Input Risk in Canadian Prairie Agriculture

by

Bijon Ainsley Brown

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Department of Resource Economics and Environmental Sociology
University of Alberta

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Abstract

It is often assumed that agricultural producers are price takers; that is, prices are beyond their control or influence. While farmers have been able to manage fluctuations in prices received for output, there is also considerable value in managing input risk. Nevertheless, there are few studies that focus on the value of input risk management. The two studies herein focus on two different forms of input risk and how the efficient management of such risks can create value for Albertan farmers.

The first study looks at the value of investing in a technology, near infrared reflectance spectroscopy (NIRS), that would reduce input quality risk. NIRS is a non-destructive technology which allows for the determination of the nutrient content in organic feedstuff. Additionally, it allows for a potential reduction in uncertainty in nutrient content resulting in adjustments in optimal rations leading to changes in feed costs.

A joint least-cost ration model (LCRM) and simulation framework is used to undertake a net present value (NPV) analysis of NIRS technology adoption by Alberta hog producers. The uncertainty model (No-NIRS scenario) is a chance constrained LCRM in which nutrients of three feedstuffs are considered to be variable. In contrast, the certainty model (NIRS adoption scenario) assumes that with NIRS the protein content of ingredients is known and the LCRM is solved. In this model, 1000 protein values are drawn from a normal distribution to simulate variable protein content in the feedstuffs. The certainty LCRM is then optimized and the total feed cost is obtained for each protein content level. The change in feed cost is obtained by comparing the costs under both models, and then aggregated to the farm-level. Net benefits are discounted and compared to the cost of procurement to assess investment feasibility.

Findings indicate median savings of more than $5 per hog can be attributed to NIRS technology. For an Alberta herd size of 1630 head of hogs this translates to savings of almost $7,300 per year and for a large farm savings could be approximately $56,000 per year. NIRS investment could generate as much as $700,000 in NPV benefits for a large-scale farm. Hence, there is evidence to suggest that investment in NIRS technology can be economically feasible for both larger and smaller sized farms.

The second study investigates the impact of diversion externalities (i.e., the inability of an agent to divert entitled allocations due to diversions made by upstream agents or agents with licences that have a higher priority) and water market price and volume risk on water market participation and farmer profitability under alternative water allocation regimes.

An agent-based model (ABM) is used to model irrigation activity around the Oldman River in southern Alberta. The model captures the complexity of multiple agents diverting water from a river according to the water allocation system, soil moisture requirements for optimal crop growth as well as river flows available for diversion. The model also simulates an endogenous water rights market from which equilibrium prices and volumes are obtained and subsequently analysed.

Simulation results indicate that if there is adequate water supply a FITFIR regime is most beneficial to crop farmers, and farmers find it economically viable not to trade. If there is inadequate water supply, however, a water sharing regime is best. For both adequate and inadequate supply scenarios, a FITFIR regime with trading is most beneficial for livestock farmers. If the objective is to have stable markets in terms of relatively low price and volume volatility, then the water sharing regime would be best whether there is adequate or inadequate water supply. There is evidence of diversion externalities and these externalities are exacerbated by a FITFIR regime. In most situations, there is evidence that water market price volatility negatively impacts crop farmer participation in the water market. Finally, there is evidence that price volatility negatively affects crop farm profitability, but volatile water prices are not significant enough to fully erode gains from trade in efficient water markets.

Acknowledgements

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1.0 Introduction

Agricultural producers make routine decisions while faced with several types of risk.[1] While many studies focus on output risk and output price risk and their economic effect on producers, the studies herein explore input quality and input price risk. In this introduction, a contextual overview of the Albertan livestock industry is provided, the economic problem addressed by this dissertation is highlighted, the objectives of the study are identified and the structure of the remainder of the thesis is outlined.

1.1 The Albertan Livestock Industry: Economic Contribution and Challenges

In 2014, agriculture accounted for approximately 1.8% of Alberta's $364.5 billion GDP. Despite this relatively small share of the overall value of production, crop and livestock agriculture represents the second largest dollar value contribution ($5.1 billion) to export revenues after petroleum and petroleum related products (Government of Alberta [GOA], 2017). In 2015, Alberta accounted for 18.1% of the total $56.1 billion (Canadian) in agri-food exports (Alberta Agriculture and Forestry [AF], 2016b). Alberta has been more inclined to export primary agri-food products than to export value added processed agri-food products (AF, 2016b). Specifically, in 2015 47.2% of Alberta agri-food production was in the form of value-added processed products- a marginal year-over-year increase of 1.7 percentage points (AF, 2016b).

The livestock sector generated 50% of total farm cash receipts of $13.6 billion in Alberta in 2015 (AF, 2016b). This represented a 6.0% year-over-year increase in Alberta's farm cash receipts (AF, 2016b). Due

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[1] Here, the term risk is used to loosely encapsulate risk and uncertainty. While uncertainty is imperfect knowledge surrounding a variable, risk assumes enough knowledge of the variable such that the decision maker can take value-based positions. These positions are consequential to the decision maker and the value for the risky variable is not known at the time of relevant decisions (Hardaker, Huirne, Anderson, & Lien, 2004).

to slower growth in expenses in 2015, net income increased by 26.1% year-over-year. Farmer net income rebounded in 2015 from a significant reduction that had occurred in the previous year. In 2014, the 27.9% annual reduction in net income was primarily driven by significant growth in costs (AF, 2015a). An important component of farm expenses for livestock operations is feed cost. Feed costs in the beef sector, which is the dominant livestock industry in Alberta, accounted for approximately 75% of total variable costs on average over the period 2012-2016 (AF, 2017). In the dairy sector, feed costs represent approximately 60%-65% of total variable cost (Gabler, Tozer, & Heinrichs, 2000) while in the hog sector, feed costs could represent as much as 75% of total variable costs (Simpson, 2012). In 2011, the average net operating income of hog farmers in Alberta was approximately $35 per hog (Statistics Canada, 2012c, 2014).[2] With margins already being narrow, unpredictable spikes in costs could have significant consequences not only on the profitability but also on the survival of livestock operations. Hence, it is important for farm operations to effectively manage feed costs. One way in which feed costs can be controlled is through the ability to confirm nutrient content in feedstuffs. This knowledge is critical for feed formulation which in turn may lead to cost savings.

Another way of mitigating livestock producers' feed related risks is the decision by some producers to grow their own feed, particularly forages. This could create a buffer from volatile feed prices and give the farmer greater control over the quality of feed. However, this could expose the producer to other significant risks. In regions where irrigated crop production is prevalent, a livestock farmer's decision to grow his own feed could result in increased exposure to water supply uncertainty. Increased demands from competing uses for water and climate change are the main factors that could influence irrigation water supply and the decision of the farmer to grow his own feed ultimately exposes him to yield risk.

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[2] Net operating income is the difference between total operating income and total operating expenses.

In the southern portion of the province it is necessary to irrigate forage crops due to the arid climate of that region and the relatively high-water demand requirements of forage crops. Expanding agricultural enterprises in conjunction with warmer climates have facilitated increased agricultural acreage and more diversified crop mixes which have resulted in increased demand for irrigation services. The irrigated acreage in Alberta accounts for 65% of all irrigated acreage in Canada (AF, 2015d). Furthermore, approximately 65% of total surface water diversions in Alberta is used to irrigate crops (Alberta Water Portal Society [AWPS], 2017). Not only is there significant demand from agricultural farms but population growth and industrial firm expansion in Alberta are beginning to place upward pressure on water demand volumes.

On the supply side, climate change may pose a significant threat to water supply stability. Warmer climates may interfere with the natural water reservoirs in the form of snow packs in the mountains. Climate change is also associated with changes in precipitation patterns and intensity. This could in turn significantly affect a farmer’s feed crop yield and quality.

To pre-empt any present and impending instability in water supply, Alberta Environment and Parks (AEP) has ceased to issue new licences for surface water diversions in the South Saskatchewan River Basin (Amec Environment & Infrasturcture, 2014). There is also legislation in place to facilitate water trading. The development of water markets is aimed at increasing the efficient use of water. This means, however, that there would be a price associated with traded volumes and this could lead to cost increases for farmers who need water for crops, especially in dry periods.[3] Furthermore, the development of water markets could result in volatile water prices (spikes and troughs in response to intra-seasonal flows), thereby exposing agricultural producers to another form of input price risk.

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[3] There is currently no variable price associated with water usage.

Given the importance of risk in many real-world decisions, risk concepts appear frequently in economics literature and there is an abundance of studies that incorporate risk into empirical economic analysis. Since optimal decisions under certainty can differ significantly from those made under risky circumstances (Robison & Barry, 1987), it is important to account for risk and responses to risk when trying to replicate real-world decisions. Failure to account for such responses could lead to inaccurate projections of decision makers' behaviour.

1.2 Economic Problem and Study Objectives

Output price risk has generally received more attention in the literature than input price risk, perhaps due to the lack of public data on private firm cost and input mixes. Most risk management tools or public programs are focused more on output-side risk than are input-side risk (e.g., crop insurance, revenue or price insurance). Governments have, in the past subsidized Prairie agriculture, incentivizing production thereby supporting revenues and profits. As the government moves toward liberalized markets and reducing subsidies, agricultural producers are focused on increasing profits through increased efficiency. The adoption of best/beneficial management practices to either improve production, improve product quality or as a method of market differentiation have helped to expand producer revenues. However, as the world becomes a unified market place, competition in agricultural production is becoming less domestic and more global. While revenue enhancement programmes create value to the producer in the short run, over time, global competition pushes the world price towards the marginal cost of the most cost-efficient producers.

The United States (US) is a major agricultural competitor to Canada producing similar type products for the global market (Statistics Canada, 2016b; United States Department of Agriculture National Agricultural Statistics Service [USDA-NASS], 2011, 2016). Yet, the average US farm has kept its operating costs around 30% below the average Canadian farm (Statistics Canada, 2016b; USDA-NASS, 2011, 2016).

Relative to other provinces, the Albertan average farm was the second highest cost of all the provinces in 2015. This showed a relative increase compared to costs reported in 2010 in which the average Albertan farm was ranked fourth. This means that cost growth in Alberta is accelerating faster than other provinces in Canada and is higher than the largest and closest competitor to the south, the US. To compete effectively on the global market, Albertan farms must also focus on cost reductions to increase efficiency. Since the optimal input decisions of a risk averse agent under certainty and full information would differ from those made under incomplete information, the selection of an optimal input mix can become crucial in trying to achieve the minimum input costs. Given the impact that information and risk may have on efficiency, this thesis is concerned with allocative efficiency, and more specifically, how attitudes toward risk affect the efficient allocation of input resources. In this thesis two important inputs, each addressed in a separate paper, are selected for analysis in the Albertan agricultural context: 1) feed for livestock and; 2) water for irrigated crop production. The first paper highlights how nutrient uncertainty within livestock feed (or feed quality risk) can alter a farmer's optimal ingredient mix (allocative efficiency of feed inputs) to the extent that the incorporation of nutrient identifying technology can create economic value for the risk averse farmer. In the second paper, the economic problem is concerned with the allocative efficiency of irrigation water. An Irrigator's participation in the water market may be influenced by externalities associated with water diversion from a river based on priority of the licence held (diversion externalities) or location of the irrigator along the river (location externalities) and could therefore distort market signals, creating uncertainty regarding water supplies and price of water rights in the water market. This in turn may result in further under-participation in the market by a risk averse irrigator.

This thesis, in the context of these inputs, seeks to address the following questions:

- What are the economic impacts associated with increased information about feed quality?

- How do diversion externalities and water market price risk affect water market participation decisions of risk averse irrigators?

Based on these questions, three objectives are defined for this thesis; specifically, a) to estimate the economic impact of nutrient identification technology on the cost structure of Albertan hog farmers, b) to determine whether it is feasible for Albertan hog producers to invest in this technology and, c) to assess and estimate the impact of water market price volatility and water availability on southern Albertan crop and livestock producers' feed grain cropping decisions under two water allocation regimes.

1.3 Contribution of Research

This thesis seeks to estimate the welfare impact of two forms of risk mitigation strategies on livestock producers and is primarily focused on two areas of risk: a) input quality risk, more specifically, the welfare impacts of risk reducing technologies for feed inputs on livestock operations; b) input price and quantity risk- the welfare impact of irrigation water trading price and volume volatility on crop feed producers who use irrigation and livestock producers.

In Alberta, a variety of risk mitigation strategies are available to agricultural producers. These may include but are not limited to public business risk management programs such as crop insurance, income and margin stability programmes (Sigurdson & Sin, 1994), or "private" strategies such as diversification (Mumey, Burden, & Boyda, 1992), hedging using futures and derivatives (Caldwell, Copel, & Hawkins, 1982) and forward contracting in agricultural markets. Vertical farm consolidation, which is a method of mitigating input supply and input quality risks, can also be considered as a form of risk management (Hennessy, 1996; Williamson, 1989). However, the literature is quite sparse with respect to technology adoption that reduces uncertainty in input quality. This thesis brings to the fore one such technology and assesses the economic impacts of its adoption in the Albertan hog sector. The method used expands upon Rahman and Bender (1971) and D'Alfonso, Roush and Ventura (1992) by combining chance-constrained least-cost ration models (LCRMs) analysis and welfare analysis.

There have been many studies that investigate the benefits of establishing water markets. These studies examine how water markets increase financial flexibility and aid in risk mitigation for producers (Zuo, Nauges, & Wheeler, 2015), and/or how water markets generally lead to more efficient use of water which enhances growth and economic development (Bjornlund, 2010; He & Horbulyk, 2010; Mahan, Horbulyk, & Rowse, 2002). These studies have not considered the possible impact that risk and uncertainty may have on participation in water markets. The usefulness of water markets has been questioned by irrigators in Chile due to rising water prices, high price volatility and increased uncertainty within the Limari Valley water market in 1996/97 (Zegarra, 2002). In Alberta, only a few trades are executed within a year and price differentials of approved trades have been quite wide (Nicol, 2005), indicating significant price uncertainty. This thesis highlights the role trade price risk and trade volume uncertainty plays in trade market abstention in Alberta.

The thesis is sub-divided into two sections, each of which is a separate paper/chapter. The first paper assesses the welfare impact of the adoption of NIRS technology by hog farmers in Alberta. The second paper explores the welfare impact of volatile water trading prices and uncertain trade execution on risk averse crop and livestock producers under the current water allocation system versus an alternative water allocation regime.

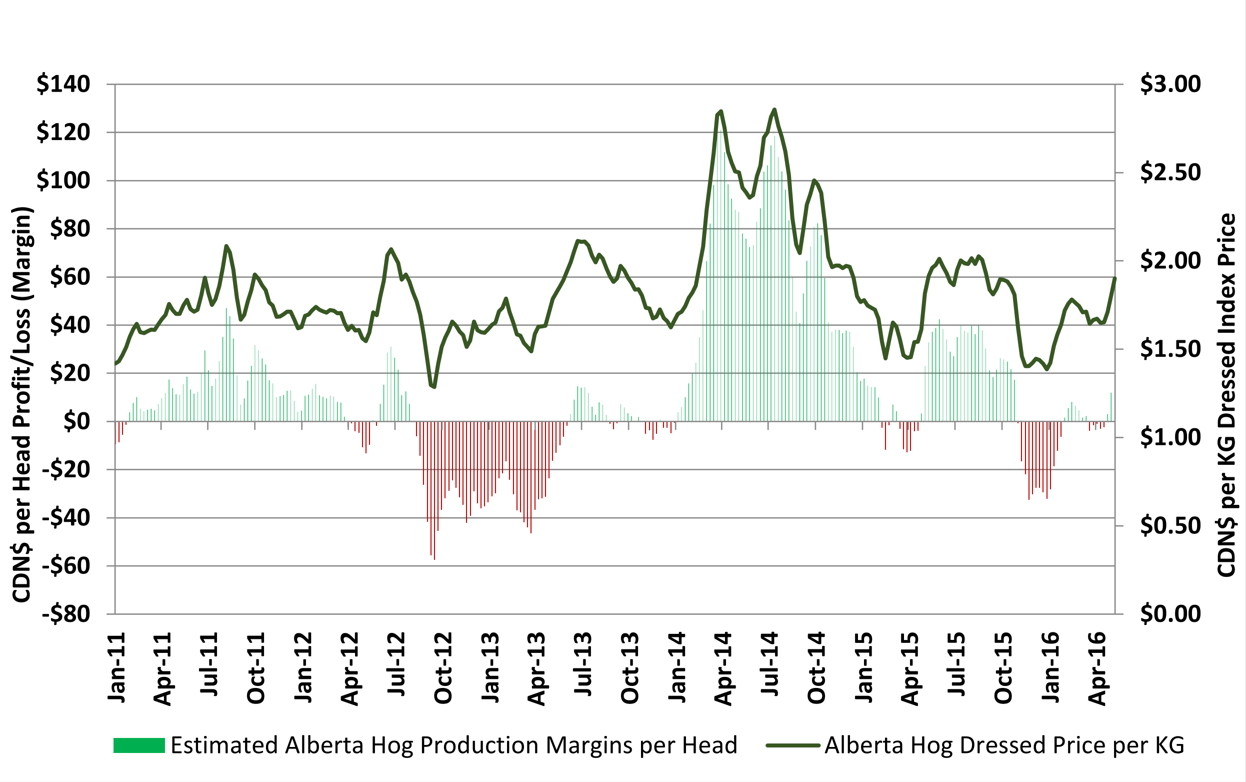
2.0 Net Present Value Analysis of Near Infrared Spectroscopy Technology Adoption by Albertan Hog Producers

2.1 Introduction

Significant increases in world feed grain prices in 2012, primarily driven by the United States (U.S.) market, contributed to increased incentives for North American hog producers to find innovative ways of lowering costs and improving overall efficiency without sacrificing output quality. The cost of feed is a significant component of production cost in the livestock industry. Due to recent shortages caused by droughts and increased competing demand for biofuels in the U.S., upward pressure has been placed on feed prices which has, in turn, affected both domestic and international livestock farmers (Tokgoz et al., 2007; United States Department of Agriculture Economic Research Service [USDA-ERS], 2013). The drought of summer 2012 in the U.S. Corn Belt resulted in significant increases in the price of corn (USDA-ERS, 2013). This high cost of corn translated to high feed prices which had far reaching impacts on downstream industries such as that of the Canadian hog producers (Reuters Canada, 2012). Specifically, Big Sky Farms, western Canada's largest independent hog producer and Canada's second largest hog producer, had to be acquired by Olymel L.P. (downstream processor) to stave off insolvency and Maple Leaf acquired Puratone in the same period as well (Alberta Pork, 2013).

Gross margins for hog producers in Alberta peaked at approximately $120 per head in 2014 but declined significantly in 2015 and by the start of 2016 gross margins were negative. As seen in Figure 2.1, margins are highly correlated with the dressed price. The dressed price is largely outside of the control of the producer. However, producers have more control over their costs.

Figure 2.1 Estimated Alberta Hog Production Margin and Dressed Price



Source: AF (2016f)

Feed costs account for up to 75% of total operating cost (Simpson, 2012). Therefore, it is crucial for hog producers to effectively manage their feed costs. Feed ingredients are selected based on perceived nutrient content, as it is the nutrients within the feedstuffs that affect growth and development of the animal. Under conditions of complete information, a producer would choose the least cost ingredient mix that meets all nutrient requirements for optimal growth. However, if nutrient levels in some feed stuffs are variable and unobservable, then there could be instances in which nutrient levels in those feedstuffs are lower than expected, thereby rendering the ration nutrient deficient. To avoid this, risk averse farmers may tend to "over feed" or over supplement the animals to avoid nutrient deficiencies which in turn result in higher costs. Hence, having full knowledge of the nutrient content in feedstuff could lead to cost savings thereby improving gross margins.

Technological advances have enabled farmers to estimate the nutrient content levels of their feed more accurately through reflectance imaging. Near Infrared Reflectance Spectroscopy (NIRS) is an application of infrared imaging technology that has been around for almost five decades. However, technological advances have resulted in a more compact and affordable machine. The adoption of this technology at the individual hog farm level may reduce the likelihood of providing insufficient or excess levels of nutrients, with corresponding cost implications. Providing insufficient nutrients could extend the time to attain market weight or hogs could be marketed at a lower than optimal weight or could alter the final price received for the hog. Conversely, providing excess nutrients results in feed wastage.[4] Therefore, use of this technology has implications on the profitability of farmers and gives rise to pertinent questions such as: what are the conditions required for hog farms to invest in this technology, and is it economically feasible to invest in these machines? To explore these questions, the objectives of this paper are to:

- quantify the feed cost differences with and without the adoption of the NIRS technology of a representative Albertan hog farm,
- utilise the cost differences to determine whether it is economically feasible for a representative Albertan hog farmer to invest in the NIRS technology and,
- identify the limiting conditions for investment in the NIRS technology by hog farmers.

This study applies an approach in which simulation analysis and programming techniques are jointly used to estimate the net present value (NPV) of NIRS technology adoption. Following the approach of D'Alfsonso et al. (1992), a chance constrained margin of safety least cost ration model is developed to reflect decisions made under greater feed nutrient uncertainty (without the NIRS machine- No NIRS Model) for a representative daily hog ration. To model nutrient certainty (with the NIRS machine- NIRS

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[4] Excess nutrient intake could also result in faster than expected weight gain or fat gain both of which have negative implications for premiums earned in the output market.

Model), distributions of nutrient content in feedstuffs are assumed and by using simulation analysis, nutrient content values are randomly drawn from these distributions after which the farmer agent optimizes for the minimum feed cost formulation.

In situations when the level of nutrient in the No-NIRS model is inadequate, based on actual sampled nutrients from the NIRS model, the effect of the nutrient deficiency on expected market lean weight is estimated. The expected weight deviation is monetized as the change in price premiums resulting from the less than optimal weight gain, referred to as premium penalties. The premium penalties represent added cost savings from adopting NIRS, which is the difference in feed costs between the NIRS and the No NIRS model.

The daily per-hog net benefits of adopting NIRS are aggregated to reflect the annual costs savings at the farm level. Thereafter, investment feasibility is assessed using an NPV analysis to compare flows of cost savings over the useful life of the machine to the procurement and maintenance cost of the NIRS machine.

2.2 Background and Literature Review

This section is comprised of three sections. The first provides insights into the current structure of the Canadian hog production sector. This is followed by a brief overview of previous literature that examines benefits of technology adoption. Finally, a brief highlight of previous studies investigating the feasibility of NIRS is presented. 2.2.1 The Canadian Hog Sector

Canada was the twelfth largest pig producer in the world in 2013; Canada produced approximately 12.9 million hogs. In 2013 Canada was a net exporter of pigs, with net exports accounting for 38.6% of hog production, and Canada was the world’s third largest exporter of hogs (Food and Agriculture Organization Statistics Division [FAOSD], 2017; Reuters Canada, 2012; Statistics Canada, 2012c). The hog industry in Canada generates approximately $3.9 billion in cash receipts or 19.1% of total cash receipts of the livestock sector (Statistics Canada, 2012c), and represents 30% of all Canadian livestock shipments (Canada Pork International [CPI], 2013b).

The Canadian pork industry consists mainly of feed producers[5], hog producers, meat processing plants, marketing agencies, retailers and the Canadian Food Inspection Agency (Figure 2.3). Each component is critical to the viability of the industry. The following subsections highlight the role of the players in the industry.

The feed or nutritional input sector is least defined as its characterisation depends on the level of vertical integration that exists between hog producers and feed producers. In general, small hog producers source their feed from commercial feed mills, family owned feed mills, or they grow their own feed. Larger farms may operate their own feed mills and purchase grain directly from crop farmers; for example, this is the case with Hylife Limited which is the largest hog producer in Canada (Hylife Limited, 2013; Reuters Canada, 2012). However, most feed mills are family-owned enterprises. In these cases, the mills purchase grains from farmers, use the grains to manufacture feeds and, sell the feed to hog producers.

Hog feed is comprised mainly of grains and hogs consume between 35% and 45% of Canadian feed grain production (CPI, 2013c). A typical hog's diet is comprised of feed grains such as corn, barley and wheat while other types of feedstock such as canola meal and soymeal are used to supplement feed grains (CPI, 2013c). While most Canadian corn is produced in central Canada, barley and wheat are

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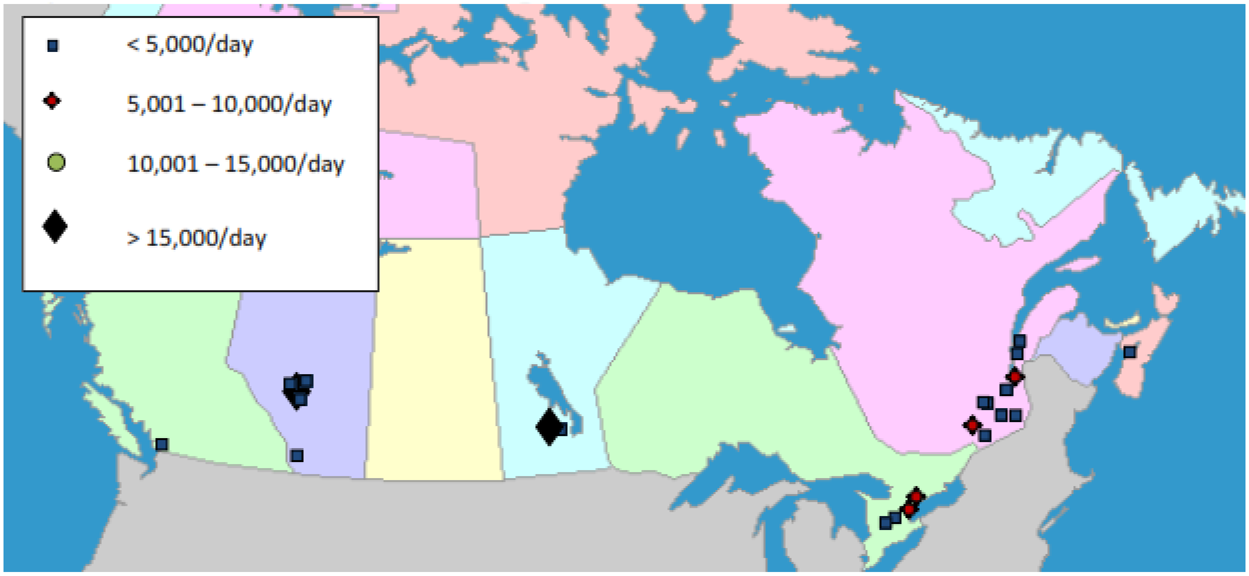
[5] There are other relevant input sectors (e.g., equipment, financial capital) involved in the hog sector. However, the discussion here is limited to feed because of a) the research topic, and b) the proportion of costs accounted for by feed.

predominantly produced in the Canadian Prairies. Therefore, hog diets in the Prairie region tend to be more wheat and barley intensive than those in central Canada.

Meat processors are also an important part of the pork supply chain. Mature hogs are transported to processing plants to be slaughtered. Processors transform finished pigs into various cuts, package them or further process the meat into cured products and market the meats to retailers. Processing plants can be characterised as either federal or provincial, where federal plants are licensed to market their products inter-provincially and internationally whereas provincial plants can only market their products within the province (Economics Research Group [ERG], 2010). The processing sector is comprised of family owned firms, investor-owned firms and producer-owned cooperatives (Canadian Agri-food Trade Alliance [CAFTA], 2012).

Figure 2.2 Canadian Federal Hog Processing Plant locations

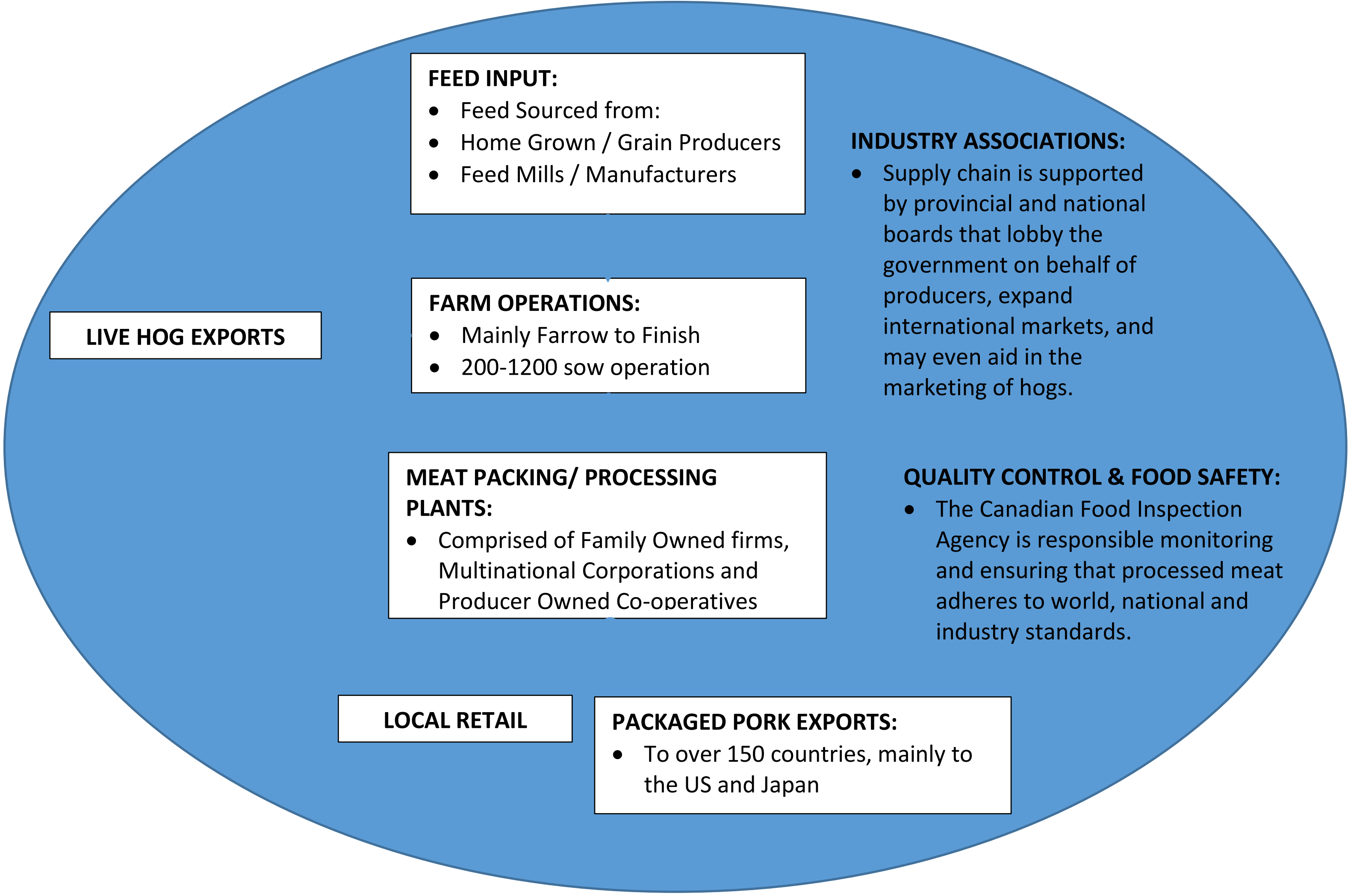


Source: ERG (2010)

Canadian hog slaughter by processors marginally declined from 21.8 million animals in 2009 to 21.3 million animals in 2012 (Statistics Canada, 2012c, 2013). This throughput is 5.2 million animals below the 26.5 million animal processing capacity (ERG, 2010). Figure 2.2 shows the spatial distribution of federal processing plants across Canada according to their capacities. As seen in the figure, Manitoba and Alberta have the largest processing plants while Quebec has significantly more processing plants with less capacity.

The most important participants in the hog industry are hog producers. In the 2011 Census of Agriculture, there were 7371 Canadian farms that reported rearing pigs (Statistics Canada, 2012c). Ontario and Quebec had the most farms, numbering 2556 and 1953 farms, respectively, while there were 857 farms reporting from Alberta. In terms of hog production, Ontario and Quebec again dominated producing a combined total of 7.2 million hogs or 61% of total Canadian production (Statistics Canada, 2012c). However, Manitoba has the highest output per farm. Hylife Limited, the largest producer in Canada, operates in Manitoba, producing 1.4 million hogs per year or 11% of 2011 hog production (Reuters Canada, 2012; Statistics Canada, 2012c). Large hog production operations consist of over 1200 sows or over 28,000 pigs per year but the most common are 200-250 sow operations (CPI, 2013c). Although Albertan hog production per farm is comparatively small compared to Manitoba, approximately 1.5 million hogs were produced in Alberta in 2015 (AF, 2016b). This represented the second largest livestock production sector in Alberta after cattle and calf production. The hog sector was the only major livestock sector in Alberta to reflect a year-over-year increase in production in 2015, growing by 1.4% (AF, 2016b). The Albertan hog industry generated almost $500 million in farm cash receipts in 2015, the second highest income generator for livestock producers after growing cattle for meat or milk (AF, 2016b).

Figure 2.3 Hog Industry Structure



FEED INPUT:

- Feed Sourced from:
- Home Grown / Grain Producers
- Feed Mills / Manufacturers

INDUSTRY ASSOCIATIONS:

- Supply chain is supported by provincial and national boards that lobby the government on behalf of producers, expand international markets, and may even aid in the marketing of hogs.

LIVE HOG EXPORTS

FARM OPERATIONS:

- Mainly Farrow to Finish
- 200-1200 sow operation

MEAT PACKING/ PROCESSING PLANTS:

- Comprised of Family Owned firms, Multinational Corporations and Producer Owned Co-operatives

QUALITY CONTROL & FOOD SAFETY:

- The Canadian Food Inspection Agency is responsible monitoring and ensuring that processed meat adheres to world, national and industry standards.

LOCAL RETAIL

PACKAGED PORK EXPORTS:

- To over 150 countries, mainly to the US and Japan

Source: Created by author with information from (CPI, 2013a, 2013c; CAFTA, 2012)

In Canada, most farms are farrow-to-finish operations (CPI, 2013c), where the farmer is involved in all phases of pig development, from impregnating the sow, to birthing and weaning, to feeder pigs or grower pigs to finishing pigs. However, in Alberta a significant number of farms specialize in breeding and nursing and selling grower pigs to other farms for the finishing stage (Komirenko, 2015). Komirenko (2015) notes that Albertan producers face relatively higher production costs and lower market prices for hogs than U.S. producers and hence opt to sell to finishing farms in the U.S.

2.2.2 Benefit Cost Analysis of Technology Adoption

Benefit Cost Analysis (BCA) is a method of evaluating the feasibility of a project based on the value of benefits derived from the project less the monetized costs associated with the implementation of the project (Boardman, Greenberg, Vining, & Weimer, 2011). Generally, BCA is used to describe the difference between social benefits and social costs, that is the net benefits to the society as a whole from the implementation of a most economically feasible project among a list of alternatives. However, BCA was not always a social welfare analysis, as early examples of implementation of BCA involved examining private benefits net of private costs (Prest & Turvey, 1965). This is equivalent to what is termed today as Capital Budgeting (CB)- the comparison of a present value flow of benefits accruing to a project(s) to the initial investment outlay(s) to determine investment or project feasibility (Peterson & Fabozzi, 2002). CB is therefore a tool used to compare the benefits and the costs of implementing a project to inform the investment decision; that is, a tool used in BCA. While BCA is used more loosely for social welfare analysis, CB has been more frequently used to analyse private investment decisions, but whether social welfare analysis or private welfare analysis BCA and CB both involve comparing benefits to cost to inform feasibility for decision making. This study is utilizing a capital budgeting framework and hence BCA and CB are used interchangeably.

CB has been widely used in agriculture. Lawrence (1996) illustrates how CB techniques can be used to compare the economic impact of alternative methods of raising hogs and further hints at the use of CB to inform the decision-making process surrounding alternative technologies. Stalder, Lacy, Cross and Conatser (2003) used CB to determine the number of litters a sow must have in order for the sow to return a positive NPV.

Other studies incorporate real option decision making models in conjunction with CB to consider inherent risks in cash flows, the irreversibility of investment and/or options to delay investment. Stokes, Rajagopalan and Stefanou (2008) analysed the feasibility of investing in methane digesters for cattle operations. Other real options agricultural applications include investments in free-stall dairy barns (Purvis, Boggess, Moss, & Holt, 1995) and hog production (Balmann & Mußhoff, 2002). The next section highlights studies investigating the investments feasibility of NIRS.

2.2.3 Prior Studies Investigating the Economic Feasibility of Commercial Investing in NIRS

Only a very limited number of academic studies assess the economic impact of NIRS on livestock producer profitability. Many NIRS studies focus on the precision of nutrient content in grains, forages, animal output, or determination of the level of moisture in soil or other organic matter. However, NIRS machine manufacturers advertise that the technology generates savings for adopting customers. For example, Unity Scientific, a NIRS manufacturer, promotes that their machine pays for itself after testing 500 samples based on US$221.00 costing on full sample analysis at a laboratory (Unity Scientific, 2015). Mills (2006) note that a feed mill could save between €2 and €5 per ton by investing in NIRS.

Li (2014) was the first to examine the net benefits of adopting the technology to the Albertan beef and dairy sectors. Li assumed that adoption of NIRS would allow producers to reject feed ingredient lots that contained less than a pre-specified level of nutrient content thereby resulting in the truncation of the distribution of feed nutrients. The model was simulated with truncation levels set at 5%, 15%, 25%, 35%, and 50%. With truncation, the mean nutrient contribution of feed ingredients is increased relative to when the distribution is not truncated. For the NIRS scenario the higher mean nutrient contribution values were used in the LCRM while in the No-NIRS scenario the model was solved using the lower mean nutrient contribution values. The difference in the feed cost of the No-NIRS scenario and the NIRS scenario was then discounted to arrive at a NPV per head of cattle (dairy cow, backgrounding beef cattle and finishing beef cattle). The cost of purchase and maintenance, spread over the twenty-year life of the machine, was converted to a present value.

Li (2014) found that adoption of NIRS would save dairy producers approximately \$0.053 to \$0.381 in daily feed costs per animal. The corresponding daily cost savings per animal for backgrounding beef cattle and finishing cattle were \$0.004 to \$0.088, and \$0.010 to \$0.194, respectively. Li (2014) concluded that it is feasible for cattle producers to invest in the technology.

2.3 Theoretical Model

This section outlines a theoretical model that assesses the welfare impact associated with increased nutrient certainty in an input. Specifically, this section is concerned with the value of reducing input quality risk. As such, the discussion combines the Input Service Quality model by Robison and Barry (1987) with the partial information welfare analysis of Just, Hueth and Schmitz (2004).

2.3.1 Model Assumptions and Setup

One of the major objectives of firms is to maximise profits. Chambers (1988) notes that in the short-run, if output is fixed then profit maximisation is equivalent to cost minimisation.[6] In this section a

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[6] Chambers (1988) notes that profit maximisation can be expressed in two stages- a short-run stage and a long-run stage. In the short-run stage the firm maximises profit for a given output while in the long-run the firm maximises

comparison is made between the welfare effects of two theoretical models of cost minimisation- one under input quality certainty and the other under input quality uncertainty.

2.3.1.1 Model of Input Quality Certainty

If in the short run there is very little scope to expand output, and if there is a degree of substitutability between inputs in the production process, then a profit maximisation problem is equivalent to a cost minimisation problem of the form:

$$\underset{X}{\text{Minimise}}\ \text{Cost} = \sum_{j} w_j x_j \tag{2.1}$$

Subject to: $\mathrm{f}(X) \geq \bar{Y}$

where $w_j$represents the input price of the j^{th}input (x_j), $f(X)$ is the production function transforming inputs to outputs and $\bar{Y}$ is the target level of output. The aim of Equation 2.1 is to minimize the input cost of production subject to the production technology $\mathrm{f}(X)$ available to produce the target output $\bar{Y}$.

From this optimization process, conditional input demands may be obtained or derived $\left(X^*(w,\bar{Y})\right)$. Consumer surplus in the input market for this firm is given by $CS = \int_{w^*}^{\widehat{w}} X^*(w,\bar{Y})\, \partial w$, where w^* is the equilibrium price and $\widehat{w}$ is the firm's choke price for an input and $w^* < \widehat{w}$.

