa, Ontario.

2.1.2.1 Beef Cattle Operations

Although the Canadian beef cattle industry is a diverse system, the main operating structure consists of three phases: cow-calf operations, backgrounding, and feedlot finishing. Cow-calf operations represent the first stage of commercial beef production. According to Canfax (2013c), there are small cow-calf operations, averaging 200 cows per farm in Alberta and western Canada, and large cow-calf operations, averaging 800 cows per farm. Typically, each cow-calf producer breeds the cow in early summer and one calf is born in the spring of the following year. The calves are then weaned in the fall when they reach a weight of 200 to 280 kg, at which point they enter into the backgrounding or feedlot phase and are fed based on their weights (FCC, 2011; ABP, 2012b). Since most of the revenue in a cow-calf operation comes from selling calves, operators usually pay more attention to the nutrition needs and the weight of calves. Calves in the cow-calf phase are mostly fed by milk from cows. Pasture can also be used when they are close to the target weight, even though pasture provides fewer nutrients than milk.

The second phase is backgrounding, which is the process of feeding the weaned calves to a desired weight of 350 to 500 kg. The objective of backgrounding is to help the calves develop bone and muscle rather than gain fat (GS, 2008). Traditionally, calves will be divided into three categories: lighter calves (200-270 kg), medium-weight calves (270-350 kg), and heavier calves (over 350kg). Different kinds of calves will be fed in different ways. For example, after calves are weaned in the fall, lighter calves will be fed a relatively lower energy forage diet, while heavier calves will be given a higher energy feed diet. Calves in these three weight categories normally need 11-17 months, 7-11 months, and 5-7 months, respectively, before they are ready to enter the finishing phase at around 450 kg (CCA and BIC, 2010; FCC, 2011; ABP, 2012b). Thus, heavier calves could be finished for the spring market.

In the backgrounding phase, ensuring that calves get enough energy and nutrients during the winter is critical. Backgrounding rations are mainly hay-based (i.e., alfalfa hay) before calves reach the 450 kg desired weight and enter into the feedlot finishing phase. However, feed grains are also commonly mixed in the backgrounding cattle rations. In western Canada, barley and oats are the main feed grains in cattle rations (ARD, 2009d). The portion of grain is based on the weight of cattle. Only heavier cattle can handle a higher grain ration. This is because cattle need time to let their rumens adjust to the higher grain ration, otherwise they will become sick and/or die (Gibb, 2013). Since the backgrounding phase usually occurs during the winter when available feed grains are limited, silages are fed as well (CCA and BIC, 2010). Normally, barley silage, wheat silage and corn silage are widely used since they are palatable to calves (ARD, 2009d).

The third phase and final stage is the beef cattle finishing phase. It is often operated by highly specialized feedlots because they have the capacity for tens of thousands of head of cattle. Thus, feedlot owners cannot only finish their own cattle, but can also sometimes help small backgrounding operators finish their cattle for a service fee. According to Canfax (2014), there were 151 finishing feedlots with a capacity of 1,000 head or greater in Alberta at the end of 2013, and over 38% had a capacity of more than 20,000 head. The potential average business size of a finishing feedlot in Alberta is more than 9,000 head. The target weight of finishing is typically set at around 600 kg (CCA and BIC, 2010). Depending on the weight of the calves entering the feedlots, the cattle can usually be ready for market at 12 to 24 months of age. These finished cattle are then sold for domestic slaughter or are exported (FCC, 2011; ABP, 2012b).

For the beef cattle finishing phase, a high grain ration (70% to 90%) is usually fed to cattle to provide more energy and protein for growth (Gibb, 2013). The feed grains in this ration include barley, wheat, oats, and corn. Eventually, rations should generally switch from a forage-based ration in the backgrounding phase to at least a 90% grain-based ration in order to provide enough nutrients (mainly energy) for cattle to gain weight. The switch here is aimed at producing more tender and marbled beef (CCA and BIC, 2010). However, similar to the backgrounding phase, cattle also need time to become acclimated to a higher grain ration while gaining weight. Hence, the portion of grain in the ration is gradually changed during the finishing phase. Meanwhile, not all grains can serve equally well in these rations. For example, wheat needs to be less than 50% of the total ration to prevent digestive problems. The mixed level of each grain also fluctuates depending on the feed intake (ARD, 2009b). Lastly, the finishing phase requires higher levels of minerals, such as potassium and sulphur (ARD, 2003).

2.1.3 Nutrient Considerations for Dairy and Beef Cattle

Nutrients in feed ingredients are critical to the performance of both dairy and beef cattle (ARD, 2009a). The balance of nutrients in a ration is critical in any cattle-feeding operation (ARD, 2009d). Although the detailed nutrient requirements for dairy and beef cattle operations (under varied operation phases) are quite different, the main nutrients required in rations are similar. These include energy, protein, fibre, minerals and vitamins.

Energy is always the first nutritional consideration for any cattle-feeding operation (ARD, 2003). Carbohydrates, which come from feed grains and forages, are the primary source of energy in cattle diets (ARD, 2003; ARD, 2009a). However, because of the increasing prices of feed ingredients, adding fats and oils is an economical approach to keep enough energy and desired cattle performance (ARD, 2012a). Cattle need sufficient energy to keep their bodies functioning and to support growth (ARD, 2009a). In addition, the energy supply must meet the requirements of production, especially when cows need to maintain milk production and breed calves at the same time. Low energy intake during pregnancy can potentially lead to consequences such as higher calf mortality, lower milk production, and lower weaning weight (ARD, 2009a). The daily amount of energy needed by cattle varies depending on such considerations as body size, weight, and milk production (ARD, 2003).

Another vital nutrient in cattle rations is protein. Proteins are made up of amino acids. Like energy, protein is essential for cattle maintenance, growth, and production (ARD, 2003), and also mainly comes from oats, barley silage, and canola meal (ARD, 2009c). If cattle do not receive adequate energy from their diet, they can break down body fat and muscle to supply energy. However, cattle are not able to compensate if dietary protein is not sufficient to meet requirements (ARD, 2009a). Therefore, the importance of protein supply cannot be overemphasized. Most cattle can obtain sufficient protein from rations, but during the cow-calf phase, they may need commercial protein supplements because of the lower feed intake and potential growth of calves (ARD, 2009c).

Fibre is another important diet component for a cattle-feeding operation (Shaver, 2007; Parish, 2007). The type, quality, and length of fibre can significantly affect cattle health and production (Parish, 2007). For example, it takes less time for cattle to digest low fibre feed ingredients, and feed intake is therefore higher. Additionally, cattle also have higher digestibility when they are fed ingredients with a low fibre content. As a result, more energy is available for cattle due to increased intake and digestibility (ARD, 2012c). However, maximizing feed intake and digestibility is not always the goal, as doing so will increase the level of rumen acid. Rumen acid will lower rumen pH level and damage the rumen wall (Parish, 2007). Feed ingredients with high fibre content are required to maintain a normal rumen pH (Shaver, 2007; Parish, 2007). Additionally, when the rumen pH is below 5.5, cows will undergo lactic acidosis, which leads to a low feed intake, low milk production and even death (Shaver, 2002). Hence, in order to determine the required fibre level in rations, two types of fibre test results are defined to reflect the relationships between fibre and feed intake, and fibre and digestibility. One is neutral detergent fibre (NDF), which is insoluble in neutral detergent and has a negative relationship with feed intake. The other is acid detergent fibre (ADF), which is insoluble in acid detergent and has a negative relationship with digestibility (Parish, 2007). Both NDF and ADF commonly exist in feed grains and forages, but forages, such as hay and silage, usually have higher fibre levels than feed grains (NRC, 2001).

Minerals include macro minerals and trace minerals. Major macro minerals for cattle operation include phosphorus, calcium, sodium and chlorine (ARD, 2003). Trace minerals include iron, zinc, copper and manganese (ARD, 2003). The requirements for minerals are varied and depend on the type and weight of cattle. For instance, beef cattle with a heavier weight usually need less calcium and phosphorus (ARD, 2010). However, calcium and phosphorus are important for calves and cows, as they are required for skeletal development and milk production (ARD, 2009a). Additionally, vitamins are also essential and commonly involved in rations, especially for immune response (ARD, 2009d). Feed grains and forages can supply most minerals and vitamins, but commercial supplements are normally used over the whole feeding operation (CCA and BIC, 2010). Nevertheless, adding commercial supplements should be done carefully, since an overdose of minerals or vitamins can harm cattle (ARD, 2003).

2.2 Near-Infrared Reflectance Spectroscopy

As discussed in the previous section, the dairy and beef cattle sectors have a significant economic impact on the agricultural industry in Alberta and western Canada. These sectors are also stressed with respect to feed costs, resulting from increasing prices of feed ingredients. Accurate nutrient content information in feed ingredients is critical to manage feed costs in dairy and beef cattle operations. Therefore, an accurate prediction of nutrient contents in rations can potentially benefit farm operators. Near-Infrared Reflectance Spectroscopy (NIRS) is one of the most promising technologies to predict nutrients. This section provides a general introduction to NIRS technology and its application on grain and forage analysis.

2.2.1 History of NIRS

NIRS is an efficient and quick technique to screen and analyze chemical characteristics of a given sample (Hue et al., 2014). NIRS technology has been implemented in a number of fields, including agriculture, food, pharmacy and health. Test samples can include grains, forages, fruits, meat products, liquids, feces, manure, medicines and blood samples. Test results can include measures of protein, carbohydrate, moisture, starch and fibre. NIRS technology involves both visible and invisible infrared lights. The normal range of wavelengths is between 750 and 2500 nm (Chodak, 2008). The amount of light energy absorbed by the test sample, due to the interactions between organic molecule chemical bonds in the test sample and infrared radiation, is measured and reported by a NIRS machine (Chodak, 2008; Hue et al., 2014). NIRS machines require calibration. Regression equations are developed to estimate the parameters of interest when the machine is calibrated to the correct spectral range.

NIRS has been used in agriculture since the second half of the 20th century (Chodak, 2008). Between 1949 and 1953, Wade Brant and Karl Norris conducted the earliest application of infrared reflectance on agriculture for the United States Department of Agriculture to build instrumentation to grade eggs (Norris, 1996).

Brant and Norris successfully built a machine that could measure the transmittance of white-shell eggs over wavelengths between 550 and 950 nm. Because of the limitation of the detector, their research was not able to explore the near infrared. The earliest studies on grain analysis using infrared-reflectance techniques can be traced to the 1960s (Hart et al., 1962; Ben-Gera and Norris, 1968; Norris and Hart, 1996). Hart et al. (1962) performed research of near-infrared spectrophotometry application on the moisture content of seeds. Their results show that the moisture level obtained using NIRS had a smaller standard deviation at ±0.24% than those obtained by the widely used titration method. Scholars concluded that NIRS was a potentially rapid technique for predicting the moisture content. The application of NIRS was extended to forage analysis for nutrient content information in the 1970s. Shenk et al. (1976) reviewed the development in the evaluation of forage quality by infrared spectroscopy. They stated that the NIRS instrumentation could predict nutrients of multiple forages with less than 5 g of sample in less than two minutes. The study successfully predicted crude protein (CP), NDF, ADF and *in vitro* dry matter disappearance (IVDMD) with small differences when compared to results from conventional chemical tests. Shenk et al. (1976) concluded that the commercial use of a NIRS instrument was acceptable and promising.

More studies have been performed using NIRS in other agriculture fields, such as animal science, food (i.e., meat products), soil and manure. Kitessa et al. (1999) concluded that NIRS could be used to measure the digestibility of feed in ruminants more accurately than the conventional *in vitro* method. The main limitations to using NIRS for prediction are the requirements for calibration and validation. Millmier et al. (2000) tested swine lagoon effluent, liquid swine pit manure, and solid beef feedlot manure using NIRS, and concluded that the technique was capable of predicting total solids, total nitrogen, ammonia nitrogen, and potassium for all three manures tested. Studies on NIRS application have also been further extended to fields other than agriculture, such as pharmacy and health science. For example, Roggo et al. (2007) reviewed previous studies in which NIRS was used in the pharmaceutical industry. They concluded that NIRS was a fast analytical method, and could be implemented to analyze solid, liquid, and biotechnological pharmaceutical forms.

2.2.2 NIRS in Grain and Forage Analysis

An accurate prediction of grain and forage nutrient contents is critical to save feed costs, and therefore to the success of the livestock operation business. In order to obtain precise results of the contents of nutrients, laboratory analysis is usually involved. According to Barnes and Marten's (1979) research, laboratory methods for grain and forage analysis can be classified into two categories, consumptive and nonconsumptive, based on the final state of tested sample. By using the consumptive laboratory methods, which include chemical, physical, *in vivo*, *in vitro* rumen fermentation, and small animal bioassay methods, the tested samples are destroyed. The nonconsumptive methods, which include infrared reflectance spectroscopy and density measurements, do not destroy the tested samples. Meanwhile, infrared reflectance spectroscopy has been treated as the most promising technique for grain and forage analysis, since it is a rapid and efficient technology for nutrient evaluation, and samples for the test can be used repeatedly (Barnes, 1973; Barnes and Marten, 1979).

Based on previous NIRS studies, NIRS technology has been widely and successfully tested for a variety of types of samples, especially grains and forages. Panford (1987) summarized former NIRS experiments in North America for wheat, barley, maize, soybean, oat, oilseeds, forages, fruits and vegetables, and animal products. In his review, high accurate protein predictions were achieved for both grain and forage analysis. Later studies also support Panford's (1987) conclusion. Garnsworthy et al. (2000) conducted a NIRS experiment for 160 wheat samples to generate calibration equations for nutrient contents. The results were quite satisfactory for the prediction of dry matter (DM), CP, ash, starch, and oil in wheat samples. Villamarin et al. (2002) performed NIRS experiments on 366 samples of various grass silage species from different provinces in northwestern Spain between 1992 and 1995. Their study successfully predicted CP, NDF, ADF, and crude fibre (CF) in these silage samples.

Gislum et al. (2004) collected 837 plant samples from 12 sampling field sites in Denmark from 2000 to 2002. After performing NIRS analysis for nitrogen concentration, they found that test samples with a range of nitrogen concentration from 0.6% to 6.26% could be well predicted. In addition, Owens et al. (2007) examined the performance of NIRS by testing wheat samples under different physical conditions. Their results suggested that NIRS provided a good prediction for CP and the rate of starch digestion for milled wheat samples, as well as for whole kernel wheat samples (not dried), and other nutrient contents, such as gross energy and NDF.

For grain and forage analysis, NIRS technology has successfully predicted levels of most nutrients. Moisture was one of the first components to be tested. Ben-Gera and Norris (1968) used direct near-infrared spectrophotometry to predict the moisture content of soybean samples. Fourteen ground samples were also examined under the oven-drying approach, as calibration. The results from the two approaches were compared, and Ben-Gera and Norris (1968) concluded that NIRS technology was a rapid method with high accuracy for grain moisture content prediction. The conclusion has been supported by later studies as well. Thiex and Erem (1999) used NIRS to predict water content in hay, haylage, and corn silage, and also suggested that the technique performed well for evaluating moisture.

Recently, more and more studies have been performed on predicting energy and protein, since they are the two most important nutrients for livestock feeds. Garcia-Criado and Garcia-Ciudad (1990) conducted a protein analysis on 77 samples of grassland herbage using NIRS technology. These samples were in various stages of maturity, ranging between the flowering stages and fruiting stages. The standard errors of calibration for NIRS measurement of crude protein ranged from 0.37 to 0.50, which showed that the protein prediction by NIRS was acceptable. Van Barnevel et al. (1999) collected various types of cereals (wheat, barley, sorghum, triticale, and maize) from sources in Australia, Canada, France, and New Zealand. Both whole and ground grains were included in the experiment in which NIRS was used to predict energy content. Despite the inaccuracy occurring between different laboratories, acceptable coefficients of determination (>0.70) were found in all the samples. Therefore, Van Barnevel et al. (1999) concluded that NIRS could measure digestible energy in grain cereals with an accuracy of 0.4 MJ/kg. Xiccato et al. (1999) used NIRS to conduct nutritive evaluation and ingredient prediction of compound feeds for rabbits. Sixty-six samples of compound feeds from Belgium, Spain, and Italy were used for NIRS evaluation. This experiment successfully predicted CP, gross energy, and gross energy digestibility with coefficients of determinations of 0.88, 0.90, and 0.85, respectively. Similar results are also found in more recent studies. Pujol et al. (2007) used NIRS to scan 20 barley samples. Losada et al. (2009) measured nutrient contents in six starchy grains and six starchy cereals samples using NIRS. Both studies received satisfactory prediction results for energy and protein. In addition, both studies concluded that prediction results in terms of nutrient contents from NIRS were better than from the *in vitro* method.

As discussed above, fibre is one of the most important nutrient contents for dairy and beef cattle feeding operations. NIRS has been applied to predict fibre in grain and forage analysis. Garcia-Ciudad et al. (1993) chose 97 pasture samples harvested between 1986 and 1989, and used NIRS to predict nutrient contents. Their experiment showed high accuracy through NIRS for predicted NDF and ADF. Deaville et al. (2009) compared NIRS prediction results of nutrient content in 134 whole wheat samples and 16 whole barley samples with laboratory and in vitro digestibility approaches. Results showed that NIRS could accurately predict NDF, DM, starch, and other nutrients with coefficients of determination greater than 0.90. Additionally, how well NIRS predicts fibre seems to depend on the type of sample. De Boever et al. performed a NIRS experiment on grass silage

(1996) and maize silage (1997). NIRS performed poorly in predicting ADF in grass silages (de Boever et al*.,* 1996). Conversely, NIRS was proven to be good at predicting ADF in maize silages (de Boever et al*.,* 1997).

In summary, NIRS has proven to be effective for the prediction of most nutrient content in grain and forage analysis. However, using NIRS does not guarantee accuracy for all nutrient content. For example, it is hard to predict mineral content in grain and forage analysis using NIRS. Clark et al*.* (1987) conducted a mineral analysis of forages on 462 samples, which included crested wheatgrass, tall fescue, and alfalfa hay. Half of the samples were used to develop calibration equations, and the rest were used for validation. The results revealed that NIRS could only accurately evaluate certain major minerals in forages, such as calcium, phosphorus, potassium, and magnesium. Clark et al*.* (1989) then conducted another experiment to analyze trace elements (beryllium, lithium, molybdenum, nickel, lead, vanadium, aluminum, sulfur, and silicon) using NIRS for the same forages used in the initial research. They found the prediction results from NIRS were still not sufficiently accurate. However, aluminum and sulfur were consistently accurate when evaluated by NIRS.

2.3 Chapter Summary

This chapter provides background on two main questions. First, what is the situation of the dairy and beef cattle industry in Alberta and western Canada now? Secondly, what is the development of NIRS technology in grain and forage analysis? Previous studies have attempted to conduct NIRS research in terms of how accurately NIRS can predict nutrient content in grain and forage analysis. It has been shown that NIRS technology is an accurate tool to conduct quick nutrient content prediction. Therefore, NIRS technology can be adopted as a tool to predict nutrient contents of the feed grains and forages used in dairy and beef cattle rations. By providing information about nutrients, dairy and beef cattle farms can potentially formulate their rations more efficiently and therefore obtain benefits.

However, to date there have been few studies to link the performance of NIRS technology with the animal operation business from an economic perspective. Black (2008) defined the economic value of NIRS in terms of the value of an extra unit of nutrient being made available for livestock. Black's (2008) estimation illustrated that the average value of 1 MJ/kg of extra energy content in cereal grains, across the major animal industries (i.e., pig, poultry, dairy, beef), was approximately $17.50/t of cereal grains. For example Black (2008) determined that a dairy farm could capture $7.48/t of cereal grains for each extra MJ of available energy in the cereal grains, while a feedlot could capture $14.20/t of cereal grains. This does not represent a comprehensive study, as it focused on only a single nutrient for one feed ingredient. However, it does represent one way of examining the economic value of NIRS.

The lack of previous economic analysis provides some justification for the analysis undertaken in the current study. This study tries to capture the economic impact of NIRS technology in the dairy and beef cattle industries in Alberta and western Canada. It is hoped that this study will obtain a reliable impact assessment of adopting NIRS, and will make a contribution to the farm business decision-making process in the research region. Chapter 4, the methodology chapter, will answer the following two questions: What are the benefits and costs from adopting NIRS in the dairy and beef cattle industries? How can those benefits and costs be measured?

Chapter 3: Conceptual framework

This chapter provides a conceptual discussion to explain the reason for choosing benefit-cost analysis (BCA) as the main method for NIRS adoption evaluation in this study. The chapter first explains BCA, and its application in the decision-making process. The process and main concepts used in valuation are then discussed. These include net present value analysis, discount rate, and measures of welfare changes. Lastly, four main limitations of BCA are discussed.

3.1 Benefit-Cost Analysis

BCA is one of the most commonly used methods to evaluate alternative options for projects that decision makers need to resolve. Values of all benefits and costs arising from implementing a project are quantified in monetary terms. The difference between benefits and costs is the net benefit (Townley, 1998; TBCS, 2007; Boardman et al., 2011).

The foundation of BCA is economic welfare theory. One standard by which to judge a project is that if implementing a project makes one or more persons better off and no person worse off, then the project should be adopted. This is called Pareto efficiency. However, this is often unlikely to happen in reality, since implementing a project normally creates both gainers and losers. Thus, potential Pareto efficiency can be adopted as an alternative principle for BCA, which means a project should be undertaken if gainers could compensate losers and still attain a net benefit[4]. The relationship between net benefit and these two welfare economic principles are clear. When the net benefit of a project is positive, then it is possible to make at least one person better off without making anyone else worse off, and the project should be undertaken. Conversely, when the net benefit is negative, two welfare economic principles are not fulfilled and the project should not be undertaken (Boardman et al., 2011). Therefore, BCA is typically

[4] This is also referred to as the Kaldor-Hicks compensating principle (Just et al., 1982).

used to determine if a project is worthwhile. According to Boardman et al. (2011), the standard process to conduct BCA involves the following nine steps:

1. Provide options for the project.
2. Identify whose welfare is being considered.
3. List potential impacts for each option.
4. Quantify the impacts.
5. Monetize the impacts.
6. Discount benefits and costs into present values.
7. Compute the net present value of each option.
8. Conduct sensitivity analysis.
9. Make recommendations.

BCA is only one of a number of methods for economic evaluation. When only one option is available for a project, then partial evaluation methods can be adopted, such as a cost-outcome description. However, when there are two or more options available, partial evaluation methods may not be appropriate since there is no comparison between alternatives (Drummond et al., 2005). For this study, a baseline case (no adoption of NIRS by a feeding operation) is compared with a comparison case (adoption of NIRS by a feeding operation) for the dairy and beef cattle industries. Full evaluation methods should be adopted for this study. According to Drummond et al. (2005), there are four full evaluation methods, including cost-minimization analysis (CMA), cost-effectiveness analysis (CEA), cost-utility analysis (CUA), and BCA. CMA should be adopted when consequences of all alternatives are the same; the alternative with the lowest cost should be adopted. Since the consequences of using NIRS and not using NIRS in feeding operations are different, CMA is not appropriate for this study.

CEA measures only the single effect of interest for consequence, which is common to all alternatives. This consequence is measured in physical units, such as days or blood pressure level. Since those physical units are hard to aggregate together, only a single effect can be measured through CEA. In contrast, CUA can measure single or multiple effects, which are not necessarily common to all alternatives, since all the consequences are measured in utility for each alternative. For example, suppose a researcher wants to conduct a CUA for patients who are or are not taking a cancer drug. Side effects (which only occur and are measured for the "taking drug" alternative) and mortality (occur for both alternatives) can both be measured. Side effects and mortality are measured in utility terms, such as quality-adjusted life-years (QALY). For both CEA and CUA, costs are still measured in monetary terms. The results can be reported as how much money it costs to achieve one unit of consequence (utility in CUA) for each alternative, such as $/day, $/QALY, etc. Thus, as was the case with CMA, the lowest-cost option should be undertaken (Drummond et al., 2005). However, CEA and CUA are still not appropriate for this study. The main reason is that potential benefits in this study, such as feed cost savings (discussed in Chapter 1), are already measured in monetary terms. It is meaningless to measure/transfer those benefits into physical units or utilities. Although arguments can be made that because the results of NIRS prediction (i.e., nutrient content levels) are presented in physical units, CEA is therefore potentially appropriate. Multiple nutrient contents (i.e., energy, protein, fibre, etc.) are included in this study, and CEA can only involve a single effect of consequence. Hence, CEA is still not ideal for this study.

BCA is the most appropriate method for this study. First, NIRS prediction results can be used to determine feed costs, which are measured in monetary terms and fit the nature of BCA. In this manner, multiple effects in terms of nutrient content levels are involved in the evaluation. Additionally, measuring benefits and costs in monetary terms makes it easier to convert net benefit to an animal unit base, such as $/head, which allows aggregation to the provincial and western Canadian level. Lastly, BCA fits the objective of this study: to determine if it is economically feasible to commercially introduce NIRS technology. BCA is good for decisions that happen one at a time to determine if a project is worthwhile or not, such as if livestock operators should adopt NIRS in this study. CEA and CUA are often used for fixed budget allocation decisions (Drummond et al. 2005).

3.2 Net Present Value Analysis

The most essential step to conduct BCA is the valuation of benefits and costs. When the project or policy has impacts that occur over time (usually over years) those impacts, including both benefits and costs, need to be aggregated together. Hence, future benefits and costs are discounted to the present in order to get present values (PV). The process to convert future values (FV) to PV is called discounting, which uses a discount rate to represent people's time preference. It means people have the preference to consume sooner rather than later (Boardman et al., 2011). For instance, when the discount rate is higher, it demonstrates that people place less value on the future benefits and costs. In other words, if the discount rate is high, people do not care about future values as much. On the other hand, if the discount rate is zero, people consider the values they will receive in the future to be as important as the values they receive in the present.

An important reason to discount FV is because people are more interested in and sensitive to the values in the present (Boardman et al., 2011). It is easier for decision maker to think in terms of the worth at present. The following is an example that reflects the relationship between PV and FV: an amount of money (as FV) will be received at year *n*, and its annual discount rate is fixed at rate i. Then the PV of the money received in the future can be shown as equation 3.1:

$$PV = FV/(1+i)^n \tag{3.1}$$

Meanwhile, based on the net benefit criterion that social welfare is maximized, net present value (NPV) needs to be calculated. The NPV is defined as the difference between the PV of benefits and costs (Boardman et al., 2011), which can be shown as equation 3.2. The basic decision rule for BCA is to adopt the project if the NPV value is positive. If the NPV is negative, the project should not be adopted (Boardman et al., 2011).

$$NPV = PV(B) - PV(C) \tag{3.2}$$

where B represents benefits and C is costs. Assuming the project lasts for *n* years, and the discount rate is fixed at rate *i*, then the NPV of the project can be shown as equation 3.3:

$$NPV = \sum_{t=0}^{n} \frac{FV(B)_t - FV(C)_t}{(1+i)^t} \tag{3.3}$$

The discount rate can be a social discount rate or a private discount rate in NPV analysis. When mainly government funds are involved (social investments), or the research is from the perspective of society and will benefit society, then the social discount rate should be adopted to value these social projects and policies. However, when private funds are the main source, and the impacts are limited to private business, then a private discount should be used. In this study, since the farms or feed mills are investing in the NIRS machine, and will directly benefit (i.e., feed cost savings), a private discount rate should be applied. The choice of discount rate is discussed in Chapter 4.

3.3 Measurement of Welfare Change

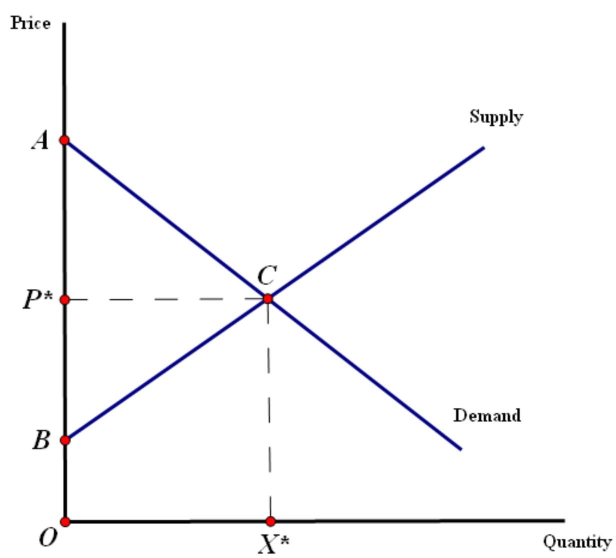
As the foundation of BCA, welfare economics provides approaches to measure welfare changes. Four concepts are introduced here, since they are commonly used to measure the change in welfare: consumer surplus (CS), producer surplus (PS), compensating variation (CV), and equivalent variation (EV).