A Cobb-Douglas functional form for the production function is used to illustrate the welfare impact; assume $\mathrm{f}(X) = f(x_1, x_2) = x_1^{\alpha} x_2^{\beta}$. Assume further that $\alpha + \beta < 1$ (i.e., decreasing returns to scale). The optimal input demand for input 1 is then $x_1^*(w,\bar{Y}) = \mathrm{K}\, \mathrm{w}_1^{-\frac{\beta}{\alpha+\beta}}$, where $\mathrm{K} = \bar{\mathrm{Y}}^{\frac{1}{\alpha+\beta}} \cdot \left(\frac{\alpha}{\beta} w_2\right)^{\frac{\beta}{\alpha+\beta}}$. The

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profit by choosing the level of output. It must be assumed that the firm is a price taker in output and input markets.

consumer surplus for input 1 generated between the equilibrium price $\mathrm{w}^*$and the choke price $\widehat{\mathrm{w}}$ is given by

$$CS_{1,1} = \int_{w_1^*}^{\widehat{w}_1} x_1^*(w_1, w_2, \bar{Y})\, \partial w_1 = \mathrm{K} \cdot \left(\frac{\alpha+\beta}{\alpha}\right) \cdot \left(\widehat{\mathrm{w}}_1^{\frac{\alpha}{\alpha+\beta}} - \mathrm{w}^{*\frac{\alpha}{\alpha+\beta}}_{1}\right) \tag{2.2}$$

2.3.1.2 Welfare Gains of Accurate Nutrient Content Identification (Model of Input Quality Uncertainty)

Following Robison and Barry's (1987) input service risk model, assume that the contribution of input x_1 to the production process $\mathrm{f}(X)$ is variable such that the actual contribution of x_1 is $\hat{x}_1 = x_1 + \hat{\theta}$, where $\hat{\theta}$ is the unanticipated perturbation of the impact of x_1 on $f(X)$. For meaningful values of output and to satisfy monotonicity of the production function, it is assumed $\hat{\theta} > -x_1$.[7] Therefore, the optimization problem becomes

$$\underset{x}{\text{Minimise}}\ \text{Cost} = \sum_j w_j x_j \tag{2.3}$$

Subject to: $$\mathrm{f}\big(X, \hat{\theta}\big) \geq \bar{Y}$$

From the optimization process, conditional input demands are obtained $\Big(X^*\big(w, \bar{Y}, \hat{\theta}\big)\Big)$. The resulting consumer surplus in the input market for this firm is given by $CS = \int_{w^*}^{\widehat{w}} X^*\big(w, \bar{Y}, \hat{\theta}\big)\, dw$. Returning to the above illustration where $\mathrm{f}(X) = f\big(x_1, \hat{\theta}, x_2\big) = \big(x_1 + \hat{\theta}\big)^{\alpha} x_2^{\beta}$, the resulting input demand for $x_1$is given by:

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[7] If $\hat{\theta} = x_1$ then the true impact of $x_1$is zero, therefore the production function would be zero as well in a Cobb-Douglas production function- a trivial and uninteresting outcome. Monotonicity implies that $f(X)$ should be non-decreasing in $x_1$but if $\hat{\theta} < -x_1$ then as more of x_1 is used there would be a fall in production.

$$x_1^*\left(w,\bar{Y},\hat{\theta}\right) = \mathrm{K}\,\mathrm{w}_1^{-\frac{\beta}{\alpha+\beta}} - \hat{\theta} \tag{2.4}$$

The impact of a marginal increase in $\hat{\theta}$ on the demand for input 1 yields:

$$\frac{\partial X_1^*\left(w,\bar{Y},\hat{\theta}\right)}{\partial\hat{\theta}} \;=\; -1 < 0 \tag{2.5}$$

This indicates that as the unobserved quality increases, "true" demand decreases for the input at the optimum. Finally, the consumer surplus generated is given in Equation 2.6. The key difference between Equations 2.2 and 2.6 is the impact of the uncertainty parameter $\hat{\theta}$ on consumer surplus. As illustrated, for every unit increase in $\hat{\theta}$ ($\hat{\theta} > 0$) implying a greater than expected input impact on output, there are surpluses of $\left(\hat{\mathrm{w}}_1^{\frac{\alpha}{\alpha+\beta}} - \mathrm{w}^{*}{}_1^{\frac{\alpha}{\alpha+\beta}}\right)$ foregone because of the uncertainty. Alternatively, if $\hat{\theta} < 0$ there gains to be had.

$$CS_{1,1} \quad = \int_{w_1^*}^{\hat{w}_1} X_1^*\left(w_1, w_2, \bar{Y}, \hat{\theta}\right) \partial w_1 \; = \left[\mathrm{K}\cdot\left(\frac{\alpha+\beta}{\alpha}\right) - \hat{\theta}\right]\cdot\left(\hat{\mathrm{w}}_1^{\frac{\alpha}{\alpha+\beta}} - \mathrm{w}^{*}{}_1^{\frac{\alpha}{\alpha+\beta}}\right) \tag{2.6}$$

Equation 2.6 highlights the paradox that indicates for certain positive values of $\hat{\theta}$ there would be welfare losses (Just et al., 2004). However, this excludes the impact of the inability to return the surplus purchased input units at full cost. This point is especially relevant in the current study where the purchased feed is consumed by the animal. Only when this inefficiency cost is considered (Foster & Just, 1989) is the true value of consumer surplus attained (Just et al., 2004):

$$CS_{1,1} \quad = IC = \left[w_1^*\cdot\left(X_1^*(\hat{\theta}=0) - X_1^*(\hat{\theta}>0)\right) - \int_{X_1^*(\hat{\theta}>0)}^{X_1^*(\hat{\theta}=0)} X_1^*\left(w_1, w_2, \bar{Y}, \hat{\theta}>0\right) \partial X_1\right] \tag{2.7}$$

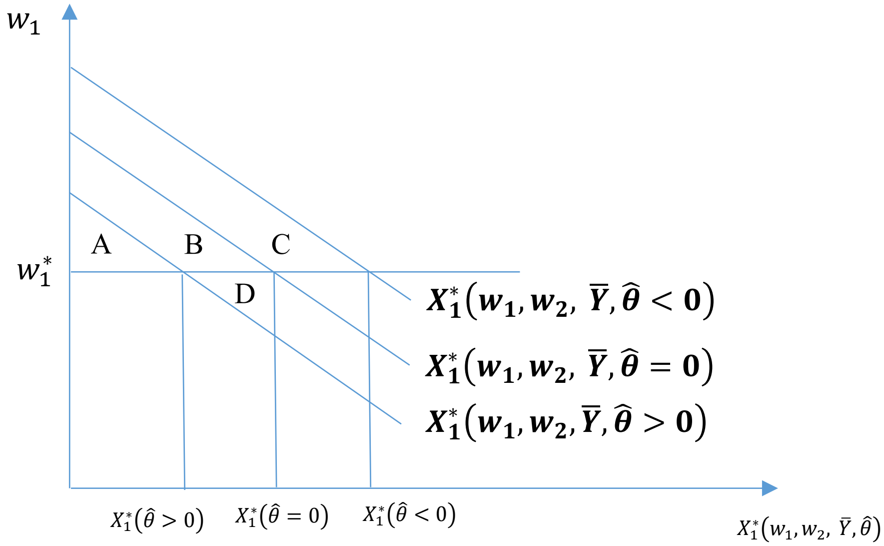
Figure 2.4 provides a graphical illustration of the welfare impact associated with input service uncertainty. The perturbation $\hat{\theta}$ can result in welfare losses due to the lack of perfect information. Let $X_1^*\left(w_1, w_2, \bar{Y}, \hat{\theta} = 0\right)$ be the input demand curve with the expected ex ante nutrient content, $X_1^*\left(w_1, w_2, \bar{Y}, \hat{\theta} > 0\right)$ be the input demand curve with surplus nutrient content ex post and $X_1^*\left(w_1, w_2, \bar{Y}, \hat{\theta} < 0\right)$ be the input demand curve with deficit nutrient content ex post.

If there are no quality variations, then the expected demand curve is the true demand curve and the consumer surplus is as expected. If in actuality $\hat{\theta} > 0$, then the ex post input demand curve $(X_1^*\{w_1, w_2, \bar{Y}, \hat{\theta} > 0\})$ would be to the left of the input demand curve when $\hat{\theta} = 0$ $(X_1^*\{w_1, w_2, \bar{Y}, \hat{\theta} = 0\})$ (Figure 2.4). The area labelled $A + B$ in Figure 2.4 represents the expected consumer surplus but the true surplus would be the area Labelled A. This reduction in consumer surplus is the paradox outlined in Just et al. (2004). The wastage resulting from the over-purchase of input 1 because $\hat{\theta} > 0$ is the area shaded D. Therefore, the value of information is positive at D.

If in fact $\hat{\theta} < 0$, then the ex post input demand curve $(X_1^*\{w_1, w_2, \bar{Y}, \hat{\theta} < 0\})$ would be to the right of the demand curve for $\hat{\theta} = 0$. In the optimum, more X_1 is required than is utilised. This results in foregone surpluses labelled as C in Figure 2.4.

This theoretical model has a key similarity with the least cost ration models (LCRM) described later in this chapter but also has a key difference. In the above model $\hat{\theta}$ encapsulates all the uncertainty regarding input quality and is akin to the uncertainty in the nutrient constraints in the LCRM. More specifically, each of the nutrient constraints in the LCRM is comprised of a linear production function on the left-hand-side (LHS) and minimum target levels of outputted nutrients on the right-hand-side (RHS), like the theoretical model presented here. The key difference is the fact that production function presented here is nonlinear while the production function in the standard LCRM is linear. The assumption of perfect substitutability of feed ingredients in the production of nutrients, which will be later discussed, may not be a reasonable assumption.

Figure 2.4: Welfare Impact of Input quality uncertainty



Source: Author

2.3.2 Link between BCA and Welfare

The computation of reliable welfare values is a key component of BCA and the policy decisions that stem from the BCA analysis. A welfare measure is the dollar value required to leave someone as well off as they were prior to the change (Grafton et al., 2004). In the input market, a firm purchasing inputs is treated as the consumer. The area under the input demand curve and above the market equilibrium price is the firm's consumer surplus for the input. It represents the sum of marginal value generated from an additional unit of a product up to the point of the equilibrium. Consumer surplus becomes useful in BCA analysis as the decision to invest in new technology may result in the input price changes or shifts in the input demand curve which would then result in changes in the firm's consumer surplus. The change in the firm's consumer surplus represents the dollar value impact of the policy change and, in some circumstances, is a reliable measurement of value. If there are multiple price changes but inputs are technically independent or if the decision affects the price of only one input, consumer surplus is a reliable measure of welfare. This is also the case if there are no income effects and if the assumption that the marginal utility of income is constant is reasonable (Just et al., 2004). In spite of so many caveats on the reliability of consumer surplus as a welfare measure, in most situations consumer surplus is a reliable method for assessing anthropocentric values for BCA (Boardman et al., 2011). In the model outlined here, changes in input demand resulting from a change in quality are reliable if we hold prices constant and output constant. Shifts in the input demand curve due to a change in $\hat{\theta}$ yield a unique consumer surplus measure. This welfare measure represents the value of decreased uncertainty in input quality. This therefore provides the platform for the empirical approach in which prices and nutrient production levels are held constant and quality in feed ingredients varies.

2.4 Empirical Methods and Data

This section explores the empirical approach utilized in the research. First a broad overview of the empirical approach utilized is presented. Thereafter, modelled farms are discussed in terms of size, stages of production and nutrient requirement by stage, available ration ingredients (nutrient content and content variability) and the prices of the ingredients. An overview of the optimising ration models is then presented followed by a description of the models used in the scenarios for this study. The discussion then focuses on the two overarching scenarios: the base scenario depicting no NIRS adoption and the counterfactual scenario with the NIRS technology. Next the method monetising the effect of nutrient deficiencies arising from the non-adoption of NIRS is outlined. The section ends with a description of capital budgeting tools utilised in the study.

2.4.1 Overview of Empirical Approach

The primary aim of this study is to determine the NPV benefits of the NIRS technology adoption to hog farmers in Alberta. To achieve this end, a "simulation-programming approach" is employed. Here, the simulation-programming approach is the approach in which simulation analysis and mathematical programming techniques are jointly used. This approach is used to estimate the NPV benefit of NIRS technology adoption. A chance constrained margin of safety programming model is developed to reflect decisions made under feed nutrient content uncertainty, which is akin to not having the NIRS technology available. To model nutrient content certainty (which demarks the use of a NIRS machine), distributions of nutrient content in feedstuffs are assumed, and by simulation analysis, nutrient content values are randomly sampled from these distributions after which the farmer agent optimizes the minimum cost formulation. In situations where the nutrient content under the uncertainty model violates the nutrient required based on the actual nutrient level, the effect on carcass weight due to the nutrient deficiency is estimated and the estimated loss of premiums (i.e., premium penalties) is computed and added to the benefit of investing in NIRS. The daily net benefit of adopting NIRS is then annualised and aggregated to the farm level for two types of representative farms

2.4.2 Model Farm Descriptions

The representative smaller sized farm used in this study is 1630 hogs approximating the average herd size in Alberta reported by Statistics Canada (Brisson, 2014; Statistics Canada, 2012a). If the value of NIRS adoption is dependent on the marginal cost savings generated for each head of hog, then the size of the hog farm can be a limiting factor for investment in the technology. To have an idea of the extent to which farm size limits investment two representative farms sizes are utilized in the analysis. The first representative farm depicts the small-sized Albertan hog farm. The other representative farm depicts a larger farm. On average, Alberta tends to have relatively smaller hog farms than Manitoba. In fact, the

Agriculture Ministry in Manitoba uses a representative farm that is approximately seven times the average Alberta herd size reported by Statistics Canada. This representative farm in Manitoba with 11920 head of hogs would be more typical of a larger Albertan farm (Manitoba Agriculture, Food and Rural Development [MAFRD], 2015). The analysis for the two farm size types gives aims to estimate the scale impacts of hog operations on investment in NIRS.

2.4.2.1 Stages of Production

It is assumed that each representative farm is a feeder-to-finish operation. As such there are no feed costs associated with sows and boars. In these representative farms, young piglets are grown until it is time for slaughter. In keeping with National Research Council (NRC, 1998, 2012) optimal hog growth is maintained by dividing the growth process of the hog into seven stages. As depicted in Table 2.1, each of the seven growth phases has a different set of nutrient requirements needed to maintain optimal growth.

2.4.2.2 Applicable Feed Ingredients

For each representative farm the initial pool of potential feed ingredients used to feed hogs is based on information in the NRC publication about nutrient requirements for hogs (NRC, 2012). To model hog diets reflective of Alberta farms, expert opinion was used to reduce the longer list to 21 potential ingredients. As seen in Table A.1, the pool of ingredients considered in the analysis comprises grains, protein feed, vitamins and minerals, and fats and oils. To reflect typical practice in industry, industry expert opinion is also used to guide maximum ingredient usage limits (Table 2.2) with diet being assessed on an as-fed basis instead of a dry matter basis. Generally, as the hog grows the diet is less restrictive.

Table 2.1 Nutrient Requirements for the Seven Hog Growth Stages

Stage	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7
Days in Stage	10	12	24	33	28	27	40
Weight Class (kg)	5-7	7-11	11-25	25-50	50-75	75-100	100-135
Feed intake (g/day)	280	493	953	1,582	2,229	2,636	2,933
Net energy, kcal/kg	2,448	2,448	2,412	2,475	2,475	2,475	2,475
Calcium (%)	0.85	0.80	0.70	0.66	0.59	0.52	0.46
Phosphorus, Available (%)	0.70	0.65	0.60	0.56	0.52	0.47	0.43
Crude Protein (%)	21	22	22	19	16	16	15
Crude Fat (%)	4	4	3	3	3	3	3
Sodium (%)	0.28	0.22	0.15	0.15	0.15	0.15	0.15
Zinc (MG/KG)	209	202	136	133	131	127	127
Copper (MG/KG)	17	22	29	24	23	23	23
Selenium (MG/KG)	0.52	0.54	0.45	0.45	0.45	0.45	0.45
Vitamin A (kIU/KG)	13	11	5	5	5	5	5
Vitamin D3 (kIU/KG)	3.10	2.63	1.00	1.00	1.00	1.00	1.00
Vitamin E (kIU/KG)	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Phytase (FTU)	2,305	1,858	500	500	499	499	499
Xylanase (U/kg)	1,120	1,120	2,800	2,800	2,800	2,800	2,800
Magnesium (%)	0.15	0.15	0.17	0.18	0.19	0.20	0.20
Potassium (%)	0.35	0.30	0.25	0.10	0.00	0.00	0.00

MG-milligrams, KG- Kilograms, %- percent of diet on an as-fed basis, g-grams, kcal-Kilo-calories, FTU-Phytase Activity Unit, kIU- 1000 International units, U- units

Source: NRC (2012) and Swift(2014c)

2.4.2.3 Nutrient Content and Variability of Feed Ingredients

It is assumed that all 21 potential feed ingredients are purchased by the producer. As a result, it is further assumed that since all the ingredients except for wheat, barley and peas undergo some level of processing, the quality is monitored and assured by the processor. It is also assumed that corn would be imported from the U.S. and the quality would be at least somewhat reflective of the grade verified at the port of entry. Conversely, wheat, barley and peas are assumed to be purchased locally and so quality as defined by nutrient content is uncertain or risky.

Table 2.2 Maximum Allowed Usage of Each Ingredient

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7
Barley (% of diet)	0	0	0	10	10	20	20
Wheat (% of diet)	100	100	100	100	100	100	100
Canola Meal (% of diet)	0	0	15	15	20	20	20
Ground corn (% of diet)	15	15	100	100	100	100	100
Oat groats (% of diet)	15	15	15	15	15	15	15
Peas (% of diet)	0	0	5	10	15	20	20
Soybean Meal (% of diet)	25	25	100	100	100	100	100
Wheat DDGS (% of diet)	1	1	10	10	20	20	20
Fish meal (% of diet)	5	5	5	5	5	5	5
Whey powder (% of diet)	10	10	0	0	0	0	0
Salt (% of diet)	10	10	100	100	100	100	100
Vitamin premix (% of diet)	1	1	1	1	1	1	1
L-methionine (% of diet)	1	1	1	1	1	1	1
L-lysine HCL (% of diet)	1	1	1	1	1	1	1
L-threonine (% of diet)	1	1	1	1	1	1	1
Poultry fat (% of diet)	0	0	5	5	5	5	5
Canola oil (% of diet)	3	3	3	3	3	3	3
Limestone (% of diet)	100	100	100	100	100	100	100
Potassium chloride (% of diet)	100	100	100	100	100	100	100
Di-calcium phosphate (% of diet)	100	100	100	100	100	100	100
Magnesium oxide (% of diet)	100	100	100	100	100	100	100

Source: Swift (2014b)

It is further assumed that only crude protein content in select feedstuffs (i.e., peas, barley and wheat) is variable.[8] It is further assumed that the distribution of crude protein content can be summarised by the mean and the variance. Figure 2.5 and Table 2.3 describe the data used to characterise variability of protein content on an as-fed basis. Table 2.3 is sourced from the NRC (2012) publication while the distributions in Figure 2.5 are generated using the parameters in Table 2.3. In the LCRMs used in this study, crude protein is linearly related to amino acid content in feedstuffs (Table 2.4). The linear

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[8] NIRS technology can test for levels of other nutrients such as starch and fibre content. Starch can be used to predict energy levels in ration ingredients. However, the available information from NRC's Nutrient Requirements of Swine did not include estimates of variability of starch, ash and fibre content for all feedstuffs of interest.

relationships are factored into the LCRM per the specifications of Nutrient Requirement of Swine Nutrition Guide (NRC, 1998). As the crude protein levels vary by feedstuff, levels of amino acid made available by the feedstuffs vary as well. Allowing crude protein levels to vary but not amino acid levels could result in inaccurate rations and associated ration costs.[9]

Table 2.3 Crude Protein Distribution Statistics

Ingredient	**Mean**(μ_{ij})	**Variance**(σ_{ij}^2)
Wheat (% on an as-fed basis)	14	6.30
Barley (% on an as-fed basis)	11	2.37
Peas (% on an as-fed basis)	22	2.28
i denotes crude protein nutrient and j denotes the crop.		

Source: NRC (2012)

Table 2.4 Relationship between Crude Protein (CP) and Key Amino Acids

	Barley	**Wheat**	**Peas**
Lysine (%)	0.133+0.0235*CP	-0.027+0.0306*CP	0.483+0.0485*CP
Threonine (%)	0.044+0.0299*CP	0.008+0.0284*CP	0.349+0.0207*CP
Methionine (%)	0.019+0.0152*CP	0.003+0.0157*CP	0.021+0.0072*CP
Cysteine (%)	(0.101+0.0301*CP)-Methionine (%)	(0.075+0.0322*CP)-Methionine (%)	(0.129+0.0155*CP)-Methionine (%)
Tryptophan (%)	0.023+0.0095*CP	0.065+0.0099*CP	0.05+0.0066*CP

Source: NRC (1998)

2.4.2.4 Feed Prices

Nutrient content of potential ingredients, per animal nutrient requirements, and ingredient prices are all important parameters used to determine the optimal ration. If the relative price of an ingredient vis-à-vis another ingredient changes significantly, then the optimal ration could change as well. However, if farmers are averse to undersupplying nutrients they may be reluctant to alter the ration due to feed price changes. Instead they may choose to absorb higher costs to ensure that adequate nutrients are

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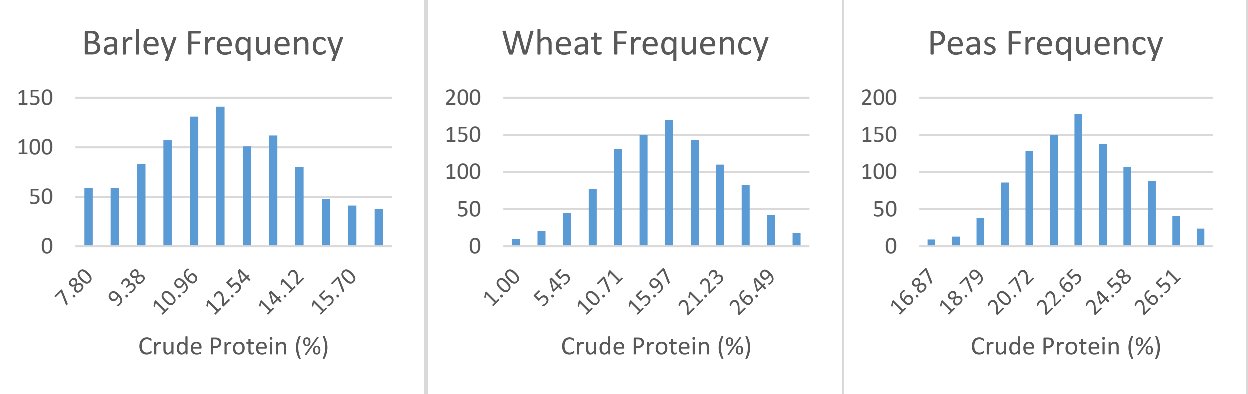
[9] From a programming perspective creating the linear dependency of amino acids on crude protein in three of 21 feedstuffs is not expected to have implications for arriving at an optimal solution. A requirement to have basic solutions is that the rows of the constraint (A) matrix must be linearly independent. For each feedstuff, the amino acid relationship to crude protein is different and so those nutrient constraint rows will be linearly independent.

supplied. Using NIRS improves the reliability of information regarding nutrient content and allows the producer to be more confident in responding to ingredient price changes. In this study, prices of feed ingredients are not allowed to vary to ensure that the welfare measure would be path independent (as discussed in section 2.3.1.3). Also, historical feed prices tend to be highly correlated and so it would be unlikely to have a significant increase in one ingredient and not have somewhat commensurate increases in other ingredients. In the end, relative price changes should be minimal. As a result, this study uses prices received as at May 31, 2014 to represent relative prices of the feed ingredients (Table 2.5). [10]

Figure 2.5 Crude Protein Distribution of Barley Wheat and Peas



Source: Author using data from NRC (2012)

2.4.3 Least Cost Ration Models (LCRMs)

As noted earlier, least cost ration models (LCRMs) are used to investigate the impact of the adoption of NIRS. This section introduces the basic structure and assumptions for LCRMs are as well as variations on the basic LCRM. In short, an LCRM is an optimization model that seeks to minimize the cost of the ration

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[10] A CAN$:US$ exchange rate of 1.39 CAN$: 1US$ (effective December 18, 2015) is obtained from Bank of Canada (BoC) website (BoC, 2015). This exchange rate is used to convert US dollar denominated feed prices into Canadian dollars.

while satisfying the minimum nutrient requirements needed for optimal growth. Linear programming (LP) techniques have been applied to minimum cost ration formulations. The general formulation is given by

$$\text{Minimise Cost} = \sum_j w_{\mathrm{j}} X_j \tag{2.8}$$

$$subject\ to: \quad AX \geq b \ldots nutrient\ requirement\ restrictions$$

$$CX \leq d \ldots ingredient\ limit\ restrictions$$

In the linear programming LCRM formulation of Equation 2.8 X_i represents the i^{th} feedstuff, w_i denotes the price of the i^{th} feedstuff, the matrix A demarks the nutrient composition coefficients (a_{ij} is the amount of the i^{th} nutrient per unit of the j^{th} feed ingredient), X is the vector of feedstuffs, and b denotes the vector of nutrient requirements that must be satisfied (b_i is the requirement for the i^{th} nutrient). C is the coefficient matrix for feed restrictions and d is the vector of feedstuff limits in the ration.

Table 2.5 Feed Ingredient Prices

Ingredient	Canadian $ / Tonne	Ingredient	Canadian $ / Tonne
Barley	170	**Vitamin premix**	4,000
Wheat	190	**L-methionine**	3,382
Canola Meal	386	**L-lysine HCL**	1,626
Ground corn	225	**L-threonine**	3,131
Oat groats	424	**Poultry fat**	780
Peas	230	**Canola oil**	924
Soybean Meal	455	**Limestone**	50
Wheat DDGS	253	**Potassium chloride**	6,263
Fish meal	2,650	**Di-calcium phosphate**	1,127
Whey powder	1,242	**Magnesium oxide**	1,065
Salt	83		
Prices are as at May 31, 2014			

Source: USDAERS(2014), ACPC (2014), Swift (2014a)

This LP approach assumes that all coefficients and RHS coefficients in the constraints are known with certainty and assumes linear relationships between ingredients. In reality, price coefficients, nutrient composition of ingredients and even nutrient requirements are stochastic. For example, published nutrient requirements represent an average guideline for a representative hog but since not all hogs are the same there is a chance that the optimal requirements for a specific hog do not align with those listed for the representative hog. In a market economy, ingredient price changes almost daily to reflect changes in demand and supply. Also, nutrient composition in grains, for instance, may vary for each grain depending on weather conditions, application of fertiliser by the farmer or by the plant's biological ability to absorb nutrients from the soil.

The assumption of linear relationships between ingredients is important in that there are no interaction effects on growth among feedstuffs, which ignores both positive and negative interactions that could arise. For example, there may be two ingredients that if used individually would result in the fixed nutrient contribution to the diet but when used together could increase the nutrient availability by more than the sum of their individual contributions. For example, the addition of phytase enzyme to a diet increases the availability of phosphorus in the ration mix. Alternatively, the combination of two or more ingredients in a ration mix could lead to reduced overall feed intake and nutrient absorption. This could be due either a change in odour or taste brought about by the combination of the ingredients in the ration mix that would not have occurred if the ingredients were used separately. Due to this palatability issue, there is reduced nutrient intake and as such the total nutrients available combined are less than the sum of the individual contributions.

Linear relationships also mean that ingredients are perfectly substitutable in the ration. This may not always be the case. For example, this could be due to palatability as well as other practical concerns such as pelleting. In the case of pelleting, if the price of wheat and barley increased significantly relative to the cost of restaurant grease (a potential alternative energy source in rations) then it would not be practical to substitute the grease for grains in the diet to keep costs low and meet energy requirements, as it would be infeasible to pellet the feed due to the high grease content. Furthermore, there is no guarantee that the hog would be willing to feast on vitamin-enriched grease sludge. To control for this, ingredient limits are added to the model.

Work by Waugh (1951), Fisher and Shruben (1953), Hutton and Allison (1957), Brown and Arscott (1960), Howard et al. (1968) and Allison and Baird (1974) lay the platform for LCRM, providing diet formulations for livestock and poultry. Subsequent LCRMs focused on addressing the limitations posed by the assumptions of the basic version of the model and include literature on chance constrained programming in ration models (the focus of this study), stochastic programming and multi-objective goal programming.

2.4.3.1 Chance Constrained Programming and Joint Chance Constrained Programming

The basic LCRM is constructed on the premise that nutrient content of feedstuffs is known with certainty. This could lead to inaccurate formulations if nutrient content variation is significant. Concurrently analysed in the emerging period of LCRMs is the notion of chance constrained programming. The work of Charnes and Cooper (1959) brings to the fore the idea (in mathematical programming) of optimising the objective function subject to a given probability of satisfying a constraint (McCarl & Spreen, 2003). This formulation is known as chance constrained programming (CCP). Charnes and Cooper (1959) use a logistical problem of a tankage facility to illustrate the increased level of complexity (in the form of non-linearities) associated with CCP. In their analysis, Charnes and Cooper (1959) assume that the RHS of a constraint is a random variable with a known distribution. Miller and Wagner (1965) later extend the work of Charnes and Cooper (1959) by highlighting that non-linearity in the optimization problem may also occur if the random variable is also on the left-hand-side

(LHS) of the constraint. This finding is important especially in LCRMs as variable nutrient content of feedstuffs (which are the LHS coefficients in the ration model constraints) are relevant in least cost ration formulations.

In the context of livestock rations, St. Pierre and Harvey (St. Pierre & Harvey, 1986) extend the work of Charnes and Cooper (1959) and Miller and Wagner (1965). Given an assumption that more than one ingredient nutrient is random, jointly distributed nutrient contributions are used. Such a framework is known as joint chance constrained programming (JCCP). The general construct of their programming problem is given by:

$$\text{Minimise Cost} = \sum_j w_j X_j \tag{2.9}$$

subject to: $$\text{Prob}\left[\sum_j a_{ij} X_j \geq b_i\right] \geq \alpha \text{ for i} = 1,2,3,\dots,\text{k uncertain nutrient constraints}$$

$$\sum_j a_{ij} X_j \geq b_i \text{ for i} = \text{k} + 1, \text{k} + 2, \text{k} + 3, \dots, \text{m certain nutrient constraints}$$

$$X_j \geq 0$$

where w_j represents the per unit cost and X_j the amount used of the j^{th} feedstuff a_{ij} represents the amount of the i^{th} nutrient provided per unit of the j^{th} feedstuff and b_i is the i^{th} nutrient requirement, $\text{Prob}[\cdot]$ denotes probability and α is the minimum required probability of meeting all nutrient constraints. The first set of constraints in Equation 2.9 imply that nutrient requirements for the first k nutrients must be met with at least the assigned probability α, while the second set represents those nutrient requirements for which there is no nutrient content variability.

If the mean nutrient content is subtracted from both sides within the probability bracket in the first constraint set of Equation 2.9 and both sides are divided by the square-root of the variance-covariance matrix we obtain Equation 2.10. The left-hand-side of the inequality resembles the standard normal statistic and so Equation 2.10 can be rewritten as Equation 2.11 assuming a normal distribution.

$$\text{Prob}\left[\frac{\sum_j a_{ij}X_j - \sum_j \mu_{ij}X_j}{\sqrt{\text{Var}\left(\sum_j a_{ij}X_j\right)}} \geq \frac{b_i - \sum_j \mu_{ij}X_j}{\sqrt{\text{Var}\left(\sum_j a_{ij}X_j\right)}}\right] \geq \alpha \tag{2.10}$$

$$Z_\alpha \geq \frac{b_i - \sum_j \mu_{ij}X_j}{\sqrt{\text{Var}\left(\sum_j a_{ij}X_j\right)}} \tag{2.11}$$

Rearranging Equation 2.11, the revised LCRM can be written as outlined in St. Pierre and Harvey (1986), D'Alfonso et al. (1992), and Tozer (2000):

$$\text{Minimise Cost} = \sum_j w_j X_j \tag{2.12}$$

Subject to:

$$\sum_j \mu_{ij}X_j + Z_\alpha \sqrt{\sum_j \sigma_{ij}^2 X_j^2} \geq b_i$$

$$X_j \geq 0$$

where μ_{ij} and σ_{ij}^2 are the mean and variance, respectively, of nutrient content for the i^{th} nutrient in feedstuff X_j. Z_i is the standard normal score for α, which represents the desired probability of meeting nutrient requirements.[11] In the above formulation, the constraints are non-linear. St. Pierre and Harvey (1986) noted that if only one nutrient is random then the first constraint in Equation 2.11 can be solved via a linear approximation but if there is more than one random nutrient then a non-linear technique

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[11] For constraints where there is no nutrient uncertainty, $\sigma_{ij}^2 = 0$ and hence the second term will equal zero and all that would remain are the means. Therefore, certainty is a specific example of this more general formulation.

should be employed. St. Pierre and Harvey (1986) assumed that crude protein and net energy were random and used non-linear techniques to determine the least cost ration formulation.

The margin of safety (MOS) model, also known as the linear programming margin of safety (LPMS) model, uses a linear approximation of the first constraint in Equation 2.12 (D'Alfonso et al., 1992; Rahman & Bender, 1971)(D'Alfonso et al., 1992; Rahman & Bender, 1971), given by:

$$\sum_j \mu_{ij}X_j + Z_\alpha \sum_j \sigma_{ij}X_j \geq b_i \tag{2.13}$$

The constraint in Equation 2.13 is more restrictive than the constraint of Equation 2.12 and hence the minimum feed cost from LPMS will be at least as great (and in general greater) than that resulting from the solution for Equation 2.12 (D'Alfonso et al., 1992). The LPMS approximation entails the assumption that the square root of the sum is approximately equivalent to the sum of the square roots. For example, D'Alfonso et al. (1992) base the approximation in Equation 2.13 on $\sqrt{a+b} \approx \sqrt{a} + \sqrt{b}$. For positive values of a and b, $\sqrt{a+b} < \sqrt{a} + \sqrt{b}$. It would require increasingly more feedstuff X_j to meet b_i relative to that of the formulation in Equation 2.12. This additional buffer is called the MOS. This holds true for $\alpha > 0.5$; as long as the exogenously set required probability of meeting the nutrient requirements is greater than 50%, then $Z_\alpha < 0$. Consequently, the closer the required probability of meeting nutrient constraints gets to 100% the larger the buffer or MOS. This approximation is quite robust in cases in which nutrient variations are relatively small (D'Alfonso et al., 1992).

Although CCP and its variants represent an intuitive approach to modelling constraint risk, there have been criticisms of the approach based mainly on the need to define a predetermined probability of meeting the stochastic constraint(s). Questions regarding the acceptable level and the overall endogeneity of the probability of not meeting the nutrient requirement (Peña, Lara, & Castrodeza,

2009) as well as the model implications in the event of a nutrient violation (McCarl & Spreen, 2003) have been some of the primary objections to this approach. In the current study a baseline probability is set based on input and insights from an industry professional. Sensitivity analyses are then undertaken for different probabilities of successfully meeting nutrient requirements as well as cost penalties for violation of the requirements.

Other approaches have been advocated to handle nutrient variability such as stochastic programming (Tozer, 2000) and fuzzy optimization (Cadenas, Pelta, Pelta, & Verdegay, 2004). Each of these alternatives have their own challenges as well. Although non-linear solvers are readily available, stochastic programming problems still suffer from convergence issues especially in large models and models with non-linear constraints. Separable programming is a means of dealing with non-linearities in feed formulations. For example, Hadrich, Wolf, Black and Harsh (2008) use separable programming in incorporating nutrient disposal costs into the ration formulation. Although separable programming may be a viable alternative for modelling non-linearities, it is still a linear approximation to a non-linear problem, similar to the LPMS model, and its use in the literature focuses mainly on non-linear responses to nutrient levels rather than the variability of nutrient content in feedstuffs (Black & Hlubik, 1980; Saxena & Chandra, 2012).

Fuzzy ration programming is a complex method dealing with nutrient uncertainty. In the general specification allowances are made for “small” violations of the constraints (Cadenas et al., 2004), but how is “small” defined? This could lead to the same limitation as seen under chance constrained programming but would be just as, or if not more, computationally intensive.

2.4.4 The Base Scenario- No NIRS Adoption

This scenario is akin to the case for the theoretical model in which $\widehat{\theta} = 0$ (Section 2.3.2). Here hog producers are aware that crude protein content in peas, barley and wheat is variable but only know the mean and standard deviation of nutrient content and are averse to under supplying nutrients to their hogs. To account for this, a linear programming margin of safety model is solved (LPMS). Recall, the LPMS is the linearized version of the chance constrained least cost ration model (CCRM) that creates a nutrient buffer as a means of giving the farmer greater confidence that nutrient requirements are not violated. Assuming normally distributed stochastic nutrient levels of feed, one can formulate and solve LPMS following D'Alfonso et al. (1992). The general specification is given by

$$\text{Minimise Cost} = \sum_{j} w_j X_j \tag{2.14}$$

subject to: $\sum_j (\mu_{ij} + Z_\alpha \sigma_{ij}) X_j \geq b_i$ ... for i = crude protein constraint

$\sum_j a_{ij} X_j \geq b_i$ for i = all other nutrient constraints

$CX \leq d \ldots ingredient\ limit\ restriction$

$X_j \geq 0$

where all parameters are defined as before. In this scenario without NIRS, the LPMS is optimized for the least cost ration given a predetermined probability of meeting the nutrient requirements. It is assumed that the required probability of meeting all nutrient requirements is 95%. This means that if the farmer purchases feed inputs weekly and the hog takes approximately 25 weeks to mature, then 5% of the time, or for approximately nine days' worth of feed purchases in a given year, the ration is expected to violate nutrient requirements. Following St. Pierre and Harvey (1986), Tozer (2000) and Roush et al. (2007) sensitivity analysis is done for the probability of not meeting the nutrient requirement by varying

α. The means and the standard deviations of protein content for barley, wheat and peas, provided in Table 2.6, are used in the first constraint of Equation 2.14. The model is solved for each of the seven growth stages and the daily cost for feeding a hog in each stage is obtained. The daily cost is aggregated across all seven growth stages based on the days in each stage, to obtain a representative cost per head.

2.4.5 The Counterfactual Scenario- NIRS Adoption

In this scenario NIRS is adopted by the representative hog farms with the intent of using it to identify crude protein levels in wheat, barley and peas. It is assumed that the NIRS machine eliminates the uncertainty of nutrient content and therefore the actual nutrient content can be observed. Hence, the use of NIRS is akin to having complete information ex ante; that is, $\widehat{\theta} = 0$ in the theoretical model. To empirically capture this certainty scenario, nutrient content in feedstuffs is assumed to follow a predetermined distribution and the true observed nutrient content in each feedstuff is observed by sampling from the distributions. A full information LCRM is optimized for each sampled observation of nutrient content. The general formulation of the problem is presented in Equation 2.8. The model is solved for the seven growth stages and the daily cost for feeding a hog in each stage is obtained. This sample (protein content draw from independent distributions) and solve (the full information LCRM) procedure for the crude protein content is repeated 1000 times. This provides a representative cost distribution under the counterfactual scenario. The daily costs are aggregated across all seven growth stages based on the days in each stage to obtain a representative cost per head.

There are two types of NIRS machines in which the representative farm can invest. The first is a process analyser. It is best suited for analysing nutrient content “on-the-fly”, and is mainly used by feed mills, flour mills, feedlots or any system in which the products to be analysed are on a conveyor belt system. The cost of the Foss NIRS process analyser is approximately CAN$130,000 and its annual maintenance cost is approximately CAN$6,000. The other mode of NIRS investment is the NIRS sample analyser.

Unlike the process analysers random samples are analysed and inference is made about the population. The cost of the NIRS sample analyser ($40,000) and its annual maintenance cost (3% of procurement cost) is adopted from Li (2014).

As noted earlier, the maintained assumption here is that NIRS adoption eliminates uncertainty. This assumption is made for both types of NIRS machines. However, in reality the use of the sample analyser technology may not eliminate nutrient variability. Given that this machine tests samples of ingredients (rather than all of feedstuff, as with the process analyser), the resulting nutrient content value is an average of the samples. There will still be uncertainty associated with the content for the entire “lot” of ration ingredient, that can be expressed as a variance. However, this variance would be smaller than if no testing is done at all.

2.4.6 Estimation of Premium Penalties, Cost Savings of NIRS Adoption and Total Net Benefits of NIRS Adoption

In acknowledging that there may be times in which the actual nutrient content in the feed is less than what was expected under the base scenario, this research asserts that there is a cost associated with nutrient intake being lower than expected. The assumption made here is that if protein consumed is less than required, there is a negative impact on the eventual lean carcass weight of the hog. This in turn will have a negative impact on the price received for the hog. This section outlines the series of steps required to monetise the impact of crude protein deficiency.

The first step in estimating premium penalties is to compute the instances of nutrient requirement violation. For each true nutrient content draw, the level of crude protein (cp) content is computed using the actual nutrient levels from the draw and optimal ration composition from the base model. If the true crude protein levels are less than what is required, then the nutrient deficiency (ND)is computed as:

$$ND = \left(b_{cp} - \left[\mu_{bar}^{actual} X_{bar} + \mu_{wht}^{actual} X_{wht} + \mu_{peas}^{actual} X_{peas} + \sum_j \mu_{cp,j} X_j\right]\right) \cdot TOTRAT \quad (2.15)$$

where bar, wht and peas denote the barley, wheat and peas ingredients, respectively, while j represents all other ingredients. μ represents crude protein in the feedstuff and b_{cp} is the required crude protein content of the ration under the base scenario. $X's$ represent the proportion of diet devoted to an ingredient. The ration size is the kilogram daily intake per head. The superscript actual indicates that crude protein content is based on the simulated draw from the distribution. TOTRAT denotes the total size of the ration fed to the hog.