3.3.1 Consumer and Producer Surplus

CS and PS are based on Marshallian demand and producer supply relationships (Boardman et al. 2011). In a competitive market, given the demand and supply curves in figure 3.1, equilibrium price and the quantity of goods can be determined as P^* and X^*. As Varian (1987) stated, the demand curve can be interpreted as how much consumers would like to pay for the last unit of goods. In figure 3.1, the area ACX^*O shows the total value of goods purchased in terms of willingness to pay. As P^*CX^*O represents the cost for consumers to purchase X^* units of goods at the equilibrium price P^*, the area ACP^* represents the CS, which measures the net benefit for the consumer to consume X^* units of goods.

Based on the theory of the firm, the supply curve can be interpreted as the marginal cost of production, or the minimum marginal or extra revenue required to produce the last unit of goods (Boardman et al., 2011). As the consumer's cost is the producer's revenue in this case, the area P^*CX^*O also illustrates the producer's revenue for selling X^* units of goods at price P^*. Thus, BCP^* becomes the net benefit earned by the producer, which is also known as the PS.

Figure 3.1 Consumer and producer surplus

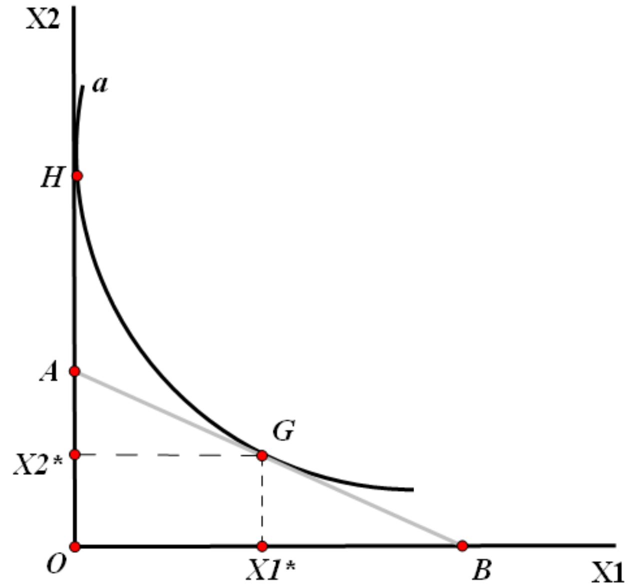


In a simple consumer-producer case, social surplus can be presented as the sum of both the CS and PS (Boardman et al., 2011), which is the area *ACB* in figure 3.1. However, this measurement is also subject to some problems or limitations. For instance, the evaluation of the consumer's satisfaction from a good or service should be the consumer's utility (Varian, 1987). But in this case, the CS is the difference between the Marshallian demand curve and the actual price (market price), and the Marshallian demand curve is determined by prices of goods and income. Thus, using the change in the CS to make a close estimation of welfare change cannot reflect the concept of consumer utility. In addition, the CS may fail as the measure of welfare change under certain circumstances (Varian, 1987). For example, suppose that a policy is introduced to make people consume fewer goods by compensating them with money. The CS can potentially decrease due to higher market prices. However, since consumers have more money available, the movements of the Marshallian demand curve will depend on using extra money to consume the same or other goods. This can result in a decrease or increase of the CS. When the income effect[5] is involved and cannot be ignored, the change of CS is not accurate enough to measure welfare changes.

Another approach to define the CS is explained in figure 3.2, and can involve the concept of utility. In figure 3.2, the budget line AB and the indifference curve *a* are given, and price of good *X2* is assumed to be equal to one. The point of tangency *G* demonstrates the optimal allocation in terms of how much of each good should be purchased. These goods are denoted as $X1^*$ and $X2^*$. The distance between point *A* and point $X2^*$ illustrates the quantity of goods *X2* that can be purchased by the amount of money spent to purchase goods *X1*. Meanwhile, the indifference curve *a* is a tangent to the *X2* axis at point *H*. Therefore, the difference between point *H* and point *A* measures the CS that a consumer can enjoy by purchasing *X1** units of goods *X1* (Varian, 1987).

[5] The income effect is the impact on the demand for goods of a change in consumer income.

Figure 3.2 Defining consumer surplus using the indifference curve



3.3.2 Compensating and Equivalent Variation

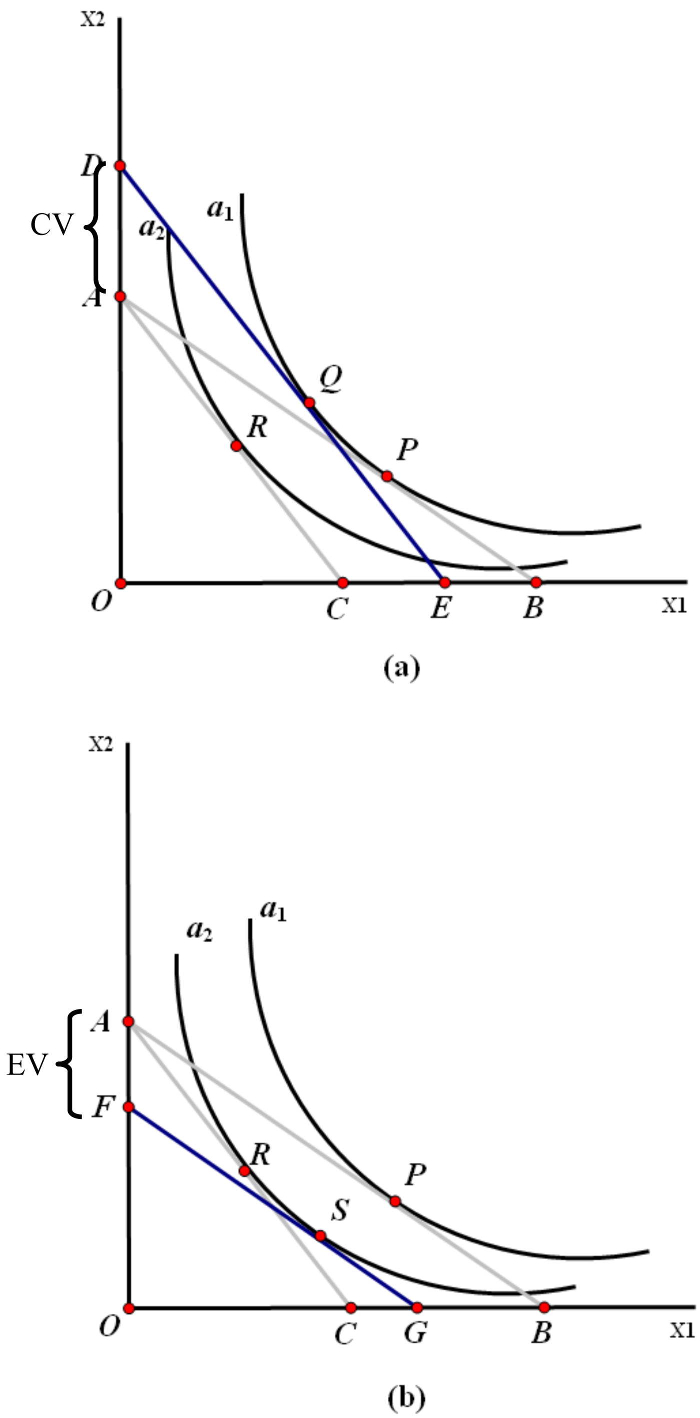
As described above, using a Marshallian demand curve to measure consumer surplus and producer surplus can raise some issues that affect the measure of welfare changes. For this reason, another approach is introduced based on the Hicksian demand curve.

The first concept is a CV, which is an estimate of the extra money that needs to be paid to consumers to ensure that they receive the same level of utility before a price increase (Boardman et al., 2011). The process for obtaining a CV is shown in figure 3.3 (a). The prices of good *X1* and *X2* are *P1* and one at the beginning, respectively. Then line *AB* is the original budget line, and its slope is *–P1*. Assume that there is a price increase for good *X1* from *P1* to *P1'*, with all other conditions being held constant. Thus, the budget line rotates to *AC*. As *a1* and *a2* are two indifference curves, the tangent points of indifference curves and budget lines are point *P* and point *R* before and after the price change, respectively. According to the definition of CV, extra money will be paid to the consumer to compensate for the price increase in good *X1* and keep the consumer enjoying the same level of utility, which is *a1* here. The budget line *DE* is shown here which is parallel with line *AC*; their slopes are both *-P1'*. The CV sets the new prices as the base. The point *Q* is the tangent point of the new budget line and indifference curve *a1*. Then, the point *Q* is the final allocation of how much *X1* and *X2* are purchased, which can maintain the same utility by paying extra money to make consumer accept the price increase for good *X1*. Because the price of *X2* is constant and equal to one, the distance between point *D* and point *A* reveals the extra money paid to consumers, which is the CV in this case.

Another important concept, the EV is shown in figure 3.3 (b). The EV is defined as the maximum amount of money that consumers will pay to avoid a price increase (Boardman et al., 2011). As was the case with the previous CV example, *AB* and *AC* in figure 3.3 (b) are still the budget lines before and after increasing the price of goods *X1*. The indifference curves are still *a1* and *a2*. However, because consumers would be willing to pay money to avoid the price increase for good *X1*, then the new budget line shifts down, as line *FG* in the graph. The new budget line *FG* is parallel with *AB* with the slope *–P1*. Thus, the EV sets the original prices as the base. The tangent point of the budget line *FG* and the lower indifference curve *a2* is point *S*, which is the final allocation as well. Then, the distance between point *A* and point *F* becomes the value of the EV here.

Although the CV and EV are the best available measures of welfare changes since they directly estimate the impact on people's utility, most analysts still use the CS to measure welfare changes (Boardman et al., 2011). This is because that CV and EV are based on the condition of utility maximization, and the utility is difficult to determine and measure. In contrast, consumer surplus is easier to measure. Also, the income effect associated with price changes is often very small, in which case the bias can be ignored (Boardman et al., 2011). Therefore, the CS is often used as an approximation measure of welfare changes (Varian, 1987). Since the CS measures the change in benefits, it is eventually used to calculate NPV.

Figure 3.3 Compensating and equivalent variation



Source: Adapted from Varian (1987)

3.4 BCA Criticism

BCA has been commonly used as a policy or project assessment method that can monetize benefits and costs of a policy or project to some or all members of a community or society in general (Osborne and Turner, 2010; Boardman et al., 2011; Beukers et al., 2012). Many analysts adopted BCA as the main approach in their studies. Meanwhile, they also offered plenty of criticism about the BCA methodology.

Firstly, it is very hard to technically estimate benefits and costs. Sometimes, analysts have to do guesswork or roughly measure, especially when valuing human life, environmental resources, etc. (Adler and Posner, 1999; Walker, 2007; Osborne and Turner, 2010). The monetizing process can be very difficult, and a lot of extra information is needed. However, most BCAs are conducted under time and resource constraints, which may make it difficult to obtain precise conclusions (Smith and Moore, 2010).

Secondly, people's preferences become the source of information to estimate the social welfare in BCA (Sugden, 2005; Fudge, 2011). It has been criticized for the way that analysts collect the data to measure preferences. Meanwhile, some BCAs can be conducted based on survey data, especially when the research area is related to behavioural economics (Smith and Moore, 2010). Economists are universally using the assumption of coherent preference to predict economic behaviour (Sugden, 2005; Osborne and Turner, 2010). However, according to Sugden (2005), there are systematic deviations between the standard assumptions for predicting preference and the actual decision-making behaviour, which are referred to as preference anomalies.

Thirdly, BCA is fundamentally a decision-making tool that aims to help to maximize welfare (Adler and Posner, 1999). For some projects, objectives other than maximization of welfare may also be valued or considered. A very commonly argued one is that of taking fairness into account in the decision-making process through BCA (Adler and Posner, 1999; Boardman et al., 2011). According to Fudge (2011), preference measurement is not a good way to solve the equity issues in the society.

Lastly, as analysts need to figure out and categorize the impacts, an author's personal views may affect the results. According to Walker's (2007) research on quantifying the benefits and costs of gambling, he found that people tended to incorporate personal beliefs into cases containing moral issues. For example, anti-gambling activists may overestimate the costs of gambling without giving justification. The same thing happened with integrated land use and transportation plans, since different participants or analysts had significant disagreements on conducting the BCA for these process-related projects (Beukers et al., 2012).

3.5 Chapter Summary

This chapter discusses the conceptual framework used in this study. BCA is introduced as a decision-making tool to evaluate economic impacts. Further information about BCA is provided in terms of net benefit criterion, process steps, comparison between BCA and other economic evaluation methods, NPV analysis, and measurement of welfare changes. Through the discussion in this chapter it is clear that although BCA has limitations, it is still an appropriate evaluation approach for this study.

A discussion is provided to compare BCA with other major economic evaluation methods, including CMA, CEA, and CUA. CMA is not adopted since it is hard to keep the consequences of alternatives (with or without NIRS adoption) at the same level for this study. CEA measures a single effect of consequence, while multiple effects of consequences need to be evaluated in this study. CUA measures multiple effects of consequences in utility, but utility is not an appropriate unit for this study since most effects of consequences can be directly evaluated in monetary terms. In contrast, BCA measures both benefits and costs in monetary terms, and is essentially adopted in this study to determine if adopting NIRS is worthwhile. BCA not only fits the objective of the study, but also provides the information about the monetary value of adopting NIRS, which is easier for decision makers to understand.

A net benefit criterion is adopted in BCA based on two welfare economic principles, including actual and potential Pareto efficiency. Net benefits are presented through NPV analysis, which assesses and aggregates the impacts that occur in this study. In order to calculate NPV, the concepts of PV and FV are provided. A discussion of discount rate is then presented, and it is decided that private discount rate should be used in this study. Additionally, as the foundation of BCA, welfare economics theory provides two approaches to measure welfare changes. Although CV and EV are better measures for welfare changes, they are rarely used in these studies, since utility is difficult to estimate. Thus, CS is still the most commonly used approach to measure welfare changes. Meanwhile, BCA also has limitations. First, not all of the benefits and costs can be accurately assessed. Second, preference anomalies may occur while using people's preference as the information source. Third, objectives other than welfare maximization may be involved. Fourth, the author's personal preference in terms of the research topic may bias the results.

In summary, despite its limitations, BCA is still used as this study's evaluation method to address the question of whether NIRS technology should be adopted for dairy and beef cattle operations in Alberta. Market information (i.e., feed prices, labour costs) is used to measure benefits and costs in monetary terms. NPV analysis is also adopted. When the NPV is positive, NIRS technology should be adopted. Conversely, if the NPV is negative, NIRS should not be adopted. Detailed modeling and evaluation information is provided in Chapter 4.

Chapter 4: Empirical Methods

An overview of the modeling approaches used to value the benefits and costs of NIRS adoption is provided in this chapter. First, representative dairy and beef cattle enterprises and their characteristics are identified for this study. Second, the Least-Cost Ration Model (LCRM) and its structure are presented. The model is used to determine minimum feed cost associated with fulfilling nutrient requirements for dairy and beef cattle feeding operations. In addition, stochastic elements, such as distribution parameters and stochastic feed price models, are used along with the results of LCRM, in a simulation analysis. A discussion of modeling adoption of NIRS is then provided, which includes measuring NIRS's effect and the cost of adoption. Finally, a Benefit-Cost Analysis (BCA) is conducted for each representative enterprise. Net Present Values (NPVs) are calculated and aggregated to evaluate the economic feasibility of Alberta dairy and beef cattle industries adopting NIRS. The results are extended to obtain estimates for western Canada. Models are created and solved in Microsoft Excel©, and feed price models are estimated using the statistical software STATA© and simulated in the Excel add-in program @Risk©.

4.1 General Modeling Approach

NIRS technology has been used to rapidly and accurately analyze feed nutrients. Adopting the technology will benefit both livestock and crop operators, as discussed in Chapters 1 and 3. However, these are future benefits. Additionally, operators need to purchase a NIRS machine, which can cost from $30,000 to $60,000 per package. There are other costs, including labour, calibration, and maintenance. Therefore, purchasing an NIRS machine can be considered an investment with future benefits and costs. Accordingly, a methodology that can evaluate future net benefits should be adopted for this study. It is assumed that operators consider purchasing NIRS machines based on NPVs, which are calculated from a BCA. Thus, a BCA is used in this study as an assessment tool to quantify all the values of benefits and costs involved in monetary terms (Boardman et al., 2011).

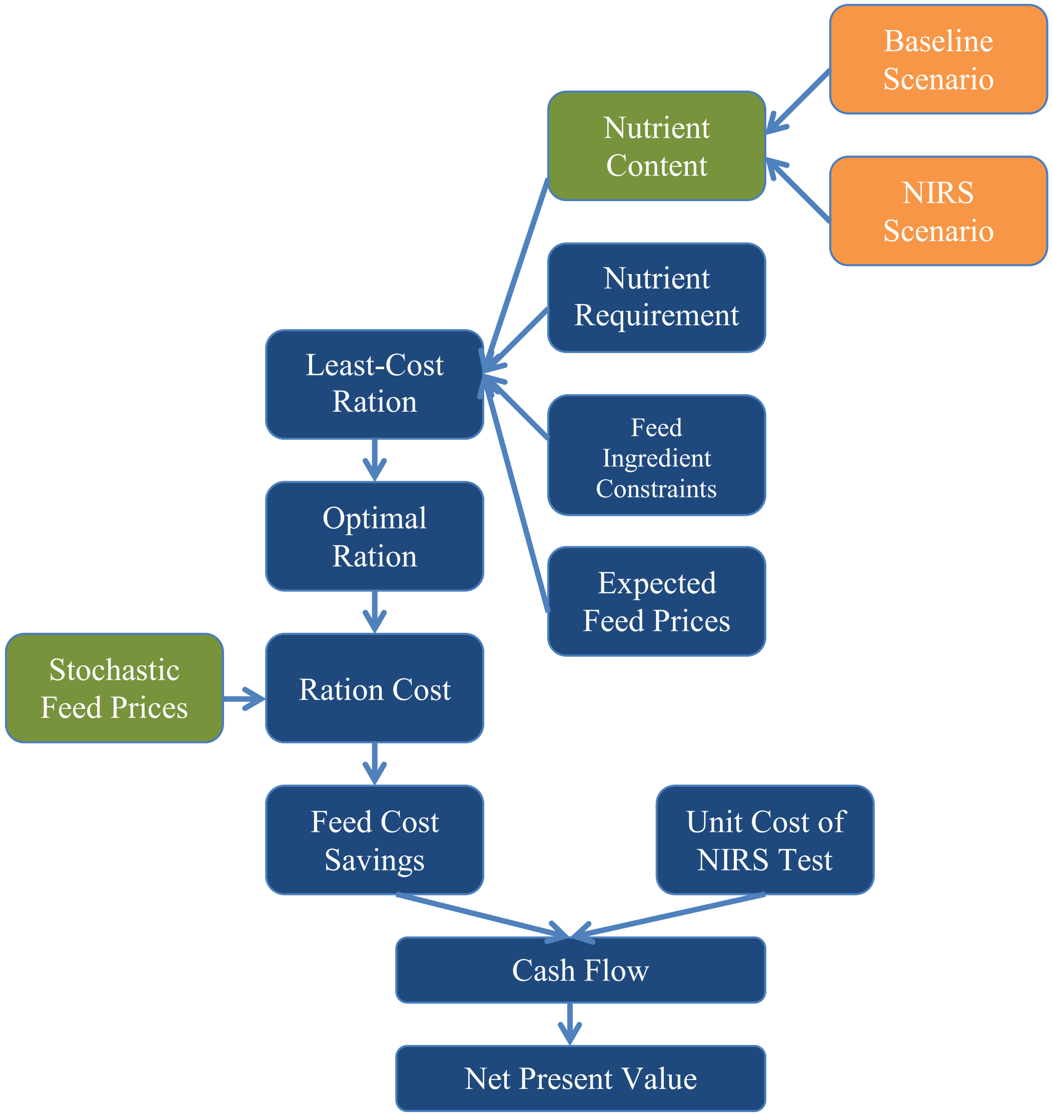
A conceptual diagram of the modeling approach is provided in figure 4.1. NPV is the present value of net benefits (net cash flow) in this study, and it provides a rational criterion for operators to make decisions. If the NPV is larger than (less than) zero, operators should (should not) adopt NIRS technology in their businesses. Cash flows are calculated for each representative enterprise on a per-animal basis. These are then used to calculate NPVs (again on a per animal basis) assuming a twenty-year horizon. The choice of this time length is based on expert opinion concerning technological innovations and machinery depreciation (Swift, 2012). Furthermore, all per-animal NPVs are also aggregated to industry-level NPVs for Alberta and western Canada.

NPV is calculated by subtracting the discounted total cost from the discounted total benefit. Thus, two categories of impacts need to be estimated in this study. For the benefit side, it is assumed that the benefits from NIRS are through feed cost savings. This assumption is based on the fact that NIRS technology provides nutrient content information about feed ingredients. It allows operators to select feed ingredients with higher nutrient values for their rations, and decrease total feed costs. In order to estimate feed-cost savings, a LCRM is adopted for use in this study. Nutrient content, nutrient requirements, feed ingredient constraints, and expected feed prices are used in the LCRM to determine the optimal ration and ration cost. For the cost side, the costs of adoption are estimated for each representative enterprise. The estimated unit cost of the NIRS test is incorporated, including capital, labour, calibration, and maintenance. Economic relationships of benefits and costs are then summed to determine the net cash flow.

The green boxes in figure 4.1 represent stochastic elements involved in this study, including stochastic nutrient content and stochastic feed prices. Nutrient contents and feed prices are employed in the LCRM to estimate feed costs. The stochastic parameters are randomly selected from the respective distributions when running the simulation models. The distributions of stochastic nutrient content are built based on experimental data from National Research Council (NRC) nutrient requirements guidebooks (NRC, 2000; 2001). The distributions of stochastic feed prices are constructed from stochastic feed price models using historical feed price data collected from the Alberta Agriculture and Rural Development (ARD) and Agriculture Financial Services Corporation (AFSC). More specifically, the stochastic feed price model is a function of historical prices for each feed ingredient. Thus, incorporating stochastic elements in this study allows the use of historical data to model the risk (i.e., weather and market effects on feed price) associated with those parameters related to farm operations. Meanwhile, historical data can also help modify the simulated data used for predictions (i.e., it can determine a reasonable boundary for distribution).

The orange boxes show two scenario categories: baseline scenarios (situations in which NIRS technology is not adopted) and NIRS scenarios. The effectiveness of NIRS is evaluated and modeled in the NIRS scenarios. By truncating the distribution of stochastic nutrient contents, lower quality feed ingredients are eliminated from simulation models if NIRS is adopted. Blue boxes represent parameters used in this study to determine a final net cash flow. Feed cost savings, unit cost of NIRS test, cash flow and net present value are boxes that make up the basic relationships to measure NPV.

Figure 4.1 Conceptual diagram of modeling approach



4.2 Representative Enterprise Characteristics

The enterprises modeled in this study all have characteristics representative of specific livestock businesses located in the study area, including dairy farm, beef cattle backgrounding farms, and beef cattle finishing feedlots. They are built based on expert opinion (Swift, 2012; Gibb, 2013; Hand, 2013). The definition of the representative farms is in part based on whether or not the farms are assumed to purchase forage, due to the resulting effect on whether NIRS is used to test the forage. The representative dairy farm is assumed either to purchase forage or test its own forage using NIRS. The representative beef cattle backgrounding farm is assumed to purchase forage. Lastly, the representative beef cattle finishing farm is assumed to grow its own forage without using the NIRS to test those forage. A further discussion is provided in section 4.6.2.

Beef cattle cow-calf production is not considered in this study because calves get most of their nutrients from milk, not from the pasture. Since calves use little pasture, the potential applicability of NIRS technology is limited for cow-calf production. In addition, calves' ability to consume pasture varies, so it is difficult to determine a reliable and representative pasture feeding diet for calves (ARD, 1998; 2008).

4.2.1 Dairy Production

According to data from the Canadian Dairy Information Centre (CDIC), in 2012 94% of herds in Canada were primarily Holstein, with the rest being Ayrshire, Jersey, Brown Swiss, Milking Shorthorn, Guernsey, and/or Canadienne. The proportion of Holstein increased to 96.88% for Alberta (CDIC, 2013a). For that reason, Holstein was chosen as the representative dairy cow for this study. Meanwhile, CDIC data also show that one mature Holstein cow in Alberta can produce 10,226 kg of milk per year on average with a milk fat level of 3.77% and a milk protein level of 3.18% (CDIC, 2013a). Assuming 300 days in milk[6], each

[6] As noted earlier, in Chapter 2, dairy cows have a 45 to 60-day dry period per year.

mature Holstein lactates 34.09 kg[7] of milk per day (10,226/300=34.09). Based on this information and available data from the NRC (2001), the representative dairy cow chosen is a mature lactating Holstein with characteristics listed in table 4.1. Although the days in milk for a Holstein are around 300 per year, operators will feed dairy cows until they are replaced, whether or not they are lactating. Thus it is assumed that there are 365 annual feeding days for the representative dairy cow.

Table 4.1 Representative dairy cow characteristics

Breed	Holstein
Age	65 months
Weight	680 kg
Milk production	35 kg/day
Milk fat	3.5%
Milk protein	3.0%
Annual feeding days	365 day

4.2.2 Beef Cattle Production

Based on the beef cattle operation review in Chapter 2 and expert opinion (Hand, 2013), two approaches for beef cattle feedings are identified: the lightweight calves approach and the heavyweight calves approach. In the cow-calf phase, calving occurs over a period of several months in late winter and into spring. This contributes to variability in the weaning weights for calves. As well, there are differences in the size of calves based on breeds. Medium frame calves would wean at a lighter weight than large frame calves. Lightweight calves are therefore either younger weaned calves with lighter weaning weights or medium frame calves, while heavyweight calves are either older weaned calves with heavier weaning weights or large frame calves.

Given this distinction, the lightweight calves approach is defined as a scenario in which calves are sent to the backgrounding farm at 250kg, then to the finishing

[7] In reality, milk production varies during the lactation cycle. As a result, the nutrient requirements for dairy cows also vary, and are different during the dry period. By using average milk production per day, an "average" situation is modeled in this study.

feedlot at 475kg, where they are finished at 635kg. Conversely, the heavyweight calves approach is defined as the scenario in which calves are sent to the finishing feedlot directly at 350kg, where they are finished at 590kg (table 4.2). The choice of these operation approaches and weights to define representative beef cattle for modeling is based on expert opinion, taking into consideration actual beef cattle operations (Hand, 2013).

Table 4.2 Weight of representative beef cattle (kg)

	Enter into backgrounding farm	Enter into finishing feedlot	After finishing
Lightweight calves	250	475	635
Heavyweight calves	N.A.	350	590

Another characteristic considered in modeling is the average daily gain (ADG), which is the amount of weight that cattle gained per day during a certain period of time (i.e., backgrounding phase). ADG is used as a characteristic for representative beef cattle operations because it can directly affect the amount of time it takes to reach the ending weight for each feeding phase. Beef cattle feeding operations with different ADGs can have different nutrient requirements, which leads to different feed costs. Using ADG will affect NPV analysis. Combining expert opinion (Hand, 2013) and NRC (2000) data, each feeding phase was defined for two alternative ADGs to provide more representative scenarios (table 4.3). The ADGs also reflect the differences in ending weights for the different classes of calves, discussed earlier.

These choices represent reasonable ADG ranges that are consistent with industry practices while considering the weaning weights in table 4.2. For example, operators usually do not choose an ADG that is less than 0.80 kg/day for the backgrounding phase, as it would result in a longer backgrounding phase, which can cause operators to miss the optimal selling time. On the other hand, operators rarely pick an ADG that is higher than 1.22 kg/day for backgrounding. A high ADG cannot only cost backgrounding operators extra money on rations, but also lower profits from selling cattle to feedlots. Finishing feedlot operators might pay less for or even decline to purchase overweight cattle (SAFRR, 2003), because overweight cattle have less potential to gain weight in the finishing phase. This is also why heavyweight calves go into the finishing phase directly without backgrounding, and why ADG choices in the backgrounding phase are all lower than the choices in the finishing phase.

Table 4.3 Average daily gain (ADG) of representative beef cattle (kg)

	Backgrounding		**Finishing**	
	ADG1	ADG2	ADG1	ADG2
Lightweight calves	0.80	1.22	1.53	1.91
Heavyweight calves	N.A.		1.46	1.81

Feeding days of representative beef cattle in different phases are determined by initial weight, target weight and ADG. Unlike dairy farmers, backgrounding farmers and finishing feedlot owners usually do not keep beef cattle for a whole year. Once beef cattle reach the target weight, they will be sent or sold to other operators, such as feedlot and slaughterhouse owners. Since feeding days are directly related to total feeding cost, they should be clearly defined and calculated. In this study, the difference between initial and target weight divided by ADG is defined as feeding days. For example, there are 281 feeding days ((475-250)/0.80=281) for lightweight calves in the backgrounding phase with an ADG of 0.80 kg. Annual feeding days for representative beef cattle operations are listed in table 4.4.

Table 4.4 Annual feeding days of representative beef cattle (day)

	Backgrounding		**Finishing**	
	ADG1[a]	ADG2[b]	ADG1	ADG2
Lightweight calves	281	184	105	84
Heavyweight calves	N.A.		164	133

[a] ADG1 refers to ADG1 in table 4.3
[b] ADG2 refers to ADG2 in table 4.3

As mentioned above, it is assumed that beef cattle finishing feedlots are mixed-enterprise farms, but they only grow crops to produce forage for their own use, so there is no transaction of forage for these particular feedlots. More specifically, it is assumed that finishing feedlots grow forages, including alfalfa hay, barley silage and straw, and use them in cattle finishing rations. Due to the limited harvest, those forages are not sold to other feedlot operators. Thus, although operators still use NIRS to predict nutrient contents in those forages, they do not reject any forage produced by their own feedlots.

4.2.3 Nutrient Requirements

Section 2.1.3 provides a discussion about various nutrients for dairy and beef cattle, as both types have some common nutrient requirements. However certain nutrients are more important for milk production in dairy cows versus weight gain in beef cattle. The section discusses and presents nutrient requirements, including net energy for lactation (NE_l), net energy for maintenance (NE_m), net energy for growth (NE_g), total digestible nutrients (TDN), crude protein (CP), dry matter (DM), neutral detergent fibre (NDF), and acid detergent fibre (ADF).

Net energy provides the net value of energy in feed ingredients after subtracting the energy lost in the process of nutrient utilization and metabolism. According to the feed nutrient content terms defined by ARD (2006), NE_m represents net energy in the feed ingredients used to keep cattle in an energy equilibrium, which means neither gaining nor losing weight. NE_g represents net energy used for weight gain. It is the value of net energy above the required NE_m. NE_l represents net energy in the feed ingredients used for both maintenance and lactation in dairy cows. Based on the definitions of these three measures of net energy, NE_m and NE_g are relevant for beef cattle ration analyses, and NE_l is relevant for dairy ration analyses.

TDN measures the total digestible nutrients for available energy estimation in feed ingredients (ARD, 2006). More specifically, TDN is the gross energy minus the energy lost in manure. It is hard to measure, and used in old system of measuring nutrient contents (ARD, 2006). It is a calculated value that is based on other nutrient contents (i.e., ADF), and expressed as a percentage of weight of feed ingredient. Comparing to the net energy system, TDN is less accurate because it does not account for the loss of gas and heat (NRC, 2000). However, TDN is useful for beef cattle rations that contain a high portion of forage (i.e., backgrounding rations) because NE_g has a tendency to overestimate the energy value of high forage rations (Rasby and Martin, 2013). TDN can provide more accurate energy information in such cases. For that reason it is used in beef cattle ration analyses in this study.

Protein is important for both animal health and productivity (NRC, 2001). CP measures both true protein and non-protein nitrogen content in feed ingredients. Although not all components in CP are true proteins, CP provides sufficient protein information for daily dairy and beef cattle rations and is commonly used in animal science studies. Because reliable nutrient content data for other protein measurements (i.e., degradable intake protein) are not available, CP is used here to measure protein in this study.

The level of dry matter intake (DMI) should also be considered in ration formulation. Dry matter (DM) is the total weight of feed ingredient minus the weight of water. It is expressed as a percentage of weight of feed ingredients, and serves to convert from as-fed weight to dry matter weight. DMI measures the total weight of nutrient contents in the ration consumed by animals (ARD, 2006). Although DMI has highly positive relationships with both weight gain and milk production, maximum DMI is used as an upper limit to indicate how much feed an animal can consume in a day.

Fibre is a nutrient used to balance pH in the rumen in order to maintain rumen function and keep cattle, particularly dairy cows, healthy (MAFRI, 1999). NDF and ADF are two commonly used measures for fibre content in feed ingredients.

NDF measures insoluble fibre in neutral detergent, including cellulose, hemicellulose, and lignin, while ADF measures cellulose and lignin that are insoluble in acid detergent (MAFRI, 1999; Parish, 2007). NDF and ADF are explicitly considered in dairy ration analyses in this study, as fibre requirements are more important to dairy cows. Fibre can significantly affect dairy cows rumen pH and milk production.

Because milk production is not the goal of beef cattle operations, operators pay less attention to fibre requirements in constructing beef cattle rations than they do to protein and energy requirements. As a consequence, NDF and ADF are not included as nutrient requirements for beef rations in this analysis. It should be noted, however, that although NDF and ADF are not explicitly considered in formulating the beef rations, they are still implicitly considered in that NDF content is related to feed intake potential while ADF is related to digestibility of ingredients (NRC, 2000).

As stated in Chapter 2, vitamins are also very important in rations, as are minerals such as calcium and phosphorus. However, minerals and vitamins are not involved in this study because NIRS does not generate a highly accurate prediction for them in feed ingredients, and operators usually use supplements to meet mineral and vitamin requirements in livestock rations. Operators purchase supplement packages formulated by feed mills and include a certain amount of supplement into their rations based on expert suggestions and experience. Detailed daily nutrient requirements for the dairy ration, beef cattle backgrounding ration, and beef cattle finishing ration are adopted from NRC (2000; 2001) and provided in tables 4.5, 4.6 and 4.7, respectively.

Table 4.5 Daily nutrient requirements for dairy ration (dry matter basis)

NE_l	≥ 34.80 Mcal
CP	≥ 3.59 kg
NDF	≥ 6.84 kg
ADF	≥ 4.48 kg
Max DMI	≤ 23.60 kg

Source: NRC (2001)

Table 4.6 Daily nutrient requirements for beef cattle backgrounding ration (dry matter basis)

	ADG=0. 80 kg	**ADG=1.22 kg**
NE_m	≥ 9.82 Mcal	≥ 11.93 Mcal
NE_g	≥ 5.64 Mcal	≥ 7.54 Mcal
CP	≥ 0.72 kg	≥ 0.88 kg
TDN	≥ 4.38 kg	≥ 4.98 kg
Max DMI	≤ 7.30 kg	≤ 7.12 kg

Source: NRC (2000)

Table 4.7 Daily nutrient requirements for beef cattle finishing ration (dry matter basis)

	Lightweight calves		**Heavyweight calves**	
	ADG=1.53 kg	ADG=1.91 kg	ADG=1.46 kg	ADG=1.81 kg
NE_m	≥ 19.38 Mcal	≥ 21.69 Mcal	≥ 15.50 Mcal	≥ 17.37 Mcal
NE_g	≥ 12.24 Mcal	≥ 14.70 Mcal	≥ 9.79 Mcal	≥ 11.77 Mcal
CP	≥ 1.17 kg	≥ 1.30 kg	≥ 1.12 kg	≥ 1.27 kg
TDN	≥ 8.10 kg	≥ 8.74 kg	≥ 6.48 kg	≥ 7.00 kg
Max DMI	≤ 11.57 kg	≤ 10.93 kg	≤ 9.25 kg	≤ 8.75 kg

Source: NRC (2000)

4.2.4 Feed Constraints

Barley, corn, oats, wheat, canola meal, alfalfa hay (1^{st} cut), barley silage, and straw are the feed ingredients used in this study. These eight ingredients are widely used in dairy and beef cattle rations in western Canada. The choice is made based on the nutritional profile. Feed grains, including barley, corn, oats and wheat, provide energy for maintenance, growth, and lactation in beef cattle and dairy cows. Canola meal and alfalfa hay are the main protein sources, although some feed grains also contain relatively high protein. Alfalfa hay and barley silage provide most of the fibre for dairy cows and beef cattle. Straw is not included in dairy rations because it is a low energy and low protein feed ingredient. Dairy farmers rarely use straw in their rations since dairy cows need high quality (i.e., high energy and high protein) feed ingredients to support milk production. Straw is often used in beef cattle rations, however, because the main objective in feeding beef cattle is weight gain, and straw is relatively cheaper than other feed ingredients. Thus, straw is considered as a supplement in beef cattle ration to meet nutrient requirements.

The mean or expected nutrient contents of those eight feed ingredients, as well as their standard deviations, are provided in table 4.8. The mean values of nutrient content for feed ingredients were collected from the NRC (2000; 2001). Standard deviations are not available for NE_l, NE_m, NE_g, and TDN (see footnote b in table 4.8). Standard deviations were used to calculate maximum and minimum values for nutrient content in order to set reasonable ranges for nutrient content distributions, as is discussed later.

Table 4.8 Nutrient contents of feed ingredients (dry matter basis)

		Barley	Corn	Oats	Wheat	Canola meal	Alfalfa hay	Barley silage	Straw
NE_l	**Mcal/kg**	1.86	2.01	1.77	1.99	1.76	1.27	1.24	N.A.[c]
	S.D.[a, b]	(0.47)	(0.36)	(0.40)	(0.73)	(0.23)	(0.15)	(0.16)	N.A.
NE_m	**Mcal/kg**	2.02	2.16	1.90	2.15	1.88	1.37	1.33	0.60
	S.D.	(0.21)	(0.19)	(0.16)	(0.20)	(0.06)	(0.11)	(0.17)	(0.07)
NE_g	**Mcal/kg**	1.36	1.48	1.26	1.47	1.25	0.79	0.76	0.08
	S.D.	(0.14)	(0.13)	(0.11)	(0.14)	(0.04)	(0.06)	(0.09)	(0.01)
CP	**%**	12.40	9.40	13.20	14.20	37.80	20.20	12.00	4.40
	S.D.	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.03)	(0.03)	(0.01)
NDF	**%**	20.80	9.50	30.00	13.40	29.80	39.60	56.30	N.A.
	S.D.	(0.09)	(0.02)	(0.11)	(0.06)	(0.07)	(0.06)	(0.07)	N.A.
ADF	**%**	7.20	3.40	14.60	4.40	20.50	31.20	34.50	N.A.
	S.D.	(0.03)	(0.01)	(0.06)	(0.04)	(0.05)	(0.05)	(0.05)	N.A.
TDN	**%**	82.70	88.70	78.50	86.60	69.90	58.90	60.20	40.00
	S.D.	(0.09)	(0.08)	(0.07)	(0.08)	(0.02)	(0.05)	(0.08)	(0.04)
DM	**%**	91.00	88.10	90.00	89.40	95.20	87.80	35.50	91.20
	S.D.	(0.04)	(0.03)	(0.02)	(0.03)	(0.03)	(0.01)	(0.10)	(0.03)

Source: NRC (2000; 2001)
[a] S.D. denotes standard deviation
[b] S.D. for NE_l, NE_m, NE_g, and TDN are calculated values (see Appendix A)
[c] N.A. denotes not applicable. Since straw is not used in dairy ration, related nutrient contents are not included in this table

Feed ingredient constraints are also included in this study. These constraints were identified by experts who looked at real operations and animal health. Detailed feed ingredient constraints for dairy rations, beef cattle backgrounding ration, and beef cattle finishing ration are also provided in tables 4.9, 4.10, and 4.11, respectively.

For dairy rations, according to Swift (2012), the proportions of grain and forage are limited to 50% of the ration, which is 11.80 kg based on maximum DMI (23.60*0.50=11.80). Grain includes barley, corn, oats, and wheat. Forage includes alfalfa hay and barley silage. The reason for blending grain and forage and setting an upper limit is that dairy cows digest grain quickly. A large portion of grain can result in acid buildup and ulcers in dairy cows. Forage can provide fibre to make digestion last longer, help balance acid in rumen and maintain rumen function. However, because forage contains a significant amount of NDF, and increasing NDF decreases DMI, a large forage portion can lead to diminished DMI. When this happens, dairy cows cannot get enough other nutrients to support lactation.

To bring dairy ration results from LCRM closer to a real operation, 25% of rations are set as barley, corn and wheat, which are the main cereals used in the study area (Swift, 2012). About 5.90 kg of rations are barley, corn, and wheat (23.60*0.25=5.90). Another constraint is set on the amount of wheat because dairy cows digest wheat faster than they digest barley and corn (ARD, 2012b; Swift, 2012). Wheat can easily cause acid buildup; using a smaller amount can prevent cows from being sick (i.e., due to sub-acute rumen acidosis). Thus, a constraint of 1.10 kg is set on the amount of wheat in the dairy ration based on farm practices (Swift, 2012). The amount of alfalfa hay in the dairy ration is also constrained to be less than 4.50 kg based on a maximum DMI of 23.60 kg (Swift, 2012). The reason for this constraint is that increasing dry hay can cause cows to selectively consume fine feeds (Leonardi and Armentano, 2003). Canola meal is involved in dairy rations as a protein source without constraint because there is limited room left after fulfilling nutrient content requirements and other feed ingredient constraints.

For the beef cattle ration, feed ingredient constraints are quite similar to the constraints for the dairy ration. According to Gibb (2013), the proportion of grain in the beef cattle backgrounding ration is between 20% and 60% (based on maximum DMI, same as below), while the proportion in the beef cattle finishing ration is between 70% and 90%. The rest of the ration is canola meal and forage, including alfalfa hay, barley silage, and straw. In the backgrounding phase, a lower grain diet is recommended because calves need time for their rumens to get used to a higher grain diet. In the finishing phase, beef cattle can have a high-grain diet and gain weight faster. The amount of wheat is still set as less than 50% of total grain used in the ration because, as mentioned earlier, cattle digest wheat quickly, which can cause acid buildup. The beef cattle finishing ration should also maintain at least 9% silage because a high grain diet needs more fibre to help balance rumen pH, and barley silage has the largest portion of fibre among the eight selected feed ingredients (table 4.8).

Table 4.9 Feed ingredient constraints for dairy ration (dry matter basis)

Grain[a]	≤ 11.80 kg
Wheat	≤ 1.10 kg
Barley, corn, and wheat	= 5.90 kg
Forage[b]	≤ 11.80 kg
Alfalfa hay	≤ 4.50 kg

Source: Swift (2012)
[a] Grain includes barley, corn, oats, and wheat
[b] Forage includes alfalfa hay and barley silage in the dairy ration

Table 4.10 Feed ingredient constraints for beef cattle backgrounding ration (dry matter basis)

	ADG=0.80 kg	**ADG=1.22 kg**
Grain[a] max	≤ 4.38 kg	≤ 4.27 kg
Grain min	≥ 1.46 kg	≥ 1.42 kg
Wheat	≤ 0.5*Grain[b]	≤ 0.5*Grain

Source: Gibb (2013)
[a] Grain includes barley, corn, oats, and wheat
[b] 0.5*Grain denotes that the constraint is the half amount of total grain in the ration

Table 4.11 Feed ingredient constraints for beef cattle finishing ration (dry matter basis)

	Lightweight calves		**Heavyweight calves**	
	ADG=1.53 kg	ADG=1.91 kg	ADG=1.46 kg	ADG=1.81 kg
Grain[a] max	≤ 10.41 kg	≤ 9.84 kg	≤ 8.33 kg	≤ 7.88 kg
Grain min	≥ 8.10 kg	≥ 7.65 kg	≥ 6.48 kg	≥ 6.13 kg
Wheat	≤ 0.5*Grain[b]	≤ 0.5*Grain	≤ 0.5*Grain	≤ 0.5*Grain
Silage	≥ 1.04 kg	≥ 0.98 kg	≥ 0.83 kg	≥ 0.79 kg

Source: Gibb (2013)

[a] Grain includes barley, corn, oats, and wheat

[b] 0.5*Grain denotes that the constraint is the half amount of total grain in the ration

4.3 Least-Cost Ration Model

Optimization is the process used to find a goal equilibrium, which is defined by Chiang (1984, p.232) as the “optimum position for a given economic unit”. The most commonly used criteria for determining this optimum position for economic related issues are maximization (i.e., maximizing profit), or minimization (i.e., minimizing cost). Optimization can be unconstrained or constrained (Hazell and Norton, 1986). An unconstrained optimization problem only has an objective function, which indicates the main structure of the model and measures the goal of the problem (Chiang, 1984; Paris, 1991). A constrained optimization problem contains one objective function, and a set of constraints in which independent variables indicate available choices in the problem. The essential process of constrained optimization is to find the set of independent variables that fulfill the goal of objective function and satisfy the constraints (Chiang, 1984).

Linear programming is a mathematical technique used to solve linear optimization problems that are subject to linear constraints (Paris, 1991). It is a special form of constrained optimization in which objective function and constraints are all linear (Chong and Zak, 2008). Linear programming also differs from classical optimization in that the objective function is subject to inequality constraints (Chiang, 1984), although equality constraints can also be involved (Hazell and Norton, 1986). A general form of a minimization linear programming model can be shown as equation 4.1 (Hazell and Norton, 1986):

$$minimize\ F(x)$$

$$subject\ to\ c_i(x) \begin{cases} \geq \\ = a_i, \qquad i = 1\ to\ n \\ \leq \end{cases} \tag{4.1}$$

where $F(x)$ is the linear objective function, $c_i(x)$ are linear constraint functions, and a_i are right hand side parameters. Linear programming has been widely used to solve decision-making problems with regard to resource allocation (i.e., land, labour) in order to maximize profit or minimize cost (Paris, 1991). In this study, linear programming is used to solve ration formulation problems.

As mentioned earlier, it is assumed that the benefits of NIRS technology come from savings from feed costs. Hence, the optimization problem in this study is to minimize total feed cost. Feed cost saving is estimated by comparing the optimal solution under the baseline (i.e., no NIRS) scenario with the optimal solution under the NIRS scenario. For this study, a commonly used linear programming model, the LCRM, was adopted to solve this optimization problem. The LCRM uses linear programming to formulate a ration for farm livestock. It aims to find the least expensive combination of feed ingredients that can fulfill prescribed nutrient requirements (France and Thornley, 1984). Howard et al. (1968), Dean et al. (1972), O'Connor et al. (1989), Tozer (2000), and Huhtanen et al. (2011) adopted the LCRM in their studies on evaluating dairy farm nutrient management, and concluded that the LCRM was able to lower feed costs while meeting nutrient requirements. Church et al. (1963), Glen (1980) and Gradiz et al. (2007) reached the same results in their studies in terms of beef cattle ration formulation. In this model, operators can choose any combination of feed ingredients, which provides flexibility in the LCRM. It is also assumed that operators are fully informed about the nutrient content of feed ingredients, nutrient requirements for their livestock, and market feed prices. Operators need to make decisions based on nutrient content and price information to meet nutrient requirements. A set of solutions may be found to fulfill nutrient requirements and feed ingredients constraints.

However, an optimal solution should be picked according to the goal of ration cost minimization.

In order to build a LCRM that is consistent with industry practice, feed ingredient constraints are incorporated in the LCRM based on expert opinion (Swift, 2012; Gibb, 2013). The LCRM in this study contains four elements, including nutrient content, nutrient requirements, feed prices and feed ingredient constraints. In general, the LCRM in this study can be expressed mathematically as:

$$\begin{aligned} &minimize\ TC = \sum_{i=1}^{n} P_i Q_i \\ &subject\ to \sum_{i=1}^{n} a_{mi} Q_i \leq (=, \geq) b_m \\ &Q_i \leq (=, \geq) c_i \\ &and\ Q_i \geq 0 \end{aligned} \tag{4.2}$$

where *TC* is the total cost of ration, P_i is the price of feed ingredient i, Q_i is the amount of feed ingredient *i* used in the ration, a_{mi} is the quantity of nutrient *m* in the feed grain *i* and b_m is the requirement of nutrient *m* in the ration. c_i is the quantity constraint required (upper or lower limit) of feed ingredient *i* in the ration. Nutrient requirements and feed ingredients can be constrained to be less than, equal to, or greater than some specified amount (see tables 4.5-4.7, 4.9-4.11). More detailed specific models used in this study are provided in Appendix B.

Nutrient contents, nutrient requirements, and feed ingredient constraints are discussed in sections 4.2.3 and 4.2.4. Feed prices used in the LCRM are generated from the stochastic feed price model, which is discussed in section 4.4. Substituting these four elements into the LCRM, models for each representative enterprise were created and solved using the Excel add-in function Solver©. The LCRM yielded three categories of results, including the minimum total feed cost, the quantity of each feed ingredient used in the ration, and the amount of each nutrient content in the ration. The LCRM is solved for both the baseline and NIRS scenarios, after which feed costs from those two scenarios are compared to estimate feed cost savings. Details about the two types of scenarios are discussed in Section 4.6.

4.4 Stochastic Elements

Agricultural operators confront many risks that can significantly affect business decisions. Those risks can involve a variety of elements such as weather changes, insect damage, market shortage, and government policy, which have the potential to impact agricultural operators. In order to capture those risks in this study, two stochastic elements, nutrient content and feed price, were introduced and modeled. More specifically, values of nutrient content were obtained by randomly drawing from predetermined distributions, while feed prices were explicitly modeled as being stochastic.

4.4.1 Stochastic Nutrient Content Distribution

For the purpose of this study, it is assumed that the nutrient content for feed ingredients have variability. In a real operation, this means that each load of feed ingredient that operators are planning to purchase from crop farms or feed mills has a different nutrient content. Thus, stochastic nutrient content distributions were set up for each nutrient in feed ingredients using data collected from the NRC (2000; 2001), which are reported in table 4.8. To set up the distributions, mean values and respective standard deviations are first used to calculate maximums and minimums of nutrient contents[8]. Those maximums and minimums provide a reasonable range to set up distributions. When only the maximum and minimum are known, uniform distributions are usually adopted (Hesse, 2000). However, when the most likely value is also known, triangular distribution can be simulated (Evans et al., 2000; Hesse, 2000). The triangular distribution is a

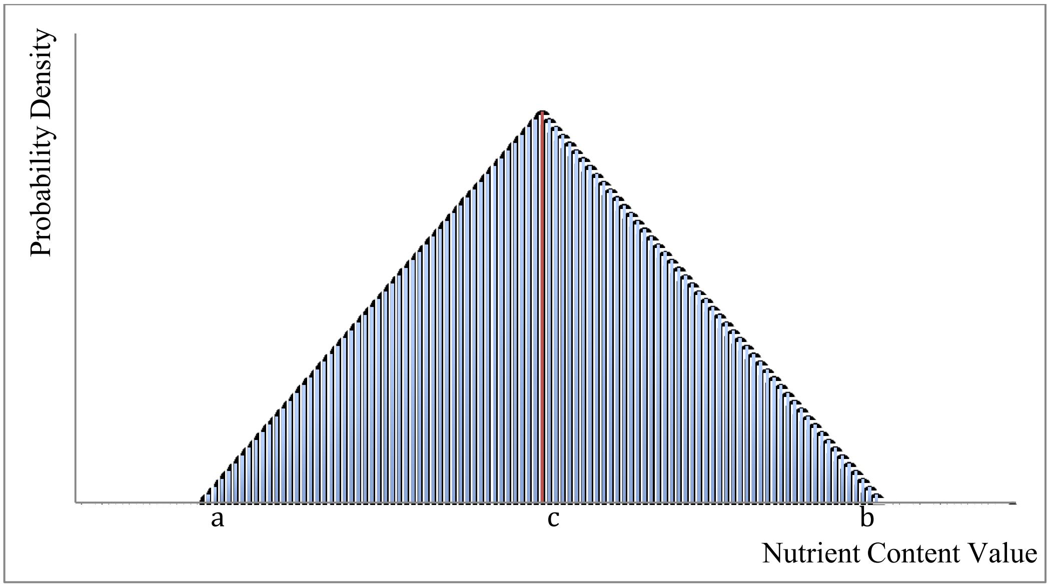
[8] The maximum value is equal to the mean value + (2 * standard deviation). The minimum value is equal to the mean value – (2 * standard deviation).

continuous probability distribution used to describe a population (Evans et al., 2000). It is typically used when information is not sufficient to determine or fit a more representative distribution. Because nutrient content should not be either negative or extremely high in this study, a bounded distribution, such as a triangular distribution, is preferred. The probability density function (PDF) of triangular distribution within the range $x \in [a, b]$ can be shown in equation 4.3 (Evans et al., 2000):

$$P(x) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} & for\ a \le x \le c \\ \dfrac{2(b-x)}{(b-a)(b-c)} & for\ c < x \le b \end{cases} \tag{4.3}$$

where $P(x)$ is the PDF, *a* is the minimum value, *b* is the maximum value, and $c \in [a, b]$ is the mode. The mode is the most likely value in the range. Therefore, assuming mean values obtained from the NRC (2000; 2001) as mode values, symmetric triangular distributions (figure 4.2) are set for each nutrient content in this study (table 4.12). Triangular distributions in this study are all symmetric because the method to calculate maximum and minimum makes the mode equal to the average of maximum and minimum (i.e., $c = (a + b)/2$ in figure 4.2).

Figure 4.2 Symmetric triangular distribution of nutrient content



Stochastic nutrient content distributions are set and simulated using @Risk. Random draws from each distribution are then generated to represent nutrient content of feed ingredients in that particular period of time. However, expected nutrient content values are used in the LCRM to estimate optimal rations. The reason to set distributions for nutrient content is to make them stochastic and closer to real situations confronted by operators. For example, even the same feed ingredient from different crop farms can have different nutrient content values. The nutrient content values of the same feed ingredients vary by location and time. Setting up distributions for nutrient contents is also helpful to model the effectiveness of NIRS technology, which is discussed further in Section 4.5.1.

Table 4.12 Parameters of triangular distributions for nutrient contents

		Barley	Corn	Oats	Wheat	Canola meal	Alfalfa hay	Barley silage	Straw
NE_l (Mcal/kg)	Max	2.80	2.73	2.57	3.45	2.22	1.57	1.56	N.A.[b]
	Mode[a]	1.86	2.01	1.77	1.99	1.76	1.27	1.24	N.A.
	Min	0.92	1.29	0.97	0.53	1.30	0.97	0.92	N.A.
NE_m (Mcal/kg)	Max	2.44	2.54	2.22	2.55	2.00	1.59	1.67	0.74
	Mode	2.02	2.16	1.90	2.15	1.88	1.37	1.33	0.60
	Min	1.60	1.78	1.58	1.75	1.76	1.15	0.99	0.46
NE_g (Mcal/kg)	Max	1.64	1.73	1.48	1.74	1.32	0.91	0.95	0.10
	Mode	1.36	1.48	1.26	1.47	1.25	0.79	0.76	0.08
	Min	1.08	1.22	1.04	1.20	1.18	0.67	0.57	0.06
CP (%)	Max	16.60	12.00	16.80	18.80	40.00	25.40	17.20	6.22
	Mode	12.40	9.40	13.20	14.20	37.80	20.20	12.00	4.40
	Min	8.20	6.80	9.60	9.60	35.60	15.00	6.80	2.58
NDF (%)	Max	38.00	14.10	51.00	25.80	43.00	52.20	70.30	N.A.
	Mode	20.80	9.50	30.00	13.40	29.80	39.60	56.30	N.A.
	Min	3.60	4.90	9.00	1.00	16.60	27.00	42.30	N.A.
ADF (%)	Max	12.80	5.40	25.80	8.80	30.70	40.40	44.30	N.A.
	Mode	7.20	3.40	14.60	4.40	20.50	31.20	34.50	N.A.
	Min	1.60	1.40	3.40	0.00[c]	10.30	22.00	24.70	N.A.
TDN (%)	Max	99.88	100.00[c]	91.97	100.00[c]	73.97	68.19	75.20	48.91
	Mode	82.70	88.70	78.50	86.60	69.90	58.90	60.20	40.00
	Min	65.51	73.31	65.03	70.65	65.83	49.61	45.20	31.09
DM (%)	Max	98.00	94.30	94.00	94.60	100.00[c]	90.60	54.70	97.82
	Mode	91.00	88.10	90.00	89.40	95.20	87.80	35.50	91.20
	Min	84.00	81.90	86.00	84.20	89.00	85.00	16.50	84.58

Source: NRC (2000; 2001)

[a] Mode values in this table are same as mean values in table 4.8

[b] N.A. denotes not applicable. Since straw is not used in dairy ration, related nutrient contents are not included in this table

[c] Since these numbers are percentages, they cannot be larger than 100, or smaller than 0

4.4.2 Stochastic Feed Price Model

Feed prices are incorporated and modeled stochastically in this study using a stochastic feed price model. The beef cattle operation cycle and ration requirements are related to seasons. For example, if calves enter into the backgrounding phase during the fall season and have a forage-concentrated diet, they usually enter into the finishing feedlot during the next spring and have a grain-concentrated diet. Therefore, because of this seasonality, modeling quarterly feed prices should perform better than other frequencies in this study. Monthly price data (September 2002 to March 2013) for feed barley, corn, oats, wheat, canola meal, alfalfa hay (1st cut), barley silage and straw were obtained from ARD and AFSC. Those monthly data were then transformed to quarterly data by using a seasonal average. Quarterly feed prices (2002Q3 to 2012Q4) were used for the stochastic feed price model. Feed prices were also converted to $/kg and adjusted for inflation using the Consumer Price Index (CPI) from Statistics Canada (2013a), setting 2013 as base year. Table 4.13 shows a statistical summary of feed prices used in this study.