Campbell, Taverner and Curic (1985) investigated the impact of changes in crude protein levels within a hog's diet on the average daily live and carcass weight gain. Based on data from Campbell et al. (1985), Ordinary Least Squares regression analysis is conducted to estimate the marginal impact of percentage protein intake on the protein weight deposition in the carcass (Table 2.6).

Table 2.6 OLS Results of Protein Composition of Carcass on Crude Protein Percent Intake

Dependent Variable: Protein Composition of Carcass (% ×10)	**Coefficients**	**Standard Error**	**t Stat**	**P-value**
Intercept	113.07	5.9465	19.01	0.0000
CP (% ×10)	0.31	0.0353	8.62	0.0000
F-statistic	74.5			
Number of Observations	23			
R-squared	0.78			
***Based on Data from Campbell** et al. (Campbell et al., 1985)**-Table 5 Effects of feeding level and dietary protein between 20 and 45 kg on the carcass composition of pigs at 45kg live weight.**				

Source: Author using data from Campbell et al. (1985)

The nutrient deficiency percentage (multiplied by 10) is multiplied by the marginal impact on carcass protein composition to estimate the protein weight loss per day per animal for the respective stage of production. The protein weight loss is then multiplied by the days spent in each stage and summed to obtain the total loss in carcass weight per animal. The protein weight loss is then valued (Table 2.7) using the estimated change in price premiums paid by the Western Hog Exchange (Table A.2) in relation to the change in carcass weight categories.

Table 2.7 Weight Change and Price Change Relationship

	Weight Change (kg)				
	-10 to -5	-5 to 0	0	0 to 5	5 to 9
Price Change (CAN$/head)	-18	-5	0	0	0

*Weight gains are not penalized by the model. Values are based on the average annual hog carcass price US$86.00 /cwt and the average annual exchange rate of CAN$1.03:US$1.00 for 2013 and a conservative 50% ad hoc reduction in the economic impact of protein deficiency.

Source: Author using data from Alberta Pork (2017), Bank of Canada (BoC) (2018), Schulz (2017)

Finally, the loss in premiums per head are added to the cost savings gained by investing in NIRS to arrive at the total net benefit of NIRS adoption. The cost savings from the investment in NIRS, for each crude protein draw in the counterfactual scenario, is the cost generated by the base scenario less the cost generated by the counterfactual scenario.

2.4.7 Net Present Value Calculations

To assess the welfare impact on hog producers, the discounted total benefits must be weighed against the cost of procurement. Based on advice from experts in the field, the estimated life of the NIRS machine is determined to be approximately 20 years. As such, the associated benefits from the adoption of the NIRS technology are assessed and quantified over a 20-year period. Since these welfare values occur over an extended period of time, the net benefits are first discounted to arrive at a present value equivalent and then summed. The discounted difference in the median annual ration cost without and with NIRS less the initial investment outlay represents the NPV benefit to the hog producer of investing in the NIRS machine. If the present value net benefit is positive, then there are welfare gains from adoption of the technology and investment in the machine is feasible.

In capital budgeting, the NPV of the adoption of the technology is given by:

$$NPV = -I_o + \sum_{t=1}^{20} \frac{NB}{(1+r)^t} \tag{2.16}$$

In Equation 2.16, I_o represents the initial outlay made in purchasing the NIRS machine, NB are the annual net benefits resulting from the use of the NIRS machine to evaluate feed protein quality, r is the discount rate and t is an annual time index.

The discount rate describes the firm's opportunity cost of capital for investment in the project. Weighted average cost of capital would be the preferred method of discounting as it likens risk of a project to the risk of the firm (Horngren, Foster, & Datar, 2000). This is a risk-adjusted discount rate that takes in to consideration a firm's financial and business risk (Logsdon, 2013) in such a way that the greater the WACC the less attractive will be longer term investment as it will be difficult to source financing to cover the cost of the project. Therefore, the WACC would by a good proxy for a discount rate. However, WACC requires detailed information on the capital structure of the farm, and as such it is not easy to define a representative hog farm capital structure by using the WACC approach. Instead, this study utilizes range of private discount rates based on previous literature. The base discount rate used in this study is 8% and follows Li (2014) who assessed NIR investment in Alberta and Savard (2000) who assessed policy impacts on trade-offs between water quality and hog industry welfare in central Canada. Apushev (2004) used a discount rate of 4.55% based on calculations of WACC for a hog farm in central Canada. This gives context for the lower bound of the range to be 5% while a discount rate of 10%, employed by Yiridoe, Gordon and Brown (2009) who assessed the feasibility of hog farm biogas energy production in central Canada, forms an upper bound to capture realistic sensitivities to the discount rate as provided in the literature.

The Internal Rate of Return (IRR) is also computed. This method reports the rate of return on the investment that would make the NPV of the project equal to zero. The return percentage can then be compared to the discount rate to determine the feasibility of investment. If the IRR is equal to or exceeds the discount rate or the required rate of return, then investment is feasible.

$$IRR\ is\ r\ such\ that\colon\ -I_o + \sum_{t=1}^{20} \frac{NB}{(1+r)^t} = 0 \tag{2.17}$$

2.5 Results and Discussion

The objective of this study is to assess the economic impact NIRS technology has on Albertan hog producers' ration cost and to assess the viability of investment in the technology. The results are presented first in terms of the cost impact of NIRS technology, followed by the NPV analysis. Thereafter, results from sensitivity analyses are presented and the section concludes with a summary and discussion.

2.5.1 Results: The Base Scenario- No NIRS Adoption

The base scenario (i.e., no NIRS adoption) results indicate daily ration costs per head increase as the hog grows; from \$0.12 for a starter to \$0.66 for the finisher (Table 2.8). For the representative hog, the costs accruing to feed it through all seven stages total \$82.42.

Table 2.8 Summary Output from the Base Optimization of Ration Costs (NO-NIRS)

Inputs					Output	
Model	**Growth Stage**	**Days in Stage**	**Daily Gain (grams)**	**Daily Ration Size (kg) on an As-Fed Basis**	**Daily Ration Cost Per Head (\$)**	**Daily Ration Cost Per Kilogram of Ration (\$/kg)**
1	5-7kg	10	210	0.28	0.12	0.44
2	7-11kg	12	335	0.49	0.18	0.36
3	11-25kg	24	585	0.95	0.28	0.29
4	25-50kg	33	758	1.58	0.42	0.27
5	50-75kg	28	900	2.23	0.54	0.24
6	75-100kg	27	917	2.64	0.62	0.23
7	100-135kg	40	867	2.93	0.66	0.23

Source: Author using data from NRC (2012) and the simulation model

2.5.2 Results: The Counterfactual Scenario- Cost Savings Associated with NIRS Adoption

In the NIRS adoption scenario the LCRM model is solved for each crude protein draw. This results in a distribution of ration costs. A summary of the results for the NIRS adoption scenario is shown in Table 2.9. As seen in Table 2.9, the mean and the range of feed costs increase as the hog progresses through the different growth stages. The base costs in Table 2.8 represent the 75th percentile of costs in Table 2.9 for the first five stages of production. For the last two stages the base cost exceeds the 75th percentile costs in Table 2.9. This indicates a high likelihood of cost savings to be realized with the adoption of NIRS.

Table 2.9 Summary Results of Simulation for LCRM Model (With NIRS)

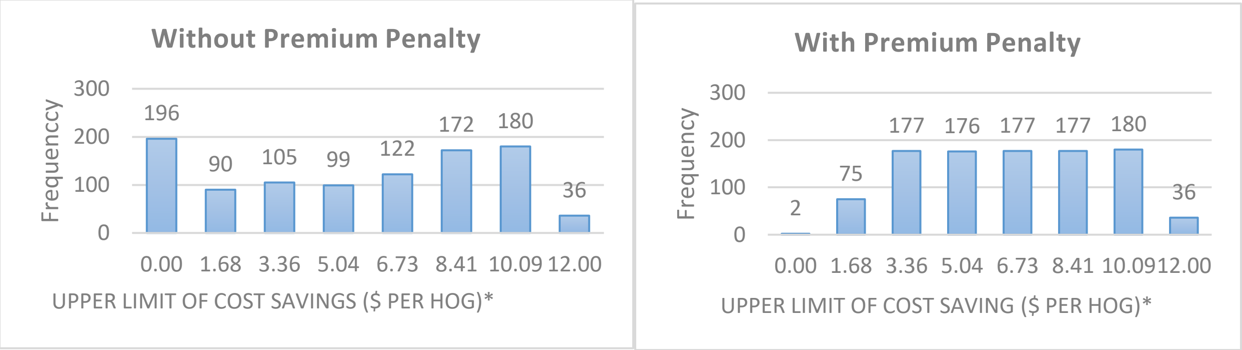
Input			**Output**					
			Feed Cost with NIRS ($/head/day)					
Model	**Growth Stage**	**Days in Stage**	**Min**	**25% Percentile**	**Average**	**Median**	**75% Percentile**	**Max**
1	0-7kg	10	0.10	0.11	0.12	0.12	0.12	0.15
2	7-11kg	12	0.15	0.16	0.17	0.17	0.18	0.20
3	11-25kg	24	0.22	0.25	0.26	0.26	0.28	0.29
4	25-50kg	33	0.35	0.36	0.39	0.39	0.42	0.45
5	50-75kg	28	0.48	0.49	0.52	0.51	0.54	0.59
6	75-100kg	27	0.55	0.56	0.58	0.58	0.60	0.65
7	100-135kg	40	0.59	0.60	0.63	0.62	0.65	0.71

Source: Author using data from NRC (2012) and the simulation model

When aggregated over the entire feeding period for a representative hog, the median feed cost under the NIRS adoption scenario is $77.22 per animal. Additionally, in slightly more than 50% of the iterations (510 of 1000) a hog farmer could save at least $5.00 per hog sold from increased information about nutrient content in the ration. The median cost savings is $5.22.

Figure 2.6 shows the distributions of cost savings with and without consideration of growth impacts of crude protein deficiency. When growth impacts are not considered, the benefits of adopting NIRS technology would be obtained 80 percent of the time. The 20 percent chance of negative benefits occurs where the actual protein content is lower than expected, so that if that's taken into account we end up with a higher feed cost. However, if the hog growth impacts of violating nutrient content (penalty premiums) are considered then the distribution changes significantly. The median ration cost savings per hog increases from $5.22 to $5.70 and the chance of benefitting from NIRS adoption climbs from 80% to almost 100%. In almost all instances where nutrient levels are lower than expected, it meant that the hogs would have been fed nutrient deficient meals. Nutrient deficiencies would then translate to losses in lean carcass weight which in turn results in foregone premiums. The true economic value of investing in NIRS not only takes into the consideration lower feed cost but also optimal feed related benefits. Putting these results in context, recall that based on information in Figure 2.1, hog margins are approximately $20.00 per head in May 2016. Expected cost savings from NIRS adoption would thus increase margins by more than 25 percent.

Figure 2.6 Comparison of Cost Saving Distributions with and without Protein Deficiency Impacts.



*Upper limit of cost savings refers to the maximum savings generated from NIRS adoption for the distribution category.
Source: Author using data from the simulation model

2.5.3 Net Present Value Benefits of Adoption

Recalling that the median net benefit of NIRS adoption, taking into consideration penalty premiums, is approximately $5.70 per day or $2100 per annum per head of hog or approximately, a comparison is now made of the NPV benefits associated with adoption of the NIR analyser, taking into account the cost of procuring the technology. As noted earlier, there are two types of NIRS analysers: a) the process analyser and, b) the sample analyser. The process analyser ($130,000) costs approximately three times more than sample analysers ($40,000) and the annual maintenance cost for the process analyser ($6,000) is five times more than that of the sample analyser ($1200). The results indicate that process analysers are financially viable for larger farms (11,920 head), generating NPV benefits between $345,000 and $565,000 (with an IRR of 43 percent). However, investment in a process analyser is not economically feasible for the smaller farm (1,630 head). Sample analysers are economically feasible for both sizes of hog farm modelled in the NPV analysis (Table 2.10).

Table 2.10 Summary of NPV Analysis of NIRS Adoption

NIRS Analyser Type	**Operation Size (Number of Hogs)**	**Discount Rate (%)**	**Present Value Net Savings ($)**	**Cost of Procuring the Machine ($)**	**Median PV Net Benefits of Investing in NIRS ($)**	**IRR (%)**
Process Analyser	11,920 (Large)	5	697,907	130,000	567,907	43
		8	549,834	130,000	418,634	
		10	476,775	130,000	345,575	
	1,630 (Small)	5	90,705	130,000	-39,295	1
		8	71,461	130,000	-58,539	
		10	61,965	130,000	-68,035	
Sample Analyser	11,920 (Large)	5	697,907	40,000	657,907	140
		8	549,834	40,000	508,634	
		10	476,775	40,000	435,575	
	1,630 (Small)	5	90,705	40,000	50,705	17
		8	71,461	40,000	31,461	
		10	61,965	40,000	21,965	

Source: Author using data from the simulation model, Statistics Canada (2012a) and MAFRD (2015a)

2.5.4 Sensitivity Analyses

In this section, three sets of sensitivity analyses are conducted. The first is a test of the loss in accuracy used in the linear approximation chance constrained programming model relative to more accurate stochastic programming model. The second set of sensitivity analyses modifies the risk preference threshold; specifically, the minimum probability of meeting nutrient requirements is relaxed from 95% to 50%. The third sensitivity analysis investigates the differences in the distribution of NPV benefits from adopting NIRS.

2.5.4.1 LPMS versus Stochastic Programming

As noted in the Section 2.4.3.1, the linearized chance constrained programming model of D'Alfonso et al. (1992), LPMS model, is a linear approximation of the non-linear stochastic programming (SP) problem in D'Alfonso et al. (1992), Tozer(2000) and Roush et al. (2007). These authors argue that a stochastic programming model yields more accurate results than a LPMS model. This section tests for any significant difference in average net benefits generated between the two models. Equation 2.12 specifies the SP problem while Equation 2.14 specifies the LPMS problem. As presented in Section 2.5.2, a summary of 1000 observations of cost savings are generated using LPMS model. Similarly, 1000 observations of cost savings are generated using the SP model. A t-test is used to test whether the means between the two samples generated by the two models are significantly different. Since the sample size is large (1000 observations), through the central limit theorem, the t-distribution approximates the normal distribution. It is found that at a 95% level of confidence there is no significant difference in the mean costs savings between the two model types. Similar results are obtained when the cost of nutrient violations (premium penalties) is taken into consideration (Table 2.11). This implies that there are no statistically significant differences between the use of SP (non-linear programming) techniques and the linear programming (LPMS) model for determining cost savings and, on average, the LPMS is a fair approximation of the SP model and there is no significant loss of efficiency in using the linear approximation to estimate cost savings.

Table 2.11 Hypothesis Test for the Difference in Mean Cost Savings between LPMS Model and SP Model

Variable	**No Penalty Premiums[a]**		**With Penalty Premiums**	
	(1)	(2)	(3)	(4)
H_0: Null Hypothesis of equal means (columns 1 and 3) or mean M_1[b] is at least large as M_2[c] (columns 2 and 4)	$M_2-M_1 = 0$	$M_2-M_1 \leq 0$	$M_2-M_1 = 0$	$M_2-M_1 \leq 0$
H_1: Alternative Hypothesis means are not equal (columns 1 and 3) or mean M_2 is greater than M_1 (columns 2 and 4)	$M_2-M_1 \neq 0$	$M_2-M_1 > 0$	$M_2-M_1 \neq 0$	$M_2-M_1 > 0$
M_1	4.40	4.40	5.68	5.68
M_2	4.59	4.59	5.88	5.88
Sigma[d]	4.24	4.24	2.77	2.77
Z-Statistic[e]	0.0460	0.0460	0.0704	0.0704
Z-Critical	8.31	6.97	5.43	4.56
Result (95% Confidence level)	Fail to reject H_0	Fail to reject H_0	Fail to reject H_0	Fail to reject H_0

[a] Penalty premiums are the lean carcass premiums lost due to the deficiency of protein in the hog's diet associated with the non-adoption of NIRS.

[b] M_2 is the mean cost savings generated from the stochastic programming model.

[c] M_1 is the mean cost savings generated from the LPMS model.

[d] Sigma is the pooled standard deviation.

[e] The sample size for all tests is 1000 observations.

Source: Author with data from the simulation model

2.5.4.2 Sensitivity analysis of the Desired Probability of Meeting Nutrient Requirements

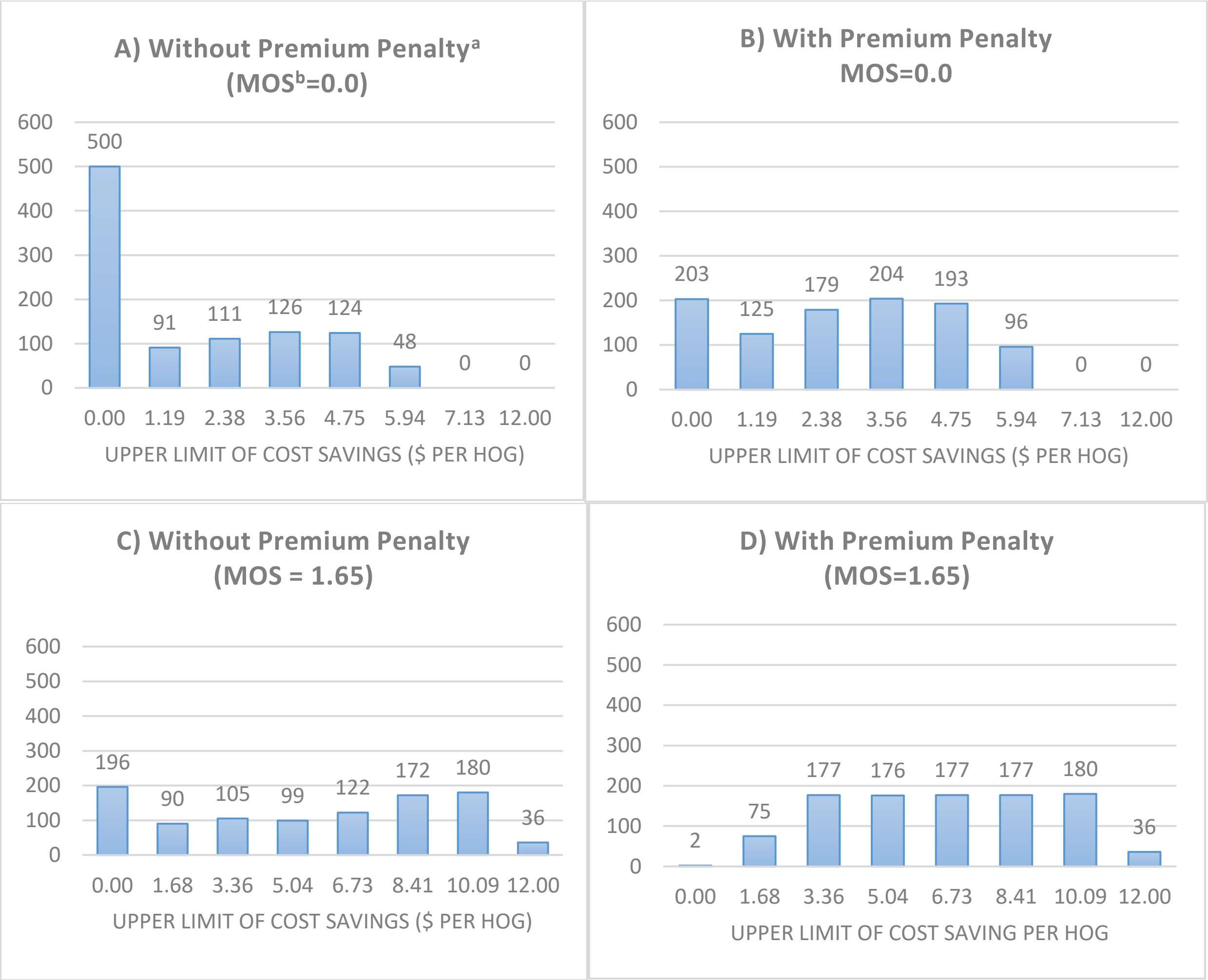
Sensitivity analyses are also conducted on the required probability of not-violating nutrient requirements. Roush et al. (2007) compared results from a 50% chance, which is equivalent to $Z_\alpha = 0$, to results from the original 95% probability which corresponded to $Z_\alpha = 1.65$. This this study follows a similar approach and finds that with $Z_\alpha = 0$ and initially ignoring growth effects, a farmer may not recognize the benefit of investing in NIRS as 50% of the times, adoption of NIRS would lead to increased feed costs. $Z_\alpha = 0$ means that the farmer's required threshold for meeting nutrient requirements is zero, therefore the farmer is not averse to risk of violating the nutrient requirement and as such optimizes the LCRM without the need of a buffer (which is created under the LPMS). This means that there is a cost associated with creating a buffer. Also, by investing in NIRS the farmer has full information about the nutrient content and in instances of nutrient deficiencies in ingredients the farmer must alter the feed mix albeit at a higher cost. The incorporation of the growth effects of nutrient requirement violations lowers the chance of obtaining a cost increase to approximately 20% from 50%. As the farmer incorporates potential losses in premiums from not knowing the true level of nutrient content, the effect of nutrient violations is made manifest in declines in lean carcass weight which translate into premiums lost. Since premiums lost are a result of non-investment in NIRS are the benefits from the technology's adoption. As depicted in Figure 2.7, the left tail reduces s significantly in the transition from Panel A) to Panel B) and from Panel C) to D).

Furthermore, farmers who are more risk averse to violating the nutrient requirement incur lower feed costs. Specifically, in the case of where penalty premiums are considered, when Z_α increases from 0.0 to 1.65 the median cost savings of NIRS technology increases from \$2.33 per hog to \$5.70. What is concluded is that the more risk averse the farmer to violating nutrient requirements the greater the value of investing in NIRS and, incorporating penalty premiums in to the analysis incentivises adoption of NIRS. That being said, risk neutral farmers would expect to make losses 20% of the time by investing in NIRS which could be a significant deterrent to investment by such farmers.

2.5.4.3 Distribution of NPV of NIRS Adoption and Sensitivity to Discount Rates

Section 2.5.3 highlights the median NPV of adopting NIRS. This section extends that analysis to a description of the distribution of the NPV of NIRS adoption. While the median analysis is useful, an examination of the tails of the distribution may be relevant, especially in the discussion of risk. An examination of the magnitude and the relative likelihood of extreme losses or gains (more so losses) associated with NIRS adoption might be important to especially a risk averse investor. The presentation of a more in-depth NPV analysis depicts the minimum, the quartiles, median and the maximum of the NPV of NIRS adoption.

Figure 2.7 Comparison of Changes to the Cost Savings Distribution with and without Growth Impacts Across a 50% and a 95% Chance of Meeting the Crude Protein Requirement



[a] Premium Penalty refers to loss in lean carcass premiums due to protein deficiencies in the hog diet.
[b] MOS refers to the margin of safety which represents the z-score related to the chance of violating the nutrient requirement. An MOS of zero is associated with a 50% chance of nutrient requirement violation while a MOS of 1.65 is related to a 5% chance of violating nutrient requirements.
Source: Author with data from the simulation model

As expected, higher discount rates decrease NIRS investment viability. Nevertheless, investment in the sample analyser is viable for all sized farms if the average NPV is obtained and the discount rate is high (10%). Generally, a small farm would find it unfeasible to invest in a process analyser as the benefits would have to be consistently near the maximum to justify investment. Larger farms would mostly find it feasible to invest in all forms of the technology as long as the NPV is not near the minimum. In sum, the distribution analysis indicated that small farm investment in the process analyser is almost always non-viable in terms of NPV. For the other three scenarios (large farm for both the sample and process analyser as well as the small farm with sample analyser), the clear majority of the distributions of NPV are positive. These reinforce the results from the median analyses.

In summary, lower discount rates increase the appeal for investment in NIRS. In the best-case scenario where NPV benefits for the small-sized firm is at the maximum of the distribution and the discount rate is at 5%, then small sized Albertan farm would find it economically feasible to invest in the NIR technology. In the worst-case scenario of minimum NPV benefits and a discount rate of 10%, it is not feasible for farms of any size to invest. Nevertheless, the results are fairly robust for the range of discount rates considered.

2.5.5 Discussion for the Feasibility for Investment

Feasibility for investment depends on multiple factors. All factors that may have an impact must be identified, impacts should be represented in dollar values, appropriate discounting used, and sensitivity analyses conducted. In this study, the impact categories are feed cost and carcass weight performance. Meat yield is affected by nutrient intake but there are other factors such as genetics (which is not considered in this thesis) that could affect feed conversion to meat. However, if there are significant nutrient requirement differences across breeds then the results are only valid for the representative breed used in the defining the nutrient requirements used in formulating the optimization models. From the results presented, if NIRS is used to detect protein levels in select feedstuffs that do not undergo primary processing, then it may be feasible for a large 500-sow hog operation to invest in process analysers. Further assuming there are no significant differences in the accuracy of quality detection between sample analysers and process analysers, then investment in NIRS sample analysers maybe worthwhile by both small and large-sized farms. Sensitivity analyses indicated that farmers who are very averse to violating nutrient requirement would see the most benefit from investing in NIRS.

Table 2.12 Distribution of Net Present Value Benefits of NIRS Adoption

Discount Rate (%)	**Measure**	**Small-sized Farm NPV ($)**		**Large-sized Farm NPV ($)**	
		Sample Analyser	**Process Analyser**	**Sample Analyser**	**Process Analyser**
5	Minimum	-73,266	-223,085	-188,867	-338,686
	25 Percentile	12,961	-136,858	441,705	291,886
	Average	60,481	-89,338	789,211	639,392
	Median	60,729	-89,090	791,026	641,207
	75 Percentile	108,148	-41,671	1,137,795	987,976
	Maximum	166,725	16,907	1,566,166	1,416,347
8 (base)	Minimum	-66,208	-203,336	-157,282	-294,409
	25 Percentile	1,724	-135,403	339,503	202,376
	Average	39,162	-97,965	613,280	476,153
	Median	39,358	-97,769	614,710	477,583
	75 Percentile	76,716	-60,411	887,906	750,779
	Maximum	122,865	-14,262	1,225,391	1,088,264
10	Minimum	-62,726	-193,591	-141,699	-272,564
	25 Percentile	-3,820	-134,685	289,077	158,212
	Average	28,643	-102,222	526,476	395,611
	Median	28,813	-102,052	527,716	396,851
	75 Percentile	61,207	-69,658	764,611	633,746
	Maximum	101,225	-29,641	1,057,253	926,387

Source: Author with data from the simulation model

NIRS adoption could however influence the pricing structure of feed. Adoption of NIRS technology by feed mills may allow them to price discriminate, charging higher prices for better quality feed. Due to sheer economies of size as well as the generally high turnover of feed it would be logistically more feasible for feed mills to invest in the process analyser technology and in turn, market feed to livestock producers. This would mean that producers purchasing feed from feed mills would not need to invest in the technology. Nevertheless, for those farmers that grow their feed, investment in NIRS could prove valuable as it would give such farmers a clear indication to the quality of feedstuff grown.

2.6 Summary and Conclusion

The aim of the study is to estimate the cost savings to Albertan hog producers of adopting NIRS technology and to determine if it is economically feasible for farmers to invest in the technology. A joint mathematical programming- simulation approach is used to estimate the cost savings generated using NIRS machines. The results indicate median savings more than $5 per hog can be attributed to NIRS technology. For the small 70 sow/ 1630 head Albertan farm this amounts to savings of almost $7,300 per year and for a larger 500 sow/11920 head farm savings could be approximately $56,000 per year. NIRS investment could generate median NPV benefits as high as $700,000 for a large Albertan (500-sow) operations when only crude protein content is variable in wheat, barley and peas. There is evidence to suggest that it is feasible for large-scale operators to invest in the NIRS technology, but it is still not economically feasible for average-sized Albertan farms to invest in the process analyser. However, investment in sample testing units is feasible for all farms.

The model does not consider breed specific impacts of NIRS. It is possible that different breeds have different response rates to feed and nutrient violations. The varying nature could result in different conclusions. Results are based on crude protein content of wheat, peas and barley. Wheat and barley would be considered as energy feedstuffs rather than a source of protein in a hog diet. Analysis of the impact of NIRS in the context of energy variability would be the next step of the analysis. Also, research has indicated that NIRS can detect mycotoxins (Berardo et al., 2005), which have significantly hampered hog growth rates and reduced survival rates. The benefits from the investment in NIRS could be increased significantly. Therefore, the estimates provided in this study may be form a lower-bound for the benefits associated with NIRS adoption.

The Alberta Government embarked on NIRS Equipment Grant, a NIRS investment pilot project, in 2011 in which 37 approved participants are subsidized up to $20 000 to invest in NIRS technology. Based on results from this study the subsidy may not be needed for small-sized farms to invest in the sample analyser. However, if NIRS investment is made by the by feed mills it may render investment by individual producers unnecessary. Furthermore, some of the large commercial operations have feed mills integrated and based on the results of this study, those farms would not need a subsidy to invest in either the sample analyser or the process analyser. The more important role of government should be to facilitate important flow of information regarding the benefits of NIRS technology to industry stakeholders and to ensure the most efficient adoption of the technology by the industry. In an industry where margins can be quite narrow, the investment in NIRS technology could be the difference between profits and losses, solvency and insolvency for the Albertan hog producer.

3.0 Impacts of Water Market Risk and Externalities on Market participation and Crop and Livestock Producer profitability: An Agent-Based Model Approach

3.1 Introduction

In the absence of efficient pricing and trading mechanisms, water as a commodity is undervalued (Chong & Sunding, 2006; Colby, 2000). As a result, there are efficiency losses in water use. The undervaluation may in part be due to the market's inability to treat water as a private good; that is, to effectively enforce property rights to water by making it excludable (Coase, 1960). The timing, quantity and the rate or intensity of diversion are all important attributes of water as a commodity and are at the root of what makes water such a difficult commodity to trade in a market setting. These water attributes can generate externalities that cause the free market to be inefficient (Burness & Quirk, 1980b). Specifically, the decision to divert water by an individual can affect others' ability to divert water. To avoid such problems in Alberta, all water trades must be approved by Alberta Environment and Parks (AEP) which ensures that there are no third-party effects of a trade (adverse effects to other rights holders and the environment) (GOA, 2000b).

Water rights trading in Alberta was sanctioned in 2000. Since then, there has been limited trading activity. Reasons for the lack of trading may include the structure of the water market, the weather, and the need for water trades to be approved by AEP (which creates increased uncertainty regarding the successfulness of a trade proposal (Bjornlund, 2010). The lack of trade may also be due to the prevalence of relatively wet cropping seasons since with sufficient precipitation there is very little need to irrigate crops.

In thinking about alternative models for water trading, one example that can be considered is the water market in Australia. Australia has a more liquid market for water trading. Their water trading markets are sufficiently advanced to include sophisticated market instruments such as water lease-backs. A

Lease-back is a flexible option in which the seller of the entitlement can lease a portion of the sold entitlement in the event of an urgent need. There are also water options which give a party the choice to exercise the right to purchase or sell entitlements at a future point in time at a prespecified price. These have had the effect of increasing the flexibility for market participants, thereby mitigating risk exposure and fostering enhanced market efficiency (Hansen, Kaplan, Kroll, & Howitt, 2007; Lefebvre, Gangadharan, & Thoyer, 2012). The efficiency in turn creates economic value to water users. In comparing the water systems for Australia and Alberta, there are other key differences to be considered.

One important difference between Australian and Albertan water markets is the system of water allocation. In Alberta water is owned by the crown and licences must be obtained to make diversions. Diversions, however, are controlled by a seniority system of allocation. In periods of water scarcity, seniority dictates that holders of senior rights (or earlier rights) are allowed their full allocation before junior rights holders can exercise their rights. This is also known as "first in time, first in right", or “FITFIR” (Chong & Sunding, 2006). In contrast, Australia utilises a pure statutory right system (Davis, 1968; Grafton, Libecap, Edwards, O’Brien, & Landry, 2011) in which water diversions are under the legislated authority’s control. Therefore, the legislated authority can modify the allocation of an entitlement depending on available water supplies. Additionally, there is no priority assigned to licence holders. Given the success observed in the Australian water market and the lack thereof in Alberta, could the difference in success be attributed to the difference in the allocation systems employed?

Another difference is that in Alberta, irrigators are generally apprehensive toward the Albertan water market; Nicol (2005) alludes to this in a cross-section study of Albertan irrigators. Nicol’s study indicated that there may be a relationship between market illiquidity and wide price spreads for traded water. Significant uncertainty regarding the trade price and market value of a water right has contributed to farmer apprehension. The ambiguity of the market and the quality of information relayed in prices may impede with an irrigator's decision to participate in the market.

Having a market for tradeable water rights allows for the downstream irrigator (or a junior right holder) to purchase the right to access water volumes from upstream (senior right holder). *Ceteris Paribus*, the downstream irrigator would have access to more water volumes, reduce the level risk exposure and possibly increase profitability. However, in reality, many factors may be "variable" (i.e., not held constant), and thus trading water rights is not the same as trading water. Trading the right to divert mays not always guarantee the volumes specified in the trade and may not always address the externality problem. The inability to secure water volumes through trade could elevate the trade price of water allocation rights, creating a bubble peaking during high irrigation demand for water and nadiring toward the end of the cropping season. Such price volatility could make decision making more complex and could ultimately force a risk averse irrigator to abstain from trade.

While evidence suggests that there is limited trading in the Albertan water market, there seems to be a difference of opinion as to the suitability of water markets in the Alberta context (Bjornlund, Zuo, Wheeler, & Xu, 2014). While academics have advocated for the use of water markets (for example Bjornlund, Nicol and Klein (2007) and He and Horbulyk (2010)), some water managers and others in industry see very little need for trading (Bjornlund et al., 2014). They argue that as managers they are already allocating resources efficiently and more importantly there is no need for trading when there are ample water supplies (Ring, 2014). As such, the economic problem here is concerned with allocative efficiency that is, the ability to use irrigation water such that the market benefit of water usage is equal to the marginal cost of its use. While free markets may foster efficiency, if diversion externalities[12] are present then uncertainty regarding water supplies can result in under-participation in the water market by risk averse irrigators and result in distorted market signals. This in turn could further hinder water market participation and lead to pecuniary externalities.[13]

Optimal decisions under full information and certainty are different from those made by risk averse decision makers under risky conditions. Risk and uncertainties associated with water rights trading can be extensive and costly. Unlike other market goods, trading water is more directly interpreted as the trading the right to divert water and not the water itself. There are instances in which a trade can be made but the buyer is unable to divert the volumes associated with the newly acquired rights. This situation is referred to as "dry rights". These dry rights would primarily result from diversion externalities as upstream users' diversions may the limit downstream users' diversions. The inability to assess if a trade made would result in dry rights could make risk averse buyers less inclined to participate in the market. Also, the presence of externalities may distort price signals as dry rights could create demand pressures resulting in price spikes. The increased volatility in return would limit participation by risk averse users further creating market illiquidity. These perceived risks may result in an under-utilization of water market and water resources.

This study addresses the following questions in the context of the water market in southern Alberta:

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[12] Diversion externalities are third party effects of diversion of water from a water source arising from the over appropriation of water rights such that the diversion of an upstream (location externalities) or a water licence holder with a higher priority directly affects the ability of a downstream or lower priority licence holder to divert water. Diversion externalities are an example of a technical externality as defined by Greenwald and Stiglitz (1986): "the action of an individual or a firm directly affects the utility or profit of another individual or firm" (p. 229). Here the action of an upstream or higher priority irrigator can influence that of downstream or lower priority irrigators.

[13] Greenwald and Stiglitz (1986) define pecuniary externalities as "the action of an individual or firm affecting another through prices" (p.229).

- Would changing the rules governing water allocation from FITFIR to a water sharing regime influence water market liquidity? Specifically, would such a change increase water market participation in Alberta?
- Do externalities in water diversion by licence holders affect water market participation? If so, does the effect of such externalities differ across water allocation regimes?
- Are farmers' intentions to participate in the water market influenced by volatility in water market trade price and volume risk, and water supply uncertainty?
- Is a farmer's economic performance significantly affected by water market price and volume risk, and water supply uncertainty?

The primary focus of the study is to identify the optimal structure of water allocation that facilitates efficient apportionment of water resources and to estimate the ensuing effects on crop, beef and dairy producers in southern Alberta. This structure would consider both the regime of water allocation as well as the appropriateness of a water market. While there have been studies that show the value of irrigation in Alberta to crop and livestock agriculture (for example, Anderson (1978) and Freeze (1993)). No study has investigated the impact that water trading could have on Alberta irrigators' participation. Furthermore, no study has investigated the role of perceived risks and externalities on the uptake of water trading in Alberta, especially when trading can be used to reduce risk and generate revenue. This study may be of interest to policy makers who want to be informed about water policy effects on the Albertan crop and livestock sector. The role of policy makers is to create policies that facilitate the most socially efficient outcome. To do so, they must have a clear understanding of the economic drivers of irrigator behaviour, the effect of different water allocation regimes may have on irrigator profitability as well as the effects of water market risks and diversion externalities that may exist on both irrigators' market participation and profitability.

Similar to studies such as Calatrava and Garrido (2005b, 2005a), Cristi (2007) and Zuo et al. (2015), a programming approach is employed to model optimal water use decisions. In this study, irrigators maximise the certainty equivalent of profits which is consistent with maximising their expected utility of profits, subject to agronomic constraints as well as water right allocation and water trading. However, this study differs in two distinct ways to prior work. First, Calatrava and Garrido (2005b, 2005a), Cristi (2007), He and Horbulyk (2010) and Zuo et al. (2015), employ static optimization techniques and there is no hydrological feedback from an irrigator's decision or ability to irrigate at a time in the growing season. Specifically, these previous studies do not account for externalities associated with water diversion. On the other hand, the current study allows for dynamic feedback, integrating irrigators' response to variable weather conditions and changing hydrological flows (which is a function of other irrigators' and licence holders' actions). Secondly, the current literature does not include risk responses to volatile water trading prices, but only to water supply risks (Calatrava & Garrido, 2005b, 2005a; Cristi, 2007). If Albertan farmers are risk averse to volatile water prices and averse to trade volume risk, then how is the farmer's level of market activity and profitability affected by water market price volatility and volume uncertainty? This question is addressed by the current study.

This study employs an agent-based model (ABM) to answer the aforementioned research questions. The ABM is developed to simulate farmer behaviour along the Oldman River in Southern Alberta. An ABM is useful in situations where there is spatial heterogeneity as well as inter-agent interactions (Gilbert, 2008). In this study agents differ in their location along the river system and the irrigation decisions of upstream users may influence downstream users' irrigation decisions. ABM also allows for a comparison of the effects of water right types by using a form of "simulated field experiment" approach. Jurisdictions differ in many characteristics such as population density in the river basin, access to ground water or the number of and location of river systems within the basin. Comparisons across jurisdictions based on the allocation regime utilised may be confounded with other jurisdiction-specific characteristics and could give biased results. The ABM also allows for emergent phenomena. The simulation of agents at a micro-level allows for emergent relationships at a macro-level. Such relationships may not be adequately captured by macro-models. For instance, macro-models may be unable to capture the effect of externalities in diversion on water market participation or spatial relationships that emerge under one system of water allocation compared to another.

3.2 Literature Review

The literature on water allocation and comparisons of different types of allocation structures is briefly reviewed in the following sections. In this section comparisons of water allocation regimes across jurisdictions and the idiosyncratic nature of markets are highlighted by jurisdiction. Next, since an agent-based framework is used in this study, a brief review is provided of prior work in this area. Finally, taking into consideration that irrigated agriculture is conducted in southern Alberta, a brief description of the nature of agriculture in general, and more specifically beef, dairy and crop operations in the region is provided.

3.2.1 Water Right Doctrines

Davis (1968) categorised water rights according to four doctrines: a) riparianism, b) prior appropriation, c) temporal non-priority permit or statutory systems, and d) water markets. These doctrines are briefly described in the context jurisdictions around the world.

3.2.1.1 Riparian Rights

Riparian rights refer to the rights of landowners to divert water from waterways where the banks are a part of the owner’s property. Riparian water rights were used in Australia in the 19th century, for example. To gain control of water resources and its distribution, the Crown in Australia abolished riparian rights in 1886 in Victoria and 1896 in New South Wales (Davis, 1968). Riparian rights were also used in Alberta until 1894 under the Northwest Irrigation Act (Percy, 1977). Riparian rights are still utilised in the eastern United States and England (Burness & Quirk, 1979; Dellapenna, 2005; Stern, 2013). Burness and Quirk (1979) noted that under riparian rights, diversions are severely constrained because use of the water by a right holder should not significantly impair the use of water by other users. They did further note, however, that such a rights system is useful in cases where water diversions are limited and used for recreational activities. The system is favourable in less arid areas where agricultural irrigation diversion is limited, in the eastern United States, for example.

3.2.1.2 Prior Appropriation

Prior appropriation is a method of water entitlement allocation which queues right holders chronologically; specifically, “first in time, first in right” (FITFIR). Chong and Sunding (Chong & Sunding, 2006) noted that if a river is over-appropriated (rights to extract exceed volumes available for extraction) senior rights holders (those with earlier rights) can divert their full allocation before junior rights can divert any of their allocation. Prior appropriation is utilised in the western United States.