Table 4.13 Statistical summary of CPI-adjusted feed prices ($/kg)

	Mean	Standard Deviation	Minimum	Maximum
Barley	0.183	0.041	0.122	0.279
Corn	0.231	0.055	0.157	0.355
Oats	0.178	0.036	0.133	0.278
Wheat	0.192	0.049	0.113	0.299
Canola Meal	0.244	0.061	0.139	0.408
Alfalfa Hay	0.094	0.034	0.062	0.204
Barley Silage	0.038	0.008	0.027	0.064
Straw	0.043	0.012	0.029	0.089

Unfortunately, the original monthly corn data from ARD have fourteen missing data points between May 2005 and April 2006. In order to avoid further problems caused by a small amount of data (i.e., lacking degrees of freedom), imputation is necessary. Since corn is a freely traded commodity in North America, corn markets are highly correlated between the United States and Canada. Therefore, the U.S. corn price and the Canadian and U.S. dollar exchange rates are used to impute missing Canadian corn prices. Details are provided in Appendix C.

4.4.2.1 Testing for Stationarity

Feed prices should be modeled using lagged prices as explanatory variables, as this is a simple approach to observe how the time-series variables in the different periods correspond with each other (Verbeek, 2008). However, this approach requires feed price data to be stationary. A stationary time series is independent of time, which means its mean and variance are constant over time, and covariance of two observations in the series only depends on the time length. Otherwise, the series is non-stationary, and it has a unit root (Hill et al., 2011). Non-stationary data run the risk of obtaining spurious regression results; the results may appear statistically significant, but they are more likely to be incorrect (Hill et al., 2011). Therefore, testing for stationarity is required before further analysis is undertaken.

An Augmented Dickey-Fuller (ADF) test was used to test the stationarity of feed price data. The null hypothesis of the ADF test is that the series has a unit root or that the series is non-stationary. ADF tests were conducted using the statistical software STATA. The process of performing the ADF test in STATA involves two steps. First, the number of lagged difference terms included in the regression of the ADF test should be determined. If there is no need to include any lagged difference term in the regression, then the test is the Dickey-Fuller (DF) test. If one or more lagged difference terms is included in the regression, then it is the ADF test. In order to determine the numbers of lagged difference terms, the Schwarz Bayesian Information Criterion (SBIC) was employed. Regressions with zero to four lagged difference terms were estimated separately, and the one with the minimum value of SBIC was chosen as the best regression to perform the ADF or DF test (Hill et al., 2011). Secondly, the ADF test, as well as the DF test, can include the option for a time trend or a constant in the regression (Green, 2008). Adding a time trend or constant in the test provides more information to determine whether or not the unit root is the reason for the non-stationarity (Verbeek, 2008).

Table 4.14 Augmented Dickey-Fuller (ADF) test results

	Lag	Test Statistics[a]		
		Baseline[b]	TREND	CONSTANT
Barley	1	-1.536	-2.573	-1.536*
Corn	1	-1.590	-3.170	-1.590*
Oats	1	-4.153***	-4.260***	-4.153***
Wheat	1	-1.978	-2.656	-1.978**
Canola Meal	1	-2.973**	-3.110	-2.973***
Alfalfa Hay	1	-4.031***	-3.887**	-4.031***
Barley Silage	1	-4.645***	-4.676***	-4.645***
Straw	1	-4.518***	-5.518***	-4.518***
1% Crit. Value		-3.655	-4.251	-2.438
5% Crit. Value		-2.961	-3.544	-1.690
10% Crit. Value		-2.613	-3.206	-1.306

[a] ***, **, and * indicates significance at 1%, 5%, and 10% level, respectively
[b] No time trend or constant

After checking the minimum SBIC values, the lag lengths were determined to be one for each feed price data series. Thus the ADF test is preferable to the DF test. Three versions of the ADF test were then performed. The first one assumes that there is no time trend or constant in the regression of the ADF test. It is the situation when a pure random walk happens if the data series is non-stationary. The second one assumes that feed prices do have a time trend. The time trend added in the ADF test can be a deterministic trend that can cause the non-stationarity in a data series (Verbeek, 2008). If the non-stationarity is caused by a deterministic trend, the data series can be trend stationary by ruling out the time trend (detrending) from the data series (Verbeek, 2008). The third one assumes a constant in the regression of the ADF test. It means there is a drift in feed prices. The drift reflects a nonzero mean of the data series when the test shows stationarity (Verbeek, 2008). It reflects a random walk with a drift when the test shows non-stationarity. A random walk with (third version of the ADF test) or without (first version of the ADF test) a drift can be made to difference stationary by differencing (Verbeek, 2008).

The results of ADF tests are presented in table 4.14. The results suggest that prices of oats, alfalfa hay, barley silage and straw do not have unit roots for all three versions of the ADF test. The null hypothesis of canola meal prices having a unit root is rejected for the first and third tests, while it is not rejected for the null hypothesis in the case of the ADF test with a time trend. However, the result from the second test is quite close to rejecting the null hypothesis for the price of canola meal. This may be due to a lack of information, as only 42 observations are included for each price data series. It is still decided to treat the price of canola meal as a stationary data series. The prices of barley, corn and wheat only show stationarity for the ADF test with a drift. The results imply that there are nonzero drifts in the prices of barley, corn and wheat, and that these drifts caused the non-stationary results in the first version of the ADF tests. However, the mean and variance values of these three feed prices are still assumed to be constant over time, because the null hypothesis of having a unit root is rejected for the third tests. In summary, all eight feed prices data series are determined to be stationary over time for at least one of the tests. It is assumed that the data series are stationary for the purpose of estimating the stochastic feed price model in this study.

4.4.2.2 Model Estimation

Considering that feed prices are stationary, a pure autoregressive model can be estimated for forecasting (Hill et al*.,* 2011). In this model the current price depends on previous values in the last *n* periods, and a random error that is assumed to have constant variance, a zero mean value and no correlation over time (Hill et al*.,* 2011). Specifically, the autoregressive model for each feed price can be shown as equation 4.4.

$$P_t = a_0 + a_1 P_{t-1} + \cdots + a_n P_{t-n} + e_t \tag{4.4}$$

where P_t is the current price, P_{t-n} is the lagged price at period *t-n*, *n* is the number of lagged prices in the regression, the $a_i s$ are the parameters estimated in the model, and e_t is the error term. This autoregressive model can be estimated separately for each feed price, using Ordinary Least Squares (OLS). However, this process assumes away other exogenous variables (i.e., weather, market, etc.), which may affect some of those feed prices in a similar way. Since these exogenous variables are not included in the regression and therefore go to error terms, error terms in each autoregressive model can be correlated. Therefore, a Seemingly Unrelated Regression (SUR) model was used to forecast feed prices as a whole system in order to capture correlations among error terms.

Each feed price equation is a function of lagged prices. The optimal lag length for each equation therefore needs to be determined. OLS regressions with lagged prices from one to five quarters were tested with Akaike information criterion (AIC) and SBIC criteria[9]. The lowest value from each criterion determines the optimal lag length used in the SUR model. A maximum of five lags (five quarters) are used because: a) there are only 42 observations in each feed price data series, so longer lags may result in lower degrees of freedom and statistical power; and b) the crop operation cycle is one year, which is four quarters.

OLS regressions were estimated in STATA. The results of AIC and SBIC values are reported in table 4.15. The optimal lag lengths for barley, corn, canola meal, barley silage, and straw are all determined to be one quarter, by both AIC and SBIC values. The optimal lag length of oats is determined as two quarters. The results of AIC and SBIC show a difference with regard to the lag lengths for wheat and alfalfa hay. The AIC values indicate that optimal lag lengths of wheat and alfalfa hay should be one quarter, while SBIC values suggest two quarters. Ivanov and Kilian (2005) demonstrate that SBIC is preferable to AIC as a

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9 AIC and SBIC values are used to determine number of lagged price (P_{t-n}) in each SUR equation, while the SBIC values are calculated to determine the number of lagged difference terms (ΔP_{t-n}) in ADF and DF tests.

criterion when the sample size is less than 120 quarters. Therefore, the optimal lag lengths of wheat and alfalfa hay are chosen to be two quarters.

The resulting lag lengths for the feed price models are one or two quarters. This implies that feed prices in Alberta respond quickly to the price changes that occurred in the previous periods. This result is consistent with other recent studies. Rude and Surry (2013) also obtained similar results for feed prices in Ontario by using monthly data from January 1988 to June 2008. Their research suggests the lag length for barley prices is four months for their autoregressive model, and the lag length for corn prices is six months. Tejeda and Goodwin (2011) used monthly feed prices in the U.S. and determined that lag lengths for corn, soybean, sorghum, and wheat were three months.

Table 4.15 Akaike information criterion (AIC) and Schwarz Bayesian Information Criterion (SBIC) results

	Lags	1	2	3	4	5
Barley	AIC[a]	-210.37*	-208.85	-201.49	-194.11	-196.31
	SBIC	-206.94*	-203.79	-194.83	-185.93	-186.65
Corn	AIC	-182.99*	-179.14	-173.50	-166.04	-159.65
	SBIC	-179.57*	-174.08	-166.84	-157.85	-149.98
Oats	AIC	-224.84	-238.73*	-233.59	-225.10	-220.78
	SBIC	-221.41	-233.66*	-226.94	-216.91	-211.12
Wheat	AIC	-189.52*	-188.34	-183.68	-177.34	-172.01
	SBIC	-184.45	-184.91*	-177.02	-169.15	-162.34
Canola Meal	AIC	-145.95*	-144.40	-141.22	-137.81	-137.18
	SBIC	-142.52*	-139.33	-134.57	-129.62	-127.51
Alfalfa Hay	AIC	-238.34*	-237.66	-231.36	-227.12	-217.90
	SBIC	-233.28	-234.23*	-224.70	-218.93	-208.23
Barley Silage	AIC	-353.77*	-349.41	-341.89	-350.34	-338.26
	SBIC	-350.34*	-344.35	-335.24	-342.15	-328.60
Straw	AIC	-324.02*	-319.25	-308.43	-318.88	-308.68
	SBIC	-320.59*	-314.19	-301.78	-310.70	-299.02

[a] the minimum values of AIC and SBIC are marked *

After determining the lag lengths, the SUR model estimated in this study was as follows:

$$P_t^B = a_0^B + a_1^B P_{t-1}^B + e_t^B$$
$$P_t^C = a_0^C + a_1^C P_{t-1}^C + e_t^C$$
$$P_t^O = a_0^O + a_1^O P_{t-1}^O + a_2^O P_{t-2}^O + e_t^O$$
$$P_t^W = a_0^W + a_1^W P_{t-1}^W + a_2^W P_{t-2}^W + e_t^W$$
$$P_t^{CM} = a_0^{CM} + a_1^{CM} P_{t-1}^{CM} + e_t^{CM}$$
$$P_t^{AH} = a_0^{AH} + a_1^{AH} P_{t-1}^{AH} + a_2^{AH} P_{t-2}^{AH} + e_t^{AH}$$
$$P_t^{BS} = a_0^{BS} + a_1^{BS} P_{t-1}^{BS} + e_t^{BS}$$
$$P_t^S = a_0^S + a_1^S P_{t-1}^S + e_t^S \quad (4.5)$$

where B, C, O, W, CM, AH, BS and S represent barley, corn, oats, wheat, canola meal, alfalfa hay, barley silage and straw, respectively[10]. P_{t-n}^i is the price of feed ingredient *i* at time period *t-n*, a_m^i are the parameters to be estimated for feed ingredient *i*, and e_t^i is the error term for feed ingredient *i*. The SUR model was estimated using STATA.

Table 4.16 Seemingly unrelated regression (SUR) model results

Variable	Estimated Coefficients[a, b]							
	Barley	**Corn**	**Oats**	**Wheat**	**Canola Meal**	**Alfalfa Hay**	**Barley Silage**	**Straw**
Lag1	0.810***	0.832***	1.330***	1.025***	0.687***	1.024***	0.666***	0.580***
	(0.054)[c]	(0.059)	(0.094)	(0.093)	(0.083)	(0.100)	(0.055)	(0.065)
Lag2			-0.539***	-0.229***		-0.286***		
			(0.084)	(0.087)		(0.083)		
Constant	0.035***	0.041***	0.036***	0.040***	0.077***	0.022***	0.012***	0.017***
	(0.010)	(0.014)	(0.008)	(0.011)	(0.021)	(0.005)	(0.002)	(0.003)
Std. Err.[d]	0.019	0.026	0.011	0.022	0.040	0.011	0.003	0.004
R^2	0.785	0.786	0.850	0.792	0.570	0.793	0.667	0.620

[a] ***, **, and * indicates significance at 1%, 5%, and 10% level, respectively
[b] Breusch-Pagan test of independence: chi (28)=202.462, p=0.000
[c] Numbers in the parentheses are standard errors for parameters
[d] Standard error here is the root mean square error (RMSE) for each equation

[10] The same feed ingredient denotations are used throughout the entire thesis.

Parameter estimation results from the SUR model are provided in Table 4.16. R^2 values of individual feed price equations range from 0.570 to 0.850. The coefficients are all statistically significant at a 1% level. Using the Breusch-Pagan test of independence, which is a chi-square test to determine whether the error terms from each equation are independent (Greene, 2008), the null hypothesis of homoscedasticity is rejected (see the footnote for table 4.16). This implies that the error terms in the SUR model are correlated. In summary, these indicate that using a SUR model to estimate feed prices is preferable to using separate OLS models.

Based on the SUR model results, quarterly prices can be simulated using lagged feed prices. In order to generate random samples and incorporate uncertainty and risk into price simulations, the stochastic effect was modeled through error terms in each equation. These error terms in each feed price equation were first assumed to be distributed as independent univariate standardized normal distributions (i.e., e~N(0,1)) when modeled using @Risk. However, the SUR approach allows all the equations in the model to be estimated as a whole system, considering exogenous variables will affect the dependent variables. This means that the error terms in each feed price equation are correlated with each other. Consequently, the error terms obtained directly from the SUR model must be adjusted accordingly by the error correlations and scaled by the standard errors from each equation (Hull, 2000). Based on Hull's (2000) procedure, which uses a Cholesky decomposition, equation 4.6 is used to correct the error terms.

$$e_{i\theta} = \sum_{\theta} \alpha_{i\theta}\beta_{i\theta} \qquad \text{(4.6-a)}$$

$$\begin{cases} \sum_{\theta} \alpha_{i\theta}^2 = 1 \\ \sum_{\theta} \alpha_{i\theta}\alpha_{j\theta} = \rho_{ij} \ \ (j \neq i) \end{cases} \qquad \text{(4.6-b)}$$

where e_i is the adjusted error term of feed price equation i, β_i is the error term of feed price equation i that is obtained directly from the SUR model, ρ_{ij} is the correlation between the error terms of the feed price equations i and j, α are the parameters, and θ is how many error terms of feed price equations have correlations. In order to calculate the adjusted error terms e_i using Equation 4.6-a, θ needs to be determined first, and then α needs to be solved from Equation 4.6-b. However, it is assumed that the θ is not larger than three, which means no more than three error terms from feed price equations are correlated. This assumption is made because the calculation of adjusted error terms according to equation 4.6-b can be difficult when the θ is larger than three.

Table 4.17 SUR estimated error correlations

	e^B	e^C	e^O	e^W	e^{CM}	e^{AH}	e^{BS}	e^S
e^B	1.0000							
e^C	0.6724	1.0000						
e^O	0.5568	0.4361	1.0000					
e^W	0.7595	0.5441	0.3650	1.0000				
e^{CM}	0.4969	0.5721	0.4147	0.5796	1.0000			
e^{AH}	-0.0510	0.1353	0.2120	-0.0100	0.1525	1.0000		
e^{BS}	0.4066	0.3203	0.5400	0.3816	0.3815	0.5519	1.0000	
e^S	-0.0003	0.0527	0.2092	0.1134	0.1150	0.6309	0.5530	1.0000

The error correlations for the SUR model were estimated by STATA. These correlation coefficients are shown in table 4.17, and used to determine the θ. When the absolute value of the correlation coefficient is less than 0.35, the correlation is believed to be weak; when the value is between 0.35 to 0.67, the correlation is moderate; when it is larger than 0.67, the correlation is strong (Mason et al*.,* 1983). The correlation results indicate that most correlations among these eight feed prices are moderate. Only the correlations between barley and corn, and between barley and wheat are strong; both coefficients are larger than 0.67. Adhering to the rule to set up a group that contains no more than three feed ingredients, barley, corn, and wheat are set as Group One. After eliminating these three feed ingredients from table 4.17, the next top three correlation coefficients are 0.6309, 0.5530, and 0.5519. These three correlation coefficients reflect the correlations among error terms for alfalfa hay, barley silage, and straw price equations. Therefore, alfalfa hay, barley silage, and straw are set as Group Two. This leaves oats and canola meal in table 4.17. The correlation coefficient between these two feed ingredients is 0.4147. However, compared with the correlation coefficients in other two groups (>0.55), there is not a strong evidence to prove that the error terms from oats and canola meal equations need adjustment due to this correlation. Hence, oats and canola meal are set individually as Group Three and Group Four, respectively. Given the identified groups of feed ingredients, θ is determined for each group, and the adjusted error terms for these eight feed price equations can be shown as equations 4.7-a to 4.7-d. The adjusted error terms are then scaled by the standard errors from each feed price equation in SUR model.

Group One:

$$e_B = \beta_B$$

$$e_C = \rho_{B,C}\,\beta_B + \left(\sqrt{1-\rho_{B,C}^2}\right)\beta_C$$

$$e_W = \rho_{B,W}\,\beta_B + \left(\frac{\rho_{C,W} - \rho_{B,C}\rho_{B,W}}{\sqrt{1-\rho_{B,C}^2}}\right)\beta_C + \left[\sqrt{1-\rho_{B,W}{}^2 - \left(\frac{\rho_{C,W} - \rho_{B,C}\rho_{B,W}}{\sqrt{1-\rho_{B,C}^2}}\right)^2}\,\right]\beta_W \quad (4.7\text{-a})$$

Group Two:

$$e_{AH} = \beta_{AH}$$

$$e_{BS} = \rho_{AH,BS}\,\beta_{AH} + \left(\sqrt{1-\rho_{AH,BS}^2}\right)\beta_{BS}$$

$$e_S = \rho_{AH,S}\,\beta_{AH} + \left(\frac{\rho_{BS,S} - \rho_{AH,BS}\rho_{AH,S}}{\sqrt{1-\rho_{AH,BS}^2}}\right)\beta_{BS}$$

$$+ \left[\sqrt{1 - \rho_{AH,S}{}^2 - \left(\frac{\rho_{BS,S} - \rho_{AH,BS}\rho_{AH,S}}{\sqrt{1-\rho_{AH,BS}^2}}\right)^2}\,\right]\beta_S \quad (4.7\text{-b})$$

Group Three:

$$e_O = \beta_O \quad (4.7\text{-c})$$

Group Four:

$$e_{CM} = \beta_{CM} \quad (4.7\text{-d})$$

Even after taking the steps described above to estimate the stochastic feed price model, the model can still simulate unrealistic price results (i.e., negative values) as it is generating random error terms. Thus, range restrictions should be incorporated to make sure those price models simulate reasonable feed prices. The maximum feed price was set as the maximum historical price plus one standard deviation calculated based on historical prices during the corresponding period. The minimum feed price was set as the minimum historical price minus one standard deviation. The maximums and minimums are set as the boundaries for each stochastic feed price model.

4.4.2.3 Validation Testing

As mentioned in section 4.1, a 20-year horizon was chosen for this study based on expert opinion concerning technological innovations and machinery depreciation (Swift, 2012). Thus, stochastic feed price models are used to simulate quarterly feed prices for twenty years from the first quarter of 2013 to the fourth quarter of 2032. However, before using the simulated feed prices in further research, they need to be validated. More specifically, since feed prices are shown to be stationary, mean values of historical and simulated price data series should be constant. The comparison of historical and simulated feed price means is reported in table 4.18.

Table 4.18 Comparison of historical and simulated feed price means ($/kg)

	Historical Mean	Simulated Mean	Difference
Barley	0.1832	0.1909	-0.0077
Corn	0.2313	0.2493	-0.0180
Oats	0.1777	0.1733	0.0044
Wheat	0.1921	0.1979	-0.0058
Canola Meal	0.2439	0.2466	-0.0027
Alfalfa Hay	0.0940	0.0846	0.0094
Barley Silage	0.0379	0.0359	0.0020
Straw	0.0433	0.0403	0.0030

In order to be more accurate, a Z-test[11] was conducted for each feed ingredient. The null hypothesis of the Z-test is that the historical prices have the same mean as the simulated prices. P-values of the Z-tests are reported in table 4.19. The p-values for corn, alfalfa hay, barley silage, and straw are all less than 0.10. It indicates that these four feed ingredients reject the null hypothesis and shows significant difference between historical and simulated prices. As a result, the constants in corn, alfalfa hay, barley silage, and straw price equations (see table 4.16) are adjusted to make the simulated means match the historical means. The adjusted simulated means and adjusted constants are provided in table 4.20. The adjusted stochastic feed price equations are then used to simulate quarterly feed prices for further research.

Table 4.19 Z-tests results

	P-value
Barley	0.2397
Corn	0.0356
Oats	0.4440
Wheat	0.4531
Canola Meal	0.7732
Alfalfa Hay	0.0774
Barley Silage	0.0883
Straw	0.0912

[11] A z-test is used to perform mean analysis for two samples with known variances. The null hypothesis of a two-sample z-test is that there is no difference between two means (Sprinthall, 2007).

Table 4.20 Comparison of historical and adjusted simulated means ($/kg)

	Historical Mean	Adjusted Simulated Mean	Adjusted constant
Barley	0.1832	0.1909	0.0350
Corn	0.2313	0.2313	0.0230
Oats	0.1777	0.1733	0.0360
Wheat	0.1921	0.1979	0.0400
Canola Meal	0.2439	0.2466	0.0770
Alfalfa Hay	0.0940	0.0940	0.0314
Barley Silage	0.0379	0.0379	0.0140
Straw	0.0433	0.0433	0.0200

4.5 Effects of Adopting NIRS

The next step is to model the adoption of NIRS, which has impacts on both the benefits and costs. For benefits, the key issue is the measurement of the effectiveness of NIRS. The advantage of NIRS technology is to quickly provide accurate predictions of nutrient content in feed ingredients, which is modeled by changing the stochastic nutrient content distributions. For the cost side, it is clear that the adoption of NIRS has costs, such as investment costs, labour costs, and calibration costs. To make the measurement of costs closer to real practices, a unit cost of the NIRS test (i.e., the cost of a single NIRS test) was used in this study. Therefore, total adoption costs can be calculated based on how many tests are needed for each representative enterprise.

4.5.1 Impact of NIRS

In section 4.4.1, triangular distributions (figure 4.2) are defined to measure stochastic nutrient content in feed ingredients. Each draw from a distribution represents a specific value for the nutrient content of one feed ingredient. According to table 4.9, any value between the maximum and minimum values of nutrient content can be selected since nutrient content values are set as stochastic. This is the situation in baseline scenarios where there is no NIRS technology adopted. The assumption here is that there is no information with regard to nutrient content value provided at the point of purchasing feed ingredients. Therefore, every nutrient content value within the distribution is possible, and operators need to determine their ration based on the nutrient content information of the purchased feed ingredients.

In order to evaluate the situation in which NIRS technology is adopted, the effectiveness of NIRS needs to be modeled first. In the NIRS scenarios, information with regard to nutrient content values is provided by NIRS tests at the point of purchasing feed ingredients. Livestock operators therefore know the nutrient content values before they purchase the feed ingredient. They can use this additional information to make purchasing decisions and formulate optimal rations using the least-cost ration model. Hence, the effectiveness of NIRS actually depends on each operator's acceptance level of the nutrient contents in the feed ingredients. NIRS machines provide nutrient content values but operators are making purchasing decisions. For example, if one operator only purchases the feed ingredients with the highest 90% nutrient content values, then he or she actually uses the NIRS test results to accept qualified feed ingredients and reject feed ingredients in the bottom 10% of nutrient content values by not purchasing them. Therefore, the effectiveness of NIRS is incorporated in this study through the acceptance level of operators. This effectiveness can be reflected in distributions by truncating the triangular distributions of nutrient contents. It means operators reject feed ingredients with low nutrient content values (figure 4.3). These distributions are called truncated triangular distributions (figure 4.4).

It is natural that operators have different acceptance levels of the nutrient content values in the feed ingredients since they all have varied considerations in terms of feed prices, nutrient content values, feeding nutrient requirements, and feeding length, etc. Therefore, based on expert opinion (Swift, 2012; Hand, 2013), alternative assumptions are made regarding rejection decisions by operators. Specifically, they reject feed ingredients with the lowest 5%, 15%, 25%, 35%, and 50% nutrient content values according to the NIRS test results. The corresponding truncated triangular distributions are then determined. More specifically, these truncated triangular distributions are used in NIRS scenarios to measure the effectiveness of NIRS, while triangular distributions of nutrient contents are used in baseline scenarios as stochastic elements.

Figure 4.3 Effect of rejecting feed ingredients on the triangular distribution

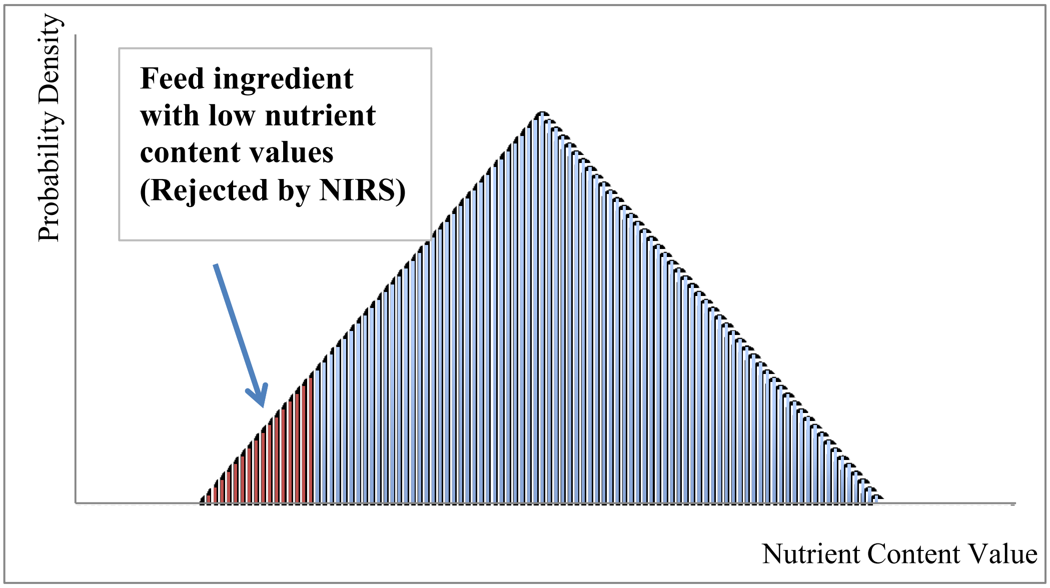
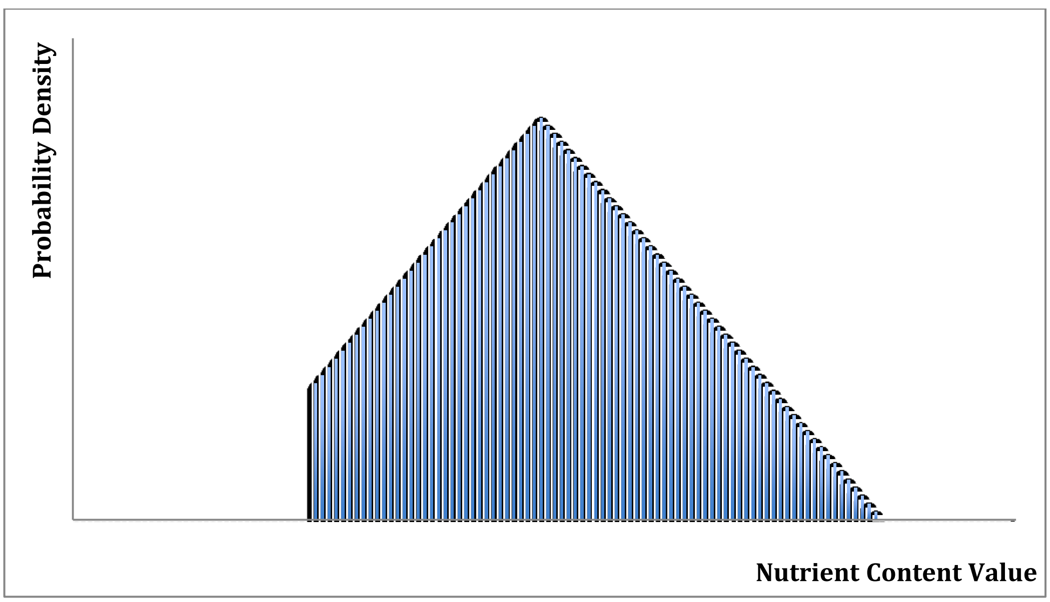
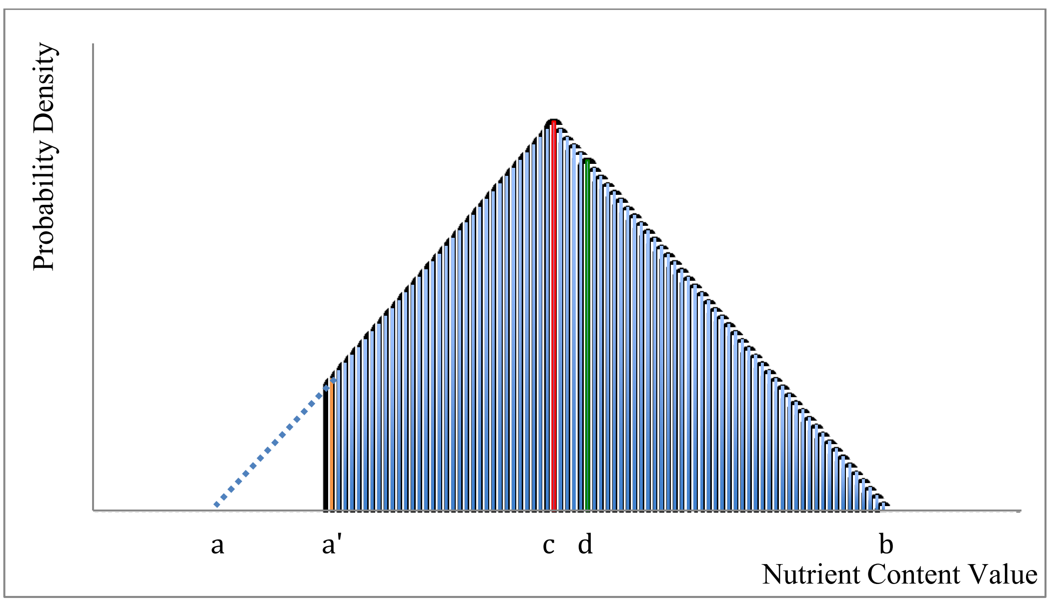


Figure 4.4 Truncated triangular distribution of nutrient content



For the NIRS scenarios, since triangular distributions are truncated, the minimum value *a* (same as point *a* in figure 4.2) shifts right to *a'* in figure 4.5. Keeping the other properties unchanged, the mean value of distribution also shifts to the right. In figure 4.2, since the triangular distribution is symmetric, the mean value equals the mode value, and both of them are at point *c*. However, after truncating the symmetric triangular distribution, it is not symmetric any more. The mode value remains unchanged at point *c* in figure 4.5 as it is in figure 4.2. The mean value shifts, however, from point *c* to point *d* in figure 4.5. In this case, random draws from a truncated triangular distribution are more likely to get a higher value than draws from the original triangular distribution. In other words, nutrient content values in the NIRS scenarios are more likely to be higher than values in the baseline scenarios. Due to this fact, operators can use feed ingredients with higher nutrient contents to formulate their rations.

Figure 4.5 Statistical properties of truncated triangular distributions



4.5.2 Costs of Adopting NIRS

In order to determine and calculate the cost of adopting NIRS for dairy, beef cattle backgrounding and finishing enterprises, the question about how these three enterprises adopt NIRS technology into their business should be considered. First, it is assumed that beef finishing feedlots purchase their own NIRS machines. Feedlots typically have more cattle than the other two types of enterprises. Due to a larger demand for feed ingredients, operators are assumed to purchase feed ingredients directly from crop farms, and plant some crops which are used into their own livestock rations[12] (i.e., grow barley for barley silage). Therefore, feedlots are more likely to purchase their own NIRS machines rather than send feed ingredient samples to consulting companies for nutrient content testing. The latter approach is time-consuming, and cannot meet the frequent needs from feedlots. In contrast, in this study dairy farms and backgrounding farms are assumed to purchase rations that are already tested by NIRS machines, from feed mills or consulting companies. Because dairy and backgrounding farms are not as large and do not require frequent testing comparable to feedlots, operators are more likely to purchase tested and formulated rations and save the cost of investing in a NIRS machine. However, this investment cost will eventually be incurred by these operators through the cost of purchased NIRS tested rations.

Although the ways in which these three enterprises adopt the NIRS are different, a NIRS test is not provided as a separate commercial service. More specifically, when dairy and backgrounding operators purchase NIRS tested rations from feed mills or consulting companies, they pay for the rations that include NIRS test costs. It is assumed that feed mills and consulting companies only make a profit from selling rations, and there is no profit from conducting an NIRS test. It means the cost of adopting NIRS in this study should be modeled based on the cost of using the technology rather than a commercial price for an NIRS test[13].

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[12] Section 4.2 defines finishing feedlots as mixed-enterprise farms, which are involved in both crop and livestock production

[13] The commercial price of a NIRS test in Alberta ranges from $20 to $30 per sample.

Since dairy and backgrounding operators do not pay the full cost of the NIRS machine, the capital cost should be estimated and incorporated into the unit cost for NIRS. Additionally, in order to capture both opportunity cost and depreciation (machine cost)[14], an amortization formula is used as shown in equation 4.8:

$$A = IC\left[\frac{i}{1-\frac{1}{(1+i)^N}}\right] \tag{4.8}$$

where *A* is the annual capital cost, *IC* is the initial investment cost, *i* is the discount rate, and *N* is the length of the project. Based on available market information, the initial investment cost of the NIRS machine cost is set at $40,000 per unit. As stated in previous sections, the project length is set as 20 years, and the discount rate is set as 8% (discussion about the discount rate is provided in section 4.7.2). Therefore, the annual capital cost is calculated as follows:

$$A = \$40{,}000 * \left[\frac{0.08}{1-\frac{1}{(1+0.08)^{20}}}\right] = \$4{,}074.09$$

Assuming one NIRS machine tests 20 samples per working day, annual usage can be calculated as 20 samples*52 weeks*5 days, or 5,200 uses. Therefore, the capital cost per sample is $4,074.09/5,200 which is $0.78 per sample.

For labour cost, average hourly wage for an agrologist in Alberta is $39.15, which is based on 2011 Alberta Wage and Salary data (GA, 2013). Since the time required for NIRS analysis of one sample is about 10 minutes, the labour cost per sample is $39.15/(60/10) samples = $6.53.

[14] This assumes the residual value of an NIRS machine after 20 years is zero.

For calibration cost, it is assumed that an agrologist spends 5% of working hours on calibration. Since the annual salary of an agrologist is $74,687 (GA, 2013), the calibration cost per sample can be calculated as $74,687*0.05/5200 samples = $0.72.

For maintenance cost, based on previous studies annual maintenance cost is 3% of replacement asset value (initial investment cost in this study) (Ahmad and Benson, 1999; Gulati and Smith, 2009[15]). Therefore, the maintenance cost per sample is $40,000*0.03/5,200 samples = $0.23.

In summary, the unit cost of an NIRS test can then be calculated by summing the above costs: $0.78+$6.53+$0.72+$0.23 = $8.26. As a comparison, the University of Alberta provides a NIRS test service for the hog industry with a charge of $10 per sample. Assuming the university does not provide this service for commercial purposes, the price of an NIRS test in the university should be close to the unit cost in this study. Hence, it is believed that the estimation of $8.26 is reasonable.

The unit cost of a NIRS test used in this study is obtained by the following steps. First, the total amount of feed ingredients used in each quarter for each enterprise is calculated using the results from the least-cost ration model. Secondly, it is assumed that a feed ingredient truck, which sends feed ingredients from crop farms to operators, feed mills, and consulting companies, has a capacity of 24,000 kg. It is assumed that an NIRS test is conducted once for each truckload. The number of trucks used for transportation is then calculated by dividing the total amount of feed ingredients used by 24,000 kg. For example, assuming 40,000 kg of ration are used in one farm, then two trucks (40,000/24,000=1.67) are used to transport feed ingredients from the crop farms to the livestock farm. The result is also the number of NIRS tests performed. So in the previous example, rations are tested by NIRS twice. Thirdly, multiplying the number of

[15] Gulati and Smith (2009) suggest the maintenance cost as a percentage of replacement asset value ranges from 2.5% to 3.5%.

NIRS tests performed by the unit cost, the total quarterly cost of adoption for the representative enterprise is therefore estimated.

4.6 Modeling and Scenarios

The main purpose of this study is to assess the benefits and costs of adopting NIRS technology that is used to predict nutrient contents in mixed rations for dairy and beef cattle feeding operations. For comparison purposes, baseline scenarios and NIRS scenarios are established. The benefit of adopting NIRS technology in each representative enterprise in this study is assumed to be the feed cost savings. These representative enterprises include dairy farms, beef cattle backgrounding farms, and beef cattle finishing feedlots. In order to estimate feed costs, a LCRM is used for each representative enterprise. In addition, stochastic nutrient content distributions and feed price models are set up and introduced to incorporate risk into the LCRM. Multiplying the unit cost of an NIRS test by the amount of NIRS tests conducted, total costs of adopting NIRS technology are determined. All benefits and costs are then discounted to present values. Net present values (NPV) are calculated by subtracting discounted total costs from discounted total benefits for each representative enterprise, assuming a twenty-year time horizon. Based on those NPVs, the decision regarding whether operators purchase an NIRS machine or not can then be determined.

Two types of scenarios are set up: a baseline scenario and an NIRS scenario. Baseline scenarios represent the situations in which NIRS technology is not adopted by the representative enterprise. NIRS scenarios represent the situations in which NIRS technology is adopted by the representative enterprise. Specifically, seven separate scenarios representing three distinct types of operations are evaluated (table 4.21). These scenarios are set up based on expert opinion. Associated nutrient requirements and feed ingredient constraints are all provided in section 4.2. It is expected that total feed cost from LCRM in the baseline scenario will be higher than the cost in the corresponding NIRS scenario.

Thus, NIRS technology should show its effect by providing nutrient content information and helping operators save money when formulating rations.

Table 4.21 Scenarios for evaluation

Scenario		Phase	ADG (kg)	NIRS adoption
1	Baseline	Dairy (Lactating)	N.A.	No
	NIRS			Yes
2	Baseline	Beef Cattle Backgrounding (Lightweight)	0.80	No
	NIRS			Yes
3	Baseline		1.22	No
	NIRS			Yes
4	Baseline	Beef Cattle Finishing (Lightweight)	1.53	No
	NIRS			Yes
5	Baseline		1.91	No
	NIRS			Yes
6	Baseline	Beef Cattle Finishing (Heavyweight)	1.46	No
	NIRS			Yes
7	Baseline		1.81	No
	NIRS			Yes

4.6.1 Baseline Scenarios

In the baseline scenarios, it is assumed that livestock operators do not have the ability to know the nutrient content values in the feed ingredients. They know those values after they purchase the feed ingredients. Therefore, these purchased feed ingredients can have any feasible nutrient content value. Livestock operators then determine their optimal rations based on nutrient content values. Therefore, operators do not have the opportunity to set minimum requirements (i.e., nutrient content level) when purchasing feed ingredients. The assumption is reflected in simulation models through stochastic nutrient content distributions in this study. More specifically, stochastic nutrient content distributions are set up as symmetric triangular distributions in the baseline scenarios. It means livestock operators cannot reject any feed ingredient from crop farms.

In addition, since operators do not know nutrient content information, their feed ingredients purchasing decisions are based on expected nutrient content values. Additionally, they make decisions based on expected feed prices. Therefore, mean feed prices (obtained from the feed price model) are used in determining coefficients for the LCRM objective equation, and mean values of nutrient contents (reported in table 4.8) are used as coefficients in the constraints. This is consistent with an assumption that the optimal rations are determined before livestock operators purchase feed ingredients. Actual feed prices are revealed at the point that livestock operators purchase feed ingredients from crop farms. Specifically, actual feed prices were simulated using estimates from the stochastic feed price model. Lastly, by multiplying optimal rations by the simulated feed prices, total feed costs in the baseline scenarios are calculated. Since the simulated feed prices are represented as distributions, total feed costs are also presented as distributions.

4.6.2 NIRS Scenarios

In the NIRS scenarios, it is assumed that livestock operators know the nutrient content values in the feed ingredients being sold by crop farms. Therefore, operators can combine nutrient content information with other information, such as feed prices and nutrient requirements of livestock, and make a final purchasing decision. Livestock operators can set up certain standards to reject the feed ingredients from crop farms and avoid potential monetary loss (i.e., pay more money for feed ingredients of lower quality). This assumption is reflected through truncated triangular distributions of nutrient contents. It shows that livestock operators can reject some feed ingredients from crop farms based on lower nutrient content values. As mentioned in section 4.5.1, rejection levels are assumed to be 5%, 15%, 25%, 35%, and 50% in this study.

As mentioned in section 4.2, it is assumed that dairy farms either purchase forage or test their own forage by NIRS. For the beef operations, the beef backgrounding farm is assumed to only purchase forage while the beef feedlot (finishing operation) produces its own forage which is not tested using NIRS. These assumptions are made based on the prevalence and importance of forage purchases in each livestock sector, and determine whether or not forages, including alfalfa hay, barley silage, and straw, are tested by NIRS. Based on table 4.9, it is noted that forage accounts for a significant amount of dairy rations. High quality forage is important in dairy rations to maintain milk production. Hence, no matter where the forages come from (grown or purchased), operators will test the nutrient contents to make sure they are high quality forages.

Additionally, due to the production capabilities for beef cattle backgrounding farms, they are assumed in this study to focus only on the livestock operation and to directly or indirectly (i.e., through feed mill) purchase all feed ingredients from crop farms. Therefore, all feed ingredients are assumed to be tested in the NIRS scenarios for dairy and beef cattle backgrounding sectors. Livestock operators then reject feed ingredients with lower nutrient content, based on NIRS testing results.

The only operation assumed not to test forages using NIRS is the beef feedlot. It is assumed that beef cattle finishing feedlots grow forage crops (i.e., use barley to produce barley silage) that they then use for their own livestock rations. Since forages only account for 10% to 20% of the weight in finishing rations, they are assumed to be less important in these rations and thus are not tested for nutrient content. Therefore, there is no NIRS impact on forages for the beef cattle finishing sector. More specifically, symmetric triangular distributions of nutrient contents are still used for forages in the NIRS scenarios for beef cattle finishing feedlots.

Further, stochastic nutrient content values were used in the NIRS scenarios since livestock operators could use NIRS to quickly predict this information at the point of purchase. However, due to technical matters and time constraints for this study, expected nutrient content values were still used in LCRM for NIRS scenarios. As mentioned in section 4.5.1, since truncated triangular distributions were adopted in the NIRS scenarios, the mean values of nutrient contents shifted to the right, so that values of nutrient content in the NIRS scenarios are larger than those used in the baseline scenarios.

As well, similar to the baseline scenarios, expected feed prices are also used to estimate optimal rations in the NIRS scenarios. Actual total feed costs are then calculated by using simulated feed prices from the stochastic feed price model in the optimal ration results. This reflects the fact that actual feed prices are considered while making purchasing decisions of feed ingredients. Those total feed costs are also presented as distributions.

4.7 Benefit-Cost Analysis

In this study, BCA was used to evaluate the adoption of NIRS technology in the dairy and beef cattle industry. Dairy and beef cattle farm operators need to pay (directly or indirectly) an initial investment cost for the NIRS machine, from which they will then get benefits from nutrition information provided by NIRS in the future. As well, additional adoption costs will also be incurred, including labour, calibration and maintenance costs. Before adopting the NIRS technology in their businesses, operators have questions about whether those NIRS adoption costs will be covered by its benefits with a long-time horizon. BCA is therefore an appropriate approach to use in evaluating this kind of investment decision and was adopted in this study.

4.7.1 Net Present Value

The most important step in conducting a BCA is the evaluation of benefits and costs, and the resulting net benefit that is calculated. For this study, the impacts of adopting NIRS are over time. Boardman et al. (2011) suggest discounting future benefits and costs to present benefits and costs. The discounting incorporates time preferences; that is, people prefer to consume now rather than later. The calculation of NPV is shown in equation 4.9:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} = \sum_{t=0}^{n} \frac{NB_t}{(1+i)^t} \quad (4.9)$$

where B_t, C_t, NB_t are the benefits, the costs, and the net benefit in time period t, i is the discount rate, n is the time length of the assessment. In this study, the benefit is measured as feed cost savings. The cost is measured as the unit cost of an NIRS test. The annual discount rate used in this study is 8%, which is discussed in the next section. The time horizon is 20 years. However, since quarterly data are used, the value of n is actually 80, and the quarterly discount rate is 2% (8%/4). If the NPV is larger than zero, then operators should adopt the NIRS technology. Conversely, if the NPV is smaller than zero, then they should not adopt NIRS.

After calculating the NPV at per animal level for each representative enterprise in this study, those NPVs are aggregated to a provincial level (Alberta) and for the western Canada region. Each per animal level NPV is estimated as $ per head. It is then multiplied by the number of dairy cows or beef cattle in the study area to determine NPVs for Alberta and western Canada. For example, assuming a 20-year NPV is $600 per dairy cow, the 20-year NPV for the Alberta dairy cow industry would be close to $48 million (600*80,400=48,240,000). According to Statistics Canada (2014b), the number of cattle by province as of January 1st, 2013 is provided in table 4.22.

Table 4.22 Number of cattle by province (thousand head, as of Jan 1st, 2013)

	Dairy	Backgrounding	Finishing[a] (Lightweight calves)	Finishing[a] (Heavyweight calves)
Alberta	80.4	1,117.3	656.0	241.5
Saskatchewan	27.6	236.7	56.5	50.2
Manitoba	45.3	126.0	54.3	28.4
British Columbia	72.9	67.9	7.6	1.9
western Canada	226.2	1,547.9	774.4	322.0

Source: Statistics Canada (2014b), Table003-0032
[a] Since Statistics Canada do not provide weight information, finishing (heavyweight calves) includes calves under 1 year that go directly into finishing operation, and finishing (lightweight calves) includes the rest cattle on finishing operation

4.7.2 Choosing the Discount Rate

According to equation 4.9, it is clear that the choice of discount rate *i* has an impact on the NPV. The discount rate is an interest rate used in the discounting process to calculate the present value of a future value (Boardman et al., 2011). Canadian BCA guidelines (TBCS, 2007) recommend an 8% social discount rate (SDR) based on a weighted social opportunity cost approach. However, it cannot be used directly in this study since the SDR is usually used to evaluate projects that involve social impacts or reflect government preferences. Conversely, this study evaluates impacts of NIRS adoption on private enterprises, such as dairy farms, beef cattle backgrounding farms and finishing feedlots. Social impacts are excluded, and so a SDR is inappropriate. Therefore, a private discount rate (PDR) needs to be employed in this study. The PDR is set to reflect the opportunity cost of investment for an enterprise. Therefore, the estimation of a PDR for one industry depends on the representative characteristics of the enterprises in the same industry. Ross et al. (2003) suggest using a weighted average cost of capital (WACC) approach that determines the PRD by the private enterprise's total market value of equity, total debt, cost of equity, cost of debt, and tax rate. However, due to the fact that the business sizes of dairy and beef cattle farms are very variable, it was not easy to define a representative capital structure for enterprises in this study by using the WACC approach.

Previous studies were reviewed to determine an appropriate PDR for this study. However, since the calculation of the PDR is highly related to market factors, only studies within the recent five years were considered, and only studies for the Canadian agriculture industry. Koeckhoven (2008) and Dollevoet (2010) picked a 10% discount rate for farm-level evaluations based on their literature reviews. Cairns and Meilke (2012) estimated a discount rate range between 8.6% and 10.4% for the Ontario dairy industry. Anderson and Weersink (2013) also used an 8% discount rate for investment decisions on Ontario dairy farms. Khakbazan et al. (2013) adopted a 6% discount rate in their evaluation of land management changes in Canada. All these studies are directly related to the Canadian agriculture industry, and some of them looked into dairy farms. A moderate PDR of 8% is therefore chosen for this study. PRDs of 6% and 10% are also used for sensitivity analysis purposes.

4.8 Chapter Summary

This chapter outlined the methodologies used to conduct benefit-cost analysis. Representative enterprises were firstly defined for dairy, beef cattle backgrounding, and finishing farms in the research area. LCRMs were constructed to estimate feed costs by solving a linear programming problem regarding feed costs minimization. By comparing LCRM results for baseline scenarios and NIRS scenarios, feed cost savings were then calculated as the benefit of adopting NIRS. Costs of adoption were then calculated as the unit cost of an NIRS test, which included capital costs, labour costs, calibration costs, and maintenance costs.

Stochastic elements were introduced into LCRM, including stochastic nutrient content values and feed prices. Stochastic nutrient content distributions were set using NRC (2000; 2001) data. These distributions not only captured risk but also measured the effectiveness of NIRS. In the baseline scenarios, nutrient content distributions were symmetric triangular distributions. In the NIRS scenarios, they were truncated triangular distributions. The truncated distributions reflected the levels at which operators rejected to purchase feed ingredients with lower nutrient contents. The stochastic feed price model was developed as a SUR model and estimated as a whole system. Adjusted error terms from the SUR were then incorporated into estimation results and used to set the stochastic feed prices. The stochastic elements were all set up based on historical data in the study area.

Lastly, the NPV analysis was conducted to provide investment decision information regarding NIRS adoption. Based on previous studies in the Canadian agriculture industry, an 8% discount rate was chosen for this study. Each per animal level NPV for each representative enterprise was estimated with a twenty-year horizon, and then aggregated to industry-level for Alberta and western Canada.

Chapter 5: Results and Discussion

This chapter provides the results from the models outlined in Chapter 4. Discussed are seven scenarios for the Alberta dairy industry, backgrounding beef cattle industry, and finishing beef cattle industry. Aggregate results are also provided for western Canada. In order to evaluate the economic impacts from adopting NIRS technology, the results are compared between a baseline model (without NIRS) and corresponding NIRS models for each scenario. Sensitivity analyses are then performed to determine the extent of change in net present values associated with feed grain price, NIRS adoption cost, and discount rate. Along with the presentation of the results, a discussion of important findings is also provided.

As described in Chapter 4, least-cost ration models (LCRM) are solved to determine optimum feed costs for representative Alberta farms. The benefits of adopting NIRS technology are then determined as the feed cost savings, by subtracting the total feed cost in the NIRS model from the total feed cost in the baseline model. The NIRS adoption cost is calculated per animal per day. Additionally, nutrient contents in feed ingredients are introduced as stochastic triangular distributions in LCRM. Five rejection levels (5%, 15%, 25%, 35%, and 50%) are then modeled using those triangular distributions and included in each NIRS model to represent the operator's acceptance level of the nutrient contents in the feed ingredients, and to determine the extent of impact on the results. In other words, rejection levels in triangular distributions determine the proportion of feed ingredients with the lowest nutrient contents that are eliminated based on the results from NIRS tests. Using an 8% discount rate, the net present value (NPV) per head for a twenty-year duration is determined by subtracting the NIRS adoption cost from the feed cost savings. Aggregate NPVs for Alberta and western Canada are then estimated. A positive NPV value can be viewed as an indication to adopt NIRS technology in the industry, while a negative NPV indicates otherwise.

Results are presented in three categories: benefits, costs, and NPV. Mean feed cost per head per day, mean feed cost savings per head per day, and associated standard deviations are reported under the benefit category. As well, the percentage change in feed cost between baseline and NIRS models is also reported. NIRS adoption cost per head per day is provided under the cost category. The twenty-year NPV is reported per head unit under the NPV category, with associated standard deviations. Standard deviations reflect the statistical variability associated with the estimates.

Lastly, three types of sensitivity analyses are performed to estimate their impact on the NPVs: (1) a 10% increase in barley price; (2) both a 10% increase and a 10% decrease in NIRS adoption cost; and (3) discount rates of 6% and 10%. All three sensitivity analyses are conducted for all scenarios, with one exception. The increase in barley price is performed only for scenario 7, heavyweight beef cattle in the finishing phase with an average daily gain (ADG) at 1.81kg, since the ration in this scenario contains more barley than in other rations.

5.1 Scenario Results for the Dairy Industry in Alberta

5.1.1 Scenario 1 - Lactating Dairy Cow

In this scenario, a baseline model and five NIRS models are estimated for the representative dairy farm in Alberta that is described in Chapter 4. The baseline model results regarding rations were reviewed using expert opinion (Swift, 2012) to make sure the results generated from LCRM were typical of rations used to feed dairy cows in Alberta. Mean and standard deviation values of NPVs from baseline and NIRS models are reported and compared in table 5.1.

Table 5.1 Scenario 1 results: lactating dairy cow

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$3.587	$3.534	$3.447	$3.373	$3.305	$3.207
Standard Deviation	$0.017	$0.017	$0.016	$0.016	$0.016	$0.015
Mean feed cost saving		$0.053	$0.140	$0.214	$0.282	$0.381
Standard Deviation		$0.001	$0.001	$0.002	$0.002	$0.003
% change of feed cost		1.48%	3.90%	5.97%	7.86%	10.62%
Cost[a]						
NIRS adoption cost		$0.014	$0.015	$0.017	$0.019	$0.024
Net present value[b]						
Mean NPV per head		$148.73	$465.22	$735.35	$980.69	$1328.62
Standard Deviation		$2.45	$4.75	$6.98	$8.89	$11.82

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

The mean feed cost decreases from $3.53 to $ 3.21 per head per day as the rejection level[16] of NIRS tests increased. Additionally, compared with the mean feed cost of the baseline model at $3.59 per head per day, the mean feed cost saving increases from $0.05 to $0.38 per head per day as the rejection level is increased. The percentage change of feed cost is also increased from 1.48% at the 5% rejection level to 10.62% at the 50% rejection level. As such, it can be interpreted that a dairy farm with 100 lactating dairy cows can save $1,934 to $13,906 per year in feed costs. When the rejection level goes up, more low quality feed ingredients are rejected by NIRS. Since the feed ingredients remaining contain higher nutrient contents, LCRM can utilize fewer feed ingredients to fulfill the same nutrient requirements for dairy cows. Given constant feed ingredient prices, lower feed costs are observed when the rejection level is increased. Second, feed costs savings and the percentage change of feed costs increase when the rejection level is increased. Third, the combination of feed ingredients in rations changes when the rejection level changes.

The associated standard deviations of mean feed costs decline slightly when the rejection level is increased. Conversely, standard deviations of mean feed cost savings increase. It is $0.001 at the 5% rejection level, and goes up to $0.003 at

[16] It shows that livestock operators can reject some feed ingredients from crop farms based on their own rejection level regarding to nutrient content values.

the 50% rejection level. This variability is due to the change in combination of feed ingredients when the rejection level changes in this study. To be more specific, feed costs are determined by prices of ingredients and quantities of ingredients formulated in the ration. However, since feed ingredient prices are expected values when the LCRM is estimated, variables that change among those rejection levels are the quantities of feed ingredients. In other words, standard deviations of mean feed costs and feed cost savings depend on the way in which the quantities of feed ingredients in rations change. For standard deviations associated with mean feed costs, it is noticed that the combination of feed ingredients in rations obtained from LCRM over time tends to be more stable at a higher rejection level. This is because nutrient content levels are so high that fewer feed ingredients are needed and, therefore, change in feed ingredient prices does not significantly affect ration results. As a result, the amounts of feed ingredients used in rations at a higher rejection level do not change a lot, so the standard deviations of mean feed costs decrease when the rejection level increases. In addition, since feed cost saving is the difference between baseline feed costs and costs from the NIRS models, and feed ingredient prices are the same for both the baseline and the NIRS models (in the same time period), standard deviations associated with feed cost savings depend on the difference in quantities of feed ingredients in rations of the baseline and NIRS models. When the rejection level goes up, fewer feed ingredients are used in the rations from NIRS models. The differences between quantities of feed ingredients in rations of the baseline model and NIRS model, therefore, become bigger and so the standard deviations of mean feed cost saving also become bigger.

From the cost side, the daily per animal NIRS adoption cost also increases when the rejection level goes up. It is $0.014 at the 5% rejection level, and goes up to $0.024 at the 50% rejection level. The percentage increase is 71.43% from the 5% to 50% rejection level, but the increases between two adjacent rejection levels are gradual. As discussed in Chapter 4, the NIRS adoption cost is a unit cost. It is fixed for every NIRS test in this study. However, when the rejection level increases, more feed ingredients are tested since more feed ingredients are rejected by NIRS and sufficient amounts of feed ingredients are needed for a feeding operation. The total cost of NIRS testing and the daily adoption cost per animal are therefore higher at a higher rejection level. The NIRS adoption cost at a daily per animal unit is therefore higher when the rejection level goes up.