Burness and Quirk (1979) analytically proposed that under prior appropriation, senior rights would always be preferred to junior rights. They also showed that under increasing marginal cost of expanding diversion capacity, equal sharing is efficient while prior appropriation is inefficient. However prior appropriation is efficient when used in conjunction with a competitive water trading market in which all firms are identical and risk neutral.

Burness and Quirk (1980b) reiterated the inefficiency in allocating scarce water resources that arises from the prior appropriation doctrine without the use of water markets. They also highlighted other efficiency barriers that may result in inefficient water allocation and noted that these may be in the form of federal, inter and intra-state restrictions, and the return-flow externalities. The authors indicated that irrespective of water right doctrine employed, if there are no transaction costs then all return flow externalities will be internalised. Also, if fees are charged on return flow externalities then return flow externalities will be internalised and the market made more efficient.

Burness and Quirk (1980a) compare water use efficiency between controlled and uncontrolled river systems in the Western United States. In doing so, the authors explore river flow manipulation in the context of the prior appropriation and correlative doctrines of water use rights. Under correlative water rights, rights are allocated based on the owner’s share of land in the basin. In using a dynamic optimization framework, the authors outline the conditions for the optimal release of water by a reservoir manager. Given the existence of a dam controlled by a reservoir manager, it would be optimal for individual firms to build off stream storage capacity. The authors highlight that diversion capacity under prior appropriation exceeds diversion under water sharing rights. They also note that prior appropriation generates inefficiencies because the risk is shared unequally. This emanates from the hierarchical nature of the priority system.

3.2.1.3 Temporal Non-priority Permit/Statutory Systems

The temporal non-priority doctrine of Davis (1968) is the same as the statutory doctrine described by Chong and Sunding (Chong & Sunding, 2006). In this system, a government agency controls water allocation and distribution. This agency has the power to issue water use rights, contracts, licenses, permits, and has the power to invalidate them as well. Under such a system, there is no regard for seniority as in prior appropriation (Davis, 1968). This system replaced Riparian rights in Southeast Australia in the late 19th century but the earliest record of the adoption of this doctrine in the United States was in 1937 in Minnesota (Chong & Sunding, 2006; Davis, 1968; Grafton et al., 2011).

3.2.1.4 People-first System of Water Allocation

Minnesota has since modified their system of water allocation. While the state still controls water allocation it assigns priority to residential and other domestic uses, followed by low water-usage users (less than 10 000 gallons), agriculture, power production, large water uses, and finally to non-essential uses such as watering athletic fields, lawns and ornamental flowers (Kunkel & Peterson, 2015). Ali and Klein (Ali & Klein, 2014) investigated the impact of adopting alternative systems of water allocation. They highlighted that while FITFIR would benefit senior rights holders the People-first policy would mostly benefit Albertan municipalities.

3.2.2 Water Allocation in Alberta

The system of water allocation in Alberta is comprised of three pillars: 1) Government ownership of water resources; 2) Approval for diversion via licenses, and 3) the FITFIR principle (Adamowicz, Percy, & Weber, 2010). Water allocation in Alberta follows a hybrid of the statutory framework seen in Australia and FITFIR from Prior Appropriation of the western United States. However, all water diversions must be licenced and approved by AEP. Transfers between licensees were made possible by the Water Act of 2000 but all transfers must also be approved by the AEP (GOA, 2000b). The approval system ensures that water resources are not consistently over-utilised and third-party effects from transfers are minimal. Although from a logical perspective these fail-safes are necessary, they may also be considered as a form of trade impediment that generates market inefficiencies. Does the structure of the Alberta irrigation system play a role in the water market flexibility and efficiency? Before highlighting some of the prior work done in the Alberta setting, a brief historical view of what has now become the current structure of the South Saskatchewan River Basin (SSRB) is described.

Like the United States, irrigated agriculture accounts for most of the surface water diversions in Alberta (Veeman et al., 1997). Most of the licenced surface water diversions are made by irrigation districts. There are thirteen irrigation districts in the SSRB and their purpose is to deliver water via the irrigation infrastructure, build, operate and maintain the infrastructure and to maintain and promote the economic viability of the region within its geographical bounds (GOA, 2000a). This means that districts hold rights to divert water, build off-stream catchment areas and distribution networks and distribute water to members (irrigators) via canals or artificial waterways and/or pipelines. In return, members pay fees to upgrade and maintain waterways and to cover distribution costs.

Legally, irrigation districts are either corporations or cooperatives. Some of the irrigation districts (EID and WID) had their genesis in the period of the construction of the trans-Canada railway system. Railway companies and the government were seeking to expand the European population in the Canadian Prairies. Two things vital to the migration west of immigrants were transportation and water. Railway companies provided both. After 1955, the railway companies handed over the irrigation infrastructure to local farmers and the resources to the government (Viney, Veeman, & Adamowicz, 1996). In other parts of the province (Lethbridge and Taber district), farmers came together and formed irrigation cooperatives out of the Alberta Irrigation Act of 1915 (Viney et al., 1996). Today, most of the water rights in the SSRB are owned by irrigation districts. The remaining portion of rights are held by private individuals, farming corporations, recreational firms, industrial firms and municipalities. Rights holders must have land adjoined to a diversion point in the river system. Otherwise, water must be obtained through the irrigation district, municipality or county.

There exists a significant body of literature exploring irrigation in Alberta. The issues examined by these papers range from efficient allocation of water, to technology adoption, to the use of water markets and the benefits of water trading. Methods of assessment vary, from surveys (Nicol, 2005) to mathematical programming models (He & Horbulyk, 2010). The following is a brief review of some of the work done in Alberta.

Bjornlund (2010) highlighted that as water scarcity increases, sleeper rights will be activated and this could have detrimental effects on the environmental flows in Alberta. He recommended that the government purchase senior rights to control environmental flows in periods of scarcity. He also recommended the establishment of tiered transfers which would have different levels of approval scrutiny. At lower levels of scrutiny, the outcome is more certain for buyers and sellers. Similar to Grafton et al. (2011), Bjornlund (2010) recommended that land ownership should not be a requirement for participation in water rights trading. Regarding prior appropriation, Bjornlund (2010) recommended the exploration of other water rights regimes that could lead to more efficient outcomes.

He and Horbulyk (2010) investigated the efficacy of short-term water trading and volumetric water pricing in the FITFIR context of southern Alberta. More specifically, the authors assessed the welfare impacts of these market-based instruments in a context of a 10%-30% reduction in available water supplies, relative to 2003 levels. They used a positive mathematical programming model that integrated the economic irrigation and cropping decisions in the context of water scarcity. The authors found that market-based instruments generally lead to more land being irrigated, and increased welfare. Also, the full information, zero transaction cost outcome could be achieved under short-term water trading.

Bjornlund et al. (2014) explore the relatively slow adoption of water markets in Alberta. They highlight that information is a critical factor in determining an irrigation district's participation in water markets. The lack of information manifests itself in wide price differentials across water traders (Nicol, Bjornlund, & Klein, 2010). The lack of market participation has led to foregone income generating methods which could be used for investment in technologies. Nicol et al. (2010) noted that the lack of financial resources and the nature of the irrigated land are the most constraining factors for adopting irrigation technologies in Alberta.

Danso (2014) also explored the benefits of water market in technology adoption and cropping decisions in Alberta. He used a simulation approach to show that when farmers are restricted to switch only to more efficient technologies, adoption generally coincides with government subsidies and high crop prices. In the unrestricted model, he found that water trading provides a lower incentive to switch to more efficient technologies. This result is quite different from the paradigm positing that water trading places a positive valuation on water where otherwise there is none, and in periods of scarcity incentivises, the internalisation of the cost of water induces the adoption of more efficient technologies. The author however caveats that his model did not to incorporate risk and fixed costs.

3.2.3 Risk and Water Trading

Zuo et al. (2015) concluded that a water market is a useful risk management tool for farmers in the Murray Darling basin, allowing risk averse buyers to purchase water rights and reduce their water supply risk exposure . This result was consistent with the findings of Calatrava and Garrido (2005b, 2005a) and Cristi (2007). Furthermore, Calatrava and Garrido (2005b) highlighted the need for a centralized platform for brokering efficient water market transactions. Like He and Horbulyk (2010), Calatrava and Garrido (2005a) utilise a programming approach to integrate cropping and irrigation decisions of farmers in Spain. Cristi (2007) contributes the perspective of the impact of risk aversion in water market activity. The author finds that more risk averse irrigators tend to purchase water from less risk averse agents, and attributes this to the discounted value of a water right being greater as the levels of risk aversion increase. From Cristi's (2007) Euler equation, the marginal benefit of using a water right is equal to the discounted value of holding the water right plus a risk premium. This risk premium is higher for more risk averse irrigators. Since more risk averse irrigators have a higher present value for using the water right than less risk averse irrigators, transfers would be executed from less risk averse to more risk averse irrigators.

3.2.4 Agent-Based Models of Water Trading

An agent-based model (ABM) is a computational simulation framework used to analyse the behaviour of simulated heterogenous decision making units that are allowed to interact with each other and the environment in which they are placed based on a set of predefined rules (Gilbert, 2008; Hamill & Gilbert, 2016). The nature of the interaction could be defined in a spatial context, temporal context or both. Decision rules can be based on economic behaviour, social interaction or responses to environmental stimuli. Such models are geared at replicating the complex interactions between heterogeneous agents that cannot be replicated by other economic models. This section provides a brief overview of prior work with ABMs and ABMs of water trading, indicating gaps within the literature and where this study addresses these gaps.

Extensive work has been conducted using ABMs to investigate potential impacts of policy decisions on land use change (for example Polhill et al. (2001), Berger (2001) and Parker and Meretsky (2004)). Such studies explore potential changes on agriculture, the environment and changes in the rural-urban fringe. There is also a body of ABM literature that looks at modelling the complexity of water management systems from a socio-ecological perspective (Barreteau & Bousquet, 2000; Becu, Perez, Walker, Barreteau, & Le Page, 2003). In these studies, agents follow a set of rules that govern their behaviour. However, there is no explicit optimization protocol followed by the agents. In contrast, this study explicitly models the economic behaviour of agents using an optimization protocol while also considering hydrological impacts of water use.

There are two distinct features that make ABMs appealing. The first is their ability to capture complexity and intertemporal feedback effects. Decision making units (agents) often interact with each other and their interactions may occur over both space and time. ABMs can easily model the complexity of multiple agent interactions and the intertemporal feedback effects of agents. The incorporation of complexity and dynamic feedback effects in traditional programming would result in extremely large and cumbersome models.

A second strength is that ABMs are designed to incorporate agent heterogeneity. Other methods of modelling water allocation and trade do not consider agent heterogeneity. For example, when considering agents along a river, rate of flows and flow volumes differ at each diversion point. Irrigation demand (dependent on precipitation) may also differ spatially. Traditional programming models, if structured to be able to account for these heterogenous features, would be cumbersome and quite large. Conversely, this would be easily captured using an ABM framework.

The use of ABMs in modelling water use decisions of irrigators from an economic perspective has been fairly limited in the literature. Thoyer and Hailu (2005) used an ABM framework to model irrigators' bidding strategies in water auctions during periods of scarcity. In their framework, the government paid farmers to desist from irrigating a parcel of cultivated land for the remainder of the growing season. Using a multi-unit auction method of bidding and bid adjustments, the authors showed that the Vickery auction type converged toward truthful bidding while the uniform auction type led to bid shading, the deliberate concealment of the true value of a bidder by bidding below that value. While there were spatial concepts utilised in their paper, Thoyer and Hailu's (2005) model was not applied to an actual market. Also, the agents in their model did not follow an explicit optimization protocol and so agent behaviour in the market was not necessarily economically optimal. Similar to the current study, Berger, Birner, Díaz, McCarthy and Wittmer (2007) combines spatial effects with optimization principles. Their study applied ABM techniques to simulate irrigator behaviour in Chile. Their ABM model employed a multi-layered approach that included a hydrological layer, layers that defined land ownership and soil properties, a layer that determined optimal land use and layers that had integrated land and water markets and agent interaction. This study employs a similar approach. However, since water rights can be traded without land under the Water Act of 2000, land is less defined in this model. Also, in their model land use decisions were separated from decisions made in water markets, while in this study land use decisions are jointly made with land use decisions. Finally, Berger et al.'s (2007) model is intended to mimic behaviour over 15 to 20 years while this study is looking at shorter-run impact of 5 to 6 years.

ABMs can be powerful tools for understanding behaviour in an actual environment, but they can become very complex. If the modeller is not careful, meaningful drivers of behaviour could easily be lost in feedback effects. More complex models can also be very data intensive and ABMs require computer programming skills which are not readily available to all economists. Nevertheless, there are a few studies that have used this simulation techniques to test economic principles, such as Parker and Meretsky (2004) with their spatial edge effects model, Hailu and Thoyer (2005) in their water trading model and Berger et al. (2007) modelling of irrigator behaviour in the Maule River basin in Chile.

3.2.5 Cattle and Crop Production in Southern Alberta

This section provides a contextual overview of agricultural production in Alberta and more specifically in the region surrounding the Oldman River in Southern Alberta. The discussion highlights the importance of Albertan agriculture to Canada. A statistical description of the size of dairy, beef cattle and crop production in relation to provincial averages and the national average is then highlighted.

Alberta is a leading agricultural producer in Canada, in fact it generates approximately 22% of Canada's $51.1 billion gross farm cash receipts, surpassed only by Ontario at 23% (Statistics Canada, 2012b). Southern Alberta[14] accounts for 52% of Alberta's farm cash receipts or 11.6 percent of national receipts (Statistics Canada, 2012b). In Alberta, livestock farm cash receipts exceed those of crop production. In 2015, 50% of $13.6 billion Albertan total farm cash receipts were generated from livestock operations with cattle and calf operations generating $5.2 billion and dairy operations generating $500 million in revenue (AF, 2016b). Crop market receipts totalled $6.1 billion with the main crop revenue drivers being wheat ($2.0 billion) and canola ($2.6 billion) (AF, 2016b).

In 2010, Alberta had the third highest count of dairy cattle in Canada, following Quebec and Ontario (Statistics Canada, 2012a). There were approximately 950 dairy farms reporting in the 2011 Census of Agriculture, with an average of 85 head of dairy. The average herd size in southern Alberta in the region

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[14] The Census of Agriculture is a quinquennial survey of agricultural producers that collects and reports data based on regions known as census agricultural regions (CARs). The regions are used to give sufficient description of the area without divulging individual's information. Southern Alberta more specifically denotes the first three CARs of the total seven CARs in Alberta.

of the Oldman River was higher at 114 head.[15] According to the Agricultural Industry Market Information System (AIMIS) dairy genetics database the number of dairy farms in operation declined steadily over the past 15 years (Canadian Dairy Commission [CDC], 2017). Despite this consistent decline in the number of farms, milk production continued to increase. Specifically, there was a 4.9% year-over-year increase in 2015 in milk production to 701 million litres of milk relative to 2014 (AF, 2016b) while there was a 3.4% decline in the number of farms in operation in Alberta over the same period (CDC, 2017). This combination of reduced farm numbers and increased total milk production is an indication of growing farm consolidation within the industry.

In 2016, there were 4.9 million head of beef cattle in Alberta, accounting for 41.6% of the national count (AF, 2017). This number reflects a 400 thousand head decline relative to the prior year (AF, 2016b). From the 5.3 million herd in Alberta in 2015, approximately 759 thousand tonnes of beef were produced (AF, 2016b). According to the 2011 Census of Agriculture, there was an average of 82 head of beef cattle per farm including cows, calves and feedlot animals (Statistics Canada, 2012a).[16] As observed in the dairy industry in the region around the Oldman River, the beef cattle count was higher than the provincial average at 110 head per farm (Statistics Canada, 2012a).

In addition to being the largest cattle producer, Alberta is also a significant grain producer. In 2010, Alberta seeded the second largest area of wheat and canola (behind Saskatchewan), and the most acres in barley, tame hay, potatoes and sugar beets in all of Canada (Statistics Canada, 2012a). In Alberta, there was a reduction in major crop production in 2015 relative to 2014 (AF, 2016c). Wheat production

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15 The counties around the Oldman River are Lethbridge county, the county of Taber, Pincher Creek and Willow Creek. The average number of heads is the total number of heads on farms reporting dairy cattle divided by the number of reporting farms. The data are obtained from the Census of Agriculture 2011 (Statistics Canada, 2012a).

[16] This average number does not take into consideration the vast variation the types of beef operations i.e., cow-calf, backgrounding, and finishing/feedlots).

fell from 9.3 million tonnes to 8.3 million tonnes. Additionally, there was a 2.3 million tonne reduction in tame hay production to 5 million tonnes and a 77 thousand tonne reduction to 503 thousand tonnes in sugar beet production over the same period. However, barley production marginally increased by 157 thousand tonnes to 4.2 million tonnes (AF, 2016c). This reduction in crop production has been attributable to lower yields due to the relatively dry conditions in the province. Nevertheless, irrigated agriculture in Alberta accounts for close to 20% of the crop production in the province, while using only 5% of arable land (AWPS, 2017). This is an indication of the importance of irrigated agriculture to Alberta and by extension to Canada as a whole.

3.3 Theoretical Water Trading Model

The theoretical model presented in this section is a simplified version of the empirical model discussed in Section 3.4. Similar to Zegarra (2002), it is illustrated how market failures influence an irrigator's decision to participate in the water market. The key distinctions here are that it is assumed that the irrigator is risk averse to market price volatility, is averse to not meeting water demand for crops planted and there is incomplete information about other potential participants' level of participation and value of water which contributes to the coordination failure.

3.3.1 Model Introduction and Assumptions

Before outlining the model assumptions, a brief illustration is first presented of the coordination failure that may present itself when instituting a water market. The model depicts a set of I irrigators diverting water from a river. Irrigators first formulate an expected bid price. Next, they use this private value to determine their crop mix and level of participation in the water market. A brief illustration of how free water trading can exacerbate diversion externalities is highlighted conceptually before the effects are shown algebraically.

Consider an example where four irrigators pull water from one stream. They are identical in every way (i.e., land size and initial water endowment of 10 ML[17]) except for their priority of diversion which is ordered according to their label; that is, farmer 1 has the highest priority while farmer 4 has the lowest priority. Further assume that if water is traded, the priority of the seller is not transferred with traded volumes. For example, if farmer 1 sells 5 ML of his endowment to farmer 4 then farmer 4 will have 15 ML of priority 4 and not 10 ML of priority 4 and 5 ML of priority 1. This standardization of water facilitates easier trade. Suppose that in inadequate water supply years there are between 20-25 ML of water available from the stream for the farmers to use in irrigating their land. In this scenario, without trade, farmers 1 and 2 would receive their full volume but farmer 3 would receive a maximum half of his allocation while farmer 4 would not receive any allocation. The lower the priority the higher the risk of obtaining irrigation water; this would result in farmers 1 and 2 bearing no risk as they would get the water required, farmers 3 and 4 bearing risk from not getting water.

Now suppose trade is possible. Assume farmer 1 can increase profits by using more water and engages in trade with farmer 4 by purchasing half of farmer 4's allocation in a dry year. Farmers 1 and 2 are still bearing no risks but farmer 3 will get no water (because the priority of the volume traded is not tied to the seller but the buyer) along with farmer 4. However, farmer 4 is compensated through trade. Therefore, trade between farmers 1 and 4 limits farmer 3's ability to divert water and ultimately his profitability. Therefore, trade in this example results in third party effects and a coordination failure.

Before expressing the coordination failure algebraically, formal assumptions of the model are outlined. The agents' objective of maximising expected utility of profit is consistent with the maximisation of the certainty equivalent of profit ($CE(\Pi)$). Under the assumption of normality and constant absolute risk

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[17] where 1 Megalitre (ML) = 1000 cubic metres = 1 cubic decametre (dam^3)

aversion (λ) the certainty equivalent can be approximated using an expected value-variance (EV) framework. It is assumed that the diversion follows a priority system of allocation such that for the i^{th} irrigator, j irrigators (j = 1, 2, … i-1) have more senior rights. These more senior irrigators can each divert $\overline{w}_j$, their licenced diversion, and buy and divert w_j units of allocation in the water market (here negative units represent allocation that is sold) before the i^{th} irrigator can divert his licenced allocation ($\overline{w}_i$) and bought (w_i) volumes.

The irrigator's revenue is given by the output price (p) multiplied by the crop production function ($f(\cdot)$), which is a function of irrigation water supply (licenced and purchased) such that $f'(\cdot) > 0$ and $f''(\cdot) < 0$. It is further assumed that all water diverted incurs a constant rate unit distribution cost (d). The expected price (bid price) of purchased or sold water right allocations is denoted by c_i which may be different for each i and is private information for each irrigator.[18] The i^{th} irrigator's problem is given by:

$$\max_{w_i} CE(\Pi) \sim E(\Pi) - \frac{1}{2}\lambda V(\Pi) \qquad (3.1)$$

subject to:

$$E(\Pi) = pf_i(\overline{w}_i + w_i) - d \cdot (\overline{w}_i + w_i) - c_i w_i$$

$$V(\Pi) = \sigma_{c_i}^2 \cdot w_i^2$$
$$\overline{w}_i + w_i \leq W_{ST} - \Sigma_{j<i}\overline{w}_j + w_j$$

In the second constraint $\sigma_{c_i}^2$ denotes the variance of irrigator $i's$ expected value of irrigation water. The third constraint indicates that the i^{th} irrigator's water diversion cannot exceed what is available in the river for diversion. The diversion volume is equal to the river flow volume at the mouth of the river (W_{ST}) less the total diversions made by more senior irrigators ($\Sigma_{j<i}\overline{w}_j + w_j$). It is assumed that the i^{th} irrigator does not know the volume bought or sold by the more senior irrigators (w_j) with certainty,

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[18] In the modelling procedure used in this analysis, c_i is the shadow price of water estimated from a preliminary optimization that maximises the expected crop returns subject to initial endowment and other irrigator characteristics.

since w_j is assumed to be a function of c_j, which is a private value. Consequently, the right-hand-side of the third constraint is uncertain; that is, the available water supply to irrigator i is uncertain. Since this is the case, then the third constraint can be more simply modelled using Chance Constrained Programming (CCP). Following McCarl and Spreen (2003) the third constraint can be restated as:

$$\overline{w}_i + w_i \leq Y_i - Z_{\alpha_i} \cdot \sigma_{Y_i} \tag{3.2}$$

Where $Y_i = E\left[W_{ST} - \Sigma_{j<i}\overline{w}_j + w_j\right]$ (i.e., the expected water supply to irrigator i), σ_{Y_i} is the standard deviation of Y_i (i.e., the standard deviation of $\Sigma_j w_j$), and Z_{α_i} is the z-score associated with α which is the required probability of not violating the constraint.

3.3.2 Model Solutions and Implications

From the first order conditions, the optimal solution for irrigator i is characterised by a water market position w_i^* such that w_i^* is feasible (i.e., $w_i^* \in w_i$) and satisfies $pf'(\overline{w}_i + w_i) - \lambda w_i = d + c_i$ and $w_i \leq Y_i - Z_\alpha \cdot \sigma_{Y_i} - \overline{w}_i$. If the w_i that satisfies $pf'(\overline{w}_i + w_i) - \lambda w_i = d + c_i$ is less than or equal to $Y_i - Z_\alpha \cdot \sigma_{Y_i} - \overline{w}_i$ then that $w_i = w_i^*$, otherwise $w_i^* = Y_i - Z_\alpha \cdot \sigma_{Y_i} - \overline{w}_i$. This means that if there is ample water in the river to divert irrigator $i's$ optimal water, then the optimal water purchase / sale does not depend on the behaviour of more senior rights holders. However, if there will be inadequate river flows then the optimal purchase of water depends solely on the behaviour of more senior rights holders. Thus, externality effects are embedded in the market for water rights. If there are relatively few irrigators along a river the optimal level of diversion may be easily computed. However, as the number of irrigators increases, computing the optimal water market activity becomes increasingly complex.

3.3.3 Welfare Impacts of Risk and Water Trading

If it is assumed that the irrigator is risk averse with respect to water trading price risk (because we also assume no trade takes place) and the irrigator does not try to mitigate against the risks of water uncertainty, then the irrigator uses water up to a maximum of the water allocation$(\overline{w}_i)$**.** Another way to describe this is to say that the optimal purchase volume satisfies the requirement of equality between the marginal value product of irrigated water and the marginal distribution cost. If the uncertainty in diversions of more senior irrigators is such that in a period of water shortage the water available for the i^{th} irrigator is given by $\kappa\,\overline{w}_i$, with $0 < \kappa \leq 1$, then irrigator $i's$ realized profit is given by:

$$Actual\,\pi_0 = pf(\kappa\,\overline{w}_i) - d\,\kappa\,\overline{w}_i \qquad (3.3)$$

Now, suppose the irrigator had taken part in water trading, and bought w_i^* units at a price of c^* to mitigate against the uncertain volume. If all rights purchased by irrigator i were purchased from more junior-rights holders (which would result in hydrological flows available to irrigator i of $\kappa\,\overline{w}_i$, then the irrigator i's profit would then be:

$$\pi_1 = pf(\kappa\,\overline{w}_i) - d\,\kappa\,\overline{w}_i - c^*\,w_i^* \qquad (3.4)$$

Here c^* is the equilibrium price and w_i^* is the equilibrium purchased volume. The equilibrium price for the buying irrigator is less than or equal to the bid price. Equation 3.4 indicates that if the trade in allocations does not absolutely guarantee flow volumes bought and volumes endowed, then all that irrigator i can divert is the fraction of his allocation that is available in-stream. This means that the irrigator would have increased costs (market price of water allocation multiplied by the volume bought) without increasing revenue, thereby reducing economic welfare.

Welfare could also decrease in an instance of surplus water availability. Let ρ denote the optimal soil moisture which is influenced by precipitation. If it is a very moist year, such that the irrigator has minimal need for irrigation then irrigator i's optimal profit would be

$$\boldsymbol{Actual\,\pi_o = pf(\rho + \overline{w}_i^*) - d\ \overline{w}_i^*} \qquad (3.5)$$

where $\overline{w}_i^*$ is the i^{th} irrigator's optimal irrigated water use based on endowed water volumes, which could be some or all his endowed allocation $(\overline{w}_i)$. However, the irrigator a priori does not know ρ and by assumption, optimizes based on the endowed allocation (without consideration of precipitation or soil moisture). Therefore, a purchasing irrigator could incur lower profits because of unnecessary purchases of rights in the market.

3.4 The Oldman River Water Trading Model (ORWTM): Study Area, Methods and Data Sources

The Oldman River water Trading Model (ORWTM) is an agent-based simulation model (ABM) designed to broadly capture crop mix and irrigation decisions by crop and livestock farmers in Alberta. This micro-simulation model is designed to capture heterogeneous effects of location along the river, priority of the licence held as well as water availability in the river. Input risk response is the main focus to this thesis and this model is intended to capture the effects of heterogeneous risk responses on water market participation. More specifically, this ABM explores how volatile prices for water affect irrigators' participation in the water market. This model also captures the impact of water supply uncertainty that would result from trading water rights. As indicated in Section 3.2.4, this model is constructed in a similar fashion to Berger et al. (2007), where landscape, hydrology and crop mix decisions are simulated in a multi-layered model. In this section, an overview of the model construct is presented. First, the landscape of the model is described. Next, rules governing agent behaviour is presented. Then a description of the flow of the simulation model is presented.

3.4.1 Landscape

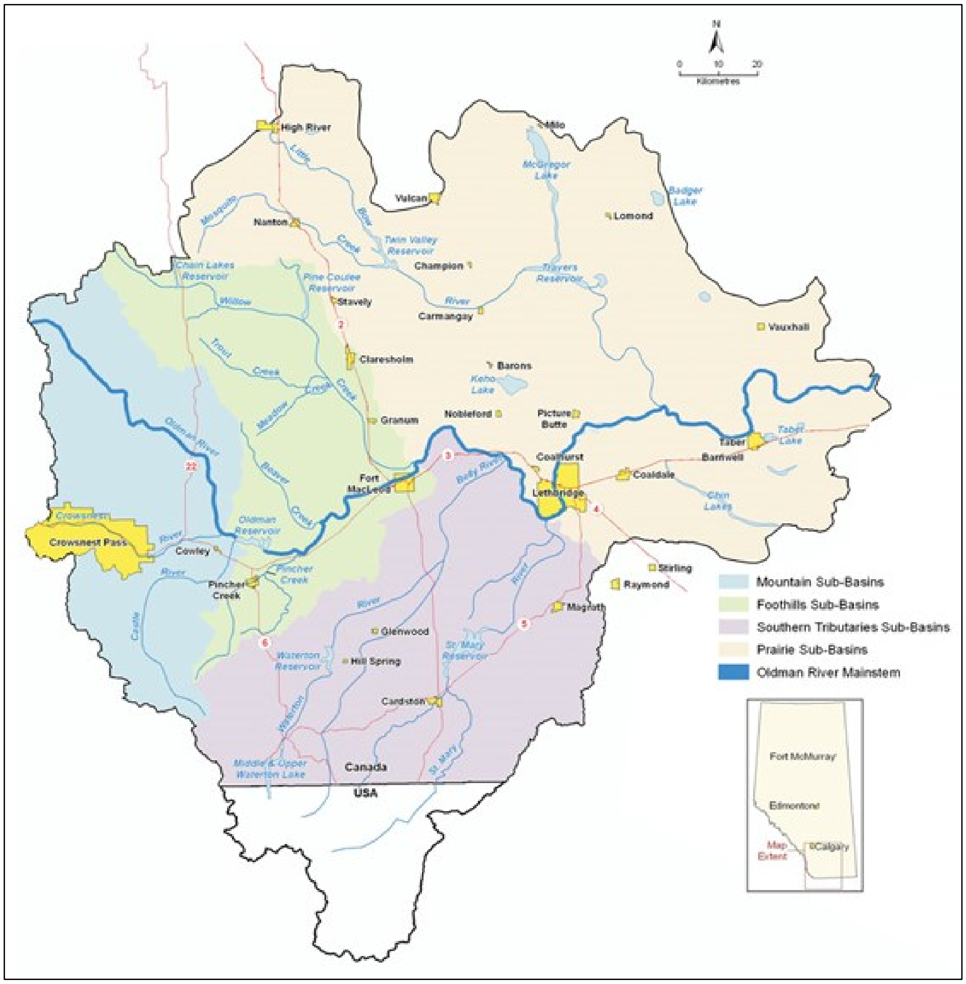
The scope of this study is limited to a sub-area of the Census Agricultural Regions 2 and 3 (CAR 2 and CAR 3) in southern Alberta. Livestock agriculture and irrigated agriculture are well represented in this region. CAR 2 is the largest producer of hogs (30%) and the third largest cattle producer (dairy and beef) in the province. CAR 3 is the second largest cattle producer and the third largest hog producer. Combined, CAR 2 and CAR 3 represent over 40% of provincial hog production and 30% of provincial cattle production. Furthermore, irrigation is extensively used in this region. The primary source of surface water diversions in this region is the Oldman River mainstream and tributaries leading to this mainstream (Figure 3.1).

The landscape of the Oldman River Water Trading Model (ORWTM) is subdivided into pixels representing approximately 1km^2 of the actual area in the region. The landscape is given attributes through GIS shapefiles. The following section describes the attributes assigned to the landscape.

3.4.1.1 GIS Shapefiles

The landscape of the ORWTM is a simplified miniature reproduction of the region surrounding the mainstream of the Oldman River in southern Alberta. The two major features of the landscape are 1) the land, on which agents are situated and; 2) the river, from which licence holders divert water. Using Google Maps a GIS file is created for the Oldman River. This GIS file is imported into the ORWTM. The GIS shapefile is read into the model as pixels (converted to raster images). Patches intersecting the GIS river shapefile are marked as the river and take attributes of the river.

Figure 3.1 The Oldman Watershed



Source: Oldman Watershed Council (2016)

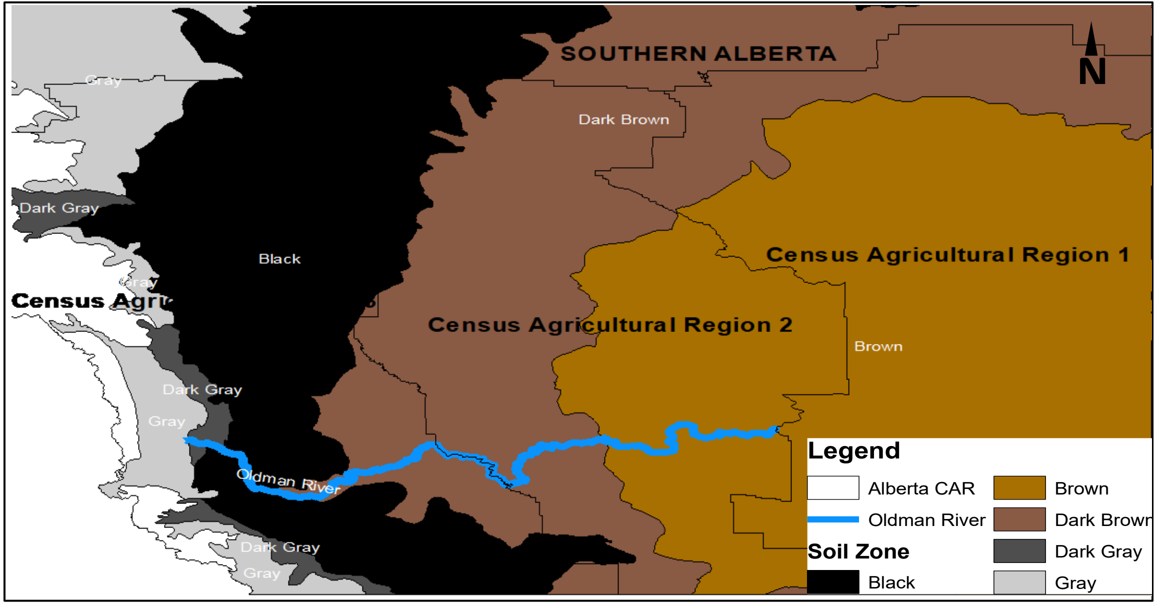
The river has three key attribute variables: the inflow volume, the outflow volume and the river flow direction identifier (Flow ID). The inflow and outflow variables depict the volume of water entering and leaving that section of the river, respectively. The Flow ID variable represents the direction in which the river flows. In ascending order, it indicates which section of the outflow of a river becomes the inflow to an adjacent river section. For example, the outflow of the river patch with Flow ID equal to1 becomes the inflow of the river patch with Flow ID equal to 2, and the outflow of the river patch with Flow ID equal to 2 becomes the inflow of the river patch with flow ID equal to 3 and so forth.

A maintained assumption of the ORWTM is that there is a general flow of water from west (left) to east (right) within the model, with all the flows entering the river at the source in the west. To keep the model tractable, the model assumes away hydrological runoff or return flows from adjacent land as well as flows from tributaries or rivers that flow into the Oldman River. Also, this model does not capture surface and ground water exchange. At some portions of the river, water seeps underground, recharging underground aquifers and in other portions resurfaces. This could significantly alter flows available for irrigation. However, this would require substantially more computing power to model this complexity. Given these simplifying assumptions, the flow volumes captured by the model will not adequately reflect historical river flow volumes at the mouth of the river. As such river flows depend on the total licenced maximum diversions from the Oldman River.

The model simulation is run under two water supply scenarios; adequate water supply and inadequate water supply. Adequate water supply is defined as the volume equal to the total maximum licenced diversion volume at the source of the river in the west, while inadequate water supply is defined as being half the maximum volume. The total maximum licenced diversions from the Oldman River as of April 2016 was slightly above 597,000 ML (Alberta Environment and Parks, 2017).

Soil zone heterogeneity is one of the primary bases of demarking the spatial heterogeneity of land use by decision agents. Crop yields, costs of production, prices earned on production, and soil moisture levels differ across soil zones. As seen in Figure 3.2, the Oldman River passes through the four major soil zones in the region: Gray (Gray and Dark Gray), Black, Dark Brown and Brown. It can also be observed that upstream soil zones (toward the west) are darker and get lighter as one goes downstream (toward the east). This may have implications for productivity and profitability differences for farmers along the river as darker soil zones are expected to be relatively more fertile. A GIS file containing the major soil zones was merged with cost per acre, average yields in tonnes per acre, for each crop. The soil zone shapefile was obtained from the Land Potential Data Base from Agriculture and Agri-food Canada (Agriculture and Agri-food Canada, 2013).

Figure 3.2 Southern Alberta Soil Zone Map



Source: Author using data from AAFC (2013)

In the model, the driving feature of soil moisture is precipitation. A precipitation-zone GIS shapefile is overlaid on the patches of the model. It contains the average monthly precipitation and snow fall in the region surrounding the Oldman River. As depicted in Figure 3.3, average monthly precipitation declines as one moves from upstream (the west) to the downstream (the east) the Oldman River.

3.4.1.2 Crop Prices, Cost of Production

Ten crops are selected to depict the cropping patterns of the southern Alberta landscape. These crops represent the ten most seeded crops in Alberta and include wheat, barley, feed wheat and feed barley, canola, sugar beets, potatoes, alfalfa hay, mixed hay and barley silage.[19] Together these crops account for over 80% of the crop area in the Lethbridge Irrigation District, which is in the vicinity of the Oldman

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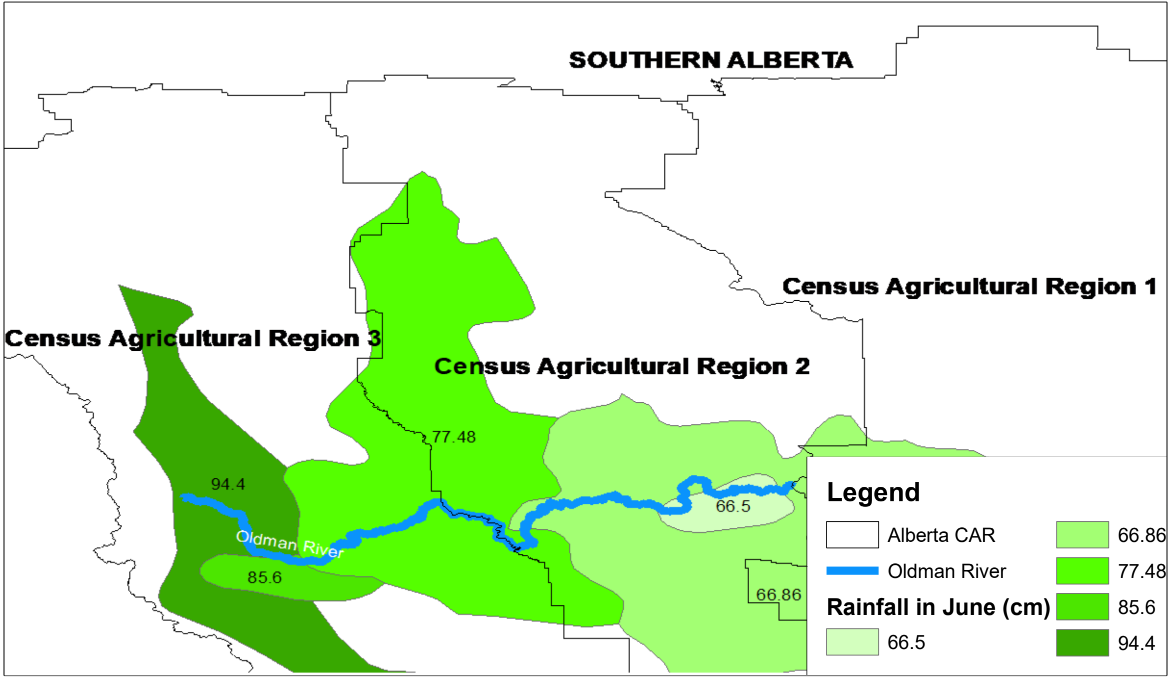
[19] The distinction made between food and feed cereals is more reflective of price differentials based on quality variances.

River (LNID, 2016). The ten crops selected to allow for greater flexibility in crop mix choices and to incorporate more variation in crop water demands. Crop mix decisions are made by farmer agents in the model and are based to a large extent on expected crop prices. The following points how these prices are developed while the crop mix decision will be discussed in a later section.

Figure 3.3 Mean Precipitation in Southern Alberta in Peak Irrigation Season



Source: Author using data from AAFC (2013)

Modelling crop prices is an important aspect of modelling cropping and irrigation decisions in southern Alberta. Crop prices determine returns which influence the optimal crop mix decision. Since different crops have different water requirements, the choice of the crop mix will ultimately determine irrigation demand decisions. Simulation allows for the sampling of crop prices since there is uncertainty surrounding actual prices in future periods. In this analysis price paths are constructed to simulate what prices could be like in the future. The resultant agent decisions are then observed based on the patterns of prices over time.

It is important to capture the correlations between the crop prices as some prices may move together. Therefore, price paths are estimated to reflect some of the historical correlations across crops. Annual historical crop prices for the ten crops are obtained from 1980 to 2014. Spring wheat (SW), barley (BAR), and canola (CAN) prices are obtained from the Alberta Agriculture Yearbook (2009)and (2015b).[20] Sugar beet prices are obtained from Laate (Laate, 2013) and the Alberta Agriculture Yearbook (2015b). Potato prices are obtained from CANSIM: Table 001-0014 (Statistics Canada, 2017)and Potato Market Information Review 2013-2014 (Agriculture and Agri-Food Canada, 2015). The price for alfalfa hay is the Canadian dollar equivalent of the average annual historical price series reported in Montana (UDMDirect Service, 2016). Mixed hay price is the average annual price of hay containing 50% alfalfa hay obtained from Alberta Agriculture and Forestry (AF, 2016d). Average annual feed wheat and feed barley prices are obtained from Alberta Agriculture and Forestry (AF, 2016d), while barley silage price per tonne is the barley price per bushel divided by 12 (Manitoba Agriculture Food and Rural Development, 2015). The historical crop price series are adjusted for inflation using the consumer price index (Statistics Canada, 2016a).

A Seemingly Unrelated Regression (SUR) model was estimated with two lags. The SUR model is based on the notion that shocks to the dependent variable (current prices and changes in prices) are related. The system-based estimation increases efficiency of parameter estimates. The model is of the form:

$$P_{it} = \beta_0 + \beta_1 P_{it-1} + \beta_2 P_{it-2} + \epsilon \quad for\ i = all\ crops\ except\ mixed\ hay \tag{3.6}$$

$$\Delta P_{it} = \beta_0 + \beta_1 \Delta P_{it-1} + \beta_2 \Delta P_{it-2} + \epsilon \quad for\ i = a\ mixed\ hay \tag{3.7}$$

where P_{it} is the price of the i^{th} crop in period t.

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[20] All wheat price is used as a proxy for spring wheat prices.

Two lags are chosen based on the AIC and the BIC criteria for choosing the lag length.[21] The coefficients and the residuals are stored. From the coefficients, a six-period-ahead forecast is generated for each crop. For each crop, 30 random shocks are created by randomly sampling from a normal distribution for which the residuals have the same mean and variance. Next, a correlation matrix is computed from the in-sample residuals and the Cholesky decomposition matrix of the correlation matrix is computed.

Following Moonan (1957), random variables can become correlated by pre-multiplying the transpose of the Cholesky decomposition matrix by the matrix of randomly generated numbers. Therefore, the Cholesky decomposition matrix from the correlation of the residuals is pre-multiplied by the randomly generated shocks to obtain correlated shocks. As a result, for each of the 10 crops there are 30 price shock paths.

Finally, the price shocks are added to the mean six-period-ahead forecast to obtain 30 possible price paths that capture cross-crop correlations (Table B.2). The prices are reviewed to ensure that prices stayed within the historical range. If necessary, the simulated inflation adjusted price is truncated such that it would neither exceed historical maximums nor fall below historical minimums. This is done to limit exorbitant and unrealistic price swings and price levels from distorting model outcomes. On average, crop prices are stable over the simulation periods (Figure 3.4), but there is sufficient variability to capture much of the historical price space of most of the crops (Figures B1-B10 in Appendix B). Lastly, the prices used in the simulation are read into the model via text files and written to a global variable; that is, a variable whose value can be observed by all agents in the model.

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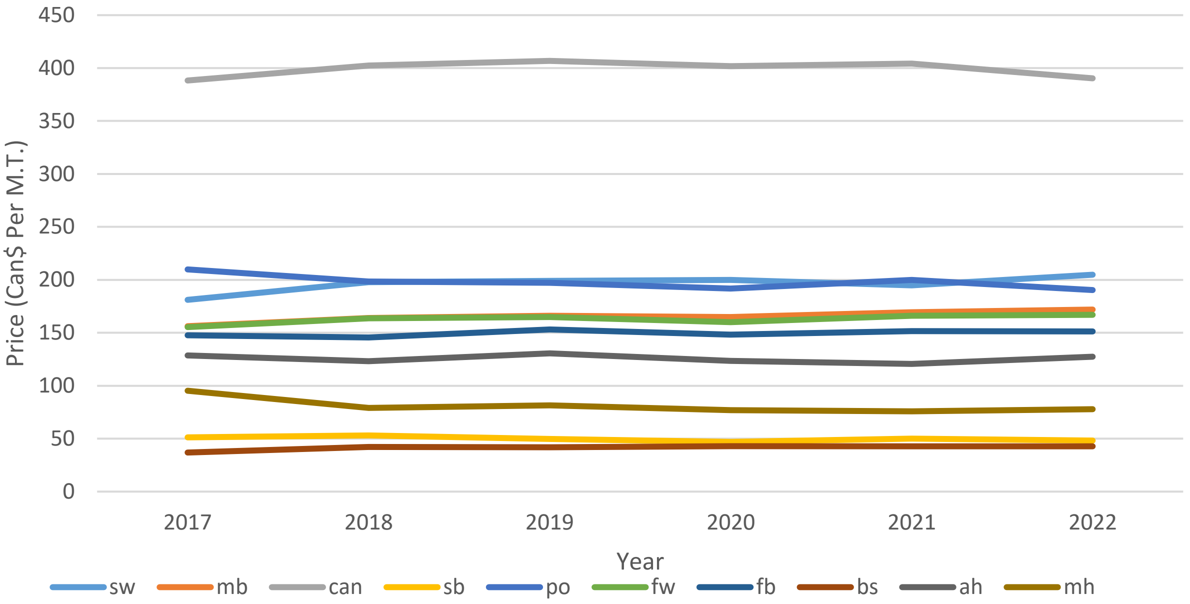
[21] This result is based on the Augmented Dickey Fuller (ADF) test. All price series are stationary except for the prices for the mixed hays. Mixed hay prices are stationary after first differencing.

Figure 3.4 Mean Crop Price Forecast across 30 Price Paths



*sw- food wheat, mb-food barley, can-canola, sb- sugarbeet, po-potato, fw-feed wheat, fb-feed barley, bs-barley silage, ah-alfalfa hay, mh-mixed hay

Source: Author

Although prices are a key component in crop choice decisions of farmers, farmers must also consider the direct costs involved in crop production.[22] The producer makes decisions based on gross margins not just on prices. For simplicity, it is assumed in the model that real direct costs are constant over time. Since the base year for adjusting prices is 2007, estimated expected 2007 costs retrieved from 2007 AgriProfit$ report (AF, 2007a) are used as the costs for the model. These cost data are especially useful because of the spatial differences across soil zones. Farmers incur relatively different direct costs per acre to achieve the optimal level of output depending on the soil type. This cost could differ by crop as well.

The spatial difference in crop revenue is also built into the model to be constant over time. It largely reflects spatial differences attributable spatial grade differentials emanating from yield differences in

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[22] Direct costs are those expenses that are tied to the level of production (e.g., fertilizer costs).

different soil regions (AF, 2016a). Historically, yields have been higher for irrigated production than for dry land farming. Therefore, farmers within the irrigation district who consistently use irrigated agriculture obtain the highest revenue. The spatial difference in revenue observed by farmers outside of the irrigation district is dependent on the farmer's ability to consistently irrigate crops and the soil zone in which the farmer is situated. As depicted in Table 3.1, A farmer in a black soil zone who is unable to irrigate all the crops within the crop season would expect to earn almost $17 less per acre for spring wheat, $14 and $15 per acre less for feed barley and food barley and $60 less per acre on mixed hay than a farmer who is either in the irrigation district or outside of the irrigation district and is able to meet all the irrigation requirements of the crops. Farmgate revenues are often influenced by quality and quantity of the crop produced. The soil quality significantly affects crop quantity and quality. Soil quality generally differs with the soil zone. Therefore, non-moisture related effects on yield and revenue are assumed to be captured in soil quality difference. The revenue differential reflects the difference in expected price in 2007 across soil zone from the irrigated region as reported in the 2007 AgriProfit$ Cropping Alternatives report.[23]

Table 3.1 Spatial Revenue Discount for Unirrigated Crop Production for Riparian Crop Farmers[1] if insufficient irrigation water ($/acre)

Soil Zone\Crop[2]:	**SW**	**FW**	**FB**	**MB**	**CAN**	**SB**	**PO**	**MH**	**AH**	**BS**
Black	-16.75	0	-13.5	-15	0	0	0	-60	0	0
Brown	0	0	0	0	0	0	0	-60	0	0
Dark Brown	0	0	0	0	0	0	0	-60	0	0
Gray	-16.75	0	-40.5	-45	0	0	0	0	-60	0

[1] Riparian crop farmer denotes a crop farmer that has land that is adjacent to the river.
[2] SW- food wheat, FW- feed wheat, FB-feed barley, MB- food barley, CAN-canola, SB-sugar beet, PO-potato, MH- mixed hay, AH- alfalfa hay
Source: Author, AF (2007b)

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[23] Price paths generated in Figure 3.4 are prices adjusted for inflation based on 2007 prices. For consistency, spatial revenue differentials are reflective of the differential in 2007.

3.4.2 Agents and Agent Descriptions

This section highlights and describes the agents and rules governing their behaviour in the ORWTM. This study utilises an ABM framework to model the behaviour of heterogeneous irrigator agents who are randomly placed on a simplified landscape along the Oldman River. There are four different types of agents that operate along the Oldman River: riparian[24] crop farmers, riparian livestock farmers, Lethbridge Northern Irrigation District (LNID), and all other licences (AOLs), which is a classification of all other licence holders that divert water from the Oldman River. AOLs comprise municipalities, recreational firms[25] and industrial firms. As can be seen in Figure 3.5, the licence holders (yellow dots) are located adjacent to the river in patches that are blue. The non-riparian crop farmer is another agent type, but is not located along the river. Instead this agent-type coordinates irrigation activities through the LNID. In the model they are located within the boundaries of the irrigation district and are the purple dots in the green patches in Figure 3.5. In this model, riparian and non-riparian crop farmers and livestock producers' decisions are characterised by solutions to optimization problems; that is, optimal behaviour of these agents is incorporated into the model. Conversely, the irrigation district's behaviour is governed by a set of predefined rules rather than by explicitly modelled optimal behaviour. It is assumed that all other agents behave passively diverting their full licence when possible. As such, most of the attention focuses on riparian and non-riparian farmers and the irrigation district.

Figure 3.5 Visual snapshot of the Oldman River Water Trading Model (ORWTM)[1] in NetLogo

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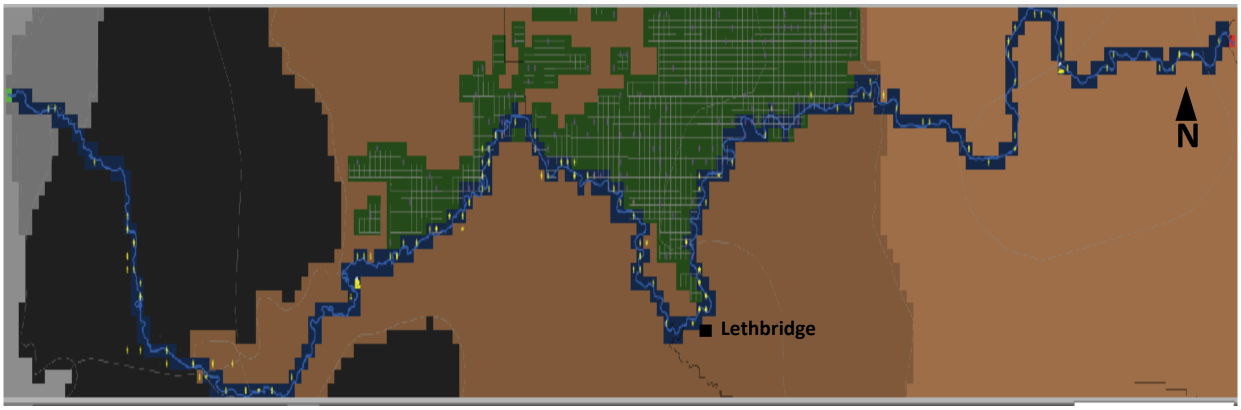
[24] Riparian farmer refers to the location of the farm; that is, the farm is situated on the banks of the river. Riparian farms can directly divert water from the river on to the farm.

[25] Recreational firms are institutions that divert water for recreational purposes. For example, one such licence concerns diversion rights for an R.V. park.



[1]Gray, black and brown colours indicate the soil zones around the blue Oldman river. The green section reflects the irrigation supply coverage area of LNID. Yellow dots represent riparian licence holders while purple dots indicate non-riparian crop farmers.

Source: Author

3.4.2.1 Riparian and Non-Riparian Crop Farmers

As noted earlier, two types of crop farmer agents are included in the ABM. Riparian farmers are located along the river and are assumed to have water allocations and so can divert water directly from the river. Non-riparian farmers are not located along the river and receive irrigation water through the Irrigation District.

In the ABM, all crop farmers are faced with the decision of allocating land to 10 available crops: wheat (SW) and barley (BAR) used for human consumption, feed wheat (FW), feed barley (FB), sugar beets (SB), potatoes (PO), canola (CAN), alfalfa hay (AH), mixed hay (MH) and barley silage (BS). A farmer's cropping decision is made under one of two contexts: water is either traded or not traded.

Without trading, supply volatility is small as farmers can more reliably estimate the diversion of more senior water rights holders. Furthermore, the model is capturing the effect of water rights trading on supply uncertainty and so if there is no trading then there is no associated uncertainty present. In such a case, the farmer's optimization problem equivalent to the maximization of gross margin:

$$\max_{X,Y} \Pi \tag{3.8}$$

subject to: $\Pi = \sum_{k=1}^{n} R_k \cdot X_k$

$\sum_{k=1}^{n} a_{jk} \cdot X_k \leq b_j \ldots$ agronomic restrictions and land constraints

$\sum_{k=1}^{n} G_{wk} \cdot X_k \leq \overline{w}_i \ldots$ irrigation demand requirements

$R_k = P_k Y_k - mc_k$

where R_k denotes average expected gross margin per acre of the k^{th} crop, $X_k$denotes acreage proportion allocated to the k^{th}crop where $k = 1$ denotes the first crop and $(k = n = 10)$ indicates the last or tenth crop, $\overline{w}_i$ is the total mega-litre (ML) volume of water permitted to divert under the license, a_{jk} denotes the agronomic land acreage coefficients while vector b_j represents the limits on X_k, G_{wk} denotes the coefficients of moisture requirements associated with the k crops multiplied by the land size of the crop farm. The gross margin per acre is computed as the price of the k^{th} crop (P_k) multiplied by the yield (Y_k) associated with that crop less the direct costs (mc_k) associated the production of the k^{th} crop.

This optimization protocol is also used for non-riparian crop farmers regardless of the water trading status. It is assumed that the irrigation district provides water to these farmers. The irrigation district sets the irrigation depth per assessed acre that is allocated to farmers and this volume represents $\overline{w}_i$ for such agents. It is assumed that the irrigation district does not allow non-riparian farmers to trade the allocation given to them by the irrigation district. The annual water expected use $\sum_{k=1}^{n} G_{wk} \cdot X_k$ is reported to the irrigation district by these farmers. The volume used each month for irrigation depends on the level of soil moisture (which is a function of precipitation) but should not exceed the average monthly water use $\left(\frac{\sum_{k=1}^{n} G_{wk} \cdot X_k}{6}\right)$.[26] Since the irrigation district sets the maximum level of water use for these irrigators, it is implied that the irrigation district can deliver the volumes without risk. Therefore, irrigators within the irrigation district (non-riparian crop farmers) are sure of their irrigation water supply.

When water is traded, it is assumed that the riparian crop farmer is averse to volatile water prices and averse to water supply risk. The crop farmer chooses the crop mix and the volume of water purchases that maximises the certainty equivalent of gross margins subject to licence restrictions, agronomic restrictions and water supply uncertainty. In assuming that it is appropriate to use the certainty equivalents in terms of an E-V framework, farmer agents' risk response to water market price risk and water supply uncertainty are integrated into the agents' optimization protocol. In the presence of risk aversion, maximising certainty equivalent of gross margin is consistent with maximising its expected utility. The following is the optimization protocol for the i^{th} riparian crop farmer:

$$\max_{X,Y} CE(\Pi_{\mathrm{i}}) \sim E(\Pi) - \frac{1}{2}\lambda_i V(\Pi_{\mathrm{i}}) \tag{3.9}$$

subject to:

$$E(\Pi_{\mathrm{i}}) = \sum_{k=1}^{n} R_k \cdot X_k - C_w w_i$$

$$V(\Pi_i) = \sigma_{C_w}^2 w_i^2$$

$\sum_{k=1}^{n} a_{jk} \cdot X_k \leq b_j$ … agronomic restrictions and land constraints

$\sum_{k=1}^{n} G_{wk} \cdot X_k \leq\leq \overline{w}_i + w_i$ … irrigation demand requirements

$\overline{w}_i + w_i \leq E\left[W_{ST} - \Sigma_{j<i}\, \overline{w}_j + w_j\right] - Z_{\alpha_i} \cdot \sigma_{w_i}$ … irrigator i's response to water availability uncertainty

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[26] The growing season differs for each crop but generally there is seeding done in the spring time and harvest in fall. It is assumed that the growing season is six months, starting in April and ending by the end of September.

where $E(\cdot)$ and $V(\cdot)$ denote expectations and variances, respectively, R_k denotes gross margin per acre of the k^{th} crop, X_k denotes acreage proportion of the k^{th}crop, w represents the acre-foot volume of temporary water allocation to purchase/sell at a particular point in time, $\overline{w}_i$ is the total volume of water permitted to divert under the license, C_w denotes the expected purchase/sale price of additional water entitlements, G_{wk} represents the water demand coefficients of the k^{th}crop, λ is the absolute risk aversion coefficient, $W_{ST}, \overline{w}_j, w_j, Z_\alpha$ and σ_{w_i} denote the river mouth flow volume, allocation endowment of more senior rights holders, expected purchase/sale volumes of more senior rights holders, z-score of the standard normal distribution associated with α (the probability of not violating the crop moisture demand requirements constraint) and the volatility of irrigation water supply, respectively. The last constraint in Equation 3.9 represents the chance constraint following the theoretical model presented in Section 3.3.1. It speaks to the farmer seeking to maximise the certainty equivalent given a 1-α percent chance of violating his minimum irrigation water requirement.

To estimate the optimal crop mix, the farmer must have an expected estimate of the value of irrigation water. In this formulation, the farmer's crop mix and level of participation in the water market is influenced by gross margins and the level of risk aversion to volatile water trading prices and water supply uncertainty. To solve Equation 3.9, a consistent estimate of C_w is required. This value is obtained from the dual value associated with the irrigation demand constraint in Equation 3.8. The dual value represents the additional gross margin generated from the use of an additional ML of irrigation water. For irrigators with a dual value of zero (Irrigators with excess water rights), it is assumed that their expected value of water would be their average value of moisture. This is computed solving the optimisation problem in Equation 3.8, obtaining the objective value and the optimal water use (left-hand-side value of the irrigation demand constraint) and dividing the objective value by the optimal water use.

Average crop farm values are computed under the assumption that water is an essential input; that is, no water results in no production. This means that, without water, gross margins are zero. Therefore, the agent is assuming zero expected precipitation. This may be justifiable to the extent that precipitation in uncertain and the distribution of the associated probabilities are unknown. Also, the valuation of water is the value of soil moisture availability. If there is no moisture available, crops will not grow. Therefore, the average value is the total expected gross margins generated under optimal crop growth divided by the total amount of moisture needed for optimal crop growth.

When bid values are generated, they are reported to the water market authority (WMA) (global variable in the model representing the clearing house mechanism for water trading). The water market selects market relevant range of prices over which irrigators re-optimize to obtain bid quantities. The market relevant range is based on the maximum and minimum bid values submitted to the WMA. The WMA selects quintiles of the range and each agent returns a discrete form of their bid demand and/or supply functions associated with the bid prices selected by the WMA. The discrete price selection is used due to the considerable runtime it would take to explore all prices greater than zero to the maximum valuation.

While constructing and testing the model it is observed that water prices greater than the maximum bid price did not yield significant changes in the water volumes supplied to the market and water volumes demanded from the market. This is due primarily to the assumption that land is not left fallow, and so, there will always be water demanded by those farmers who have insufficient water endowments. This means that the choke price would be unrealistically high. As a simplification, it is further assumed that water market demand and supply are discontinuous at the market maximum and minimum prices selected by the WMA. For any price level above the maximum price demand is zero, and for any price below the minimum market price, the supply is zero.

Using the irrigators' private values for water, the certainty equivalent models are solved to determine the optimal crop mix and the level of water market participation. For water buyers, the level of water market participation multiplied by the private water value represents the maximum water expenditure budget for the crop year. For sellers, the level of water sale represents the annual expected water sale. Buyers remain in the market until either they have bought their desired volume, or they have exhausted their budget while sellers remain in the market until they have sold their desired volume.

At the end of the growing season gross margins are computed. If water trading is activated in the model, then gross margins plus revenue from water right sales less cost of water right purchases are computed. Gross margins depend on the yield. There are two types of yield- a wet yield and a dry yield. The wet yield occurs when the farmer can meet the moisture requirement in every period of the growing season. Otherwise, the dry yield is used. At the end of the growing season, farmers update expected water price as well as price and volume variances emanating from the water market, which are used to inform the following year's optimal decisions.

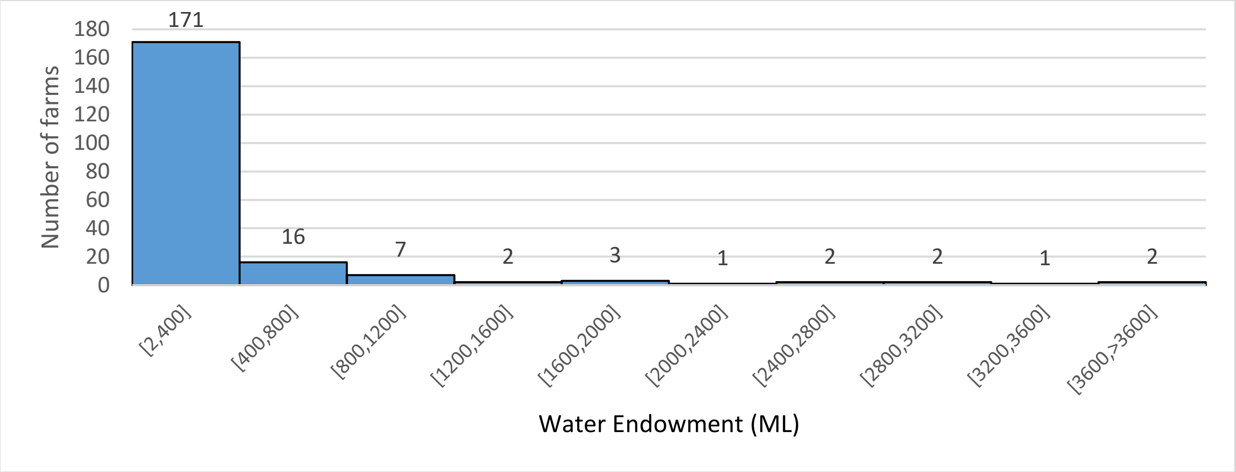
Crop farmers differ not only in terms of their location on the landscape or their diversion point along the river, but with respect to extrinsic and intrinsic attributes. They differ based on their farm size (i.e., cropping area), level of water right endowment, priority, level of absolute risk aversion (λ_i), level of acceptable water supply risk (α_i), and speed of adaptation to the water market variables (γ).

Licenced crop farmer agents are placed on the landscape according to the location of their diversion point from the river. The diversion points are obtained from AEP (AEP, 2017). The locations, in legal subdivisions (LSD), are geocoded into a decimal point system in ArcGIS and then imported into the

ORWTM. There are 207 riparian crop farmer agents. There are also 100 representative crop farmer agents that operate within the irrigation district and hence do not divert water from the river but obtain their water from the irrigation district.

Also, imported with diversion point coordinates are the priority licenced farmer's maximum diversion volume. As seen in Figure 3.6, licenced volumes are positively skewed with 171 of the 207 farmers licenced to divert 400 ML or less. Unfortunately, for most licences there is no information provided on the area irrigated associated with each licence. It is therefore assumed that the land size of licenced crop farmers is positively but not perfectly correlated with the endowed maximum permitted diversion volume. As such, the distribution land size of licenced crop farmers is also positively skewed (Figure 3.7).

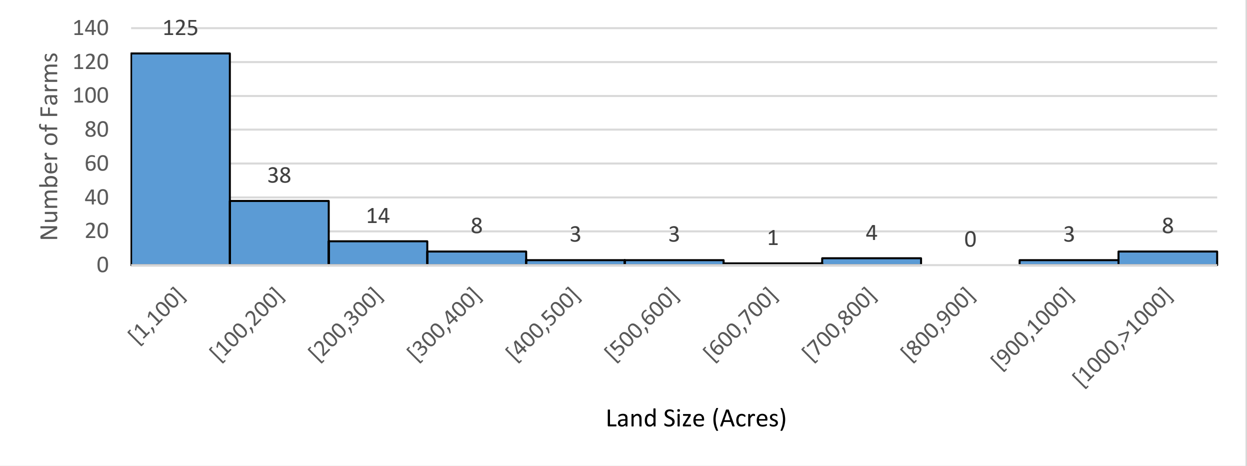
Figure 3.6 Distribution of Licenced Crop Farmers' Permitted Maximum Water Diversion Endowment



Source: AEP(2017)

When Equation 3.8 is solved for a representative farmer, not considering water availability constraints, it is found that 2 ML per acre is the optimal water to land ratio required to attain the maximum net income in the absence of trade. Therefore, a water to land ratio between 1 and 3 is targeted to generate water demand heterogeneity amongst licenced crop farmers.[27] Therefore, the distribution of land is such that 99 of the 207 licenced crop farmers have a water-to-land ratio between 1.0 and 1.7, 69 of the 207 licenced crop farmers have a water-to-land ratio between 1.7 and 2.2 and 39 of the 207 licenced crop farmers have a water-to-land ratio between 2.2 and 3.0. Furthermore, taking into consideration the expectation that the irrigation district would be the largest supplier, the distribution is skewed to the right to generate proportionately more buyers than sellers of water.

Figure 3.7 Distribution of Cultivatable Land Size of Licenced Crop Farms



Source: Author using data from AEP (2017)

Anderson and Dillon (J. R. Anderson & Dillon, 1992) indicated that as a broad rule of thumb, farmers' relative risk aversion (r) is between 0 and 4.[28] Consistent with this it is further assumed that farmer are risk averse such that their relative risk aversion (r) values uniformly lie between 1 and 4. The values of relative risk aversion are used to compute the absolute level of risk aversion (λ), as relative risk aversion is directly proportional to absolute risk aversion. A wealth measure is needed to compute λ. The wealth measure used in the literature has been either net worth (assets less liabilities) or profit, which is a

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[27] The endowed water entitlement to land ratio indicates how much water per acre of farmland a farmer is entitled to divert water from the river for irrigation purposes.

[28] Relative risk aversion speaks to an individual becoming less risk averse regarding risky situations which vary with wealth as wealth increases (Mas-Colell, Whinston, & Green, 1995)

partial wealth measure. Since very little is known about the individual crop farmer wealth, it is assumed that the wealth measure used varies with their land size as land ownership typically represent the largest contributor to farmer net worth.[29] So, farmers with more land are assumed to be wealthier.

Furthermore, if one assumes that the farming enterprise has an infinite useful life, and that wealth is the present value accumulation of profits into perpetuity, then wealth can be proxied as the present value of expected returns into perpetuity. An expected return per acre of $370 for Albertan irrigators in 2016 is obtained by using expected crop returns from the AgriProfit$ 2016 Cropping Alternatives publication from Alberta Agriculture (AF, 2016a) and Forestry to solve Equation 3.5 for a representative crop farmer. Using this value and an assumed discount rate of 10%, wealth per acre can be calculated using the present value of an infinite annuity formula (Equation 3.10):

$$PV = \frac{A}{i} \tag{3.10}$$

where PV is the present value (or wealth per acre), A is the annuity and i is the discount rate. Using an annuity of $370 and the 10% discount rate, per acre wealth is $3700 ($370/0.10) This can be multiplied by the land area of the farmer to obtain an estimate of wealth. Given the relationship between relative and absolute risk aversion, the level of absolute risk aversion for farmer i is given by:

$$\lambda_i = \frac{r_i}{(10 \cdot 370 \cdot land\ size)} \tag{3.11}$$

An original premise of this study is that farmers are averse to fluctuations in wealth via profitability, but this study assumes that farmers are only concerned about fluctuations in profitability emanating from variability in trade price and volumes in the local water market. Price swings in trade in water rights would cause a risk averse farmer to under participate in the market. Also, thin markets may also signal

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[29] Here, it is assumed that there are no differences in debt load amongst farmers.

the inability for buyers to secure needed volumes, resulting in market under participation. As such, a framework is needed to assess the effects of both trade price and volume variability. The E-V approach breaks down when joint analysis of price and volume are used in the optimization. To jointly capture the effects of trade price and volume risk, this study employs an E-V framework to capture price risk while chance constrained programming is used to model trade volume risk. However, risk aversion is tied to both the price and volume risk. Hence there must be consistency between the parameters if risk aversion in the E-V framework and in the chance-constrained programming approach. Pyle and Turnovsky (1971) speak to the consistency of constrained programming and the standard expected utility theory. They however highlight that chance constrained programming problem would have the more desirable aversion property of decreasing absolute risk aversion while the E-V framework is consistent with a quadratic expected utility function which would imply that the agent exhibits increasing absolute risk aversion (Arzac, 1974; Lambert & Mccarl, 1985; Pyle & Turnovsky, 1971). In Equation 3.9, α_i is an informal measure of capturing a farmer's unwillingness to take on risk. An α_i of 0.50 is pseudo-equivalent to risk neutrality while a value approaching 1 is akin to extreme risk aversion. It is assumed that a farmer's level of relative price risk aversion monotonically related to his unwillingness to accept water volume risk. The degree to which the two parameters α_i[30] and r_i are related is assumed by:

$$\alpha_i = 0.5 + \left(\frac{r_i}{8}\right) - 0.05 \tag{3.12}$$

This means that r_i and α_i are related such that at the minimum value of $r_i = 1$, $\alpha_i = 0.575$ and for $r_i = 4$, $\alpha_i = 0.95$

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[30] This relationship between α_i and r is ad hoc. No study has examined such a relationship before but this assumption is necessary to ensure that aversion to water market volatilities (price and volume) are consistent.

As such the z-score associated with α_i is given by:

$$Z_{\alpha_i} = \sqrt{2 * ln(\alpha_i \cdot \sqrt{2\pi})}, \text{where } \pi = \frac{22}{7} \tag{3.13}$$

When the water market setting is activated, it is assumed that agents optimize for their water market demand or supply volumes once at the beginning of the crop season. Buyers establish the volume they want to buy for the year and the price they are willing to pay, the product of which is the buyer's budget. Throughout the course of the growing season (monthly for six months), the buyer adjusts price expectations using a partial adjustment framework. The buyer adjusts demand according to the budget, the total previous month(s) spending on water rights, the volume bought in the previous month and the updated price as well as changing moisture requirements. Conceptually, if water inadequate higher prices would force the buyer to buy less than he would have anticipated at the start of the cropping season in order to stay within the spending budget. Alternatively, if it is a relatively moist year then the lower crop moisture demand would lower the need to irrigate. Sellers, on the other hand, need only to establish their optimal bid price and volumes at the beginning of the year. Unlike buyers being constrained by their budget, sellers are only constrained by their endowment. Nevertheless, throughout the growing season sellers update their price expectations. Sale volumes are only modified if there is a difference between what they intended to sell in the previous period and the actual amount sold in the previous period. This section provides more detail on how farmers adjust their bid prices and volumes.

It is assumed that licenced crop farmers adjust their expected bid values according to actual market equilibrium using a partial adjustment framework made prominent by Nerlove (Nerlove, 1956, 1958). Given equilibrium market price (P^*) and the private bid value $(wpbid)$, then for the next month, the private bid value is given by:

$$wpbid_t \;=\; wpbid_{t-1} + \left(P^*_{t-1} \;-\; wpbid_{t-1}\right) * \gamma \qquad (3.14)$$

In Equation 3.14 γ represents the speed of adjustment to the new equilibrium market price. Also, t denotes the current month and $t - 1$ denotes the previous month. A value of one for γ denotes a very fast adjustment to the new price while a value of zero represents the case where the agent does not change the bid price over time.

If the farmer has an original disposition as a buyer in the water market at the start of the growing season and the market price is above the private bid value, then in the ensuing month of trading the farmer's demand curve shifts to the right. The magnitude of the shift $(\Delta wbuy)$ is determined by estimating the total additional rights that the farmer can afford without exceeding his budget. The term $[\mathrm{wbudget}_{t-1} \;- \sum_{t=0}^{t-1} \mathrm{wcostlist}_t]$ denotes the farmers budget less the total cost rights bought previously within the growing season. When this new budget is divided by the farmers updated bid price, the bid volume for the remainder of the season is obtained. It is assumed that the remaining bid volume is evenly split over the months left in the growing season $(7 \;-\; month)$, where month is the numerical representation of the sequence of months in the growing season, where April = 1, May = 2, June = 3 and so on. The change in the monthly bid volume is the difference between this new monthly bid volume and the previous month bid volume. $\frac{\gamma}{10}$ is the assumed factor of bid volume adjustment.[31]

$$\Delta wbuy_t = \left(\frac{(\mathrm{wbudget_t} \;-\; \sum_{\mathrm{t=0}}^{\mathrm{t-1}} \mathrm{wcostlist_t}\;\;)}{wpbid_t \cdot \;(7 \;-\; month)} \;-\; wbuy_{t-1}\right) \cdot \frac{\gamma}{10} \qquad (3.15)$$

If the farmer's original disposition is to sell water rights, then the farmer adjusts the supply schedule inwards such that the reduction in supply is given by the difference between actual units sold on the market $(qsold_t)$ and the units he intended to sell on the market $(wpsell_t)$, weighted by the speed of

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[31] Various speeds of adjustment were tried; $\frac{\gamma}{10}$ yielded reasonably conservative shifts in the demand curve. Practically this is a calibration coefficient used to tweek shifts in demand.

adjustment $\left(\frac{\gamma}{100}\right)$.[32] If the selling farmer's bid price exceeds the market price, that farmer would not have sold any units when the market cleared. This would imply that $(qsold_t - wpsell_t) < 0$. However, the farmer would be able to sell that volume in the following period. Therefore, the change in bid sale volumes would be a fraction of the unsold volume the period prior.

$$\Delta wsell_t = (qsold_{t-1} - wpsell_{t-1}) \cdot -\frac{\gamma}{100} \tag{3.16}$$

If the market price (P^*) is less than private bid value $(wpbid)$, then the farmer's valuation is too low, and the farmer must reduce demand volumes and increase the valuation to be more successful in the following month. The next month's increase bid value is determined using the partial adjustment framework given by Equation 3.14. The degree to which of farmer's demand curve shifts to the left, $\Delta wbuy$ is provided in equation 3.17.

$$\Delta wbuy_t = -\left(\frac{(\mathrm{wbudget_t} - \sum_{t=0}^{t-1} \mathrm{wcostlist_t})}{wpbid_t \cdot (7 - month)} - wbuy_{t-1}\right) \cdot \frac{\gamma}{10} \tag{3.17}$$

If the farmer's original disposition at the start of the season is to sell water rights, then the farmer shifts the supply schedule, such that his increase in supply is given by the difference between actual units sold on the market $(qsold_t)$ and the units he intended to sell on the market $(wpsell_t)$

$$\Delta wsell_t = (qsold_{t-1} - wpsell_{t-1}) \cdot \frac{\gamma}{100} \tag{3.18}$$

Equation 3.16 is expected to be redundant as it is anticipated that a farmer with a bid price lower that the market price will sell water rights and as such the amount sold and the amount of water the farmer

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[32] Similar to the tweaking coefficient for the demand curve, various speeds of adjustment were tried on the supply side with $\frac{\gamma}{100}$ yielding reasonable results for equilibrium volumes and prices and price and volume variability over time.

wanted to sell in the period prior would be equal. So, Equation 3.17 would equal zero. It means that the farmer will adjust the bid price higher in and keep the supply volume constant.

3.4.2.2 Livestock Farmers (Licenced to Divert Water Directly from the River)

Livestock farmers are assumed to be either dairy farmers or cattle farmers. Based on water licence data obtained from Alberta Environment, there are 24 livestock farms that are licenced to divert water from the Oldman River in the model- 20 beef cattle and 4 dairy farmers in the model.[33] Similar to licenced crop farmers, the licenced livestock farmers are placed on the landscape according to the diversion point associated with the licence. Maximum diversion volumes and the priority of the licence are read into the ORWTM in GIS files similar to the crop farmers.

Chambers (1988) notes that in the short-run where output is fixed If the farmer is a price taker in output and input markets, then profit maximisation is equivalent to cost minimisation. Therefore, the farmer seeking to maximise profits could do so by minimising costs of production, which are a function of feed (purchased or home-grown). The cost of production is subject to the production technology and water availability under the licence. It also follows that the partial wealth measure is no longer based on profits but on costs denoted by $C(\Psi)$„ where Ψ_i denotes the feed cost of the i^{th} livestock farmer.[34] When trading is not activated in the model the riparian livestock farmer is assumed to behave according to the solution of the following optimisation problem:

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[33] The licence data does not specifically indicate dairy or beef cattle farm. However, based on the use of “cattle ranch” or “feedlot” in the name of the licence holder it is assumed that such a firm is a cattle farm and based on the use of “dairy” in the name it is assumed that such a firm is a dairy farm. It is further assumed that all other licenced irrigators designated as agricultural are to be a crop farms with no livestock enterprises.

[34] De et al. (1992) outline an E-V framework for cost minimization based on the producer’s utility of cost and show the consistency with utility maximisation. They do not incorporate the producer’s level of absolute risk aversion into the analysis. Consistent with Pope and Just (Pope & Just, 1991) definition of partial relative risk aversion being the absolute risk aversion parameter multiplied by profit, it is assumed that wealth is replaced by a feed cost measure. For livestock producers, the stock of wealth varies only by the changes in feed cost and revenue is not risky. Therefore, the utility of cost is driven by the utility associated with cost derived from the ingredient mix choice of the farmer.

$$\min_{Q_{com},X} C(\Psi_{\mathrm{i}}) = E(\Psi_{\mathrm{i}}) \tag{3.19}$$

subject to: $$E(\Psi_{\mathrm{i}}) = \sum_{k=1}^{K} C_{com,k} \cdot Q_{com,k} + \sum_{k=1}^{K} C_{hg,k} \cdot X_k$$

Nutrient j: $$\sum_{k=1}^{K} \aleph_{com,k,j} \cdot Q_{com,k,j} + \sum_{k=1}^{K} \aleph_{hg,k,j} \cdot X_k \geq \aleph_{req,j}$$

Land: $$\sum_{k=1}^{K} \left(\frac{TDI * 365 * HS}{Yield_k}\right) X_k \leq Landsize$$

Irrigation: $$\sum_{k=1}^{K} \left(\frac{TDI * 365 * HS}{Yield_k}\right) \cdot G_{w,k} \cdot X_k \leq \bar{w}_i$$

Where TDI is the total daily intake in tonnes per head of cattle on the farm, HS is the herd size of the farm, $Yield_k$ denotes the yield in tonnes per acre for the k^{th} crop, $G_w$denotes the annual crop water demand coefficients of the k^{th} home-grown crop. G_w incorporates the per crop water required to feed all the cattle on the farm. C_{com} denotes the price of commercial feedstuff and is equivalent to the price crop farmers receive for feed and forage crops, $Q_{com,k}$ represents the quantity of the kth commercial feedstuff purchased, , X_k - share of the ingredient mix, C_{hg} is the cost of production per acre of the k^{th} homegrown crop, $\aleph_{com,k,j}$ and $\aleph_{hg,k,j}$ represents the j^{th} nutrient content in the k^{th} commercial and homegrown feedstuff, respectively and, $\aleph_{req,j}$ is the minimal amount of nutrient j required for a cow.

In the above formulation, the livestock farmer has the flexibility to purchase feed or grow his own feed. Purchased and home-grown feed must satisfy minimum nutrient requirements for optimal growth. Any yield short fall from home-grown feed must be offset by increased purchases of commercial feed. Since there is no trade, then, the licenced maximum water diversion volume and land availability can constrain crop production. The farmer choosing to grow feed must ensure that the total land space required to feed livestock herd for the year $\left(\frac{TDI*365*HS}{Yield_k}\right)$ as well as the volume of irrigation water required to grow the crops for feed $\left(\left(\frac{TDI*365*HS}{Yield_k}\right)\cdot G_{w,k}\cdot X_k\right)$ do not exceed the land available and the water entitlements held by the farmer, respectively (i.e. last two constraints of Equation 3.19).