A twenty-year NPV is calculated for each rejection level, assuming an 8% discount rate. The mean NPVs per head are $148.73, $465.22, $735.35, $980.69, and $1328.62 for rejection levels of 5%, 15%, 25%, 35%, and 50%, respectively. All the NPVs are positive, which suggests that adopting NIRS in the Alberta dairy industry would be profitable. The mean NPV per head shows an increasing trend when the rejection level goes up. This indicates that although feed cost savings and NIRS adoption costs are both growing while the rejection level is increasing, the growth in benefits can still cover the growth in costs. However, although the rejection level goes up ten times from 5% to 50%, the NPV at the 50% rejection level is slightly smaller than ten times of NPV at the 5% rejection level. This is due mainly to the fact that the combinations of feed ingredients in rations from NIRS models are different for each rejection level. This may result in varying degrees of improvement in NPV. In addition, the mean NPVs per head are larger than their associated standard deviations. The standard deviation of mean NPV per head is only $2.45 at the 5% rejection level while the largest standard deviation is $11.82 at the 50% rejection level. This indicates that the likelihood of a negative NPV under scenario 1 is very low. Conversely, when the mean NPV is smaller than its associated standard deviation, the likelihood of a negative NPV is higher. This situation happens only under scenario 2, and a detailed discussion is provided in the section describing scenario 2. Meanwhile, in relative terms (i.e., coefficient of variation[17]), the mean NPV per head has lower variability at a higher rejection level. A possible reason is that the combinations of feed

[17] Coefficient of variation is a measure of dispersion for a probability distribution, which is also used in Appendix A. It is defined as the ratio of the standard deviation to the mean of the distribution. A smaller coefficient of variation indicates lower variability relative to the mean. See Appendix A for an application.

ingredients in rations are more stable at a higher rejection level. For example, when they are less stable over time (i.e., 50% rejection level under scenario 4 and 6), the variability of NPV does increase.

5.2 Scenario Results for the Backgrounding Beef Cattle Industry in Alberta

As described in Chapters 2 and 4, lightweight calves are sent into backgrounding farms at a weight of 250kg and need to meet a target weight of 475kg. Two scenarios are discussed for backgrounding beef cattle; an ADG of 0.80kg (scenario 2), and an ADG of 1.22kg (scenario 3). Lightweight calves spend 281 days and 184 days in backgrounding farms under scenarios 2 and 3, respectively.

5.2.1 Scenario 2 - Backgrounding Lightweight Calves (ADG=0.80kg)

In this scenario, a baseline model and five NIRS models are estimated for backgrounding lightweight calves in Alberta with an ADG of 0.80 kg. For this and all following scenarios for the beef cattle industry (scenarios 2-7), baseline model results regarding rations were reviewed using expert opinion (Gibb, 2013) to ensure the results generated from LCRM were typical of rations used to feed beef cattle in Alberta. Mean and standard deviation values of NPVs from baseline and NIRS models are compared and reported in table 5.2.

Table 5.2 Scenario 2 results: backgrounding lightweight calves (ADG=0.80kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$0.820	$0.816	$0.805	$0.796	$0.788	$0.775
Standard Deviation	$0.002	$0.002	$0.001	$0.001	$0.001	$0.002
Mean feed cost saving		$0.004	$0.015	$0.024	$0.032	$0.045
Standard Deviation		$0.001	$0.001	$0.001	$0.001	$0.002
% change of feed cost		0.49%	1.83%	2.93%	3.90%	5.49%
Cost[a]						
NIRS adoption cost		$0.004	$0.003	$0.004	$0.004	$0.005
Net present value[b]						
Mean NPV per head		$1.73	$34.22	$58.87	$81.33	$114.93
Standard Deviation		$2.29	$4.20	$4.25	$4.23	$6.78

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

The mean feed cost per head per day is $0.82 for the baseline model, while the mean feed costs for the NIRS models decrease from $0.82 per head per day at the 5% rejection level to $0.78 per head per day at the 50% rejection level. The mean feed cost savings are $0.004, $0.015, $0.024, $0.032, and $0.045 per head per day at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. The change in feed cost increases from 0.49% at the 5% rejection level to 5.49% at the 50% rejection level. Similar to the situation in the dairy cow scenario, the mean feed cost savings increase when the rejection level increases. However, the percentage changes of feed costs under scenario 2 are only half of the percentage changes under the dairy cow scenario. These results suggest that NIRS potentially can save more feed costs in the dairy industry than the backgrounding industry. The main reason for this difference is that the quantity of the total daily ration for backgrounding cattle is only one third of the total daily ration for dairy cattle. Another contributing factor is that more feed grains are used in the daily ration for dairy cattle, and feed grains are usually more expensive than other ingredients in the ration, which amplifies the feed cost savings effect of NIRS.

The standard deviations associated with the mean feed costs decline slightly when the rejection level goes from 5% to 15%, and stay at $0.001 per head per day until the 35% rejection level. The standard deviation at the 50% rejection level increases to $0.002 per head per day again. According to the NIRS model results at the 50% rejection level, it is mainly because the rations obtained from the LCRM are changing over time. The LCRM-determined ration contains oats, alfalfa hay and straw for the first 6 years in the NIRS model, but in the fourth quarter of the sixth year, oats are replaced by barley. Although barley contains a slightly higher nutrient content than oats (i.e., energy, total digestible nutrients, etc.), the simulated barley price is initially $0.04/kg more expensive than the simulated oats price in the LCRM. The price difference narrows in the first six years, then the barley price remains only $0.01/kg more expensive than the oats price after the sixth year. Based on the LCRM results, it can be concluded that using barley after the sixth year is more cost-effective than using oats in NIRS models. Although the quantities of alfalfa hay and straw in the rations after the sixth year remain at almost the same level, the change in the main feed grain in the ration still causes a larger variation in mean feed costs.

From the cost side, the NIRS adoption cost is $0.004 per head per day at the 5%, 25%, and 35% rejection levels, $0.003 per head per day at the 15% rejection level, and $0.005 per head per day at the 50% rejection level. The reason for the increasing adoption cost is the same as in the dairy cow scenario; that is, more feed ingredients are tested when the rejection level goes up. However, it is also noted that the increasing trend is not as substantial as it was for the dairy cow scenario. One reason is the fact that the quantity of the beef cattle ration is only about one third of the quantity of the dairy cattle ration in this study. This results in a more gradual increasing trend in adoption cost under the beef cattle scenarios. Additionally, the adoption cost actually decreases at the 15% rejection level, and starts to increase at the 25% rejection level. According to the LCRM results at this level, the decrease in adoption cost at the 15% rejection level compared with the 5% rejection level is because the total weight of feed ingredients tested by the NIRS machine at the 15% rejection level is smaller than the total weight of feed ingredients tested at the 5% rejection level. According to table 4.8, the moisture of barley silage is higher than for any other feed ingredients (dry matter level is the lowest). Due to its high moisture level, barley silage makes the weight of the ration at the 5% rejection level heavier than at the 15% level, while the amounts of other feed ingredients are almost the same at the 5% and 15% rejection levels. Since the estimation of the NIRS adoption cost is based on the weight of feed ingredients, a heavier ration eventually increases the adoption cost. On the other hand, although there is no barley silage in rations at 25% and larger rejection levels, a higher rejection level leads to more feed ingredients being tested, which increases the NIRS adoption cost at those rejection levels.

The mean NPV per head is $1.73, $34.22, $58.87, $81.33, and $114.93 at the 5%, 15%, 25%, 35%, and 50% rejection level, respectively. As expected, all the mean NPVs are positive, which suggests it is advisable to introduce NIRS technology to the backgrounding beef cattle industry under this scenario. Unlike in the dairy cow scenario, the mean NPV value increases over ten times from the 5% rejection level to the 50% rejection level. Meanwhile, the range of the associated standard deviations is also narrower than the range of standard deviations under the dairy cow scenario. It is $2.29, $4.20, $4.25, $4.23, and $6.78 for the rejection levels at 5%, 15%, 25%, 35%, and 50%, respectively. It is noted that the standard deviation of the mean NPV per head ($2.29) at the 5% rejection level is larger than the mean NPV per head ($1.73). There is a larger variation of the mean NPV per head and a high likelihood of getting a negative NPV at the 5% rejection level under this scenario due to the fact that the feed cost saving is not large enough to cover the NIRS adoption cost. However, since the mean NPV per head at this level is still positive, the conclusion about the benefit of adopting NIRS technology remains the same.

5.2.2 Scenario 3 - Backgrounding Lightweight Calves (ADG=1.22kg)

In this scenario, a baseline model and five NIRS models are estimated for backgrounding lightweight calves in Alberta that have an ADG of 1.22 kg. Mean and standard deviation values of NPVs from these baseline and NIRS models are compared and reported in table 5.3.

Table 5.3 Scenario 3 results: backgrounding lightweight calves (ADG=1.22kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$1.090	$1.077	$1.058	$1.041	$1.025	$1.002
Standard Deviation	$0.006	$0.006	$0.006	$0.006	$0.005	$0.005
Mean feed cost saving		$0.013	$0.032	$0.049	$0.064	$0.088
Standard Deviation		$0.000	$0.001	$0.001	$0.001	$0.002
% change of feed cost		1.19%	2.94%	4.50%	5.87%	8.07%
Cost[a]						
NIRS adoption cost		$0.003	$0.003	$0.004	$0.004	$0.005
Net present value[b]						
Mean NPV per head		$19.21	$54.80	$85.83	$114.54	$156.17
Standard Deviation		$1.00	$1.98	$2.37	$3.05	$3.64

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

Compared with the results of scenario 2, the results of scenario 3 in terms of mean feed costs, mean feed cost savings, percentage changes of feed costs, as well as NPVs, are all substantially larger. The mean feed cost in the baseline model is $1.090 per head per day, while mean feed costs in the NIRS model are $1.08, $1.06, $1.04, $1.03, and $1.00 per head per day at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. In addition, the mean feed cost savings are $0.013, $0.032, $0.049, $0.064, and $0.088 per head per day at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. The changes in feed costs vary from 1.193% to 8.073% under the rejection levels from 5% to 50%. However, since the maximum dry matter intake (DMI) under scenarios 2 and 3 are close, the NIRS adoption costs for these two scenarios are almost the same. It varies from $0.003 to $0.005 per head per day under this scenario.

As in previous scenarios, the standard deviations associated with mean feed costs show a declining trend from $0.006 to $0.005 per head per day while the rejection level is increasing. However, these standard deviations are larger under scenario 3 than under scenario 2, which means more variations happen in mean feed costs under scenario 3. These variations occur due to the changes in the rations that are determined from LCRM. The ADG is larger under scenario 3 than under scenario 2. The nutrient requirements under scenario 3 are accordingly higher than under the previous scenario, especially for energy. For example, net energy for growth increases from 5.64 MCal/kg to 7.54 MCal/kg when the ADG goes up from 0.80 kg (scenario 2) to 1.22 kg (scenario 3). In order to meet the increased nutrient requirements within the maximum allowable DMI level, ration results from the LCRM need to contain more feed ingredients that have higher nutrient content. Such high nutrient content feed ingredients also have a more expensive price. That is the reason why the mean feed costs under scenario 3 are all higher than the costs under scenario 2. Additionally, since more feed ingredients with higher nutrient contents and higher prices are involved in the ration, the feed cost savings effect of NIRS is larger. Hence, larger feed cost savings and percentage changes of feed cost are observed under scenario 3 compared to the results under scenario 2.

The mean NPV per head are $19.21, $54.80, $85.83, $114.54, and $156.17 at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. Since these are all positive values, this scenario indicates that it is advisable to introduce NIRS technology to the backgrounding beef cattle industry. These results are also higher than the mean NPV per head at the same rejection levels under scenario 2, because the feed cost savings are higher while the NIRS adoption costs remain the same. Furthermore, the associated standard deviations of the mean NPV per head vary from $1.00 to $3.64 per head, which are all relatively smaller than the mean NPVs per head. Hence, the likelihood of getting negative NPVs under this scenario is very low.

5.3 Scenario Results for the Finishing Beef Cattle Industry in Alberta

As described in Chapters 2 and 4, after lightweight calves reach the weight of 475 kg on backgrounding farms, they are then sent to feedlots to be finished-- that is, to reach the a target weight of 635 kg. Two scenarios are discussed for finishing lightweight beef cattle: scenario 4 has as its goal an ADG of 1.53 kg, while scenario 5 aims for an ADG of 1.91 kg. Lightweight calves spend 105 days and 84 days in feedlots under scenarios 4 and 5, respectively. On the other hand, heavyweight calves (350 kg) are sent into feedlots to reach a target weight of 590 kg directly after cow-calf operations. Two scenarios are also discussed for finishing heavyweight beef cattle: scenario 6 has as its goal an ADG of 1.46 kg, and scenario 7 has an ADG of 1.81 kg. Heavyweight calves spend 164 days and 133 days in feedlots under scenarios 6 and 7, respectively.

5.3.1 Scenario 4 - Finishing Lightweight Calves (ADG=1.53kg)

In this scenario, a baseline model and five NIRS models are solved for finishing lightweight calves that have an ADG of 1.53 kg in Alberta. Representative beef cattle are sent into feedlots after reaching the target weight of 475 kg in backgrounding farms. Mean and standard deviation values of NPVs from baseline and NIRS models are compared and reported in table 5.4.

Table 5.4 Scenario 4 results: finishing lightweight calves (ADG=1.53kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$1.875	$1.862	$1.840	$1.821	$1.803	$1.775
Standard Deviation	$0.012	$0.012	$0.012	$0.012	$0.012	$0.016
Mean feed cost saving		$0.013	$0.035	$0.054	$0.072	$0.100
Standard Deviation		$0.000	$0.000	$0.000	$0.000	$0.015
% change of feed cost		0.69%	1.87%	2.88%	3.84%	5.33%
Cost[a]						
NIRS adoption cost		$0.005	$0.006	$0.006	$0.007	$0.009
Net present value[b]						
Mean NPV per head		$8.43	$30.95	$50.78	$69.26	$96.57
Standard Deviation		$0.07	$0.19	$0.30	$0.40	$11.07

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

The mean feed cost is $1.88 per head per day in the baseline model. In the NIRS models, mean feed costs decrease from $1.86 per head per day at the 5% rejection level to $1.78 per head per day at the 50% rejection level. The mean feed cost savings rise when the rejection level goes up. They are $0.013, $0.035, $0.054, $0.072, and $0.100 per head per day at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. The mean feed cost savings are greater than the feed cost savings achieved under the backgrounding cattle scenarios, yet they are still less than the feed cost savings for the dairy cattle scenario. This is because the total amount of ration under the finishing cattle scenarios is greater than in the backgrounding cattle scenarios, and less than in the dairy cattle scenario. As stated earlier, a larger amount of ration leads to a higher feed cost and amplifies the feed cost savings effect of NIRS. Additionally, the feed cost is increasing from 0.69% at the 5% rejection level to 5.33% at the 50% rejection level.

The associated standard deviations are constant at $0.012 per head per day before the rejection level reaches 50%. With a rejection level of 50%, the standard deviation of the mean feed cost increases to $0.016 per head per day. The increased standard deviation is because the ration obtained from LCRM changes from an oats-based ration to a barley-based one at the 50% rejection level. This situation is not observed at other rejection levels. Barley has higher nutrient content and is more expensive than oats. Hence, the change from an oats-based ration to a barley-based one causes a slightly wider range of feed costs at the 50% rejection level. Likewise, the standard deviations of the mean feed cost saving are zero until the rejection level gets to 50%, where it becomes $0.015 per head per day.

From the cost perspective, NIRS adoption costs increase from $0.005 per head per day at the 5% rejection level to $0.009 per head per day at the 50% rejection level. The NIRS adoption costs under this scenario are almost twice the costs under the backgrounding cattle scenarios. This is because the maximum DMI under this scenario is 11.57 kg per head per day while it is 7.30 kg per head per day under scenario 2 and 7.12 kg per head per day under scenario 3. More feed ingredients need to be tested under scenario 3 and the adoption costs are therefore higher than for the backgrounding cattle scenarios.

The mean NPV per head for twenty years increases from $8.43 at the 5% rejection level to $96.57 at the 50% rejection level. These results are smaller than the mean NPVs per head achieved under the dairy and backgrounding cattle scenarios, except for the mean NPV per head at the 5% rejection level which is larger than the corresponding value under scenario 2. All of the NPVs are positive, which means that cattle farm operators under this scenario can earn higher profits by adopting the NIRS machine. Like the results from other scenarios, the associated standard deviations increase when the rejection level goes up. At rejection levels of 5% to 35%, those standard deviations of NPV per head varied from $0.07 to $0.40. These are smaller than the standard deviations under other scenarios. However, the standard deviation increases to $11.07 at the 50% rejection level, which is larger than the corresponding values under the backgrouding cattle scenarios. This is mainly because the ration obtained from LCRM has changed from an oats-based ration to a barley-based one under this high rejection level. The change of ration is caused by the increased nutrient requirements and the change of feed ingredient prices. As a result, the 50% rejection level has a wider range of mean feed cost savings and mean NPV per head, which means there is a larger variation associated with those values. However, it is still relatively smaller than the mean NPV itself, which means there is no significant risk of Alberta beef cattle finishing farm operators having a negative NPV under this scenario.

5.3.2 Scenario 5 - Finishing Lightweight Calves (ADG=1.91kg)

In this scenario, a baseline model and five NIRS models are solved for finishing lightweight calves that have an ADG of 1.91 kg in Alberta. Representative beef cattle are sent into feedlots after reaching the target weight of 475 kg in backgrounding farms. Mean and standard deviation values of NPVs from the baseline and NIRS models are compared and reported in table 5.5.

Table 5.5 Scenario 5 results: finishing lightweight calves (ADG=1.91kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$2.226	$2.199	$2.154	$2.116	$2.082	$2.033
Standard Deviation	$0.022	$0.021	$0.021	$0.020	$0.019	$0.019
Mean feed cost saving		$0.028	$0.072	$0.111	$0.144	$0.194
Standard Deviation		$0.001	$0.003	$0.005	$0.005	$0.006
% change of feed cost		1.26%	3.24%	4.99%	6.47%	8.72%
Cost[a]						
NIRS adoption cost		$0.005	$0.006	$0.006	$0.007	$0.009
Net present value[b]						
Mean NPV per head		$21.40	$62.11	$96.95	$125.50	$166.39
Standard Deviation		$1.73	$4.13	$6.39	$6.87	$7.49

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

As with the backgrounding scenarios, the results for finishing lightweight calves in terms of mean feed costs, mean feed cost savings, percentage changes of feed costs, as well as NPVs are all substantially larger under scenario 5 when compared with the results under scenario 4. The mean feed cost in the baseline model is $2.23 per head per day, which is 18.72% higher than the value from scenario 4. Although the ADG is higher under scenario 5 than scenario 4, the maximum DMI is 10.93kg per head per day, which is lower than the maximum DMI of 11.57kg per head per day under scenario 4. Therefore, the higher mean feed cost under scenario 5 is because rations obtained from LCRM contain more feed ingredients that have higher nutrient content, such as barley and wheat. At the same time, feed ingredients with higher nutrient content normally have more expensive prices, which leads to a higher mean feed cost. The situation is comparable to the difference in mean feed costs for scenarios 2 and 3 for backgrounding cattle farms.

As with the previous scenarios, when the rejection level goes up, the mean feed cost declines from $2.199 per head per day at the 5% rejection level to $2.033 per head per day at the 50% rejection level. The associated standard deviations also decrease slightly from $0.022 per head per day at the baseline model to $0.019 per head per day at the 50% rejection level. The mean feed cost savings and their associated standard deviations both increase in this scenario. The mean feed cost savings are $0.028, $0.072, $0.111, $0.144, and $0.194 per head per day as rejection levels increase from 5% to 50%. Accordingly, the savings in feed costs increase from 1.26% at the 5% rejection level to 8.72% at the 50% rejection level. On the other hand, the NIRS adoption costs under scenario 5 are the same as the adoption costs under scenario 4.

Twenty-year NPVs are then calculated for scenario 5. The mean NPVs per head are $21.40, $62.11, $96.95, $125.50, and $166.39 at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. The associated standard deviations also show an increasing trend from $1.73 per head to $7.49 per head. All the NPVs under this scenario are positive, which means finishing cattle farm operators should adopt NIRS technology for their feeding operations.

5.3.3 Scenario 6 - Finishing Heavyweight Calves (ADG=1.46kg)

In this scenario, a baseline model and five NIRS models are solved for finishing heavyweight calves that have an ADG of 1.46 kg in Alberta. Representative beef cattle are sent into feedlots directly from cow-calf farms at a weight of 350 kg. Mean and standard deviation values of NPVs from the baseline and NIRS models are compared and reported in table 5.6.

Table 5.6 Scenario 6 results: finishing heavyweight calves (ADG=1.46kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$1.500	$1.489	$1.472	$1.457	$1.442	$1.420
Standard Deviation	$0.009	$0.009	$0.009	$0.009	$0.009	$0.009
Mean feed cost saving		$0.010	$0.028	$0.043	$0.058	$0.080
Standard Deviation		$0.000	$0.000	$0.000	$0.000	$0.007
% change of feed cost		0.67%	1.87%	2.87%	3.87%	5.33%
Cost[a]						
NIRS adoption cost		$0.004	$0.004	$0.005	$0.006	$0.007
Net present value[b]						
Mean NPV per head		$10.54	$38.67	$63.48	$86.62	$120.61
Standard Deviation		$0.09	$0.23	$0.36	$0.49	$8.01

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

The mean feed cost decreases from $1.500 per head per day in the baseline model to $1.420 per head per day at the 50% rejection level, while the standard deviations remain unchanged at the level of $0.009 per head per day. The mean feed costs are lower than the corresponding values under scenarios 4 and 5 because, according to table 4.7, heavyweight calves have a lower nutrient requirement than lightweight calves for the finishing cattle operation under the scenarios for this study.

Likewise, the mean feed cost savings are also lower than in the previous finishing cattle scenarios. They are $0.010, $0.028, $0.043, $0.058, and $0.080 per head per day at the 5%, 15%, 25%, 35%, and 50% rejection levels, respectively. The associated standard deviations for the mean feed cost savings are zero at rejection levels of 5% to 35%. This figure reaches $0.007 per head per day at the 50% rejection level. As in the previous scenarios, the sudden increase in standard deviation is due to the change in rations obtained from LCRM at the 50% rejection level. The ration is initially oats-based but then becomes barley-oats-based. This change in the ration causes a wider range of feed cost savings at this rejection level. The changes of feed costs are 0.67%, 1.87%, 2.87%, 3.87%, and 5.33% at the different rejection levels. From the cost side, the NIRS adoption cost shows an increasing trend from $0.004 per head per day to $0.007 per head per day when the rejection level goes up.

An 8% discount rate is used to calculate a twenty-year NPV for each rejection level. The mean NPV per head is $10.54, $38.67, $63.48, $86.62, and $120.61 at rejection levels from 5% to 50%. The associated standard deviation increases slightly from $0.09 per head at 5% to $0.49 per head at the 35% rejection level and increases even more to $8.01 per head at the 50% rejection level, which means that a bigger variation is associated with the mean NPV per head at this rejection level. This trend is also due to the change in the ration at this rejection level. Since all the NPVs are positive under this scenario, finishing cattle farm operators should adopt the NIRS technology for their feeding operations.

However, the twenty-year NPV that operators potentially can get from the adoption of NIRS technology has a wider range due to the larger standard deviation associated with the NPV.

5.3.4 Scenario 7 - Finishing Heavyweight Calves (ADG=1.81kg)

In this scenario, a baseline model and five NIRS models are solved for finishing heavyweight calves that have an ADG of 1.81 kg in Alberta. Representative beef cattle are sent into feedlots directly from cow-calf farms at a weight of 350 kg. Mean and standard deviation values of NPVs from the baseline and NIRS models are compared and reported in table 5.7.

Table 5.7 Scenario 7 results: finishing heavyweight claves (ADG=1.81kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$1.817	$1.787	$1.739	$1.695	$1.667	$1.628
Standard Deviation	$0.017	$0.017	$0.016	$0.016	$0.016	$0.015
Mean feed cost saving		$0.030	$0.079	$0.122	$0.150	$0.189
Standard Deviation		$0.001	$0.003	$0.004	$0.005	$0.005
% change of feed cost		1.65%	4.35%	6.71%	8.26%	10.40%
Cost[a]						
NIRS adoption cost		$0.004	$0.004	$0.005	$0.006	$0.008
Net present value[b]						
Mean NPV per head		$37.35	$106.85	$166.58	$205.03	$257.03
Standard Deviation		$2.64	$6.64	$9.54	$9.87	$10.55

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

With a higher nutrient requirement, a higher feed cost is generated for scenario 7 than for scenario 6. However, those mean feed costs are still smaller than they are for the finishing lightweight cattle scenarios. It is $1.82 per head per day for the baseline model, and declines from $1.79 per head per day at the 5% rejection level to $1.63 per head per day at the 50% rejection level for the NIRS models. A decreasing trend in standard deviation for the feed cost from $0.017 to $0.015 per head per day is noted. Additionally, a higher mean feed cost saving is generated under this scenario than for scenario 6; $0.030, $0.079, $0.122, $0.150, and $0.189 per head per day at rejection levels from 5% to 50%. The associated standard deviations increase slightly from $0.001 per head per day to $0.005 per head per day when the rejection level goes up. The percentage changes in feed costs are larger than for the other finishing cattle scenarios. They rise from 1.65% at the 5% rejection level to 10.40% at the 50% rejection level. The main reason is that rations under scenario 7 are mostly barley and wheat based, while rations for the other finishing cattle scenarios are mostly oats-based. Meanwhile, according to table 4.13, the mean prices of barley and wheat are both higher than the mean price of oats. It is noted that involving more feed ingredients with higher prices in the ration potentially can result in a bigger feed cost saving. For example, when the same amounts of feed ingredients are saved, a higher feed ingredient price leads to a bigger feed cost saving. On the cost side, the NIRS adoption costs remain at the same level as in the other finishing cattle scenarios. This cost is $0.004 per head per day at the 5% rejection level, and increases to $0.008 per head per day at the 50% rejection level.

The mean NPVs per head are $37.35, $106.85, $166.58, $205.03, and $257.03 at rejection levels from 5% to 50%. A relatively small standard deviation is associated with the corresponding mean NPV per head under this scenario, which rises from $2.64 per head to $10.55 per head when the rejection level goes up. It is noted that not only are all the mean NPVs per head under this scenario positive, but also that they are larger than the values under other finishing cattle scenarios due to the barley-wheat composition of the ration under this scenario. As a result, finishing beef cattle farm operators under this scenario should adopt NIRS technology for their feeding operations.

5.4 Results for Alberta and Western Canada

Using the numbers of cattle reported in table 4.22 and the mean NPVs per head reported in the previous sections in this chapter, the aggregate NPV results at various rejection levels for Alberta and western Canada are calculated and reported in table 5.8.

Table 5.8 Aggregate net present value results for Alberta and western Canada (millions of dollar)

	NIRS model (rejection level)				
	5%	15%	25%	35%	50%
Alberta					
Dairy					
Mean NPV for western Canada	$11.96	$37.40	$59.12	$79.85	$106.82
Standard Deviation	$0.20	$0.38	$0.56	$0.71	$0.95
Backgrounding (ADG=0.80kg)[a]					
Mean NPV for western Canada	$1.93	$38.24	$65.78	$90.87	$128.42
Standard Deviation	$2.55	$4.70	$4.75	$4.73	$7.57
Backgrounding (ADG=1.22kg)[a]					
Mean NPV for western Canada	$21.46	$61.22	$95.90	$127.98	$174.49
Standard Deviation	$1.11	$2.21	$2.65	$3.41	$4.07
Finishing (ADG=1.53kg)[b]					
Mean NPV for western Canada	$5.53	$20.30	$33.31	$45.44	$63.35
Standard Deviation	$0.05	$0.12	$0.19	$0.26	$7.26
Finishing (ADG=1.91kg)[b]					
Mean NPV for western Canada	$14.04	$40.74	$63.60	$82.33	$109.15
Standard Deviation	$1.14	$2.71	$4.19	$4.50	$4.91
Finishing (ADG=1.46kg)[c]					
Mean NPV for western Canada	$2.54	$9.34	$15.33	$20.92	$29.13
Standard Deviation	$0.02	$0.06	$0.09	$0.12	$1.93
Finishing (ADG=1.81kg)[c]					
Mean NPV for western Canada	$9.02	$25.80	$40.23	$49.51	$62.07
Standard Deviation	$0.64	$1.60	$2.30	$2.38	$2.55
western Canada					
Dairy					
Mean NPV for western Canada	$33.64	$105.23	$166.34	$221.83	$300.53
Standard Deviation	$0.55	$1.03	$1.50	$1.95	$2.58
Backgrounding (ADG=0.80kg)[a]					
Mean NPV for western Canada	$2.68	$52.97	$91.12	$125.89	$177.91
Standard Deviation	$3.62	$6.57	$6.65	$6.61	$10.21
Backgrounding (ADG=1.22kg)[a]					
Mean NPV for western Canada	$29.74	$84.82	$132.86	$177.30	$241.74
Standard Deviation	$1.56	$2.94	$3.53	$4.64	$5.55
Finishing (ADG=1.53kg)[b]					
Mean NPV for western Canada	$6.53	$23.97	$39.33	$53.64	$74.79
Standard Deviation	$0.05	$0.14	$0.22	$0.30	$9.26
Finishing (ADG=1.91kg)[b]					
Mean NPV for western Canada	$16.58	$48.12	$75.12	$97.21	$128.88
Standard Deviation	$1.31	$2.93	$4.67	$5.09	$5.52
Finishing (ADG=1.46kg)[c]					
Mean NPV for western Canada	$3.39	$12.45	$20.44	$27.89	$38.84
Standard Deviation	$0.03	$0.08	$0.12	$0.16	$2.68
Finishing (ADG=1.81kg)[c]					
Mean NPV for western Canada	$12.03	$34.41	$53.64	$66.02	$82.76
Standard Deviation	$0.85	$2.13	$3.06	$3.16	$3.38

[a] Lightweight beef cattle in the backgrounding phase
[b] Lightweight beef cattle in the finishing phase
[c] Heavyweight beef cattle directly enter into the finishing phase

According to table 5.8, all twenty-year NPVs are positive, which means that there are positive net benefits for dairy and beef cattle operators in Alberta and western Canada associated with adopting NIRS technology for their feeding operations. Similar to the previous cow level dairy results, the mean NPVs and standard deviations increase as the rejection level goes up for the dairy industry in Alberta and western Canada. Additionally, when compared with the beef cattle industry, the dairy industry can get greater benefit from adopting NIRS technology and the standard deviations associated with NPVs are smaller. This is mainly because the rations within the same rejection levels are more stable for dairy than for beef cattle.