When water trading is introduced, risk responses to water trading also enter the model. The farmer seeks to minimise the certainty equivalent of net feed costs, which are a function of feed (purchased or home-grown) and water sold or purchased. The problem therefore becomes:

$$\min_{Y,Q_{com},X} CE(\Psi_{\mathrm{i}}) = E(\Psi_{\mathrm{i}}) + \frac{1}{2}\lambda_i V(\Psi_{\mathrm{i}}) \tag{3.20}$$

subject to: $V(\Psi_{\mathrm{i}}) = \sigma_{C_w}^2 w_i^2$

$$E(\Psi_{\mathrm{i}}) = \sum_{k=1}^{n} C_{com,k} \cdot Q_{com,k} + \sum_{k=1}^{n} C_{hg,k}\cdot X_k + C_w w_i$$

Nutrient requirement: $\sum_{k=1}^{n} \aleph_{com,k,j} \cdot Q_{com,k,j} + \sum_{k=1}^{n} \aleph_{hg,k,j}\cdot X_k \geq \aleph_{req,j}$ …

Land: $\sum_{k=1}^{K}\left(\frac{TDI*365*HS}{Yield_k}\right)X_k \leq Landsize$

Irrigation: $\sum_{k=1}^{K}\left(\frac{TDI*365*HS}{Yield_k}\right)\cdot G_{w,k}\cdot X_k \leq \overline{w}_i + w_i$

$w_i + \overline{w}_i \geq 0$ … Farmer can opt to sell all or a portion of his entitlement

$\overline{w}_i + w_i \leq E\left[W_{ST} - \Sigma_{j<i}\, \overline{w}_j + w_j\right] - Z_{\alpha_i}\cdot \sigma_{w_i}$ … irrigator i's response to water availability uncertainty

where C_w represents the purchase/sales price of additional water entitlements, G_w denotes the water demand coefficients of the k^{th} home-grown crop, λ_i is the absolute risk aversion coefficient, $Var(C_w)$ is the variance of water trading prices, C_{com} denotes the price of commercial feedstuff, $Q_{com,k}$ represents the quantity of commercial feedstuff home-grown feed, X_k- ingredient mix proportion, $C_{hg,k}$ is the cost of production per acre of the k^{th} crop, $\aleph_{com,k,j}$ and $\aleph_{hg,k,j}$ represents the j^{th} nutrient content in the k^{th} commercial and homegrown feedstuff, respectively and, $\aleph_{req,j}$ is the minimal amount of nutrient j required for a cow.

If the farmer grows the required feed, a feedstuff mix will be chosen that that minimises expected costs taking into consideration livestock nutrient requirements as well as water availability for the crops. With trade in water rights, the decision is slightly more complex than the scenario without trade. If the farmer had inadequate water entitlements in the scenario without trade, the farmer could purchase more entitlements on the market but must also take into consideration the risk of water price volatility (the first constraint of Equation 3.18) and the uncertainty that may arise from accessing adequate water volumes given that more purchases are made (the final constraint of Equation 3.20). On the other hand, if the farmer chooses to buy feed, then surplus rights could be sold and used to offset the higher purchased feed costs.

Like crop farmers, the level of water right endowment, priority, level of risk aversion λ_i, level of acceptable water supply risk α_i, and speed of adaptation water market variables (γ) differ across livestock producers. There is no specific information available highlighting the amount of land a cattle producer has for grazing or growing feed. It is assumed in the ORWTM that land used by the livestock producer is for growing crops to feed cattle and so it is further assumed that there is adequate land available to grow all the feed necessary for all cattle each year. Based on preliminary simulations, it would take approximately 250 acres to adequately feed 114 head of cattle. However, it is assumed that livestock producers have 500 acres of land to irrigate crops for feed, more than ample land to feed cattle. The constraining factor on land for cattle farmers is the endowed water diversion licenced volumes.

For livestock producers, λ_i represents the absolute risk aversion to volatile net feed costs. The absolute risk aversion level is the relative risk aversion level (r_i - uniformly distributed between 1 and 4) divided by the wealth measure (cost). The cost measure of \$65,000 in Equation 3.21 reflects the objective value result obtained from solving Equation 3.16 using expected prices of feed grain (for the portion of the model that contains feed purchased grain) and the expected cost (for the section of the model that incorporates home-grown options for feed), obtained from the AgriProfit\$ 2016 publication. Similar to the case for crop farmers, water volume aversion parameters $\alpha_i$and $Z_{\alpha_i}$are computed according to Equations 3.8 and 3.9, respectively.

$$\lambda_i = \frac{r_i}{(\$65000)} \tag{3.21}$$

Also, similar to the licenced crop farmers, livestock farmers develop private values for C_w based on shadow values from the irrigation demand requirement after solving the no trade Equation 3.16. For the cattle farmers that have shadow values equal to zero, average values are used. The determination of average water values is a bit different for livestock producers as their model construct is different from crop farmers. Livestock producers have the option to buy feed grains as opposed to growing their own feed. The determination of the average value for the livestock producer is the difference between the total cost generated when feed is only purchased (no water forces the producer to only purchase) and the total cost when he can grow crops, divided by the total water used in the latter formulation. Nutrient requirements for cattle are obtained from published nutrient requirements for the relevant categories of cattle (NRC, 2000). Bid water value and volume adjustments made during a growing season trading are consistent with that of the crop farmer in Equations 3.14 through 3.18.

3.4.2.3 Irrigation District

There is one irrigation district (ID) in the model-Lethbridge Northern Irrigation District (LNID) (Figure 3.8). The ID's licenced volume, priority and water diversion location are imported into the model using GIS shapefiles. The ID acts as a private entity with a structured relationship with unlicensed crop farmers (non-riparian crop farmers). Since unlicensed crop farmers are either unable to obtain a licence to divert water or are not adjacent to the river, they must rely on the irrigation district for the provision of water. These crop farmers are sometimes referred to as the members of the ID. The ID sets the irrigation water depth per acre (17 inches or approximately 1.7 ML/acre) allocated to each of its members. The ID's members optimize Equation 3.8 given the water allocated by the ID. The farmers communicate how much water is required to service their operations. The ID services members' demand and then in cases where there is trading allowed, the ID makes available for trade with other licence holders up to 80 percent of the surplus water. The proceeds from trade go to the irrigation district.[35] If there is no trading, volumes not diverted by the ID for its members would continue to flow through the river.

3.4.2.4 All Other Licences (AOLs)

AOLs are assumed to divert their total licenced volume and are excluded from trade in the water market. Their location, timing and volumes of diversion are however still important to model outcomes. As such, these agents' locations, licenced volumes and priorities are imported into the ORWTM via GIS shapefiles. The AOL's licenced volume is equally divided across each of the six months in the growing season. However, the outcome of their performance is not tracked in this model as it is not relevant to this study.

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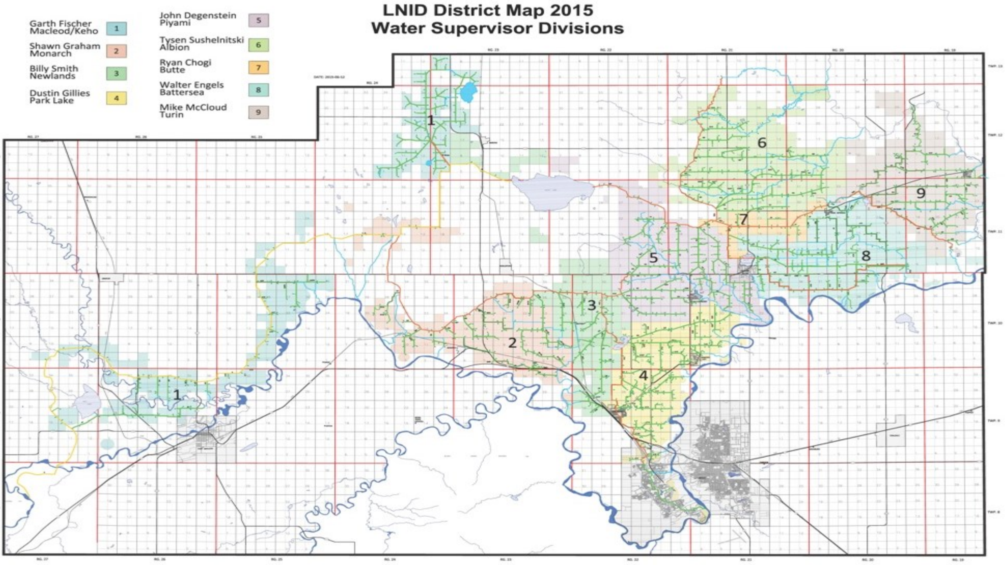
[35] The model is simulated with the fraction the ID makes available for trade being 90 percent and 70 percent in the development stages. It is found that at 90 percent there is always a supply surplus and prices are depressed at the minimum price. The opposite is true for the simulation at the 70 percent level as prices remain high at the maximum. In both cases, there is not much price volatility which is crucial for testing hypotheses.

Figure 3.8 Map of LNID service Area



Source: LNID (2015b)

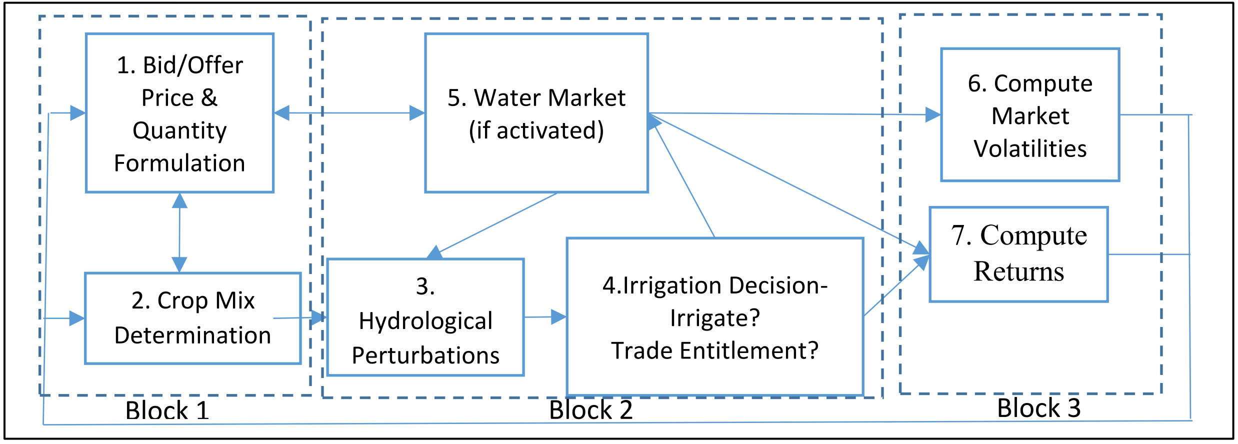
3.4.3 Agent Heterogeneity

The risks and decisions under uncertainty differ across farms and are not only based on farm type, land size, endowed water diversion allocation but also on geographical location on or off the banks of the river. Heterogeneity in the ORWTM is not only implied by the aforementioned characteristics but is a necessity for the model to work. The model relies on the heterogeneity of agents to construct an endogenous water market. If all agents are homogenous then all agents would take similar positions in the market and hence there would be no trade. All farmers would have the same crop mix, have the same crop water requirement and if water diversion allocations are the same then they would also have the same irrigation requirement and ultimately water right demands or supplies which would result in no market.

3.4.4 Order of the Simulation

Highlighted in Figure 3.9 is a pictorial synopsis of the simulation process. It is comprised of three main model blocks. In the first block, farmers jointly decide on the crop mix and level of water market participation. In the second block, the water market block, precipitation is observed, equilibrium prices and quantities are determined, and tradable entitlements are reallocated, and irrigation decisions are made. Finally, in the evaluation block actual farmer crop returns or net costs are computed. Also, market volatility variables such as trade price and volume volatility are updated.

Figure 3.9 Progression of the ORWTM[1]

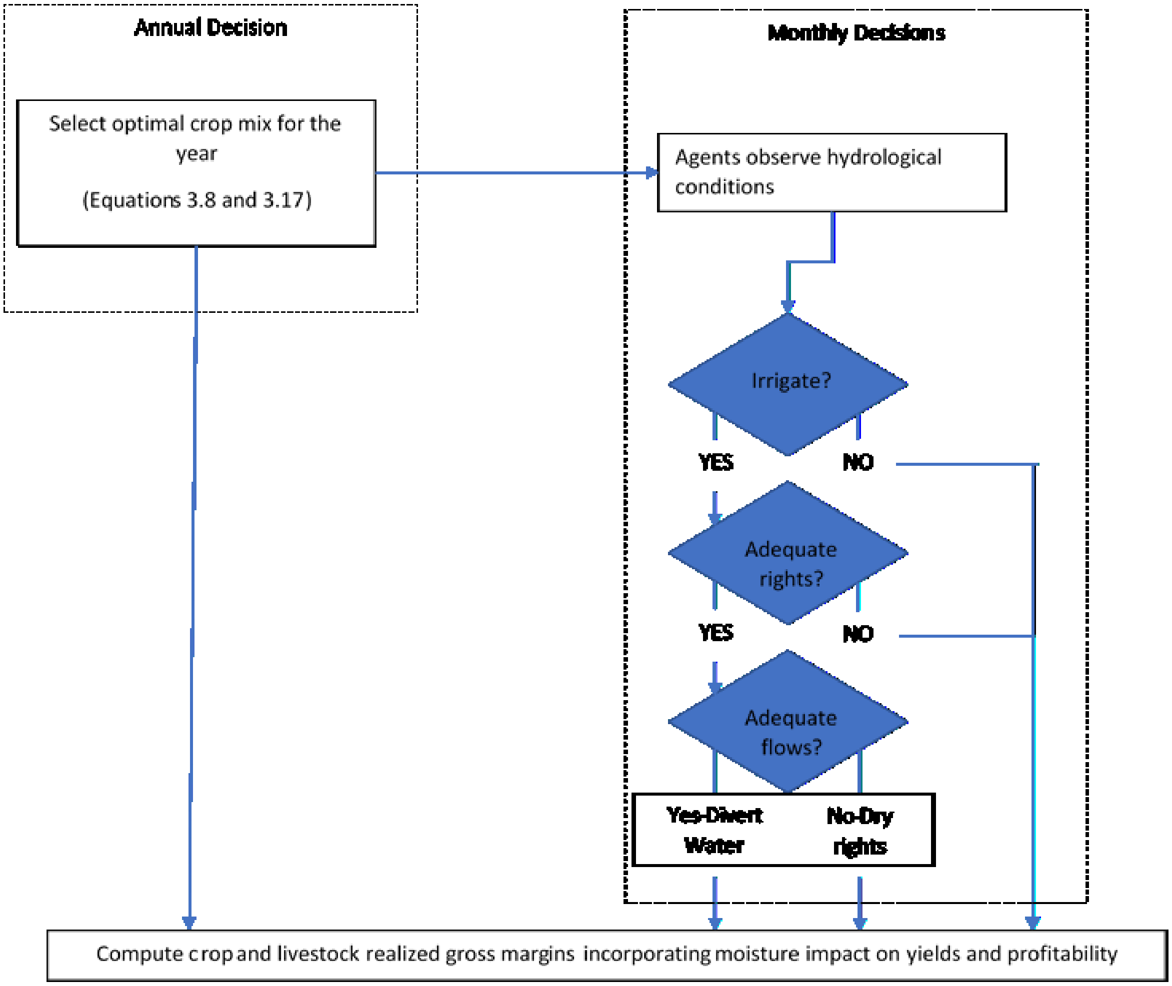


[1]The ORWTM in general terms sequentially through stages1 and 2 in Block 1 each crop year. Within each crop year the model cycles through stages 3 to in Block 2 and at the end of the crop year the model completes stages 6 and 7 in Block 3.

Source: Author

The OWTRM is simulated under two broad settings for which the first describes a model in which there is no water trading. As shown in Figure 3.10, the decision regarding crop mixes is made based on exogenous price data developed under section 3.4.1.2. This decision is done once for each cropping season in block 1. In block 2, hydrological effects are observed each month within the cropping season and licenced irrigators divert water according to their needs and their endowment. At the end of the cropping season (in block 3), if there are moisture deficiencies during the season, the yield impact on moisture is estimated and the realized gross margins are computed.

Figure 3.10 Flow Chart of the ORWTM when water trading is not activated

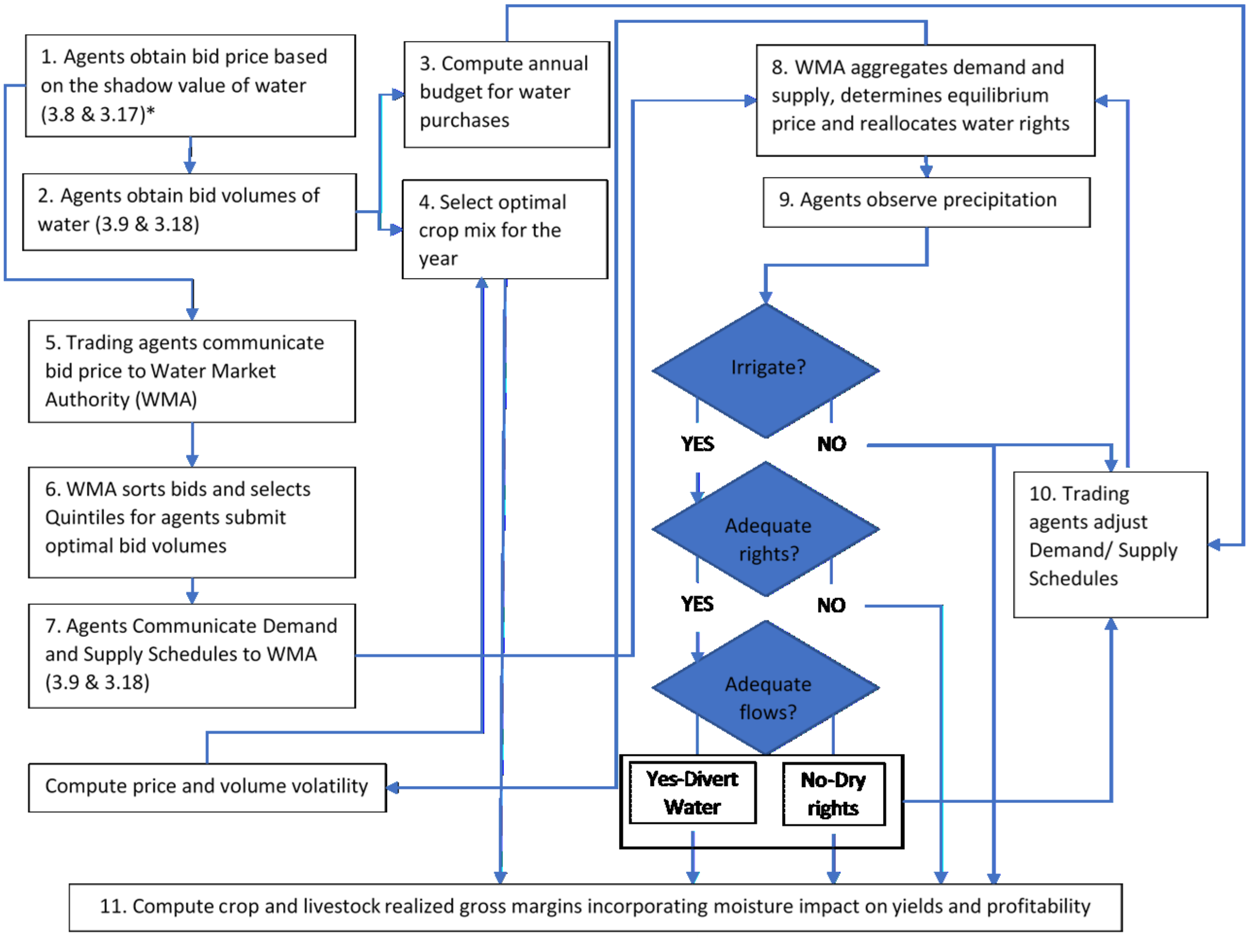


Source: Author

When water trading is activated, the flow diagram becomes a bit more complex. Water demand or supply schedules are needed for each licenced irrigator. In Block 1, the optimisation model is first solved for each agent in the model without any trade of water, or any risk aversion, to obtain implicit values for water (shadow values) as per Equations 3.8 and 3.17. The implicit values are used to form maximum purchase bid/minimum offer prices. The model is re-solved with bid prices and risk aversion to obtain bid quantities (by solving Equations 3.9 and 3.18). Also, crop farmers determine their optimal crop mix. Concurrently, the bid price is communicated to the WMA which selects a narrowed price range for which farmers corresponding trade volumes. This is done at the beginning of each cropping season. For each month during the cropping season, the farmer observes moisture conditions and determines whether to irrigate crops. If the farmer chooses to irrigate crops, the irrigator must then assess if there are adequate rights and in-stream flows to meet the irrigation requirement. The farmer accordingly adjusts the demand/supply schedule. Adjustments in the aggregated demand and supply schedules are used arrive at the new equilibrium price and volumes in the ensuing month. Irrigators again observe hydrological conditions and make irrigation decisions. This process continues until the end of the cropping season (after six months). At the end of the cropping season, moisture impacts on crop yields and gross margins (feed costs for livestock farmers) are estimated. Also, water market price and volume volatility are computed. This is used to inform crop mix decision in the next crop year.

Cost and profitability impact comparisons are made between two water-right structures. In Figures 3.10 and 3.11 it is a set of rules that determine the ordering of irrigators who choose to irrigate crops. Under FITFIR irrigators with a higher priority are allowed to divert all of their monthly right before junior irrigators, under a water sharing regime the ordering of the irrigator's priority is random. FITFIR is the current structure that governs water allocation in Alberta. However, the 2001/02 crop year was particularly dry and to avoid extreme agricultural losses, water was shared by irrigators in the basin (Nicol & Klein, 2006). The agreement somewhat mimicked a water sharing regime. As such, the comparison is made between FITFIR and water sharing regime; all licence holders have equal claim to available water. In the following stage (Block 2), bid prices and quantities are collated. A simulated multi-unit water auction market for tradable temporary water rights is generated. The collated bid price and quantities are entered into a simulation auction market. A modified version of Ausubel (2004) multi-unit auction is used to clear the market. Ausubel (2004) outlines an auction in which the price is announced by the auctioneer, buyers and sellers submit quantity bids, bid price increments upward until the market clears.

Figure 3.11 Flow Chart of the ORWTM when water trading is activated



* Related equation references are in parenthesis

Source: Author

In this model, it is computationally infeasible to obtain bid volumes for every price point in the market. As such, farmers with water licences communicate their initial bid price to the water market authority (WMA) market (Shadow prices of water availability under Equation 3.8 and 3.19). The WMA then ranks prices and then the WMA selects five price points over which the farmers report their optimal bid volumes.[36] It is further assumed that exchange will occur within the range of the minimum and

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[36] It is assumed that the WMA would choose quintiles of the ranked bid prices $\frac{1}{5}$ of maximum bid price up to $\frac{5}{5}$ of the maximum bid price. The use of quintiles is assumed to yield more information regarding the nature of supply

maximum prices set by the WMA. The licenced farmers return their demand and supply schedule which is then aggregated to the market level by re-estimating Equations 3.9 and 3.20. It is further assumed that demand and supply are linear between the price points and so the equilibrium is estimated, and the market clears at the equilibrium price.

Market allocation is coded such that the buyer who assigns the greatest value to water rights is allotted the full bid volume, if the bid does not exceed the equilibrium volume. If the bid volume exceeds the market equilibrium, then buyer receives the market equilibrium. The bidder with the second highest valuation is granted the full bid volume if the bid sum of already allocated bid volumes plus his bid volume does not exceed the equilibrium volume. If it exceeds the market equilibrium, then the buyer receives the difference between the market equilibrium and the sum of already allocated bids. This occurs for the third highest valued then the fourth and so on until equilibrium volumes are fully allocated.

In contrast, the seller who assigns the least value to water right the least can sell the full bid volume if the bid does not exceed the equilibrium volume. If the bid volume exceeds the market equilibrium, then the seller sells the market equilibrium volume. If the equilibrium is not attained, then the bidder with the second lowest valuation is granted his full bid volume if the sum of allocated bid volumes plus his bid volume does not exceed the equilibrium volume. If it exceeds the market equilibrium, then he receives the difference between the market equilibrium and the sum of already allocated bids. This occurs for the third lowest valued then the fourth and so on until equilibrium volumes are fully allocated.

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and demand schedules. Also, it is the maximum number of price points that would allow for a computationally feasible outcome. Quintiles are assumed to be most stable as the minimum price did not materially differ from the minimum price. Also, while the distribution of the mean bid price varied, the range selected by the WMA adequately captured most of the market and more importantly most of the changes in equilibrium.

This rationing method is important for efficient allocation of water resources. It allows for buyers who place the highest value on the resource to have the highest the highest likelihood of winning their bid and obtaining the resource (that is, the right to the water). It also allows sellers with the lowest valuation the highest probability of transferring their water right.

Next farmers observe incorporate hydrological perturbations. At this stage, the crop season would have been underway and crop mixes would have already been decided. Irrigators decide only whether to irrigate or to sell their unused entitlements or purchase additional entitlements in response to moisture conditions specific to their location. The adjustments to licenced farmers demand or supply is given by Equations 3.14 to 3.18. This interaction between agents and the landscape proceeds for six periods symbolising six months in the growing season.

The final stage (Block 3), entails agents evaluating the performance over the cropping season. Performance for crop farmers are determined by the actual gross margins per acre. For cattle farmers, performance is determined by the total feed cost per head. The higher the gross margins, the better the performance. In contrast, the lower the feed cost the better the performance. When trading is involved, net water sales are added to the gross margin. On the other hand, the net purchase of water rights is divided by the number of head of cattle and added to total feed cost to obtain the total economic impact (TEI). The use of an endogenous clearinghouse allows for endogenous water price and volume volatility determination. This updates the irrigators' expectation of gross margins in the future year and therefore could influence acreage allocation. The water market price and volume volatility could also affect farmers' future level of water market participation. Also, an evaluation of flows is computed and the determination of the proportion of dry water rights (entitlements cannot be exercised because there is not enough water) are computed. Farmers' profitability is tracked through time. Crop farmers' profitability is influenced by crop yield which is a function of moisture available to the crop through the cropping season.

3.4.5 Other Data Sources

For this study, secondary data are utilised for analysis. The simulation is conducted in the simulation programme NetLogo® which allows for spatial relationships in the model. For this, GIS shape files for the Oldman River as well as agent locations are loaded into the software. Data on licences are obtained from the AEP website (AEP, 2017). Historical yields and rainfall are also loaded into the model via GIS shapefiles obtained from Agriculture and Agri-food Canada's Land Potential Database (AAFC, 2013). Water requirements of crops are obtained from Bennett and Harms (Bennett & Harms, 2011). Farm level data on farm size, number of farms, type of farms and are inferred from aggregated CAR-level or provincial-level data sourced from the CANSIM database (Statistics Canada, 2012a). These aggregated data form the basis for the means for each farm type, and hypothetical distributions are constructed around these means.

3.4.6 Model Initializations

Before the simulation commences, there are a few variables that must be set. The first of such is volume of water flowing in the river. In this model there are assumed to be only two level of flows, an adequate flow being equal to 100% of the total licenced diversion in the model and the second is assumed to be 50% of total licenced volume. The other variable that must be set is the type of water rights allocation, which could either be FITFIR or water sharing. The third setting is one that indicates trades would be permitted through a water market relative to no trade. Finally, an initial price volatility must be selected to start the model. In order to not bias participation away from the water market the initial volatility is low and assumed to be a value of 1.

3.4.7 Post Simulation Analysis and Estimations

The data generated by the ORWTM provide useful insight into macro-level effects of water trading under alternative water allocation regimes. The aggregated data are displayed in graphs and tables to show the general performance of crop farm and livestock farm agents based on gross margin and feed cost metrics, respectively. Also, macro-level analysis provides an overall description of the performance of the water market. The water market metrics tracked are the average monthly volumes sold in mega Litres (ML), the average monthly price per ML, the average annual volume and price volatility. In the ORWTM, if there is enough water for the crops seeded by a farmer, then the farmer realizes expected gross margin associated with that irrigated area. However, if a farmer at any period in the growing season has inadequate supply of water, then he realizes proportionately reduced gross margins to the point where margins are consistent with dry land farming. In the case of potatoes and sugar beets, a 50% reduction in yields are assumed if moisture is inadequate.[37]

In addition to macro-level results, significant insight can be gained by conducting micro-level analysis. The micro-level analysis explored in this thesis are: whether water market volatility influences economic performance, affects market participation and whether externalities affect market participation and economic performance of farmer agents. While relationships can be expressed in charts and table, it may be more succinct to use regression analysis to describe relationships. For this thesis, the direction and statistical significance is more important than the magnitude of the coefficient.[38] Since multiple

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[37] No data are available on yield potato yield in unirrigated areas. It is therefore assumed that there is a conservative 50% reduction in unirrigated yield (which can also reflect the processor's rejection based on low quality production due to moisture deficits).

[38] It would be redundant to use regression analysis on simulation output that depended purely on parametric estimates from regression analysis. However, this ABM model output depends on regressed coefficients, non-linear rules and spatial relationships as well as other complex interactions. Therefore, the application of econometric tools is not redundant. While there may be issues regarding model specification, linear regressions are robust in capturing the general direction of an impact of an independent variable on a dependent variable.

agent variables are being tracked over time, a panel data framework is utilized to demonstrate these relationships.

Panel data regression analysis is used to assess the: 1) impact of water market price and volume volatility on crop farm profitability and livestock farm net feed costs (TEI); and 2) the impact of volatilities and externalities on water market participation. To extract the effect of the water market volatility variables and externality variables, one must control for other determinants of farmer profitability (TEI in the case of the livestock producer) and water market participation. Econometric model specifications vary across scenarios. In scenarios where there is a water sharing allocation regime, priority is omitted.

3.4.7.1 Estimation of the Risk Impact on Crop Farm Profitability

This section outlines the method used to assess the drivers of crop farm profitability. Panel regression analysis is used to tease out the relationship between profitability and anticipated key drivers. Specifically, this section is interested in estimating the impact of water market risk (in the form of water trade price volatility and trade volume volatility) impacts crop farm profitability. The dependent variable is the farmer's gross margin per acre ($\pi^{cf}{}_{it}$). A whole suite of independent variables is used in the regression; most are used as controls, but some are of particular interest to the study. The independent variable-water extraction location along the river (x_1) is the pseudo-externality variable in the regression in that the further downstream the diversion point of a farmer, the less likely it is that the farmer will obtain water and is more likely to have lower returns. It is also of interest to know if the level of risk aversion of the agent (x_2) (in scenarios with water trading) affected profitability. The anticipated crop returns $(x_3 - x_{12})$ and water licence endowment per acre of land(x_{13}) are used as controls. As a control for weather perturbations, the average monthly amount of irrigation water required (x_{14}) is included in the regression. The priority of the licence to divert water held by the farmer(x_{15}) is also used as an explanatory variable. The land size of the farmer (x_{16}) is another control variable. Water market variables: water trading price volatility (x_{17}), water trading volume volatility (x_{18}), average equilibrium price $(x_{19})$and average equilibrium volume (x_{20}) capture the impact of water markets on farmer profitability. The lagged gross margin per acre(π_{it-1}) and the vector D containing year-specific, replication-specific and agent-specific dummies are used to control for serial correlation and unobserved effects, respectively.

The general model follows the form:

$$\pi_{it}^{cf} = \beta_0 + \sum_{k=1}^{20} \beta_k x_{kit} + \gamma \pi_{it-1}^{cf} + \psi' D + \epsilon_{it} \tag{3.22}$$

Where β_0, β_k and γ are parameters and ψ is a vector of parameter related to dummy variables in the model.

This formulation assumes that errors (individual specific error (u_i) and otherwise (ϵ_{it})) are not correlated to the independent variables. If errors are correlated then the fixed effects estimator is consistent while the random effects estimator is biased (Cameron & Trivedi, 2010). The drawback with the fixed effects estimator is that the impact of individual specific independent variables (that do not vary over time) on the dependent variable is lost. Since the aim is to consistently capture the impact of risk, which varies over time, the fixed effects model is used. This means that $x_2, x_{13}, x_{15} - x_{17}$ would be omitted from the regression which is of the form:

$$\pi_{it}^{cf} - \pi_{it-1}^{cf} = \sum_{k=1}^{21} \beta_k (x_{kit} - x_{kit-1}) + \epsilon_{it} - \epsilon_{it-1} \tag{3.23}$$

Since the aforementioned variables do not change over time, then taking the first difference eliminates the variable from the regression. Furthermore, since water market price volatility and volume volatility variables are highly correlated, separate regressions are estimated.

Holding all else constant, it is expected that volatility variables will negatively affect profitability. Higher volatility indicates higher risk, the optimal decision for a risk averse crop farmer is to seed less risky crops, reducing risk exposure but also reducing profitability (assuming risk and return are positively related).

It is also suspected that there may heterogenous impacts on profitability based on the position taken in the water market. Generally, if prices are high due to a shortage, it may be reasonable to observe sellers being more profitable than buyers and vice versa. To capture this, regressions are executed on split samples categorized by buyers and sellers.

3.4.7.2 Estimation of the Risk Impact of Livestock Farm Profitability

For livestock farmers, the dependent variable is the Total Economic Impact (TEI) (${\pi^{LF}}_{it}$). It is comprised of the cost of feed less revenue from water market sales, on a per head of cattle basis. As with crop farms, the independent variables: the water extraction location along the river (x_1) captures location externalities while the level of risk aversion of the agent (x_2) (in scenarios with water trading) captures the impact of risk aversion on profitability. The anticipated cost for purchased feed$(x_3 - x_7)$, water licence endowment per acre of land (x_8) are model controls. The average monthly amount of irrigation water required (x_9) controls for weather perturbations. The dairy variable (x_{10}) is an indicator variable that denotes difference between dairy and beef farmer average costs. The water market variables water trading price volatility (x_{11}), water trading volume volatility (x_{12}), average equilibrium price (x_{13}) and average equilibrium volume (x_{14}) estimate the impact of water market variables on livestock farms on net feed costs. The lagged gross margin per acre (π_{it-1}) and the vector D containing year-specific, replication-specific and agent specific-dummies used to control for serial correlation and other unobserved effects. The equation estimated is as follows:

$$\pi_{it}^{LF} = \theta_0 + \sum_{k=1}^{14} \theta_k x_k + \sigma\pi_{it-1} + \eta' D + \epsilon_{it} \tag{3.24}$$

where $\theta_0, \theta_k,$ and σ are parameters and η is a vector of parameters related to dummy variables in the model.

Similar to the crop farm model, the first differenced estimator is used to ensure a consistent estimate of risk impacts on Livestock farm's TEI. As in Equation 3.22, time invariant variables in Equation 3.24 are omitted from the estimation. It is expected that volatility would increase net feed costs for livestock farms. As risk increases, it is expected that the risk averse farmer would limit exposure to the water market and would therefore limit opportunities to reduce net feed costs.

$$\pi_{it}^{LF} - \pi_{it-1}^{LF} = \sum_{k=1}^{14} \theta_k (x_{kit} - x_{kit-1}) + \epsilon_{it} - \epsilon_{it-1} \tag{3.26}$$

3.4.7.3 Estimation of the Risk and Externality Impacts on Crop Farmer Water Market Participation

In this thesis, water market participation is viewed as the intent to buy and sell water rights. Normally, market data do not provide this information, only information on volumes bought or sold. However, a farmers' willingness and ability to buy or sell at a specified price in a specific period extends beyond the market clearing outcomes. For instance, an agent selling water with a reservation price above the equilibrium price would not sell water, but this does not mean that he is not willing to participate in the market. Fortunately, the ORWTM provides information on bids; that is, the actual demand and supply schedules. Econometric estimation of the schedules allows for the identification of some key factors that cause demand and supply to shift (controlling for bid price levels). It also allows for the comparison of the sensitivity of volumes demanded and supplied to changes in price across scenario settings.

For econometric estimation of demand and supply, the data must be restructured. First, to facilitate computational analysis, the data are averaged over the simulation replications. This is done to reduce the size of the matrix that has to be inverted. Next the data are converted into a multi-dimensional panel indexed by agent, time and price level. Since demand and supply are being jointly estimated it may be more efficient to estimate the models as a system. Therefore, a panel estimation is utilised to analyse the determinants of crop farm water market participation.

$$Y_{itp}^{D} = \beta_0 + \sum_{k=1}^{21} \beta_k x_{kitp} + \psi' D + \epsilon_{itp} \; \ldots Demand \tag{3.27}$$

$$\mathrm{Y}_{\mathrm{itp}}^{\mathrm{s}} = \alpha_0 + \sum_{k=1}^{21} \alpha_k x_{kitp} + \eta' D + \epsilon_{itp} \; \ldots Supply \tag{3.28}$$

where i denoted i^{th} agent in period t for the price level p

The bid demand volumes Y_{itp}^{D} are assumed to be a function of the bid price (x_{1itp}), the level of relative risk aversion x_{2itp}, lagged water market price volatility (x_{3it-1p}), endowed water allocation per acre (x_{5itp}), lagged monthly irrigation water requirements (x_{6it-1p}), the location of the diverter along the banks of the river (x_{7itp}) and the priority of the licence held by the farmer (x_{8itp}) (in FITFIR scenarios). Expected crop returns, a vector of year-specific, month-specific and agent-specific dummy variables are also used to control for unobserved time and agent effects (D).

The bid supply volumes Y_{itp}^{S} are assumed to be a function of the bid price (x_{1itp}), the level of relative risk aversion x_{2itp}, lagged water market price volatility (x_{3it-1p}), lagged volatility of volumes traded (x_{4it-1p}), endowed water allocation per acre (x_{5itp}), lagged monthly irrigation water requirements

(x_{6it-1p}), the location of the diverter along the banks of the river (x_{7itp}), and the priority of the licence of the farmer (x_{8itp}) (in FITFIR scenarios). Additionally, expected crop returns, a vector of year-specific, month-specific and agent-specific dummy variables (D) are used to control for unobserved time and agent effects.

Being consistent with the law of demand, it is expected that the bid price should be negatively correlated with bid volume. The higher the volume of irrigation water required last period, the greater the expected bid demand volume. The expected impact of relative risk aversion on bid volumes can either be positive or negative, as higher levels of relative risk aversion could reduce bid volumes through the farmer's aversion to water price volatility. This could, however, be offset by farmers' aversion to not meeting crop water requirements as farmers may opt to participate more in the market to secure water volumes. The impacts of location and priority are uncertain, but it is one of the aims of this thesis to investigate what impact, if any, agent location or agent priority has on water market participation. In line with the theoretical model, if priority or location impacts participation then there are externalities present in diversion as the diversion of a farmer would impact the ability of other farmers to divert volumes from the river. If the coefficient for location is positive, it implies that farmers further downstream generally want to purchase more water than upstream farmers. If the coefficient for priority is negative, then it indicates that lower priority farmers (higher priority values) want to buy less water than higher priority farmers (lower priority values).

As per the law of supply, it is expected that the bid price should be positively correlated with the bid volume. It is expected that the higher the volume of irrigation water required, the lower the expected bid supply volume. It is expected that since farmers may use irrigation water to water crops, if there is increased moisture required, then a seller may choose to reduce his supply to water his crops. The impact of relative risk aversion on bid sale volumes is expected to be positive as the water market is providing an alternative method of raising revenue for farmers and hence farmers can further diversify their risks. As such, the more risk averse the farmer the greater is expected the water supplied to the market. As under the demand model, it is uncertain what are the impacts of location. If the coefficient for location is positive, it implies that farmers further downstream generally want to sell more water than upstream farmers. If the coefficient for priority is negative, then it indicates that lower priority farmers (higher priority values) want to sell less water than higher priority farmers (lower priority values).

3.5 The Oldman River Water Trading Model (ORWTM): Results and Discussion

The ORWTM generates a significant amount of data. However, the analysis of the data is confined to the behaviour of licenced crop and livestock farmers under different settings. In the following sections, the base scenario is discussed, followed by the model validation and verification. Thereafter, selected results from the model are highlighted. At the macro-level, the discussions are segmented according to water adequacy levels, and water allocation regimes (FITFIR and water sharing). This entails a discussion of farmers' profitability, water market equilibrium prices and volumes, and water market price and volume volatility-indicators of riskiness in the water market. Counterfactual results at the micro-level are then presented in comparison to the base scenario as per Section 3.4.5. Finally, a brief discussion of some key issues arising from the results are presented.

3.5.1 Description of the Base Scenario- Adequate Water Supply and No Trade

The model is constructed to simulate behaviour under two broad scenarios: adequate water supply and inadequate water supply. It is assumed that under adequate water supply starting flows are equal to the entitlements allowed to be diverted from the Oldman River (approximately 597 000 ML of water; AEP, 2017). The gross margins of crop farmers, the feed costs, water price and quantity are monitored in cases of market trading under a water sharing regime, no trading under a FITFIR regime, and trading under a FITFIR regime.

Six scenarios are simulated in the ORWTM; three water allocation settings combined with two levels of river water supply. The base scenario is intended as a depiction of current conditions. Given no recent (2010-2016) widespread droughts in the LNID, the base scenario is modelled under adequate water supply. As well, the base scenario is defined as having no water trades. Although there is currently legislation that facilitates trade of water rights, there is no market clearinghouse analogous to the Water Market Authority modelled in the ORWTM (as discussed in section 3.4.3.1) to facilitate water trades. Also, historically, there have been very few trades. Between 2000 and 2010, there were a total of forty trades with four of them being temporary trades; that is, virtually no trading of temporary rights (Adamowicz et al., 2010). The base scenario, therefore is the one that closest mimics current conditions of virtually no trade in temporary water rights; that is the “adequate water supply no trade” scenario.

3.5.1.1 Model Verification and Validation

Model verification is the process of checking that commands and rules that govern the model are reasonable and are followed by the agents in the model. For the ORWTM, model verification involved a series of steps. First, miniature prototypes of each of the blocks outlined in Figure 3.10 are built and tested before the coding is integrated into one model. The integrated model has undergone multiple tests for accurate agent response, environmental response and correct market water response. To do this, agent model outputs are evaluated for random agents to ensure actions are consistent with decision rules for the agent and that the decision rules are realistic. Also, the model output is analysed over simulated months and years to ensure that dynamic rules are being followed to verify that the mode is adequately calibrated. It is found that the model is effectively calibrated and sufficiently verified.

Model validation describes the process of ensuring that the model is accurately portraying the system it is intended to mimic. The simulation output is compared to historical data from Lethbridge Northern Irrigation District (LNID) which is representative of the region. The first comparison is the proportion of acres seeded to each crop. The average simulated seeded acre percentages for most crops fall within range for of the historical minimums and maximums of the region (Table 3.2). The seeded acres are very similar across the different scenario settings. This primarily is due to the change in returns being formulated outside the model and being consistently applied across differing model settings. Hay is marginally over produced while barley is under produced. Silage is the most prevalent crop in the region. The optimization model is constrained to the historical maximums produced under LNID, the general geographic region of the model.

The drivers for seeded acres under the base scenario are expected crop returns and water diversion licence volume. High value crops such as potatoes and canola are consistently seeded at levels consistent with the historical maximum (Figure 3.12). Because water is a limiting factor, sugar beets are not grown at the historical maximum despite having high returns. This is likely due to the crop water demand for sugar beets being much greater than for potatoes. The under production of barley in the model results from the comparatively low average returns for barley despite barley having the second lowest water demand behind barley silage. Since it is assumed that real costs are held constant, the real cost associated with barley production as well as the relatively low yield of barley depresses the average anticipated return and results in the lower than expected seeded acres in the simulation.

For model tractability, simplicity and due to the lack of data it is assumed that farms are either crop or livestock farms. This assumption could also influence the disparity in barley and hay allocations. If there are mixed farms in the model, the acreage allotted towards barley would not necessarily be based on the market returns for barley but instead would be influenced by its nutritive value as a feed for livestock.

Table 3.2 Comparison of Simulated Land Allocations to Actual historical LNID Land Allocations

	Min (2009 -2015)[1] %	Max (2009 -2015)[1] %	Model Average* %
Non-Feed Wheat	6.6	11.00	9.3
Feed Wheat	1.4	4.10	3.6
Barley	9.2	12.8	4.1
Canola	10.9	19.30	19.3
Sugar Beets	1.2	2.30	1.6
Potatoes	0.5	0.80	0.8
Hay	15.3	22.2	23.3
Cereal Silage	36.7	47.20	38.0

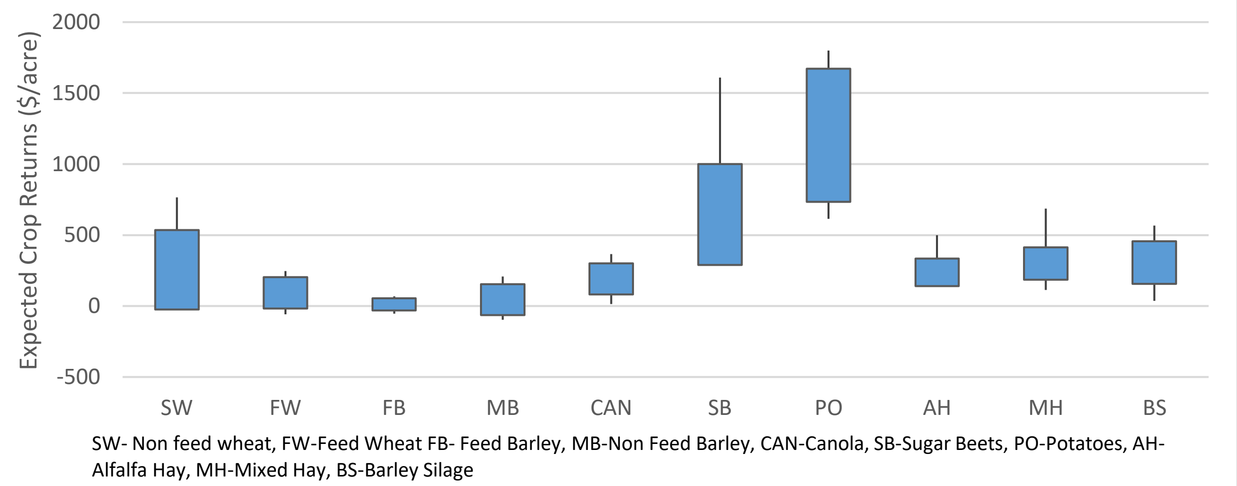
[1] 2011 and 2012 data are not available.
*The Model Average is the seeded acre percentage averaged across agents across year of cultivation and across model replications.

Source: ORWTM, Alberta Irrigation Information (2015c, 2016e, 2011, 2014; 2010)

The under production observed is, however, not central to agent's behaviour in the water market and would be of minimally influence to water market trade price and volume volatility since barley is a relatively low water demand crop. The over production of hay is an over compensation for the under production of barley. This occurs as the barley and mixed hay compete for acres at the margin. Furthermore, the over-production of hay is marginally above the seven-year historical maximum and is well within seeding rate ranges of other southern Albertan irrigation districts and is therefore plausible.

Another measure of model validation is the analysis of how well the ORWTM mimics the irrigation district's (ID) water extractions from the river under the base scenario. In each crop season, the ID is licenced to extract just over 412,000 ML of water from the Oldman River. Historically, between 1982 and 2015 the irrigation district utilised 58.9% of its licenced allocation, on average (LNID, 2015a). In 2001, approximately 92.2% of the licenced volume was diverted from the river (LNID, 2015a). The base simulation results indicate that approximately 305,000 ML of water (or 74.1% of licenced volume) is diverted from the Oldman River, within the range of historical extractions.

Figure 3.12 ORWTM: Box Plot of Anticipated Crop Returns that Farmers Use to Determine Crop Mix



Source: ORWTM

The ID's volume of diversions has tended to be greater in more recent years than in more distant years. Finally, model precipitation is incorporated by sampling from an assumed distribution based on the historical range of actual readings. Conservatively, the model chooses precipitation values from the lower half of this distribution, to replicate relatively dryer conditions.[39] All these would mean that model diversions should be slightly greater than the historical mean.

The final measure of validation is the comparison of livestock rations in the model to diets formulated by based on industry information. As depicted in Table 3.3, the ORWTM grain and forage inclusion rates closely approximate or falls within the range of sample rations posted by Prairie agricultural ministries AF (AF, 2007d, 2016g; MAFRD, 2017; Van Biert, 2017) or as seen in industry literature (Cottonseed, 2017). However, the model protein meal inclusion rate for dairy is marginally higher than those posted

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[39] Due to the very limited number of cropping seasons and model replications, the focus is to replicate irrigation under relatively dryer conditions.

in industry and the Alberta agricultural ministry, while protein inclusion rates for beef are substantially above those posted by Prairie agricultural ministries. This indicates that feeding plans between dairy and beef may differ more than is modelled. As per internal model validation, grain use in dairy does not exceed 18.5 percent, the only distinction made between the beef and dairy operations.[40] This restriction requires a costly shift from barley to wheat, increased forage use and increased protein and mineral supplementation for dairy operations. These metrics used for validation indicate that the model is fairly robust at capturing what is occurring in the real world and is therefore valid.

Table 3.3 Livestock Ration Composition in the OWTRM Compared to Sample Rations

	Dairy (% of diet)			Beef (% of diet)		
	Wisconsin	Alberta	Model	Manitoba	Alberta	Model
Grain	14.5	13.0	18.5	37.7	60.8	45.6
Forage	67.8	61.6	60.6	60.9	33.8	38.7
Protein meal	13.8	-	14.9	0.0	5.1	11.9
Other	18.4	25.4	6.0	1.4	0.3	3.9

Source: ORWTM, AF (2007d) MAFRD (2017) AF (2016g) Van Biert (2017) and Cottonseed (2017)

3.5.2 Macro-comparison of Output

This section presents a discussion of the simulation results on a macro-level; that is data are aggregated for all irrigators that use the Oldman River. Specifically, comparisons are made for two water supply conditions- adequate and inadequate water supply. For the purposes of a generalized discussion, key variables of interest are discussed. These include the average realized gross margins of crop farmers, the average total net costs (feed costs + net water purchases, also known as TEI) for livestock farmers, water market trade volumes and trade prices. Counterfactual scenario results are compared to base scenario results. The base scenario is one in which there is no efficient water rights trading platform in operation,

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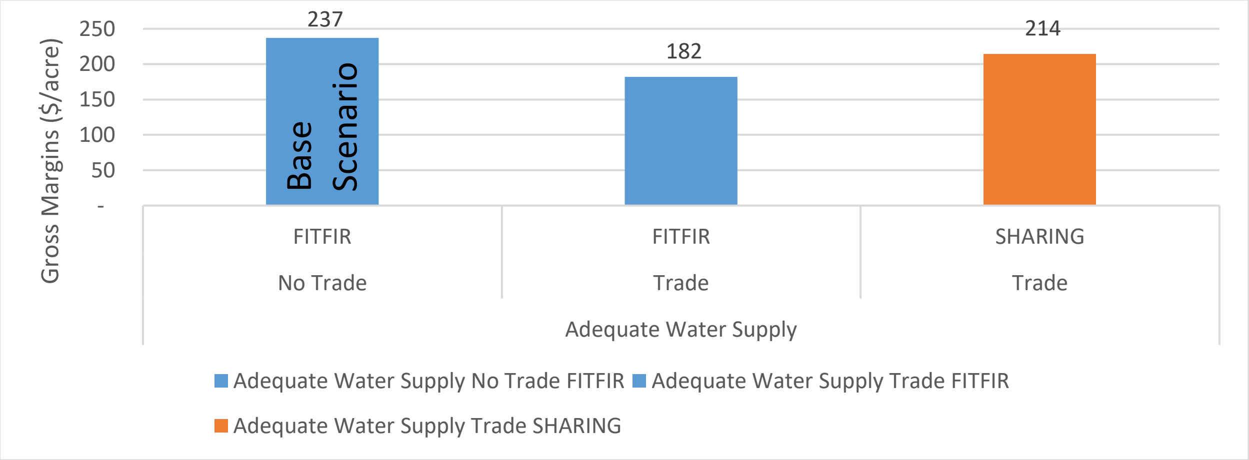
[40] Increased grain use increases the risk of rumen acidosis (AF, 2007c). As such the standard practice is to limit grain intake to 2.45kg/day (Penner, Menajovsky, & Paddick, 2017), which represents 18.5% of total daily intake of the lactating cow (NRC, 2001).

the water allocation regime is governed by the FITFIR principle and river flows are adequate to supply existing rights. Five counterfactual scenarios are compared with the base scenario: 1) no trading with inadequate water supply under a FITFIR water allocation regime; 2) efficient trading with adequate water supply under a FITFIR water allocation regime; 3) efficient trading with adequate water supply under a water sharing regime; 4) efficient trading with inadequate water supply under a FITFIR water allocation regime and 5) efficient trading with inadequate water supply under a water sharing allocation regime.

3.5.2.1 Adequate Water Supply: Crop Farmer Average Realized Gross Margins

The simulated results for five growing seasons indicate that if there is adequate water supply, then crop farmers are better off on average when there is no water market, that is the no trading scenario (where there is no transfer of rights) would yield higher returns than the trading scenarios (Figure 3.13). This is consistent with the belief that if there is enough water there is no need to make changes to the regime; that is, the view of industry stakeholders. However, given a regime structure that facilitates efficient trade of water rights, it is optimal to have a water sharing regime as realized gross margins are higher under this scenario. This is consistent with the views of academics, as discussed earlier.

Figure 3.13 Average Simulated Gross Margins per Acre for Licenced Crop Farms under Adequate Water Supply

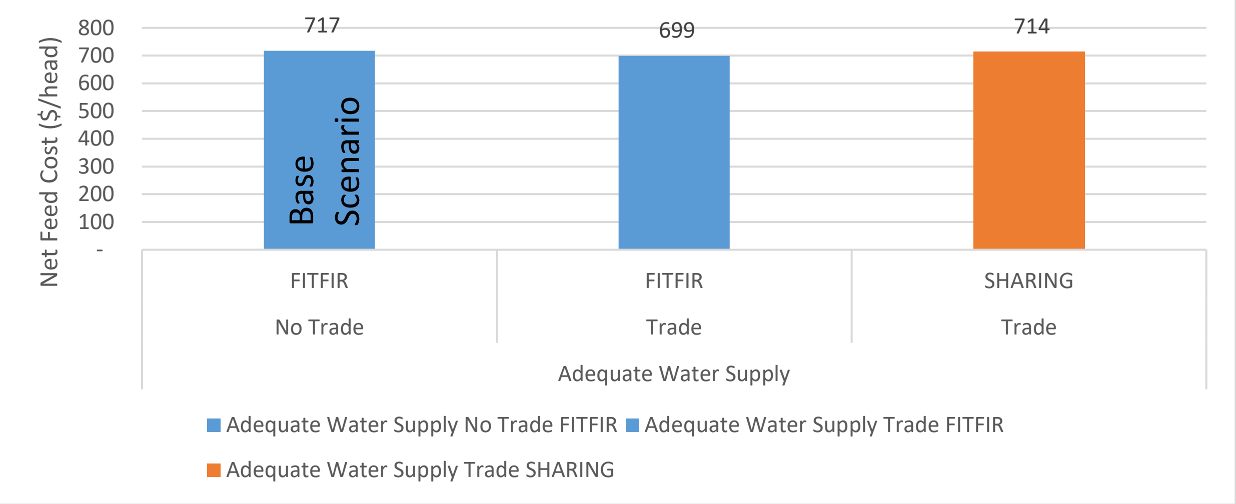


Source: ORWTM

3.5.2.2 Adequate Water Supply: Cattle Farmers Average Realized Feed Costs

As opposed to trade being less preferred by crop farmers, cattle producers with licences incur the least net costs when there is trade in water rights. Nevertheless, feed costs of dairy farmers are almost indistinguishable when comparing feed costs across all scenarios under adequate water supply. As depicted in Figure 3.14, FITFIR with trade results in slightly lower net feed costs associated with dairy production. These producers prefer to buy most of the required feed and sell most of their water allocation. The marginally lower prices under adequate water supply as well as a significantly lower endowment volume imply that these farmers are notable make substantial used of the water market.

Figure 3.14 Average Simulated Annual Feed Costs per Head of Dairy Cattle under Adequate Water Supply

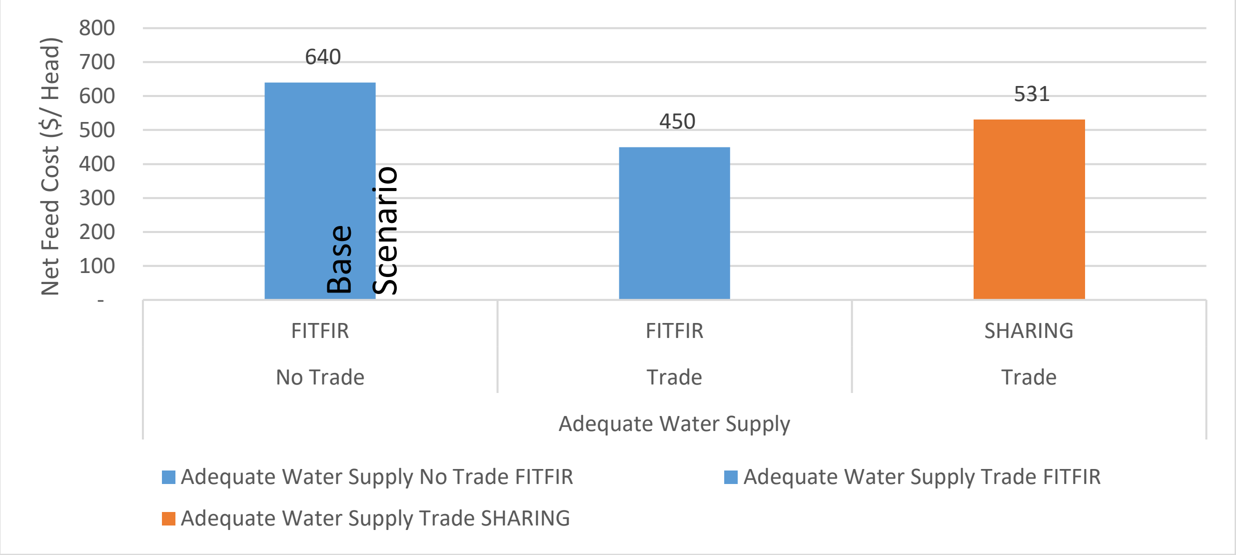


Source: ORWTM

As for beef farmers, the difference in cost across regimes is more distinguishable with beef farmers incurring considerably lower cost under FITFIR regime with trade (Figure 3.15). In general, beef cattle producers have lower feed costs than dairy producers and benefit the most from trade in water rights (Figure 3.15). This is primarily due to the substantial larger endowment volume of beef producers and the grain diet limitation in dairy as this is the only distinguishing factor between the two farm types.

Based on the literature, a constraint in the model restricted the use of grains in dairy cattle feed to a maximum of 18.5 percent of the total diet. Therefore, dairy farmers must substitute other forms of energy and protein feedstuff to meet the diet requirements, at a higher cost. Since beef farmers don't have that limitation they can feed more grains, which means they can grow more grains or purchase more grains thereby reducing costs. Additionally, these farmers can sell surplus water rights in the market to improve their income and lower TEI.

Figure 3.15 Average Simulated Annual Feed Costs per Head of Beef Cattle under Adequate Water Supply



Source: ORWTM

3.5.2.3 Adequate Water Supply: Water Market Trade Volumes and Prices

Table 3.4 depicts a comparison of results with respect to water price, for the FITFIR regime and the water sharing regime with efficient trading, under adequate water supply. Mean trade price is on average higher under FITFIR, while trade volumes are marginally lower, compared to the sharing regime. FITFIR having higher prices supports the notion that livestock farmers would prefer a FITFIR regime as opposed to a water sharing regime as higher prices would lead to higher revenues and lower net costs. On the other hand, crop farmers who are generally buyers would prefer the water sharing regime as they would have a lower purchase cost and higher gross margins under this regime. Also, these risk averse crop farmers would prefer the water sharing regime because the market is typically less volatile, and these farmers are able to access marginally more units.

Table 3.4 Simulated Water Market Trade Price and Volume under Adequate Water Supply (Mean and Standard Deviation), by Water Trading Regime

	FITFIR	**SHARING**
Average Trade Price ($/ML)	214	131
Trade Price Standard Deviation ($/ML)	323	297
Average Trade Volumes (ML)	2,531	2,540
Trade Volume Standard Deviation (ML)	374	372

Source: ORWTM

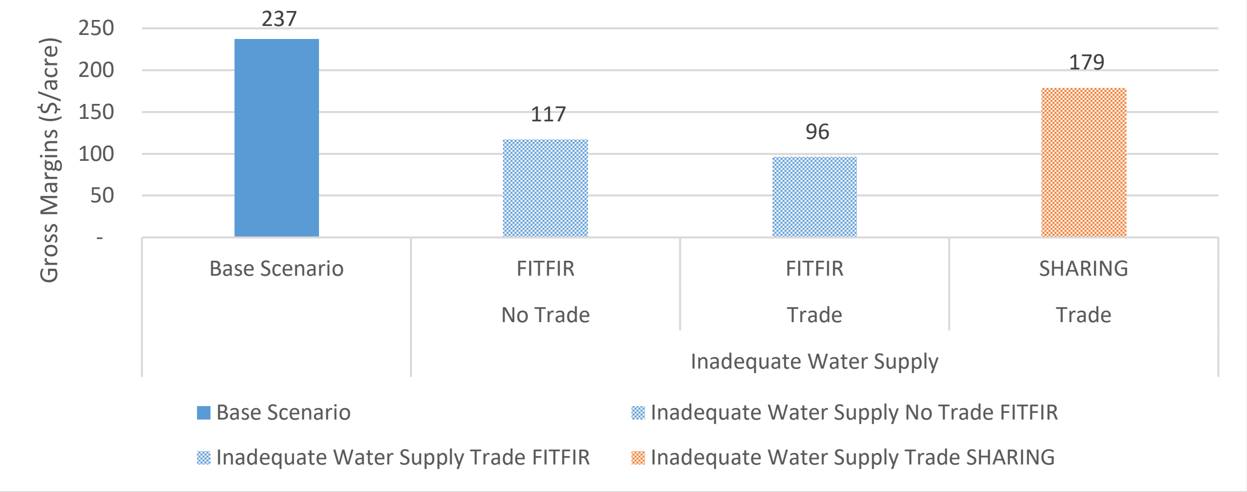
3.5.2.4 Inadequate Water Supply: Crop Farmers Average Realized Gross Margins

Inadequate water supply is modelled as the situation where beginning inflow is 50% of total annual permitted rights. As depicted in Figure 3.16, returns are lower when there is inadequate water supply. In fact, the highest average returns under inadequate water supply are lower than the lowest average returns under adequate water supply. This is because of the effect of reduced yields due to water shortage. In contrast to the scenario of adequate water supply, the type of the governing water allocation regime significantly impacts crop farmers. Crop farmers are most adversely affected under the trade with FITFIR regime (Figure 3.16). On the other hand, crop farmers benefit the most in a scenario where there is trade under a water sharing regime. This corroborates with past events in the 2001-2002 crop year in Alberta where irrigators chose to share water when there was a severe water shortage (Nicol & Klein, 2006).

3.5.2.5 Inadequate Water Supply: Cattle Farmers Average Realized Feed Costs

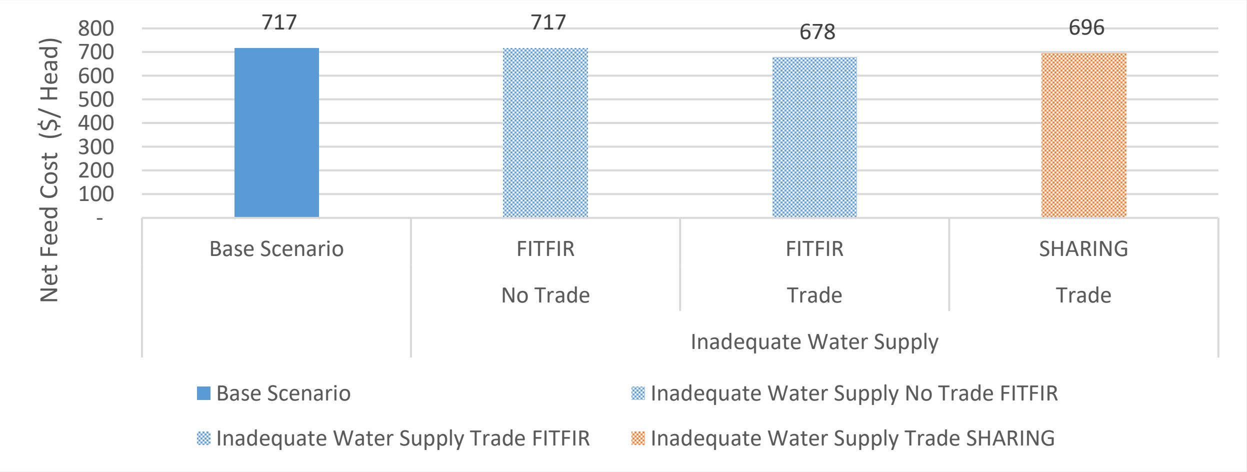
In the case of inadequate water supply, there are no significant differences in costs when compared to the scenario of adequate water supply for dairy farmers (Figure 3.17). The key drivers are the limited availability of initially endowed volumes and additional limitation on grain used for dairy cattle. The relatively low level of endowed volumes means that dairy producers are limited in raising revenue from the sale of water rights. The relatively higher prices due to water scarcity mean that dairy producers will generate more revenues than they would under adequate water supplies thereby reflecting a marginally lower TEI. The restriction of grain use by dairy cattle implies that the ration mix would be less flexible and costlier.

Figure 3.16 Average Simulated Gross Margins per Acre for Licenced Crop Farms under Inadequate Water Supply



Source: ORWTM

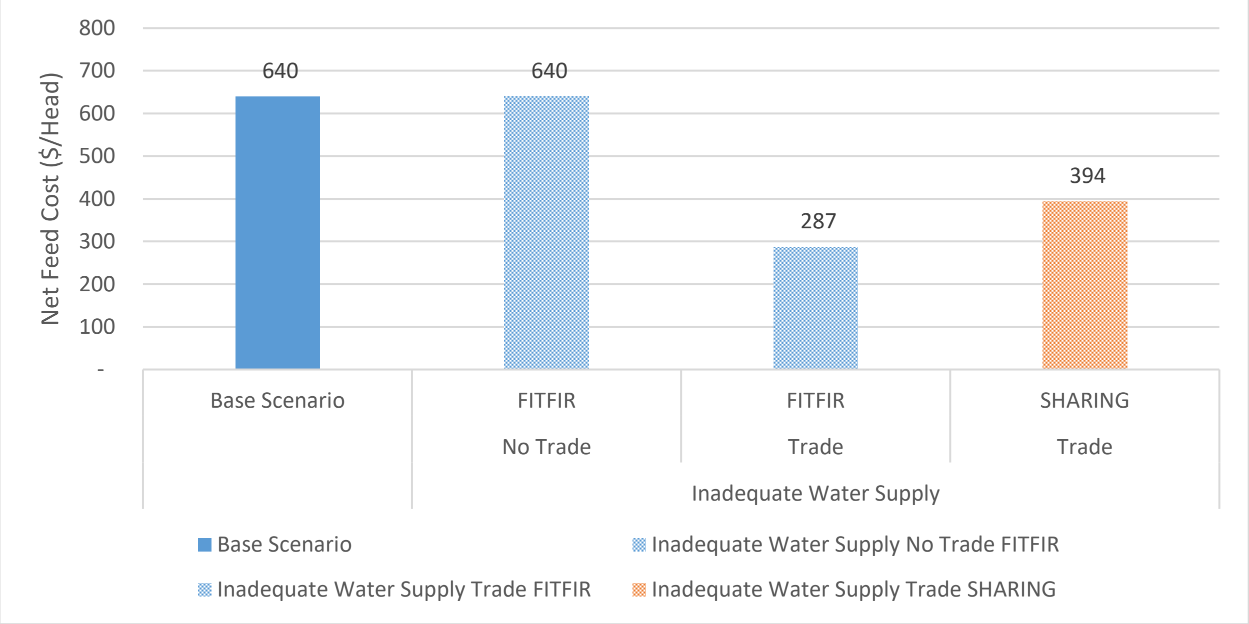
Figure 3.17 Average Simulated Annual Feed Costs per Head of Dairy Cattle under Inadequate Water Supply



Source: ORWTM

Under inadequate water supply, trading with FITFIR is preferred for both beef and dairy farmers. The degree of cost savings for beef farmers are especially notable under water scarcity. Specifically, beef farmers can recover approximately 55% of total feed cost incurred under the no trade FITFIR regime (Figure 3.18). This is mainly attributable to the relatively sizeable endowment rights as well as the higher equilibrium prices for tradeable rights due to scarcity.

Figure 3.18 Average Simulated Annual Feed Costs per Head of Beef Cattle under Inadequate Water Supply



Source: ORWTM

3.5.2.6 Inadequate Water Supply: Water Market Trade Volumes and Prices

In general, prices are higher under inadequate water supply than adequate water supply. Also, FITFIR exhibits higher average prices totalling $397 per ML as opposed to $274 per ML under water sharing regime. FITFIR also exhibits higher price and volume volatility in comparison to the water sharing regime. However, there is no significant difference in the mean volumes traded under FITFIR regime and water sharing regime. This is primarily due to the requirement that farmers cannot leave the land fallow. If farmers had the option to leave their land fallow, many may have opted to sell rights and demand would be much weaker. The weaker demand would lead to greater market instability and equilibrium price and volume volatility. The stability under FITFIR facilitates marginally higher trade on average (Table 3.4).

Table 3.5 Simulated Water Market Trade Price and Volume under Inadequate Water Supply (Mean and Standard Deviation), by Water Trading Regime

	FITFIR	SHARING
Average Trade Price ($/ML)	397	274
Trade Price Standard Deviation ($/ML)	1264	645
Average Trade Volumes (ML)	2,288	2,355
Trade Volume Standard Deviation (ML)	525	492

Source: ORWTM

3.5.3 Impact of Risk and Diversion Externalities on Farmer Water Market Participation and Profitability

From earlier in this chapter, recall that this thesis aims to assess: 1) the impact of water market price and volume risk on water market participation; 2) the impact of how water market variables influence farmers' economic performance and 3) how the economic performance of crop and livestock producers differ under alternative water regimes. Thus, an analysis of water market performance is required. Through a presentation and discussion of regression results, the following subsections highlight pertinent relationships results regarding the impact of water market price volatility, location and priority (where relevant) externalities on farmer water market behaviour.

Panel data regression analysis is also used to assess the impact of trade price and volume volatility on the profitability for crop farmers and per-head feed costs for livestock producers. A fixed effects panel specification is used to estimate the marginal effect of trade price and volume risk on crop farm profitability and livestock farm net feed cost (TEI). In the base scenario, there is no active water market. Therefore, there is no means of estimating how the water market affects profitability. Since the following four scenarios include an endogenous water rights market, risk impacts on the water market participation as well as market risk impact on farmer economic performance can be estimated. The tables of descriptive statistics for the various regression models estimated can be found in Appendix D.

3.5.3.1 Adequate Water Supply and Trading under FITFIR

In this scenario, also called HIFITFIR, flows are equal to the total licenced volumes and trade in water rights is permitted under a FITFIR regime. The discussion is subdivided into four sections. The first section highlights the impact of risk and externalities on crop farmer water market participation and the second section highlights the water market risk impact on crop farmer economic performance. The last two sections present similar analysis for livestock farmers.

Table 3.6 Regression Results: Water Market Participation on Water Market Variables and Externalities, Adequate Water Supply and a FITFIR Regime

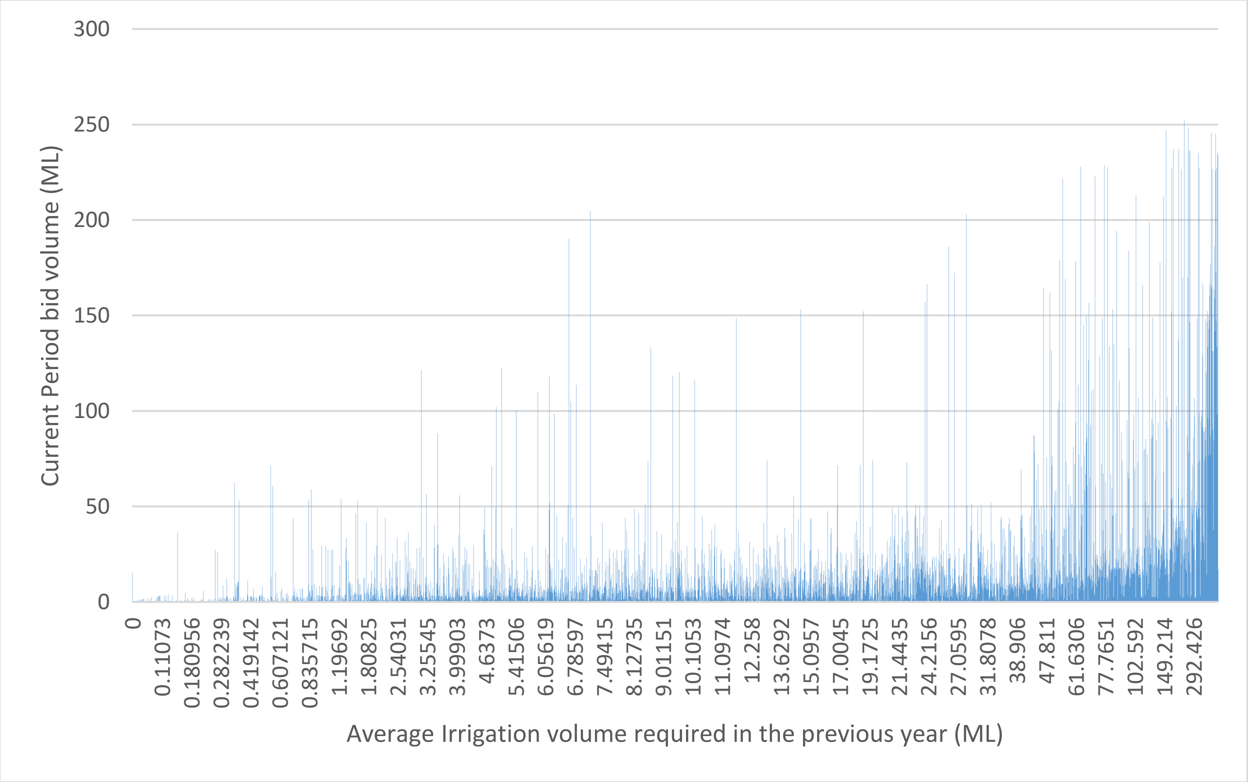
	Bid Demand Model	**Bid Supply Model**
Bid Price	-0.000186*** (0.00000458)	0.000431*** (0.0000326)
Relative Risk Aversion	-0.0505 (0.422)	-0.111 (0.0894)
Lagged Water Market Price Volatility	-0.00123 (0.00243)	-0.00247*** (0.000706)
Endowed Water Allocation per Acre	-13.70*** (0.500)	4.408*** (0.184)
Lagged Irrigation Water Required	0.167*** (0.00969)	0.00493*** (0.00118)
River Diversion Point	0.0271*** (0.00404)	0.00874*** (0.000986)
Priority	-0.0175*** (0.00173)	-0.00420*** (0.000722)

Standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Source: ORWTM

Table 3.6 presents the regression results outlining the impacts of risk and externality variables on crop farmer participation in water markets. As expected, increases in bid price are associated with lower volumes demanded. Relative risk aversion is not statistically significant but the sign of the coefficient on risk aversion indicates that more risk averse farmers are less likely to want to participate in the market. Increases in the volume of irrigation required in the previous period (i.e., Lagged Irrigated Water Required) leads to increased bid volumes. As farmers require more water they try to purchase more volumes in the following period of trading (Figure 3.19).

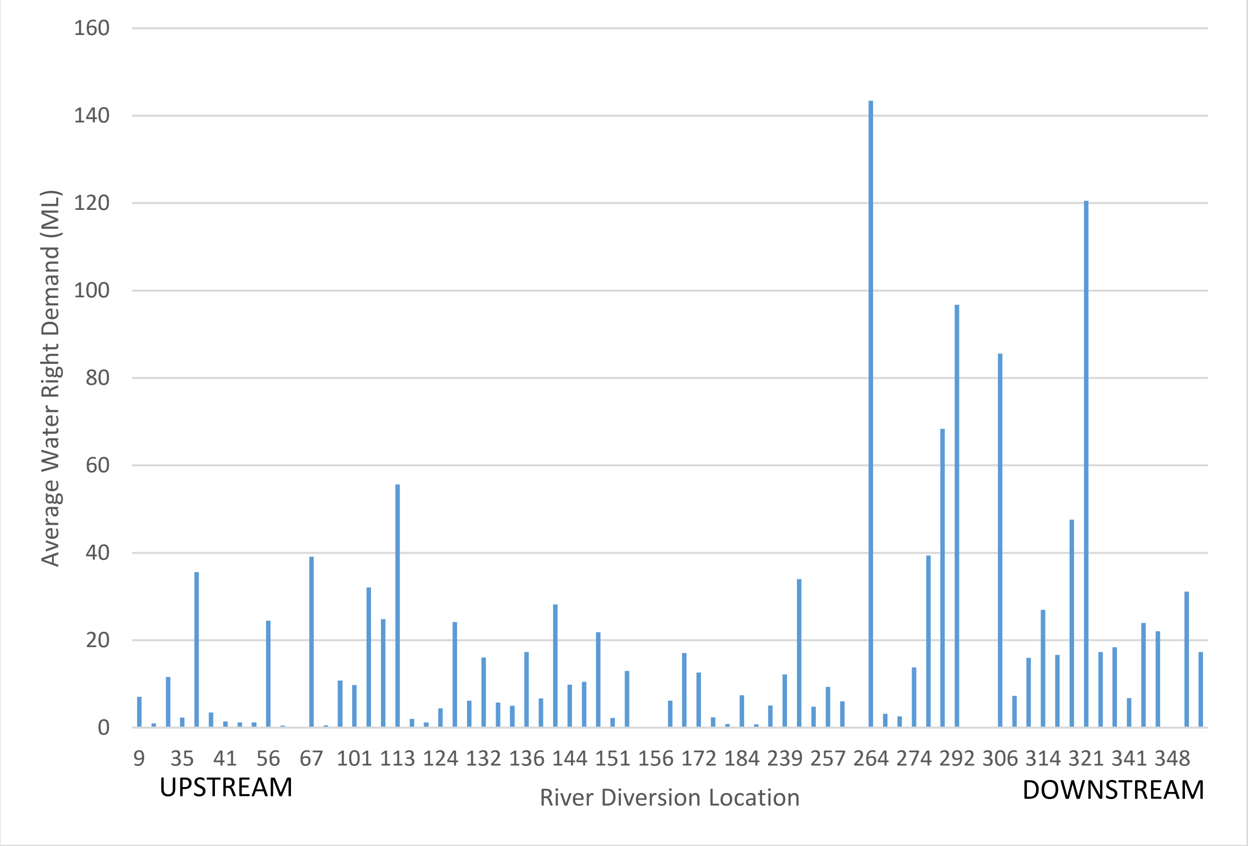
Figure 3.19 Plot of Current Period Bid Volume Demand on Prior Period Irrigation Required Volumes



Source: ORWTM

It is also indicated in Table 3.6 that there are endowment effects as well as priority and location externalities on farmer water right demand. Specifically, farmers with greater water right endowments demand less water in the market (i.e., endowed water allocation per acre). This is intuitive since with increased water rights (i.e., right to divert more water) the farmer will have less need to enter the market to purchase rights. Also, downstream buying farmers want to buy more rights (i.e., river diversion point). This is consistent with the notion of location driven externalities. Since the diversions of upstream farmers affect the ability for downstream farmers to divert water volumes, they seek to buy relatively more rights to reverse the effects of the externalities (Figure 3.20).

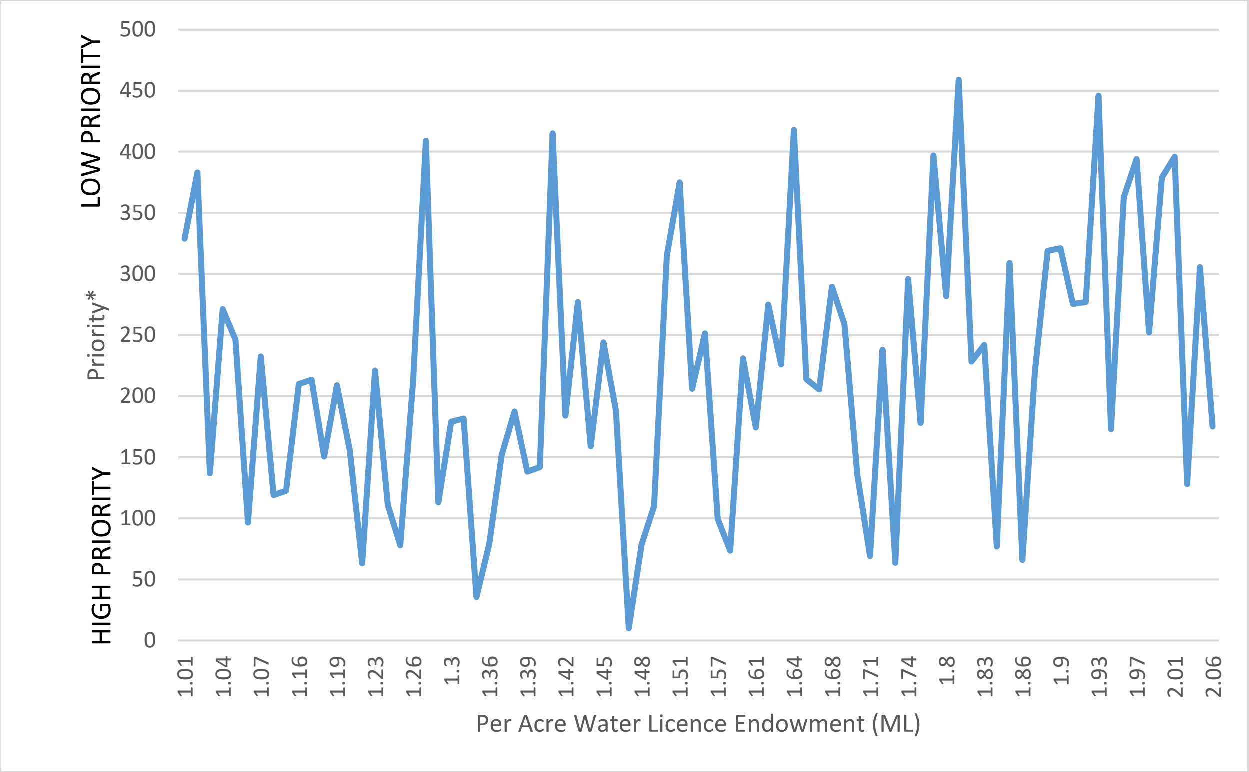
Figure 3.20 Plot of Irrigation Water Demand on Water Diversion Point along the River



Source: ORWTM and AEP (2017)

The coefficient of priority in Table 3.6 is negative, indicating that lower priority buying farmers try to buy less rights. This seems counter-intuitive, however, if we recall that more endowed buyers try to buy less volumes and now combine that with the fact that buyers with greater water right endowments have a lower priority (Figure 3.21), then it is reasonable to see that farmers with a lower priority would try to buy less irrigation water volumes.