More specifically, mean NPVs for the Alberta dairy industry vary from $11.96 million to $106.82 million, while they vary from $33.64 million to $300.53 million for western Canada. For the backgrounding beef cattle sector, the mean NPVs for Alberta vary between $1.93 million to $174.49 million, while they vary from $2.68 million to $241.74 million for western Canada. For the finishing beef cattle sector, the mean NPVs in Alberta vary from $5.53 million to $109.15 million, while they are between $6.53 million to $128.88 million for western Canada.

The highest beef NPVs were for backgrounding lightweight beef cattle with an ADG of 1.22kg. The other backgrounding cattle scenario also has higher NPVs than all the finishing cattle scenarios except the at 5% rejection level. For the finishing beef cattle industry in Alberta and in western Canada, the lightweight sector gains greater benefits than the heavyweight beef cattle sector. In addition, a higher ADG leads to a higher NPV result in the same sector. This is mainly because a higher ADG normally necessitates a higher nutrient requirement, which often leads to a ration containing feed ingredients that have high nutrient content and high prices. Since the per unit feed ingredient saving is associated with more value, it results in higher feed cost savings for high ADG scenarios when the saved amount of rations are small and close at the same rejection level within the same sector. However, the NIRS adoption costs remain at almost the same level since the total amount of ration does not change significantly. Thus, NPVs are often higher with a high ADG in the beef sector in Alberta and western Canada.

5.5 Results of Sensitivity Analysis

In order to test whether or not a change in key elements can bring significant changes to the final results, sensitivity analyses are undertaken. Three elements are tested in this study: the price of barley, the NIRS adoption cost, and the discount rate. First, barley is the most commonly used feed grain for both dairy and beef cattle feeding operations in Alberta and western Canada. Additionally, a price change for feed ingredients can affect LCRM results regarding which feed ingredient is used in the ration, and eventually affect feed costs and feed cost savings. Second, the NIRS adoption cost is the only direct cost of adoption in this study, and it includes capital costs, labour costs, calibration costs, and maintenance costs. Thus, a change of adoption cost can directly affect the NPV result. Last, since NPV analysis is adopted in this study, a moderate 8% private discount rate is chosen based on recent literature reviews (Koeckhoven, 2008; Dollevoet, 2010; Cairns and Meilke, 2012; Anderson and Weersink, 2013; Khakbazan et al., 2013). However, those studies indicate a range of discount rate between 6% and 10%. Hence, sensitivity analysis regarding the discount rate is necessary in order to evaluate the impact of choosing another discount rate on the NPV result in this study.

Five specific sensitivity analysis scenarios are solved in this study. A 10% increase in barley price is assumed for scenario 7, finishing heavyweight calves with an ADG=1.81kg. Both a 10% increase and decrease of NIRS adoption cost is included for all seven NIRS scenarios. Lastly, both 6% and 10% discount rates are also applied to all seven scenarios. Thus, three categories of sensitivity analyses mentioned above are examined individually, and the results are reported and discussed in the following sections.

5.5.1 Price Increase in Barley

Changes in feed grain prices have a most significant impact on livestock feeding operations. Feed grain prices are not only important parameters in LCRM to determine optimal rations, but they are also the largest cost component in a feeding operation. In addition, as mentioned in Chapter 2, Canadian dairy and beef cattle operations commonly use barley-based rations. It has also been shown in this study that almost all the rations obtained from the LCRM contain barley as the main feed ingredient. Therefore, in order to examine the impact of the changes in feed prices, especially the price increase in the main feed ingredient, it is assumed there is a 10% increase in barley price under scenario 7 (finishing heavyweight calves, ADG=1.81kg). The sensitivity analyses results of the increasing barley price are reported in table 5.9.

Table 5.9 Sensitivity analysis results: a 10% increase of barley price for finishing heavyweight calves (ADG=1.81kg)

	Baseline	NIRS (rejection level)				
		5%	15%	25%	35%	50%
Benefit[a]						
Mean feed cost	$1.883	$1.841	$1.773	$1.718	$1.687	$1.647
% change from original	3.63%	3.02%	1.96%	1.36%	1.20%	1.17%
Standard Deviation	$0.013	$0.016	$0.015	$0.016	$0.015	$0.014
Mean feed cost saving		$0.042	$0.110	$0.164	$0.196	$0.236
% change from original		40.00%	39.24%	34.43%	30.67%	24.87%
Standard Deviation		$0.006	$0.003	$0.004	$0.004	$0.004
Cost[a]						
NIRS adoption cost		$0.004	$0.004	$0.005	$0.006	$0.008
Net present value[b]						
Mean NPV per head		$52.29	$146.90	$222.54	$265.53	$322.30
% change from original		40.00%	37.48%	33.59%	29.51%	25.39%
Standard Deviation		$6.95	$5.43	$6.72	$6.88	$6.79

[a] unit of all categories in benefit and cost is $ per head per day
[b] twenty-year net present value (NPV) unit: $

The mean feed cost in the baseline model is $1.88 per head per day, which is 3.63% higher than the value derived under scenario 7. The main reason is the higher price of barley: rations obtained from the LCRM for the baseline model squeeze out barley from the formula and use corn as a protein/energy replacement. Since corn is the most expensive feed ingredient in this study according to table 4.18, the mean feed cost at the baseline model under the sensitivity analysis scenario is higher than the value under the original scenario. Likewise, the mean feed costs of the NIRS models are also all higher than the corresponding values under scenario 7. However, the differences in mean feed costs from the NIRS models vary from 1.17% to 3.02%, which are relatively smaller than the difference at the baseline model. This is because rations obtained from LCRM are mainly comprised of wheat and barley in the NIRS models, and the original prices of wheat, oats, and barley are very close. When the price of barley increases, rations in NIRS model contain more wheat and oats to replace the barley, and feed costs do not increase very much.

After the 10% increase in the barley price, mean feed cost savings are also higher than the corresponding values under scenario 7. The mean feed cost saving shows an increasing trend from $0.042 per head per day at the 5% rejection level to $0.236 per head per day at the 50% rejection level, while it varies from $0.030 per head per day to $0.189 per head per day in the original scenario. The increasing feed cost savings are so substantial that the percentage change from the original values in scenario 7 varies from 40% at the 5% rejection level to 24.87% at the 50% rejection level. The reason for the big difference is the slow increase in mean feed cost in the NIRS models as compared to the mean feed cost in the baseline model under the sensitivity analysis scenario, compared with the original scenario. Hence, the differences in mean feed cost among baseline and NIRS models, the feed cost savings, are larger under this scenario. The decreasing trend of percentage change happens for feed costs, feed cost savings, and NPVs. This is because less barley is involved at the higher rejection level in scenario 7 and the sensitivity scenario. Hence, the impacts of the increase in barley price on feed costs, feed cost savings, and NPVs are smaller at the higher rejection level than at the lower rejection level.

From the cost perspective, the increase of barley price does not cause a significant change. This is mainly because the total amounts of ration obtained from the LCRM are usually close to the maximum DMI. There is not a significant difference between the original scenario and sensitivity analysis scenario for the total amount of ration. Therefore, as a unit cost, the NIRS adoption cost does not have a noticeable change on the sensitivity analysis scenario.

The mean NPV per head under the sensitivity analysis scenario rises from $52.29 at the 5% rejection level to $322.30 at the 50% rejection level. All the NPVs are positive, so the conclusion still holds that finishing beef cattle operators under the assumption of this scenario should adopt NIRS technology for their feeding operations. In addition, all the NPVs obtained under this scenario are higher than the corresponding values under scenario 7, since the mean feed cost saving discussed above are higher than in the original scenario while the NIRS adoption cost remains the same. Additionally, since NIRS adoption costs do not exhibit a noticeable change, the percentage changes in NPV are very close to the percentage changes in feed cost saving.

The mean NPV per head under the sensitivity analysis scenario is close to 40% higher than the mean NPV per head under scenario 7 at the 5% rejection level. However, when the rejection level goes up, the difference in mean NPV per head between the original scenario and the sensitivity analysis scenario narrows. For example, the difference declines from 40% at the 5% rejection level to 25.39% at the 50% rejection level. One reason to explain this is that rations at the higher rejection levels do not include barley any more, and only the 5% and 15% rejection levels have barley in the ration formula. As explained above, involving a higher nutrient content and price feed ingredient potentially can increase the mean NPV since the per unit value associated with the ration is higher, and the feed cost saving is therefore higher when the same amount of ration is saved. After the 10% increase in barley price, barley is the third most expensive feed ingredient, after corn and canola meal. When the use of barley is (generally) reduced from the levels in rations at high rejection levels, the use of relatively lower value feed ingredients, such as wheat and oats, is increased. Therefore, the degree of increase in mean NPV is reduced as the rejection level goes up. In summary, a 10%

increase of barley price can increase feed costs and feed cost savings, as well as NPVs. NPVs are still positive, so the conclusion in terms of recommending NIRS adoption is still valid with even larger NPVs. However, the change of barley price can have a moderate impact on NPVs, between 25% and 40%, especially when rations are barley-based.

5.5.2 Changes in the NIRS Adoption Cost

Using the method discussed in Chapter 4, NIRS adoption cost is estimated as a unit cost, which includes capital costs, labour costs, calibration costs, and maintenance costs. However, there is a possibility that the NIRS adoption cost will change in the future. The direction of change cannot easily be determined. Although capital costs, such as the investment in the NIRS machine, may have a declining trend consistent with most technologies, labour and maintenance costs have a potentially increasing trend. Due to the uncertainty in the NIRS adoption cost, a sensitivity analysis is performed. A 10% increase and then a 10% decrease in adoption cost are assumed and tested in this section. Sensitivity analyses results are reported in tables 5.10 and 5.11.

Table 5.10 details the mean NPVs per head after a 10% increase in the cost of adopting NIRS as estimated for seven scenarios, as well as a comparison with the results from the original scenarios. It is noted that mean NPVs per head all decrease after the increase in cost. However, they are still all positive, which means the conclusions from the original scenarios, that Alberta dairy and beef cattle operators should adopt NIRS technology for their feeding operation, remain unchanged. The percentage changes in NPVs from the original scenarios are small, mostly below 10%. This suggests that a 10% increase in NIRS adoption cost does not affect the final conclusions in this study, although the NPVs are decreased due to the higher cost. However, a significant difference occurs under the backgrounding (ADG=0.80kg) scenario at the 5% rejection level. The mean NPV per head decreases 63.01% more than in the original scenario, which produced a decrease in NPV of $1.09 per head. The main reason is because the mean NPV per head under the original scenario is small ($1.73), so the impact of the increasing NIRS adoption cost in percentage term is more significant than in the other scenarios.

Table 5.10 Sensitivity analysis results: net present values per head after a 10% increase of NIRS adoption cost

	NIRS model (rejection level)				
	5%	15%	25%	35%	50%
Dairy					
Mean NPV per head	$143.72	$459.69	$729.16	$973.62	$1,319.58
% change from original	-3.37%	-1.19%	-0.84%	-0.72%	-0.68%
Standard Deviation	$2.40	$4.54	$6.71	$8.59	$11.45
Backgrounding (ADG=0.80kg)[a]					
Mean NPV per head	$0.64	$33.27	$57.81	$80.12	$113.40
% change from original	-63.01%	-2.78%	-1.80%	-1.49%	-1.33%
Standard Deviation	$2.35	$4.24	$4.29	$4.27	$6.50
Backgrounding (ADG=1.22kg)[a]					
Mean NPV per head	$18.67	$54.20	$85.15	$113.76	$155.15
% change from original	-2.81%	-1.09%	-0.79%	-0.68%	-0.65%
Standard Deviation	$1.03	$2.02	$2.43	$3.14	$3.74
Finishing (ADG=1.53kg)[b]					
Mean NPV per head	$7.90	$30.35	$50.12	$68.51	$95.63
% change from original	-6.29%	-1.94%	-1.30%	-1.08%	-0.97%
Standard Deviation	$0.07	$0.19	$0.29	$0.39	$11.03
Finishing (ADG=1.91kg)[b]					
Mean NPV per head	$20.97	$61.64	$96.42	$124.88	$165.59
% change from original	-2.01%	-0.76%	-0.55%	-0.49%	-0.48%
Standard Deviation	$1.80	$4.28	$6.61	$6.86	$7.50
Finishing (ADG=1.46kg)[c]					
Mean NPV per head	$9.87	$37.93	$62.66	$85.68	$119.41
% change from original	-6.36%	-1.91%	-1.29%	-1.09%	-0.99%
Standard Deviation	$0.09	$0.23	$0.35	$0.48	$7.97
Finishing (ADG=1.81kg)[c]					
Mean NPV for western Canada	$36.81	$106.25	$165.90	$204.24	$256.02
% change from original	-1.45%	-0.56%	-0.41%	-0.39%	-0.39%
Standard Deviation	$2.61	$6.61	$9.48	$9.74	$10.33

[a] Lightweight beef cattle in the backgrounding phase
[b] Lightweight beef cattle in the finishing phase
[c] Heavyweight beef cattle directly enter into the finishing phase

Based on this finding, it is expected that a decreasing NIRS adoption cost should also significantly impact this scenario. Meanwhile, although the increasing NIRS adoption cost has a greater impact on high rejection levels since more feed ingredients need to be tested, the percentage changes in mean NPV decline while the rejection level goes up. This is because the changes of mean NPV per head occur faster than the increasing impact of a NIRS adoption cost variation. On the other hand, although the mean NPVs per head decline due to a higher cost, the associated standard deviations under the sensitivity analysis scenarios are almost the same as the values under the original scenarios. Since the NIRS adoption cost is a fixed unit cost under every scenario, there is no variation associated with it within each NIRS model under each scenario. Thus, the change in NIRS adoption cost cannot cause changes in standard deviations under sensitivity analysis scenarios.

The estimated mean NPVs per head after a 10% decrease in NIRS adoption cost for the seven scenarios are presented in table 5.11, and are compared with the results from the original scenarios. Similar to the impact of increasing the NIRS adoption cost, decreasing the NIRS cost does not significantly change the mean NPV per head resulting from the original scenarios. All NPVs are positive, so the conclusion that operators should adopt the NIRS technology is unchanged. As expected, since the NPV is small under the backgrounding (ADG=0.80kg) scenario at the 5% rejection level, the percentage change of mean NPV per head is 63.01%, which is more significant than in other scenarios. The mean NPV per head and its associated standard deviation under this assumption demonstrates the same trend under various rejection levels, similar to the original scenarios. Meanwhile, the percentage change of mean NPV also shows a decreasing trend when the rejection level goes up under the same scenario. Thus, changes in NPV per head are still faster than the increasing impact of a NIRS adoption cost decrease. Finally, all of the standard deviations associated with the mean NPV per head under the decreasing NIRS adoption cost scenarios are close to the values under the original scenarios and the increasing NIRS adoption cost scenarios, since the adoption cost does not bring any variation into the models. In summary, a10% increase in the NIRS adoption cost can decrease NPVs, while a10% decrease in the NIRS adoption cost does the opposite. However, the impact from the change in NIRS adoption cost on NPVs is very small and does not change the conclusion about adopting NIRS technology.

Table 5.11 Sensitivity analysis results: net present values per head after a 10% decrease of NIRS adoption cost

	NIRS model (rejection level)				
	5%	15%	25%	35%	50%
Dairy					
Mean NPV per head	$153.74	$470.74	$741.53	$987.73	$1,337.63
% change from original	3.37%	1.19%	0.84%	0.72%	0.68%
Standard Deviation	$2.38	$4.37	$6.40	$8.21	$10.89
Backgrounding (ADG=0.80kg)[a]					
Mean NPV per head	$2.82	$35.18	$59.93	$82.55	$116.48
% change from original	63.01%	2.78%	1.80%	1.49%	1.33%
Standard Deviation	$2.32	$4.24	$4.28	$4.26	$6.39
Backgrounding (ADG=1.22kg)[a]					
Mean NPV per head	$19.75	$55.40	$86.51	$115.33	$157.19
% change from original	2.81%	1.09%	0.79%	0.68%	0.65%
Standard Deviation	$1.03	$2.02	$2.41	$3.09	$3.62
Finishing (ADG=1.53kg)[b]					
Mean NPV per head	$8.97	$31.54	$51.45	$70.02	$97.53
% change from original	6.29%	1.94%	1.30%	1.08%	0.97%
Standard Deviation	$0.07	$0.19	$0.29	$0.40	$12.02
Finishing (ADG=1.91kg)[b]					
Mean NPV per head	$21.82	$62.59	$97.50	$126.12	$167.19
% change from original	2.01%	0.76%	0.55%	0.49%	0.48%
Standard Deviation	$1.80	$4.12	$6.39	$6.69	$7.30
Finishing (ADG=1.46kg)[c]					
Mean NPV per head	$11.21	$39.41	$64.31	$87.56	$121.80
% change from original	6.36%	1.91%	1.29%	1.09%	0.99%
Standard Deviation	$0.08	$0.22	$0.35	$0.47	$7.95
Finishing (ADG=1.81kg)[c]					
Mean NPV per head	$37.89	$107.45	$167.25	$205.80	$258.04
% change from original	1.45%	0.56%	0.41%	0.39%	0.39%
Standard Deviation	$2.68	$6.82	$9.79	$10.15	$10.86

[a] Lightweight beef cattle in the backgrounding phase
[b] Lightweight beef cattle in the finishing phase
[c] Heavyweight beef cattle directly enter into the finishing phase

5.5.3 Changes in Discount Rate

An 8% private discount rate is assumed for the original seven scenarios discussed earlier. It is a moderate discount rate based on a review of current literature. However, the discount rates that are used in most studies on Canadian agricultural industry fall in a range from 6% to 10% (Koeckhoven, 2008; Dollevoet, 2010; Cairns and Meilke, 2012; Anderson and Weersink, 2013; Khakbazan et al., 2013). Therefore, a sensitivity analysis is required to test the change in results caused by the choice of discount rate. As discussed in Chapter 4, a 6% and a 10% discount rate are employed, and the sensitivity analyses results are reported in table 5.12 and 5.13.

Table 5.12 Sensitivity analysis results: net present values per head using 6% discount rate

	NIRS model (rejection level)				
	5%	15%	25%	35%	50%
Dairy					
Mean NPV per head	$172.32	$539.24	$852.41	$1,136.80	$1,540.07
% change from original	15.86%	15.91%	15.92%	15.92%	15.92%
Standard Deviation	$2.66	$5.20	$7.66	$9.89	$13.11
Backgrounding (ADG=0.80kg)[a]					
Mean NPV per head	$1.63	$39.08	$67.71	$93.80	$132.96
% change from original	-5.78%	14.20%	15.02%	15.33%	15.69%
Standard Deviation	$2.41	$4.14	$4.21	$4.20	$7.67
Backgrounding (ADG=1.22kg)[a]					
Mean NPV per head	$21.99	$63.21	$99.14	$132.37	$180.52
% change from original	14.47%	15.35%	15.51%	15.57%	15.59%
Standard Deviation	$1.12	$2.19	$2.68	$3.46	$4.19
Finishing (ADG=1.53kg)[b]					
Mean NPV per head	$9.79	$35.94	$58.97	$80.44	$112.21
% change from original	16.13%	16.12%	16.13%	16.14%	16.20%
Standard Deviation	$0.07	$0.18	$0.27	$0.37	$15.15
Finishing (ADG=1.91kg)[b]					
Mean NPV per head	$24.16	$70.44	$110.12	$143.05	$190.28
% change from original	12.90%	13.41%	13.58%	13.98%	14.36%
Standard Deviation	$1.89	$4.59	$7.08	$7.39	$8.01
Finishing (ADG=1.46kg)[c]					
Mean NPV per head	$12.24	$44.90	$73.73	$100.60	$140.11
% change from original	16.13%	16.11%	16.15%	16.14%	16.17%
Standard Deviation	$0.08	$0.21	$0.33	$0.44	$10.65
Finishing (ADG=1.81kg)[c]					
Mean NPV per head	$42.47	$121.93	$190.52	$234.66	$294.71
% change from original	13.71%	14.11%	14.37%	14.45%	14.66%
Standard Deviation	$2.60	$6.61	$9.50	$9.83	$10.54

[a] Lightweight beef cattle in the backgrounding phase
[b] Lightweight beef cattle in the finishing phase
[c] Heavyweight beef cattle directly enter into the finishing phase

A smaller discount rate is expected to produce a larger mean NPV per head, since future returns or benefits are "penalized" to a lesser extent. Therefore, almost all of the NPVs reported in table 5.12 with a 6% discount rate are higher than the NPVs obtained under original scenarios. However, the mean NPV per head under the backgrounding (ADG=0.80kg) scenario at the 5% rejection level is smaller than the value under the original scenario. This is because under this scenario the costs start to exceed feed cost savings in the fourth quarter of the third year after the adoption at the 5% rejection level, which means that present values are negative from that point on. Therefore, not only are the positive present values becoming larger when the discount rate is smaller, but also the negative present values are becoming increasingly negative. In this case, although the twenty-year NPV per head is still positive, the change in discount rate has more impact on negative NPVs than on positive NPVs. Hence, the twenty-year NPV under the sensitivity analysis scenario is smaller than under the original scenario. At the same time, except in the situation mentioned above, it is noted that the percentage changes in mean NPV reported under the same scenario are similar, despite the different rejection levels, while the changes between scenarios vary in a small range from 13% to 17%. The associated standard deviations for the mean NPV per head under the sensitivity analysis scenario are also only slightly different from the values under the original scenarios. The differences are moving in either directions, and do not have a pattern within or among scenarios. Therefore, it can be concluded that although the change of discount rate can have an impact on the variation of NPV results, it is limited and does not occur in one direction only.

Similar results can be found in table 5.13, which shows the results for a 10% discount rate. All the NPVs are still positive, which means the conclusion about adopting NIRS technology is unchanged. Since the discount rate is increased for this scenario, all mean NPVs per head are smaller than the values achieved under the original scenarios. The percentage changes in mean NPV fall in a small range between -10% and -13%. However, there is an increase in NPV at the 5% rejection level for the backgrounding (ADG=0.8kg) scenario. The explanation for this change is the same as the reason mentioned above; that is, since the costs generally exceed the feed cost savings under this scenario, both positive and negative annual present values are present. Thus, a bigger discount rate not only makes the positive NPVs smaller, but also makes the negative NPVs less negative. In this case, a 10% discount rate results in the twenty-year NPV being 4.62% larger than the value under the original scenario. Meanwhile, the increase in discount rate has a limited impact on the variation of the mean NPV, since the standard deviations of the mean NPV reported in table 5.13 are close to the value under the original scenarios. In summary, choosing a 6% or a 10% discount rate can cause a 10% to 16% change in NPVs. However, it does not change the sign of NPVs, and the conclusion to adopt NIRS technology is still valid.

Table 5.13 Sensitivity analysis results: net present values per head using 10% discount rate

	NIRS model (rejection level)				
	5%	15%	25%	35%	50%
Dairy					
Mean NPV per head	$129.94	$406.26	$642.12	$856.36	$1,160.22
% change from original	-12.63%	-12.67%	-12.68%	-12.68%	-12.67%
Standard Deviation	$2.38	$4.24	$6.18	$7.93	$10.49
Backgrounding (ADG=0.80kg)[a]					
Mean NPV per head	$1.81	$30.25	$51.82	$71.39	$100.58
% change from original	4.62%	-11.60%	-11.98%	-12.22%	-12.49%
Standard Deviation	$2.23	$4.09	$4.13	$4.10	$5.95
Backgrounding (ADG=1.22kg)[a]					
Mean NPV per head	$16.99	$48.10	$75.23	$100.35	$136.77
% change from original	-11.56%	-12.23%	-12.35%	-12.39%	-12.42%
Standard Deviation	$1.02	$1.90	$2.28	$2.94	$3.51
Finishing (ADG=1.53kg)[b]					
Mean NPV per head	$7.35	$26.97	$44.26	$60.37	$84.14
% change from original	-12.81%	-12.86%	-12.84%	-12.84%	-12.87%
Standard Deviation	$0.07	$0.20	$0.31	$0.42	$9.11
Finishing (ADG=1.91kg)[b]					
Mean NPV per head	$19.18	$55.43	$86.41	$111.46	$147.30
% change from original	-10.37%	-10.76%	-10.87%	-11.19%	-11.47%
Standard Deviation	$1.75	$4.26	$6.58	$6.84	$7.36
Finishing (ADG=1.46kg)[c]					
Mean NPV per head	$9.19	$33.70	$55.33	$75.49	$105.10
% change from original	-12.81%	-12.85%	-12.84%	-12.85%	-12.86%
Standard Deviation	$0.09	$0.25	$0.38	$0.51	$6.37
Finishing (ADG=1.81kg)[c]					
Mean NPV per head	$33.24	$94.79	$147.43	$181.34	$226.94
% change from original	-11.00%	-11.29%	-11.50%	-11.55%	-11.71%
Standard Deviation	$2.43	$6.18	$8.86	$9.16	$9.79

[a] Lightweight beef cattle in the backgrounding phase
[b] Lightweight beef cattle in the finishing phase
[c] Heavyweight beef cattle directly enter into the finishing phase

5.6 Chapter Summary

Results of this study are reported in three categories: benefits, costs, and net present value. Mean feed cost, mean feed cost saving, NIRS adoption cost, mean NPV per head, and aggregate NPV for both Alberta and western Canada are reported for seven scenarios that are designed for the dairy, backgrounding and finishing beef cattle businesses. Within each scenario, a baseline model and five NIRS models at 5%, 15%, 25%, 35%, and 50% rejection levels are examined. In order to test the impact changes in key elements on the final results, sensitivity analyses are performed. Variations in three parameters are tested: the price of barley, the NIRS adoption cost, and the discount rate. Through scenarios 1 to 7, there are several common patterns observed from the results. First, when the rejection level goes up, the mean feed cost, mean feed cost savings, and the mean NPV per head increase. Second, the cost of NIRS adoption also demonstrates a rising trend when the rejection level increases, but the trend is small. Third, the standard deviations associated with the previously mentioned results have trends following the increasing rejection levels. However, the trend can be in either directions and needs to be discussed based on model results, such as the ration obtained from the LCRM.

All twenty-year NPV results for the seven scenarios are positive, which suggests that dairy and beef cattle operators in Alberta and western Canada should adopt NIRS technology under the assumptions in this study. However, the standard deviation of the mean NPV per head at the 5% rejection level under scenario 2 is larger than the mean NPV per head value. This indicates that the operators under this scenario potentially can get negative twenty-year NPV values.

For the sensitivity analyses, a 10% increase in barley price, a 10% increase as well as decrease of the NIRS adoption cost, and the application of a 6% and a 10% discount rate, are performed to test the impact of those changes on the final NPV results. Throughout the five sensitivity analysis scenarios, all the mean NPVs per head are still positive, which suggests that the conclusion about adopting NIRS technology remains unchanged. The effect from the increasing barley price has the most significant impact on the final NPV results. In particular, a 10% increase of barley price has the effect of increasing the per head NIRS benefits from 25% to 40%. On the other hand, the increase and decrease of the NIRS adoption cost has the least significant impact on the final NPV results. It varies from 0.4% to 6.4%, except for the situation at the 5% rejection level under scenario 2 that has an impact of 63% change on the mean NPV. Likewise, the same exceptional situation also happens under the discount rate sensitivity analysis scenarios. A normal range of impact from a different discount rate is 13% to 15% under the 6% discount rate scenarios, and 10% to 13% under the 10% discount rate. The reason for the exceptional situation at the 5% rejection level under scenario 2 is because the costs generally exceed the feed cost savings (benefits). Thus, both positive and negative NPV can be found for each time period (quarter) in this study. However, within the twenty-year time length for this study, the twenty-year NPVs under this scenario are still positive, keeping the conclusion to adopt unchanged.

In summary, this study includes common operation scenarios for various sectors of the dairy and beef cattle industries in Alberta and western Canada. After analyzing results for those scenarios, it is concluded that the adoption of NIRS technology is beneficial and commercially feasible for the dairy cattle, backgrounding beef cattle, and finishing beef cattle sectors in Alberta and western Canada.

Chapter 6: Conclusions and Further Research

The dairy and beef cattle industries are two of the largest and most important agricultural industries in Alberta and western Canada. Each of them has a major impact on the economy in the region. However, dairy and beef cattle operations are confronted with high feed costs due to increasing feed ingredient prices. By predicting and providing the nutrient content information of feed ingredients to livestock operators, NIRS technology can potentially benefit livestock operators with lower feed costs. However, although NIRS technology can be used to quickly and accurately analyze nutrient contents in rations, the initial capital cost to purchase an NIRS machine is $30,000 to $60,000, posing a major barrier for the adoption of NIRS technology. Hence, in order to examine the economic feasibility of the commercial use of NIRS, this study investigated the private benefits and costs to dairy and beef cattle operators of adopting NIRS technology in their businesses, especially at the point of purchasing and testing feed ingredients for livestock feeding operations. The study was conducted initially for the Alberta region, and later extended to the rest of western Canada.

6.1 Summary of Empirical Methods

The study's objectives were analyzed using the framework of benefit-cost analysis (BCA). The main benefit was assumed to be the feed cost savings associated with the adoption of NIRS, while the main cost was estimated as a unit cost for using NIRS technology. Least cost rations were estimated using a least-cost ration model (LCRM), which incorporated feed ingredient prices, nutrient content in feed ingredients, and animal nutrient requirements. The LCRM minimized feed costs while meeting key nutrient requirements. Feed ingredient prices and nutrient contents were set as stochastic elements to introduce risk into the LCRM to represent the potential impact of unpredictable factors, such as weather. The effect of NIRS was also introduced into the LCRM by setting five different rejection levels (5%, 15%, 25%, 35%, and 50%). Rejection levels represented the level at which feed ingredients were rejected by NIRS based on nutrient content.

In this manner, dollar value results for benefits and costs were eventually presented on a per animal basis, which was easier for aggregation and interpretation. A twenty-year net present value (NPV) analysis was then performed to determine whether a long-term decision regarding the adoption of NIRS technology was economically rational or not. Positive NPVs indicated that operators should adopt NIRS technology for their feeding operations, while a negative NPV suggested otherwise. Lastly, sensitivity analyses were conducted to examine the impact on the final results of changing key elements. The key elements tested included an increase in feed ingredient price, a change in the cost of adopting NIRS, and changes in the discount rate. Additionally, the analyses were performed for seven scenarios in the dairy cow, backgrounding beef cattle, and finishing beef cattle sectors, which represented common dairy and beef cattle operation settings in Alberta and western Canada. Results from all seven scenarios were used to form the conclusions presented in this chapter. The limitations of the research as well as possibilities for further research are discussed following the conclusions.

6.2 Summary of Empirical Results

Based on the discussion in Chapter 1, four research questions were addressed in this study: 1) is it economically feasible to commercially introduce NIRS technology to commercial dairy and beef cattle farms in Alberta and western Canada; 2) is there any difference in net benefit to different dairy and beef cattle sectors by adopting NIRS, and what causes the difference if it exists; and 3) how do final results change when key variables are allowed to vary?

First, it is feasible to introduce NIRS technology to commercial dairy and beef cattle farms in Alberta and western Canada. In this study, mean NPVs are initially measured on a per animal basis. All mean NPVs generated for the seven scenarios are positive for both dairy and beef cattle sectors in the research region. Thus, based on the BCA metric for decision-making, dairy, backgrounding beef cattle, and finishing beef cattle operators in the research region should adopt NIRS technology for their feeding operations. In this manner, aggregate industry-level NPVs for the dairy and beef cattle industries in Alberta and western Canada are also positive and point to the same conclusion of recommending NIRS adoption. Additionally, most associated standard deviations of NPVs are smaller than the corresponding mean NPVs. This means the likelihood of getting a negative NPV is very small for operators in those sectors under representative scenarios. However, the standard deviation of NPV in backgrounding beef cattle with an average daily gain (ADG) of 0.80kg is larger than its mean NPV at the 5% rejection level. Thus, by adopting NIRS technology there is a relatively higher possibility for operators under this scenario and assumed rejection level to get a negative NPV than for operators under other scenarios. Given that the mean NPV is positive, the conclusion to recommend NIRS adoption is still valid for operators within the backgrounding beef cattle sector in the study region.

Second, there are differences in terms of NPVs among different dairy and beef cattle sectors. The dairy sector has a larger mean NPV per head from the adoption of NIRS technology than the backgrounding beef and finishing beef cattle sectors. On a per animal basis, there are two reasons for this: firstly, the dairy sector has a longer period of total feed days than do the two beef cattle sectors, and NPVs are positively related to total feeding days. Secondly, the total amount of daily rations for dairy cows is almost three times greater than the total amount of daily rations for beef cattle in order to meet higher nutrient requirements, so the feed cost saving effect of NIRS is amplified. Within beef cattle sectors, the finishing beef cattle sectors, and especially the finishing heavyweight beef cattle sector, have higher NPVs per head than the backgrounding beef cattle sector in the study region. The two reasons mentioned above still hold to explain this finding. However, the backgrounding beef cattle sector has a longer period of total feeding days than the finishing beef cattle sector. This means the effect from larger amounts of rations with higher nutrient requirements outweighs the effect from a longer period of total feeding days in this situation. Additionally, mean NPVs per head are aggregated to the industry-level for Alberta and western Canada. Although the number of dairy cows is smaller than the numbers of backgrounding calves, finishing lightweight calves, and finishing heavyweight calves in the study region, mean NPVs in the dairy industry are generally bigger than mean NPVs for the three mentioned three sectors in the beef cattle industry. This is mainly because the effect from a higher mean NPV per head outweighs the effect of having a larger number of animals in this situation.

Meanwhile, a higher mean NPV per head is associated with a higher ADG within the same livestock sector for all dairy and beef cattle sectors in this study. This is because the nutrient requirements of feeding operations are higher under the scenarios with a higher ADG. While having a similar maximum DMI (total ration a cattle can have) under both scenarios within the same livestock sector, more feed ingredients with higher nutrient contents and higher prices are required in rations for a higher ADG scenario. Thus, when comparing the situation with or without NIRS technology, the saved rations are more expensive in a high ADG scenario, which means more feed costs are saved by NIRS technology. As a result, a higher NPV per head is eventually observed under the scenario with a higher ADG within the same livestock sector. The aggregate industry-level NPVs for Alberta and western Canada are consistent with the original animal unit results.

Third, the effect of introducing NIRS technology is analyzed at different rejection levels in the models, and there are differences in terms of NPVs when various rejection levels are measured. Generally, when the rejection level goes up within the same livestock sector, the mean NPV per head also increases. The main reason is that feed ingredients have higher nutrient contents at higher rejection levels since more feed ingredients with lower nutrient contents are eliminated by NIRS. Fewer feed ingredients are utilized to meet the same nutrient requirements.

However, feed ingredient prices are still the same under the assumptions of this study. Hence, livestock operators can spend less on feed and achieve a higher mean NPV per head due to a higher benefit regarding feed cost savings.

Additionally, sensitivity analyses were performed for the situations, including a price increase in barley, a 10% increase and decrease of the adoption cost of NIRS, and a 6% and 10% discount rate. A 10% increase in the price of barley causes a 25% to 40% increase of NPV, which means the barley price is important in this study. Additionally, the changes in the adoption cost only cause small NPV changes under 10%. An increase in the adoption cost of NIRS causes a decrease in NPVs, while a decrease in the adoption cost causes the reverse. Changes to the discount rate cause a moderate change in NPV of around 11% to 17%. The change in NPV is in the direction opposite of the change of discount rate. This shows that the results of this study are not sensitive to either changes in NIRS adoption costs or discount rates. NPV remains positive under all the cases explored by the sensitivity analysis, which suggests that the decision to recommend the adoption of NIRS technology by the dairy and beef cattle industries in Alberta and western Canada is valid across a wide range of conditions.

6.3 Study Conclusions and Policy Implications

Based on the discussion above, it is concluded that the introduction of NIRS technology is economically feasible for commercial dairy and beef cattle industries in Alberta and western Canada. It is estimated that dairy operators would spend \$0.014 to \$ 0.024 per animal per day by adopting NIRS in their feeding operations, which would save around \$0.053 to \$0.381 in feed costs per animal per day. The cost of adopting NIRS for backgrounding beef cattle operators would be about \$0.003 to \$0.005 per animal per day, while it could save \$0.004 to \$0.088 per animal per day of feed cost. Lastly, finishing beef cattle operators would spend from \$0.004 to \$0.009 per animal per day, and save between \$0.010 and \$0.194 on feed costs per animal per day.

The current price of an NIRS machine ranges from $30,000 to $60,000. Even though the results of this study indicate a net gain based on the implementation of NIRS technology in dairy and beef cattle feeding operations, any purchasing decision is always tied to available funds at the moment. Thus, when a policy encourages operators to adopt NIRS technology in terms of lowering costs, it has a positive impact on the commercial introduction of NIRS technology. Current policy provides an equipment grant from the government or organizations to operators or researchers who have the intention of purchasing NIRS machines. For example, the Alberta Livestock and Meat Agency (ALMA) provides a grant totaling $750,000 for the time period from April 2011 to March 2015. Under the current regulation, the grant can provide up to $20,000 per NIRS machine, which is approximately half of the investment cost cited in this study. This policy not only reduces the investment costs for operators and researchers, but also encourages the introduction of NIRS technology for commercial use in Alberta. This kind of subsidy is still limited for future NIRS machine buyers, however. For instance, more than 27 units have already been approved and have received a grant from ALMA, according to ACIDF (2013). Additionally, research agencies can also apply for this grant, which means fewer farm operators can benefit from it. In summary, it is certain that subsidies in terms of equipment grant can lower the purchasing barrier, but it is not possible for most operators to access and therefore benefit from such a subsidy. Hence, in order to have a discussion about the more general situation in the research region, a subsidy is not considered in this BCA study.

Another potential policy recommendation is to focus on supporting the establishment of NIRS networks, thereby reducing the calibration cost of NIRS within a certain region. Calibration is one of the most important steps in the process of adopting NIRS technology into livestock operations with a certain region because even the same feed ingredient can have varying nutrient content levels, depending on location, harvest year, etc. For this reason, an NIRS machine needs to be calibrated based on a local dataset regarding the nutrient contents of feed ingredients in the region. The establishment of the initial calibration database is expensive, while follow-up database maintenance by experts is also necessary. The establishment of the calibration database and the related maintenance are currently performed mainly by separate organizations. Therefore, by collaborating and sharing calibration database and even the calibration equations for the NIRS machines, NIRS networks can potentially save labour and time costs. However, setting up NIRS networks also requires investment, which will trade off potential future benefits. Due to the lack of available data, and the fact that NIRS introduction into commercial operations is still in the beginning stages, the value of NIRS networks is not clear. What is clear is that the establishment of NIRS networks can lower the long-term cost of an NIRS machine and bring its benefit to all operators and researchers in a region.

6.4 Limitations of the Research

Four limitations are discussed in this section. First, it needs to be recognized that the results in this study are specific to the assumed scenarios and representative enterprise characteristics, including dairy and beef cattle characteristics and nutrient requirements. Different animals and even the same animal in different operational phases can have different nutrient requirements. This study consulted experts in related animal science areas and tried to design representative scenarios and use representative animal characteristics. However, those representative dairy cow and beef cattle characteristics are an "average" situation for modeling. This means that while potential variations do exist regarding various characteristics, they may not even be mentioned in this study. For example, beef calves in the backgrounding and finishing phrases are gaining weight every day, which results in a slight difference in nutrient requirements. But only representative nutrient requirements based on the initial and target weights of calves are available for modeling. Thus, one set of nutrient requirements is used for each livestock sector. The loss of variation regarding nutrient requirement changes are not captured, and can potentially cause NPV results to change in either direction.

The second limitation is not explicitly incorporating into the model the reaction from crop operators to receiving additional nutrient information. The additional nutrient content information regarding to crop operators' own products can bring indirect benefits to them. For example, this study assumed that feed ingredient prices are fixed at the point of purchasing and NIRS testing. Therefore, livestock operators can utilize the nutrient content information and decide their own rejection level to maximize their profits. In reality, crop operators can also use the nutrient content information to perform different pricing strategies regarding nutrient content level, which has the potential to increase crop operators' revenue and decrease livestock operators' revenue.

The assumption of rejection levels is the third limitation. The purpose of introducing rejection levels into this study is to evaluate the NIRS effect under various scenarios. The assumption that livestock operators can set their own rejection levels may not be realistic. The accessibility of feed ingredients is always restricted by transportation costs and, therefore, limited in a small region. Thus, livestock operators are not always able to reject a particular amount of feed ingredients due to the lack of available sources of feed ingredients. Those livestock operators get smaller NPVs than the results from this study, since they actually use a smaller rejection level. Additionally, livestock operators will probably bid a higher price to get the chance to buy feed ingredients first, which eventually makes feed ingredient prices different for each livestock operator.

The fourth limitation is using expected values in the LCRM. The initial intention was to set feed ingredient prices and nutrient contents as stochastic elements. Values would then be randomly drawn from a stochastic feed ingredient price model and from nutrient content distributions to be used in the LCRM. This approach can generate different combinations of feed ingredient prices and nutrient content, which is closer to reality. However, technical issues and time constraints made this difficult to implement, which meant that expected values were used for feed ingredient prices and nutrient content in LCRM to determine optimal rations. Stochastic feed ingredient prices were then introduced into optimal rations to get actual feed costs (i.e., as discussed in section 4.6.1). Using expected values cause a smaller variability in NPV results. However, since the standard deviations of NPVs are very small, it is expected that the sign of NPVs should not change and the conclusions are still valid.

In spite of these limitations, the results of this study are valid. The data used in this study, including prices, nutrient contents, nutrient requirements, and labour costs are representative of the regions of interest. Sensitivity analyses also confirmed that changes to key variables used in this study have no qualitative effect on the final results. Additionally, the fact that the price of an NIRS machine is declining and the accuracy of NIRS technology has been widely validated lends additional support to the conclusion that the introduction of NIRS technology into commercial operations is economically feasible.

6.5 Further Research

As stated above, this study focused on estimating the private benefits and costs from adopting NIRS technology in feeding operations by dairy and beef cattle operators in Alberta and western Canada. Further studies can be extended to other livestock industries, such as pork and poultry. Similar results are expected for the pork and poultry industries in western Canada, although other provinces, such as British Columbia, may enjoy more substantial net benefits because of its larger scale. Meanwhile, a comparison study between NIRS technology and similar technologies and methods that provide nutrient content information can be conducted to provide more detailed information for decision makers. Although NIRS technology has been proven to be efficient in nutrient content prediction, these further studies can potentially enhance decision makers' understanding of NIRS technology from an economic perspective, especially when multiple operation phases and industries are involved.

The perspective in this study for assessing the impacts from adopting NIRS is that of a livestock operator. A further study from society's perspective by estimating the impacts on society's welfare of a NIRS feed evaluation program is necessary and may also involve a discussion about the potential benefits of establishing NIRS networks. On the other hand, while this study simply aggregates NPV per animal to an industry level, a more rigorous industry-level analysis can be done to address the question of whether there is an additional benefit from NIRS adoption at the industry level. Additionally, since crop operators can also get direct or indirect benefits from additional nutrient contents information from NIRS technology, livestock operators would have less net benefit since crop operators may adopt pricing strategies against them, and the overall benefits of the technology would be shared between livestock and crop operators. Hence, the question of how crop operators might use NIRS technology to help set feed ingredient prices needs to be addressed, as well as a further study of the estimation of distribution of net benefits of NIRS testing between the livestock and crop industries.

Last but not least, further research could be conducted to more fully incorporate the distribution information (i.e., nutrient contents and feed prices) into the analysis in order to provide better estimates of net benefits of NIRS. For example, it would be possible to quantify the "costs" to the producer of actual nutrient requirements not being equal to the expected values in the baseline scenarios. There are costs in terms of lost production when there are not enough nutrients in the rations. Likewise, nutrients (and money) may be wasted if animals are over fed. As well, instead of using the expected nutrient content values and the expected feed prices to formulate NIRS scenario rations, actual nutrient and price values (drawn from the distributions) could be used.

It is more convenient and faster for operators to analyze the nutrient content of rations by adopting an NIRS machine, especially if the operators purchase the machine and set it on their farm. When livestock operators utilize that more accurate nutrient content information gained by NIRS technology, it potentially can improve animal performance (i.e., milk production, weight gain, etc.). For example, beef calves can gain weight faster due to higher accuracy in nutrient content from rations when NIRS is adopted. In other words, nutrient content in rations can more closely meet nutrient requirements for optimal animal performance when more accurate information is provided. Thus, future studies can be done to evaluate the accuracy of NIRS technology in terms of predicting nutrient contents and the effect this has on improving animal performance.

The analysis in this study provides an initial understanding of the impact of adopting NIRS on dairy and beef cattle farms within an Alberta setting, and extends its results to the region of western Canada. Although the initial capital cost of an NIRS machine is relatively high, its adoption generates net gains for dairy and beef cattle operators in the study region. The dairy industry can potentially gain more benefit from NIRS technology than the beef cattle industry. A general discussion in terms of policy implication is also provided, which concludes that the effectiveness of encouraging the adoption of NIRS by subsidies regarding equipment grants is limited to certain operators, but supporting the establishment of NIRS calibration network can spread the benefits in terms of lowering costs in a long-term way to all operators and researchers in the region.

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Appendix A - Imputing missing standard deviations for net energy and total digestible nutrients

In order to set distributions for each nutrient content in feed ingredients, mean values and respective standard deviations are collected from NRC (2000; 2001). However, NRC does not report any standard deviations of net energy for lactation (NE_l), net energy for maintenance (NE_m), net energy for growth (NE_g), or total digestible nutrients (TDN). Net energy and TDN are usually not measured directly, but calculated based on other nutrient contents in the feed ingredients. More specifically, acid detergent fibre (ADF) is used to calculate net energy (GPEI, 1998) and TDN (NRC, 2000). The reason to not measure them directly is that measures combine both chemical and physical approaches (NRC, 2000; 2001), and it is time-consuming to test several times to get mean values and related standard deviations. So although NRC (2000; 2001) provides laboratory predictors of net energy and TDN, standard deviations are not provided. Therefore, a coefficient of variation was used to calculate these missing standard deviations. Coefficient of variation is a measurement of dispersion of probability distribution. For each nutrient, dividing its standard deviation by the mean value is the coefficient of variation. Assuming nutrient contents in each feed ingredient share the same coefficient of variation, the missing standard deviations can then be imputed.

NE_l, crude protein (CP), neutral detergent fibre (NDF), ADF, and dry matter (DM) are involved in dairy ration analysis. In order to get standard deviations for NE_l, coefficient of variations are first calculated for other nutrient contents based on NRC (2001) data (table 4.8). Then, the mean value of coefficient of variation is calculated and set as the coefficient of variation for NE_l in each feed ingredient (table A.1). For example, the coefficient of variation for NE_l in barley is 0.253 ((0.169+0.413+0.389+0.038)/4=0.253). Finally, based on the calculated coefficient of variation and mean value of NE_l, the standard deviation of NE_l is estimated for each feed ingredient (table 4.8).

Table A.1 Coefficients of variation for feed ingredients in dairy ration

	CP	NDF	ADF	DM	NE_l
Barley	0.169	0.413	0.389	0.038	0.253[a]
Corn	0.138	0.242	0.294	0.035	0.177
Oats	0.136	0.350	0.384	0.035	0.226
Wheat	0.162	0.463	0.818	0.022	0.366
Canola meal	0.029	0.221	0.249	0.029	0.132
Alfalfa hay	0.129	0.159	0.147	0.029	0.116
Barley silage	0.217	0.124	0.142	0.033	0.129

[a] green boxes contain calculated numbers (mean value of coefficient of variation)

Table A.2 Coefficients of variation for feed ingredients in beef cattle ration

	CP	DM	NE_m/NE_g/TDN
Barley	0.169	0.038	0.104[a]
Corn	0.138	0.035	0.087
Oats	0.136	0.035	0.086
Wheat	0.162	0.022	0.092
Canola meal	0.029	0.029	0.029
Alfalfa hay	0.129	0.029	0.079
Barley silage	0.217	0.033	0.125
Straw	0.207	0.016	0.111

[a] green boxes contain calculated numbers (mean value of coefficient of variation)

NE_m, NE_g, TDN, CP and DM are involved in beef cattle ration analysis. Following steps to estimate the standard deviations for NE_l in dairy rations, coefficient of variations are first calculated for other nutrient contents based on NRC (2000) data (table 4.8). Then, the mean value of the coefficient of variation is calculated and set as the coefficient of variation for NE_m, NE_g, and TDN in each feed ingredient (table A.2). For example, the coefficient of variation for NE_m, NE_g, and TDN in barley is 0.104 ((0.169+0.038)/2=0.104). Finally, based on the calculated coefficient of variation and mean values of NE_m, NE_g, and TDN, standard deviations of NE_m, NE_g, and TDN are estimated for each feed ingredient (table 4.8).

Appendix B - Least-cost ration models

For the models below, TC represents total cost, P represents feed price, Q represents feed quantity, NEl represents quantity of net energy for lactation, NEm represents quantity of net energy for maintenance, NEg represents quantity of net energy for growth, CP represents quantity of crude protein, NDF represents quantity of neutral detergent fibre, ADF represents quantity of acid detergent fibre, DMI represents quantity of dry matter intake, and TDN represents quantity of total digestible nutrients. For subscripts, B, C, O, W, CM, AH, BS, and S represent barley, corn, oats, wheat, canola meal, alfalfa hay, barley silage, and straw, respectively.

LCRM for dairy ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS}$$

Subject to

$$NEl_B Q_B + NEl_C Q_C + NEl_O Q_O + NEl_W Q_W + NEl_{CM} Q_{CM} + NEl_{AH} Q_{AH} + NEl_{BS} Q_{BS} \geq 34.80\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} \geq 3.59\ kg$$

$$NDF_B Q_B + NDF_C Q_C + NDF_O Q_O + NDF_W Q_W + NDF_{CM} Q_{CM} + NDF_{AH} Q_{AH} + NDF_{BS} Q_{BS} \geq 6.84\ kg$$

$$ADF_B Q_B + ADF_C Q_C + ADF_O Q_O + ADF_W Q_W + ADF_{CM} Q_{CM} + ADF_{AH} Q_{AH} + ADF_{BS} Q_{BS} \geq 4.48\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} \leq 23.60\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 11.80\ kg$$

$$Q_W \leq 1.10\ kg$$

$$Q_B + Q_C + Q_W = 5.90\ kg$$

$$Q_{AH} + Q_{BS} \leq 11.80\ kg$$

$$Q_{AH} \leq 4.50\ kg$$

LCRM for beef cattle backgrounding (ADG=0.80 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq 9.82\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq 5.64\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq 0.72\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq 4.38\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq 7.30\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 4.38\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq 1.46\ kg$$

$$Q_W \leq 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

LCRM for beef cattle backgrounding (ADG=1.22 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq 11.93\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq 7.54\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq 0.88\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq 4.98\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq 7.12\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 4.27\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq 1.42\ kg$$

$$Q_W \leq 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

LCRM for beef cattle finishing (lightweight, ADG=1.53 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq\ 19.38\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq\ 12.24\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq\ 1.17\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq\ 8.10\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq\ 11.57\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq\ 10.41\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq\ 8.10\ kg$$

$$Q_W \leq\ 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

$$Q_{BS} \geq\ 1.04\ kg$$

LCRM for beef cattle finishing (lightweight, ADG=1.91 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq 21.69\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq 14.70\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq 1.30\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq 8.74\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq 10.93\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 9.84\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq 7.65\ kg$$

$$Q_W \leq 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

$$Q_{BS} \geq 0.98\ kg$$

LCRM for beef cattle finishing (heavyweight, ADG=1.46 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq 15.50\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq 9.79\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq 1.12\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq 6.48\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq 9.25\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 8.33\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq 6.48\ kg$$

$$Q_W \leq 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

$$Q_{BS} \geq 0.83\ kg$$

LCRM for beef cattle finishing (heavyweight, ADG=1.81 kg) ration:

$$minimize\ TC = P_B Q_B + P_C Q_C + P_O Q_O + P_W Q_W + P_{CM} Q_{CM} + P_{AH} Q_{AH} + P_{BS} Q_{BS} + P_S Q_S$$

Subject to

$$NEm_B Q_B + NEm_C Q_C + NEm_O Q_O + NEm_W Q_W + NEm_{CM} Q_{CM} + NEm_{AH} Q_{AH} + NEm_{BS} Q_{BS} + NEm_S Q_S \geq 17.37\ Mcal$$

$$NEg_B Q_B + NEg_C Q_C + NEg_O Q_O + NEg_W Q_W + NEg_{CM} Q_{CM} + NEg_{AH} Q_{AH} + NEg_{BS} Q_{BS} + NEg_S Q_S \geq 11.77\ Mcal$$

$$CP_B Q_B + CP_C Q_C + CP_O Q_O + CP_W Q_W + CP_{CM} Q_{CM} + CP_{AH} Q_{AH} + CP_{BS} Q_{BS} + CP_S Q_S \geq 1.27\ kg$$

$$TDN_B Q_B + TDN_C Q_C + TDN_O Q_O + TDN_W Q_W + TDN_{CM} Q_{CM} + TDN_{AH} Q_{AH} + TDN_{BS} Q_{BS} + TDN_S Q_S \geq 7.00\ kg$$

$$DMI_B Q_B + DMI_C Q_C + DMI_O Q_O + DMI_W Q_W + DMI_{CM} Q_{CM} + DMI_{AH} Q_{AH} + DMI_{BS} Q_{BS} + DMI_S Q_S \leq 8.75\ kg$$

$$Q_B + Q_C + Q_O + Q_W \leq 7.88\ kg$$

$$Q_B + Q_C + Q_O + Q_W \geq 6.13\ kg$$

$$Q_W \leq 0.5 * (Q_B + Q_C + Q_O + Q_W)$$

$$Q_{BS} \geq 0.79\ kg$$

Appendix C - Imputing missing corn price data

Monthly Alberta corn prices ($CAD/kg) from September 2002 to March 2013 were collected from ARD. However, there are fourteen months of missing data from March 2005 to April 2006. In order to calculate estimated values for missing Alberta corn prices, monthly U.S. corn prices ($USD/kg) and monthly exchange rates between the U.S. dollar and the Canadian dollar from September 2002 to March 2013 were collected from the U.S. Department of Agricultural (USDA) and Statistics Canada, respectively. A simple ordinary least squares (OLS) regression was performed as the following equation:

$$ACorn_t = a_0 + a_1 USCorn_t + a_2 ER_t + a_3 T + e_t$$

where $ACorn_t$ is the Alberta corn price at time *t*, $USCorn_t$ is the U.S. corn price at time *t*, ER_t is the exchange rate in Canadian dollars at time *t*, *T* is the time trend, e_t is the error term, and a_i are coefficients. The regression was conducted in STATA, and the results are listed in table C.1.

Table C.1 Regression results for Alberta corn price

	Coefficient	**Std. Err.**
USCorn	1.1468***[a]	0.0394
ER	0.0197	0.0146
T	-0.0003***	0.0001
Constant	0.0406***	0.0201
R-squared=0.9616		**F (3,109)**=909.60***

[a] *** indicates significance at 1% level

From table C.1, all the variables are significant at a 1% level, except the exchange rate that is not significant. Using the results from the regression predicted Alberta corn prices were obtained for the time period from March 2005 to April 2006 to fill in the original dataset and used for further research. Table C.2 shows U.S. corn prices and estimated Alberta corn prices in the modeling time period.

Table C.2 U.S. and Alberta corn prices (Mar. 2005 – Apr. 2006)

Time	U.S. corn price ($USD/kg)	Alberta corn price ($CAD/kg, estimated)
Mar. 2005	0.080	0.147
Apr. 2005	0.079	0.147
May. 2005	0.078	0.146
Jun. 2005	0.080	0.148
Jul. 2005	0.083	0.151
Aug. 2005	0.077	0.143
Sep. 2005	0.075	0.140
Oct. 2005	0.072	0.136
Nov. 2005	0.070	0.133
Dec. 2005	0.076	0.139
Jan. 2006	0.079	0.143
Feb. 2006	0.080	0.143
Mar. 2006	0.081	0.145
Apr. 2006	0.083	0.147