Figure 3.21 The Relationship between the Priority and the Per Acre Endowment Volumes of Buyers



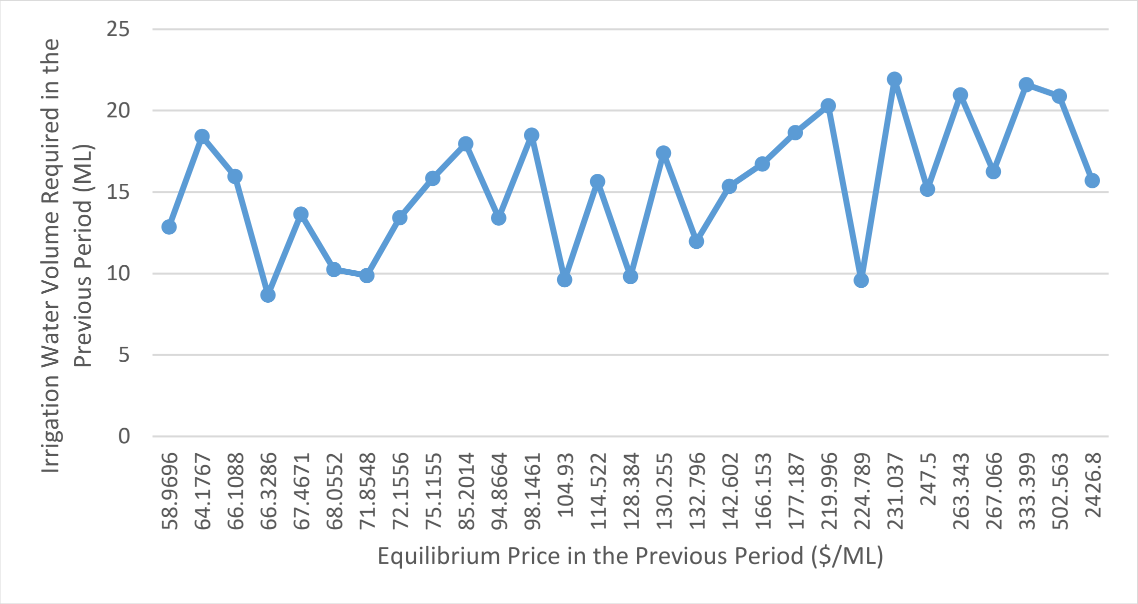
* Priority is a numerically assigned value with the highest priority assigned a value of 1 and the lowest a value of 460

Source: ORWTM and AEP (2017)

Finally, marginal increases in lagged water market price volatility do not significantly affect buyer demand for water rights. This occurs despite the expected negative relationship in the signs.

Consistent with the theory of supply, in table 3.6, a marginal increase in bid prices results in an increase in bid supply volumes. Despite the signs being consistent with the idea that holding water rights reduces risk associated with moisture deficits, the coefficient on risk aversion of sellers is not statistically significant. It may have been difficult to distinguish risk aversion effects from other intrinsic effects, or this result may have been due to the offsetting price risk and volume risk effects. The results also indicate that sellers with higher water right endowment volumes per acre (i.e., endowed water allocation per acre) are willing to sell relatively more rights than sellers with lower endowments. The higher the endowment the more likely the farmer will have surplus supplies and hence will try to sell more units on the market. Interestingly, farmers who required more irrigation water in the prior period (i.e., lagged irrigation water required) are willing to sell more in the current period. This result is unexpected. However, it may be due to the fact that if the irrigation requirement in the previous period is relatively high then market price for water would be expected to be high as well. The positive relationship between lagged equilibrium prices and average lagged irrigation volume required is shown in Figure 3.22. Since farmers adjust the bid price towards the prior period equilibrium price, they will expect higher prices in the current period and, all other things constant, will supply more to the market.

Figure 3.22 Plot of Lagged Irrigation Requirement Volumes on Lagged Equilibrium Price



Source: ORWTM

Downstream sellers want to sell more rights (i.e., river diversion point). This may be expected as downstream sellers hold more than double the rights of upstream sellers, and as noted before, the more rights endowed the more likely a farmer would be to sell water rights. Also, as the downstream sellers perceive higher revenues from the sale of rights relative to the expected returns from crops, they are enticed to supply more. Also, lower priority sellers want to sell less rights (i.e., priority). This is consistent with the notion that crop farmers with low priority licences will try to retain as much of their rights as possible since they need the water to irrigate their crops in the event of negative externalities associated with water diversion (Table 3.6).

Results from regressing crop farm profitability on risk measures are presented in Table 3.7. As seen, price volatility and volume volatility effects (i.e. lagged water price volatility and lagged price volume volatility, respectively) on sellers and buyers are different. Specifically, price and volume volatility results in lower profits to buyers but higher profits to sellers. While the results for buyers are in line with expectations, the results for sellers may seem less straight forward. All else constant, theory suggests that the level of risk associated with an asset and its expected return are positively related. If farmers are risk averse, then the farmer would under invest in the risky asset (water rights) hence forfeiting profits. As such the sign on the coefficient on buyers is expected.

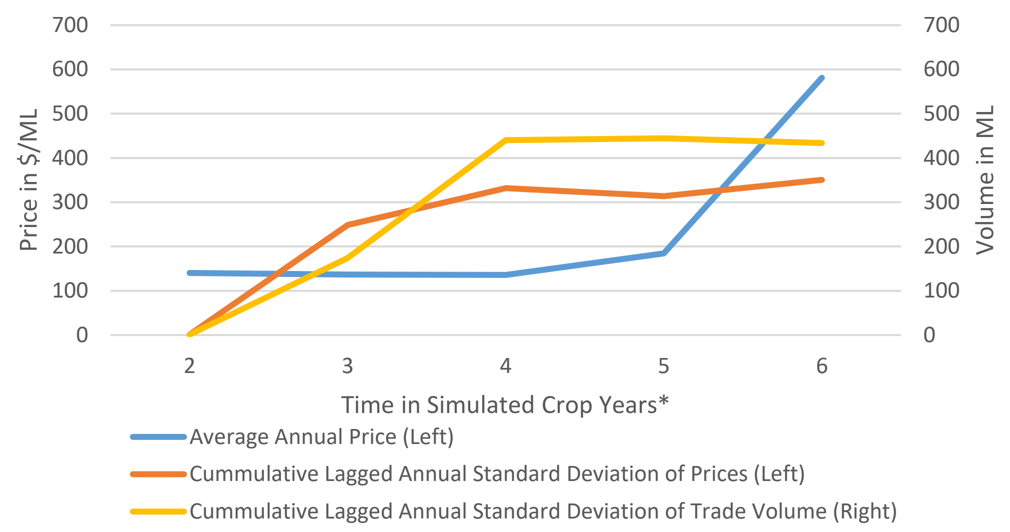
Table 3.7 Regression Results: Crop Farm Profitability on Water Market Risk Measures, Adequate Water Supply and a FITFIR Regime

	Dependent Variable: Gross Margin per Acre			
	Buyers	Sellers	Buyers	Sellers
Lagged Water Price Volatility	-0.276*** (0.0425)	0.145*** (0.0424)		
Lagged Water Volume Volatility			-0.0594*** (0.0139)	0.0255* (0.0143)
Standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Other regressors which are used as controls to ensure consistent estimation of volatility impacts are not displayed here but are presented in Appendix D.				

Source: ORWTM

Also, on further inspection of prices it is observed that as the simulation progresses the market price for water rights trends upwards and so does the price and volume volatility (Figure 3.23). This means that prices are increasing, and buyers must pay more for water rights thereby reducing their profits, but sellers would have increased revenues from the sale of water rights. As such the coefficient for the volatility variable for sellers is positive.

Figure 3.23 Simulated Water Market Price, Trade Price and Volume Volatility over Time



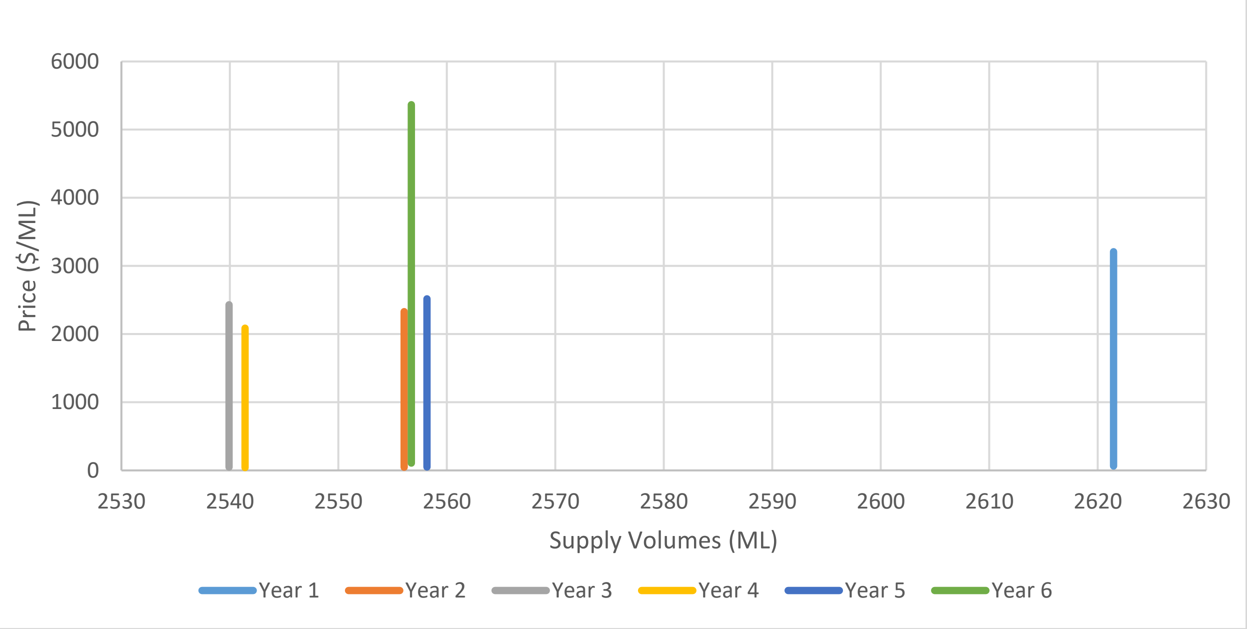
*The first year simulation is not shown in line with lagged volatility variables.

Source: ORWTM

There is not enough variability in the data to estimate risk and externality impacts on livestock farm water market participation. Due to the inherent flexibility in the livestock farm operation (i.e. the ability of livestock farms to purchase feed) as well as their relatively low valuation of on irrigation water, livestock farms take short positions in the water market. In other words, they opt to purchase feed and sell water rights. Within a given growing season, these livestock farmers opt to sell all their water rights regardless of the price in the market; that is, their supply schedules are perfectly Inelastic (Figure 3.24). Over the six years in the simulation, the first year exhibits the farmer's highest willingness to participate in the water rights market. Bid sale volumes decrease in year 2 and year 3 but increase in year 4 and year 5. This is followed by a marginal decline in the final year of the simulation (Figure 3.24).

Placed in context, the first year of the simulation had the lowest variance. Thereafter, there are increases in both trade volume and price variance, indicating increased risk associated with the water market. This coincides with reductions in market participation in years 2 and 3. In year 4, the decline in water price variance indicates a reduction in water price risk and coincides with increases in bid supply by livestock farmers. In year 5, there is an average reduction in water volume risk which seemingly facilitates an increase in bid supply. The increase in both trade price and volume risk in year 6 captures the reduction in bid supply for that year (Figure 3.24). This pattern for livestock producers is maintained through all water trading scenarios. This is due mainly to their decision to sell all their rights regardless of the scenario.

Figure 3.24 Simulated Livestock Farm Supply Curve for Water Rights over Time



Source: ORWTM

The risk impacts on livestock farm total economic impact (TEI) are depicted in Table 3.8. Livestock farmers are assumed to be cost minimising agents. When they participate in the water market, the proceeds from sales offset feed costs. The total net effect (net costs) is henceforth denoted as the total economic impact (TEI). From Table 3.8, increases in water trading price volatility and trade volume volatility are expected to reduce TEI (the coefficient on volume volatility is not significantly different from zero). This is consistent with the price discussion outlined for crop farmers, where price risk is more precisely positive price volatility indicating higher prices, greater sales revenue for livestock farmer who are sellers in the water market and lower TEI.

Table 3.8 Regression Results: Livestock farm TEI on Water Market Risk Measures, Adequate Water Supply and a FITFIR Regime

	Dependent Variable: Net Feed Costs (TEI)	
Lagged Water Market Price Volatility	-0.590** (0.262)	
Lagged Water Market Volume Volatility		-0.0000390 (0.0000400)
Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Expected returns are used as controls in the regression and are not reported here but in the Appendix D.		

Source: ORWTM

3.5.3.2 Adequate Water Supplies and Trading under a Water Sharing Regime

In this scenario, also called HISHARING, flows are equal to the total licenced volumes and trade in water rights is permitted under a water sharing regime. The following subsections highlight pertinent relationships from the regression results regarding the impact of water market price volatility and location externalities on farmer water market behaviour and farmer profitability.

The regression results highlighting the effects of risk and externalities on crop farmers' water market participation are presented in Table 3.9. As indicated, bid prices (bid price variable in the table) have a negative impact on how much buying crop producers are willing to buy but a positive impact on how much crop producing sellers are willing to sell. Unlike the HIFITFIR scenario, in the HISHARING scenario, buyers who are more risk averse seek to purchase more rights (i.e. risk aversion). This is consistent with the expectation that buyers seek to hold more rights to mitigate against risks of insufficient water volumes. By contrast, in the HIFITFIR scenario the water market may have been perceived as risky especially with priorities dictating initial allocations.

In the HIFITIR scenario water market price volatility has a statistically significant negative effect on seller participation. However, the results under the HISHARING scenario indicate that the impact, while numerically negative, is statistically insignificant for both buyers and sellers. The negative signs are expected based on the optimizing framework in which increased water price risk or volatility is expected to reduce participation in the market. The volatility impact is muted due to both the allocation regime and the adequate water supply in the market. There is less market volatility because priority effects have been nullified under the water sharing regime. As well, since there are generally higher flows in the river, prices are lower and more stable.

Similar to the HIFITFIR scenario, higher levels of water endowment are associated with lower water demand and higher water supply to the market. Farmers with greater water endowments are more likely to have surplus volumes and therefore would need to by less from or sell more to the market.

Consistent with expectations, increased levels of required irrigation volume in the prior period (Lagged irrigated water required variable) increases current period demand and reduces current period supply. The lower level of prices for irrigation water relative to those under the FITFIR regime results in sellers adjusting their sale volume downwards as their irrigation demands increase. In other words, the lower expected prices under the sharing regime means that the farmer will sell less and will try to maximise profits from a balance from crop production and water rights sales. Under FITFIR the farmer relied on the relatively higher irrigation water prices to maximise profits.

Farmer location along the river affects intent to participate in the water market (river diversion point variable). Similar to the HIFITFIR scenario and consistent with expectations, downstream buyers want to buy more rights to divert water. This shows that location externality effects are evident across regimes. In contrast to the HIFITFIR scenario and in line with expectations, however, downstream sellers want to sell less rights. In this scenario downstream sellers are the ones with relatively lower water endowment volumes and have higher irrigation requirements. Since these farmers are cultivating crops, they are more likely to retain water rights, as a precaution.

Table 3.9 Regression Results: Water Market Participation on Water Market Variables and Externalities, Adequate Water Supply and a Water Sharing Regime

	Bid Demand Model	**Bid Supply Model**
Bid Price	-0.000284*** (0.00000665)	0.000614*** (0.0000449)
Relative Risk Aversion	2.483*** (0.0915)	0.0595 (0.0407)
Lagged Water Market Price Volatility	-0.00193 (0.00294)	-0.000680 (0.00147)
Endowed Water Allocation per Acre	-5.666*** (0.293)	0.405*** (0.0885)
Lagged Irrigation Water Required	0.00677*** (0.00201)	-0.000468** (0.000214)
River Diversion Point	0.107*** (0.00357)	-0.00226** (0.00108)

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Source: ORWTM

The regression results of modelling the impact of marginal changes in water market risk measures on crop farm profitability are presented in Table 3.10. In terms of crop farmer profitability, increases in water market price and volume volatility contribute to increases in profitability for buying crop farmers but reduce profitability for selling crop farmers. This differs from the result outlined in the HIFITFIR scenario. In contrast to the FITFIR scenario, equilibrium prices for the sharing regime scenario are more stable and trend down over time (Figure 3.25) This results in a more favourable outcome for purchasers. However, lower prices as well as downward risk in price negatively impact selling crop farmers. The change in the allocation regime reduces the negative externalities; there are no priority externalities but there are still location externalities. This reduces the degree of excessive price bidding to secure volumes and as such more trade takes place at lower and more stable prices.

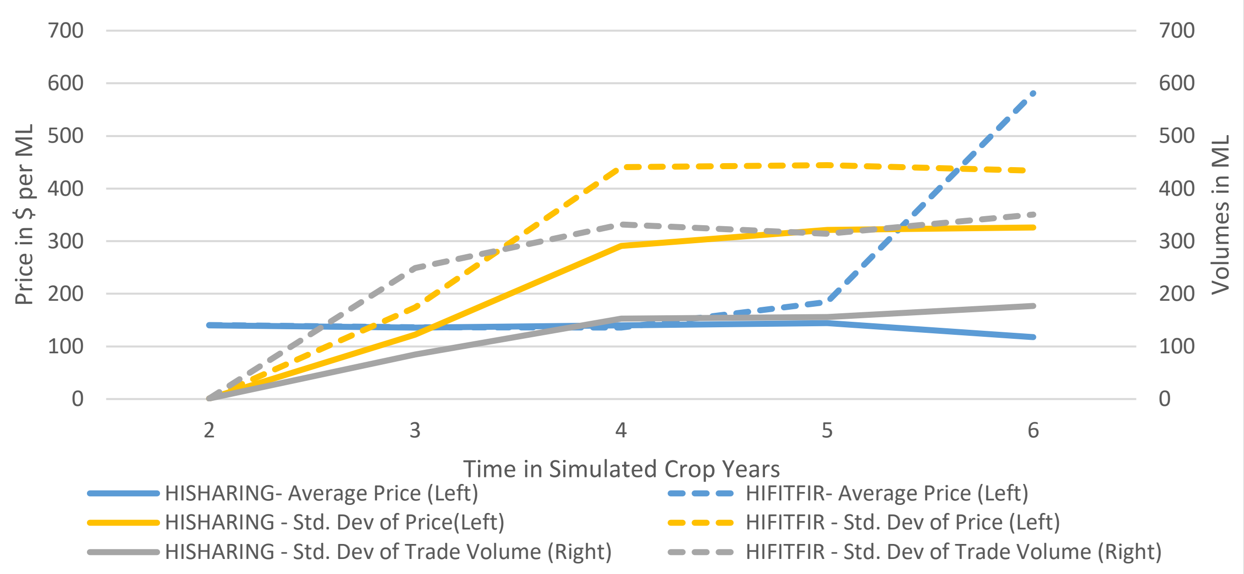
Table 3.10 Regression Results: Crop Farmer Profitability on Water Market Risk Measures, Adequate Water Supply and Water Sharing Regime

	Dependent Variable: Gross Margin per Acre			
	Buyers	Sellers	Buyers	Sellers
Lagged Water Price Volatility	0.0863*** (0.00459)	-0.0599*** (0.00749)		
Lagged Water Volume Volatility			0.0533*** (0.00292)	-0.0422*** (0.00449)

Standard errors are in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Other regressors which are used as controls to ensure consistent estimation of volatility impacts are not displayed here but are presented in Appendix D..

Source: ORWTM

Figure 3.25 Comparison of HIFITFIR and HISHARING Simulated Water Market Price, Trade Price and Volume Volatility over Time



*The first year simulation is not shown in line with lagged volatility variables.

Source: ORWTM

Table 3.11 depicts the results of examining the effects of risk on livestock farmers' TEI. As indicated in the table, an increase in the water market price volatility is expected to increase net cost (TEI). This is consistent with the discussion highlighted for the impacts on selling crop farmers. Declining market prices, indicating downward price risk, reduces the revenues generated from the sale of water rights which is used to offset higher costing (relative to the homegrown alternative) purchased feed. Therefore, net feed costs are higher in this scenario.

Table 3.11 Regression Results: Livestock farm TEI on Water Market Risk Measures, Adequate Water Supply and a Water Sharing Regime

	Dependent Variable: Net Feed Costs (TEI)	
Lagged Water Market Price Volatility	0.131*** (0.0340)	
Lagged Water Market Volume Volatility		0.0847*** (0.0213)
Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Expected returns are used as controls in the regression and are not reported here but are presented in Appendix D..		

Source: ORWTM

3.5.3.3 Inadequate Water Supply and Trading under FITFIR

In this scenario, also called LOWFITFIR, flows are equal to half of the total licenced volumes and trade in water rights is permitted under a FITFIR regime. The following subsections highlight pertinent relationships based on the regression results for the impact of water market price volatility, location and priority externalities on farmer water market behaviour and profitability.

The regression results of the impact of risk and diversion externalities on crop farmers' water market participation are displayed in Table 3.12. As expected, higher bid prices have a negative impact on how much buyers are willing to buy and a positive impact on how much sellers are willing to sell. In comparison to the HIFITFIR scenario, where flows are higher, both demand and supply under the LOWFITFIR scenario are less responsive to changes in price as the sizes of the coefficients of bid price in both demand and supply are substantially smaller than those in the HIFITFIR scenario. This is expected given that as the need for irrigated water becomes greater in the LOWFITFIR scenario, farmers have less flexibility in their ability to respond to significant price swings.

Also, as the level of risk aversion for buyers and sellers increases, the desire to participate is reduced (the relative risk aversion variable in the table). In the HIFITFIR scenario the signs are similar but insignificant. Here, the water market is seen as being riskier and hence more risk averse farmers reduce their exposure to the risks. This is expected as the shortage of water supply results in higher and more volatile prices and as such risk averse farmers respond by limiting their exposure.

The intuition provided for the effects of risk aversion is consistent with the results for water market price volatility (Lagged water market price volatility variable). The riskier the water market price the less buying farmers wanted to buy. The sign of the coefficient is also the same for sellers wanting to sell but the coefficient is insignificant.

Consistent with expectations and results for all previous scenarios is the effect of per acre endowment volumes (endowed water allocation per acre variable in the table). Buyers with greater water endowments want to buy less and sellers with greater water endowments want to sell more.

Also, in line with expectations, buyers with greater water volume needs to irrigate their crop in the prior period will want to purchase more water (lagged irrigated water required variable). Although insignificant, the sign on the coefficient in the supply function is opposite that of its counterpart in the HIFITFIR scenario.

The river diversion point variable in the table indicates that downstream participants want to participate more in the water market than their upstream counterparts. The results indicate that higher priority licence holders want to buy more water rights, but higher priority sellers want to sell less (i.e., the priority variable). As is the case in the HIFITFIR scenario, higher priority buyers are endowed fewer permitted volumes for diversion. All else equal, they would be more likely to buy more rights in the market than farmers with greater water endowments. Although the coefficient on priority in this scenario is opposite that of the one in the HIFITFIR scenario, it is explained by the consistent relationships of other variables. In this scenario, downstream farmers hold more rights and have lower priority. Since higher priority sellers are further upstream and hold less rights, then consistent with the endowment results, such farmers would want to hold more rights and sell less. The results for both location and priority indicated that there are diversion externalities manifested in both the demand-side and the supply-side of the market.

Table 3.12 Regression Results: Water Market Participation on Water Market Variables and Externalities, Inadequate Water Supply and a FITFIR Regime

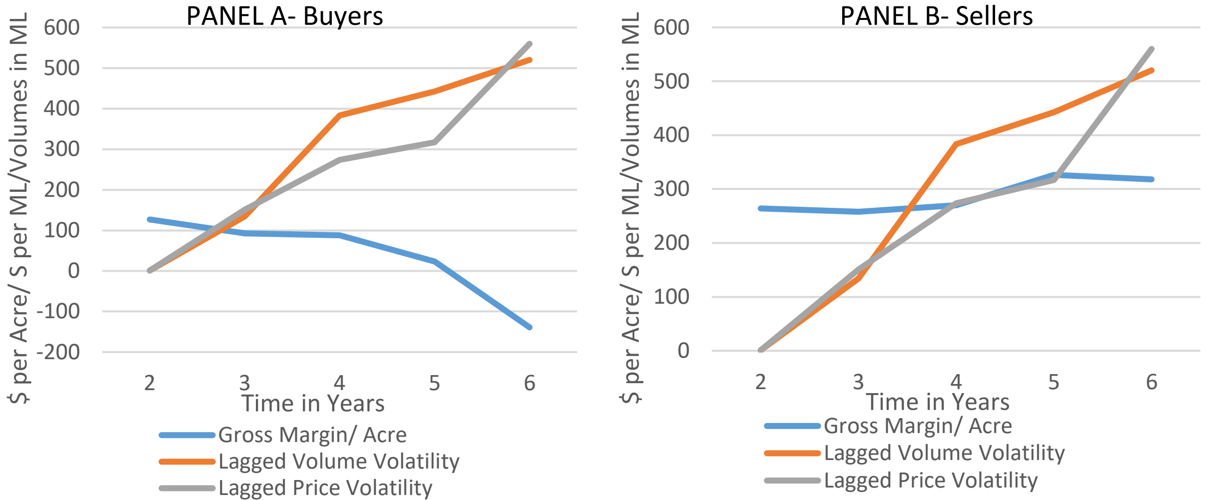
	Bid Demand Model	**Bid Supply Model**
Bid Price	-0.00000254*** (0.000000371)	0.0000260*** (0.00000270)
Relative Risk Aversion	-0.00160*** (0.000334)	-0.000211*** (0.0000818)
Lagged Water Market Price Volatility	-0.00178*** (0.000326)	-0.000109 (0.0000863)
Endowed Water Allocation per Acre	-5.711*** (0.442)	0.432*** (0.0887)
Lagged Irrigated Water Required	0.0131*** (0.00219)	-0.00107 (0.000787)
River Diversion Point	2.135*** (0.141)	0.112** (0.0498)
Priority	-0.0350*** (0.00235)	0.000962** (0.000446)

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

Source: ORWTM

Depicted in Table 3.13 is the marginal impact of trade price and volume volatility on crop farm profitability. Unlike scenarios of adequate water supply, when there is a shortage both buying and selling crop farmers' profitability is negatively impacted by trade price volatility. Consistent with the discussion in the HIFITFIR scenario, higher price volatility through positive price risk depresses buying crop farmer participation and profitability. In scenarios of adequate water, there is enough water to meet moisture requirements of crops and make positive returns from the sale of excess rights. In this scenario, yield losses compounded by underutilization of the water market due to the increased riskiness (increase price and volume volatility sparked by the scarcity), translates to lower returns for buying crop farms. In scarcity, prices are more volatile but more importantly market becomes increasingly illiquid overtime as the scarcity persists. This could be either due more farmers holding on to more volumes due to the scarcity or to dry rights encountered even after purchasing volumes. As shown in Figure 3.26 Panel A, Buyers level of profits decline as trade price volatility increases.

Figure 3.26 Simulated Risk and Profitability for Crop farms (buying versus selling), by year



*The first year simulation is not shown in line with lagged volatility variables.

*The first year simulation is not shown in line with lagged volatility variables.

Source: ORWTM

For selling farmers, higher water market price volatility leads to risk averse farmers limiting their exposure and thereby forfeiting higher revenue that would be earned otherwise. Conversely, as volume volatility increases, (indicative of downward volume risk as trade are volumes declining over time) occurs in a context of even larger positive price swings therefore volume volatility would lead to increased revenue and profits for selling crop farmers.

Table 3.13 Regression Results: Crop Farm Profitability on Water Market Risk Measures, Inadequate Water Supply and a FITFIR Regime

	Dependent Variable: Gross Margin per Acre			
	Buyers	Sellers	Buyers	Sellers
Lagged Water Price Volatility	-0.0983*** (0.0100)	-0.0939*** (0.00962)		
Lagged Water Volume Volatility			-0.155*** (0.0187)	0.0363*** (0.0128)
Standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Other regressors which are used as controls to ensure consistent estimation of volatility impacts are not displayed here but are presented in Appendix D..				

Source: ORWTM

The impact of trade price and volume risk on the net feed cost of livestock farms is presented in Table 3.14. Since all livestock producers are taking short positions in the market and have the flexibility to purchase all their feed, then higher prices would increase proceeds from sale of water rights, thereby offsetting purchased feed cost and lowering TEI. Greater positive price swings generate revenue that offset feed costs. Greater volume volatility, primarily due to decreases in trade volume, occurs in a context of even larger price swings and therefore volume volatility would lead to increased revenue and lower costs.

3.5.3.4 Inadequate Water Supply and Trading under a Water Sharing Regime

In this scenario, also called LOWSHARING, flows are equal to half of the total licenced volumes and trade in water rights is permitted under a water sharing regime. The following paragraphs highlight pertinent relationships based on the regression results regarding the impact of water market price volatility, location externalities on the water market behaviour of farmers and their profitability.

The effects of risk and diversion externalities on crop farm water market participation under the LOWSHARING regime are presented in Table 3.15. From the table it is observed that higher bid prices (the bid price variable in the table) have a negative impact on how much buyers are willing to buy and a positive impact on how much sellers are willing to sell. Like the LOWFITFIR scenario, the sensitivity of a change in bid price of buyers is smaller than when river flows are adequate (HISHARING scenario).

Table 3.14 Regression Results: Livestock farm TEI on Water Market Risk Measures, Inadequate Water Supply and a FITFIR Regime

	Dependent Variable: Net Feed Costs (TEI)	
Lagged Water Market Price Volatility	-0.312*** (0.0852)	
Lagged Water Market Volume Volatility		-0.210** (0.103)
Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Expected returns are used as controls in the regression and are not reported here but are presented in Appendix D.		

Source: ORWTM

As in the HISHARING scenario, greater risk aversion for buyers is associated with greater desire to purchase water rights. This is consistent with the expectation that the buyer seeks to hold more rights to mitigate against risks of insufficient water volumes. In the FITFIR scenarios, the water market may have been perceived as risky especially with priorities dictating initial allocations. However, in the sharing scenarios risk averse farmers want to engage in the market. The coefficient on risk aversion for sellers is insignificant, indicating a negligible effect of risk preferences for engaging in the market.

One of the key differences between the HISHARING and LOWSHARING scenarios is the effect of water market price risk on market participation (lagged water market price volatility variable). While in the HISHARING scenario the effect of water market price volatility on water market participation for both buyers and sellers is insignificant, in this scenario both water market price volatility affects buyers and sellers. Specifically, higher price volatility discourages buyers. This is expected as higher volatility is expected to reduce utility. Interestingly, the results indicate that sellers are willing to participate more with increased water price volatility. The higher prices in this scenario stem from the water shortage which results in positive price shocks. For the seller, higher prices in the previous period prompts increased supply in the current period. The level of price increase outweighs the negative effect of increased volatility leading to the positive relationship. Recall from Table 3.4, the average price in the LOWSHARING scenario is $274 per ML, which is more than double the price under HISHARING with the associated risk approximately a quarter of that produced under the LOWFITFIR scenario

Like all preceding scenarios, higher levels of water endowment are associated with lower water demand and higher water supply to the market. Farmers with greater water endowments are more likely to have surplus volumes and therefore would need to by less from or sell more to the market.

Also, consistent with expectations, increases in the required irrigation volume (lagged irrigated water required variable) in the prior period increases current period demand and reduces current period supply. The lower level of prices for irrigation water relative to those under the FITFIR regime results sellers adjusting their sale volume downwards as their irrigation demands increase. The lower expected prices under the sharing regime means that the farmer will sell less and will try to maximise profits by balancing crop production and water rights sales. Under FITFIR the farmer relies on the relatively higher irrigation water prices to maximise profits.

Farmer location along the river affects sellers' intent to participate in the water market (river diversion point variable in the table). Similar to the HISHARING scenario and consistent with expectations, downstream buyers want to buy more rights to divert water. This shows that location externality effects are evident across regimes. However, despite a negative sign on the coefficient there is a lack of statistical significance to support downstream sellers wanting to sell less rights.

Table 3.15 Regression Results: Water Market Participation on Water Market Variables and Externalities, Inadequate Water Supply and a Water Sharing Regime

	Bid Demand Model	**Bid Supply Model**
Bid Price	-0.0000774*** (0.00000181)	0.000219*** (0.0000136)
Relative Risk Aversion	2.331*** (0.165)	0.0560 (0.0547)
Lagged Water Market Price Volatility	-0.00277*** (0.000676)	0.000456** (0.000224)
Endowed Water Allocation per Acre	-4.955*** (0.514)	0.360*** (0.120)
Lagged Irrigated Water Required	0.0162*** (0.00240)	-0.00150* (0.000787)
River Diversion Point	0.0936*** (0.00646)	-0.00204 (0.00149)

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

Source: ORWTM

Table 3.16 presents the marginal impact of trade price and volume volatility on crop farm profitability under water scarcity and a water sharing regime. The signs and significance of the coefficients are like those reported in the LOWFITFIR scenario. Specifically, higher price volatility depresses buying crop farmer participation and profitability. In this scenario, yield losses compound underutilization of the water market due to the increased riskiness sparked by the scarcity.

Similar to in the LOWFITFIR scenario, higher water market price volatility leads to risk averse farmers, who are short in the market, limiting their exposure and thereby forfeiting higher revenue that would be earned if they are not risk averse. In contrast, trade volume volatility negatively impacts the profits of buying crop farmers while it boosts the profitability of selling crop farmers. For selling farmers, as volume volatility increases occur in a context of even larger positive price swings, volume volatility would therefore lead to increased revenue and profitability. The key in this scenario, as well as in the

LOWFITFIR scenario, is that scarcity drives significantly different outcomes in farmer profitability and it varies depending on the position taken in the market.

Table 3.16 Regression Results: Crop Farmer Profitability on Water Market Risk Measures, Inadequate Water Supply and Water Sharing Regime

	Dependent Variable: Gross Margin per Acre			
	Buyers	Sellers	Buyers	Sellers
Lagged Water Price Volatility	-0.119*** (0.00923)	-0.0344*** (0.00853)		
Lagged Water Volume Volatility			-0.107*** (0.0103)	0.0417*** (0.00900)
Standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Other regressors which are used as controls to ensure consistent estimation of volatility impacts are not displayed here but are presented in Appendix D.				

Source: ORWTM

The impact of trade price and volume risk on the net feed cost of livestock farms is presented in Table 3.17. Like in the LOWFITFIR Scenario, the proceeds from sales offset feed cost from purchased feed and lower TEI. Since all market sales results in lower TEI, greater positive price swings generate revenue that offset feed costs. Furthermore, greater volume volatility occurs in a context of even larger price swings and therefore volume volatility would lead to increase revenue and lower costs.

3.5.4 Summary and Discussion

If there is adequate water supply FITFIR regime is most beneficial to crop farmers, and farmers find it economically viable not to trade. If there is inadequate water supply, however, a water sharing regime is best. In both adequate and inadequate water supply, a FITFIR regime with trading is most economically beneficial for the livestock farmer as higher prices under the FITFIR regime entice them to sell water rights and offset the cost of purchased feed. If the objective is to have stable markets in terms of relatively low price and volume volatility, then the water sharing regime would be best whether there is adequate or inadequate water supply. If the objective is to achieve water market liquidity, then the more volumes are traded under a water sharing regime (Table 3.18).

Table 3.17 Regression Results: Livestock farm TEI on Water Market Risk Measures, Inadequate Water Supply and a Water Sharing Regime

	Dependent Variable: Net Feed Costs (TEI)	
Lagged Water Market Price Volatility	-0.332*** (0.0738)	
Lagged Water Market Volume Volatility		-0.212*** (0.0643)
Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Expected returns are used as controls in the regression and are not reported here but are presented in Appendix D.		

Source: ORWTM

Table 3.18 Summary of Simulation Results: The Optimal Allocation Regime for Agent Types and Market Liquidity and Price stability

	Adequate Water Supply (100 % of total annual allocation)			Inadequate Water Supply (50 % of total annual allocation)		
	No trading	Trading		No Trading	Trading	
	FITFIR	FITFIR	Water Sharing	FITFIR	FITFIR	Water Sharing
Crop Farmer Gross Margins	✓					✓
Cattle Producer Feed Cost		✓			✓	
Water Market Trade Volumes (higher)			✓			✓
Water Market Price Volatility (lower)			✓			✓
Check marks represent the preferred regime for water right allocation from the ORWTM						

Source: Author with information from the ORWTM

3.5.4.1 Impact of Risk Aversion on Crop Farmers' Market Participation

One of the key objectives is to assess the effects of crop farmer risk attitudes on water market participation. In general, risk aversion effects are more visible on the demand side than on the supply side. Buyers who are more risk averse respond to the risky nature of the market. When the market is more volatile (evidenced in the FITFIR scenarios) buyers who are more risk averse are at least as apprehensive to participate in the water market as less risk averse buyers. In other words, the FITFIR regime is less accommodative for the buyers who are more risk averse. Conversely, in the water sharing regime, buyers who are more risk averse participate to a greater extent. This indicates that the choice of the regime used for water allocation can influence farmer participation, especially when they are responsive to trade price risk and this gives credence to the notion that a change in the water market regime can improve water market liquidity.

3.5.4.2 Some Key Elements of a Successful Water Market in the Southern Alberta Context

In this study it has become apparent while modelling that there are several factors required to facilitate efficient trade. These factors are assumed but a broader discussion regarding these factors is now presented in the context of policies that exist in southern Alberta. These factors include agent heterogeneity, the role of the irrigation district, the agents that participate in the water market and the trading platform for water.

From the outset, it is apparent that farmer agents participating in the water market must be heterogenous. Heterogeneity, as highlighted in section 3.4.2.5, is necessary so that farmers could take opposing sides in the water market. If farmers are homogenous then all farmers would be either long or short in the market, and hence no trade would take place. In the context of the Oldman River Water Trading Model, weather variation in the form of precipitation and soil quality heterogeneity, although present, is not significant enough to drive heterogeneity. In the model, heterogeneity depends on the size of the water volume approved by licencing authority relative to the land size the farmer uses the water to irrigate. In this study, it is assumed that there is some variation regarding the volumes approved and the land size. However, if there is a predefined relationship for approving volumes relative to the irrigated area, then based on this study, farmers in this model would be homogeneous and therefore trade would be very limited. In general, if farmers are effectively homogenous then there could be a limited market for rights among farmers as most of them may take the same position in the market. In such a case, in order to improve market liquidity either existing rights could be amended, new rights issued to more farmers in a way that would dilute the relationship between volumes and irrigated area or, non-use agents could be allowed to trade.[41]

This leads to the second factor- the agent type that is permitted to trade in the water market. Initially, industrial users were incorporated in the market. However, they were subsequently taken out of the market. In the model, these industrial users are in the oil and gas industry. They are modelled as net purchasers of water as water is a significant input in their extractive process. It is observed that their bid prices are so elevated that they priced agricultural producers (who are long in the market) out of the market. This drove significant price volatility in the market and drove irrigators out of the market (both buyers and sellers).[42] Nevertheless, as highlighted above, allowing only use traders to participate in the market may result in homogeneity and market thinness. Although not examined in this study, market depth may be added by allowing the participation of non-use traders in the market, thereby requiring a change in the existing rules of water trading in Alberta. Speculators make bets on market outcomes (prices or volumes) but have no interest in possessing the commodity itself. Therefore, their engagement in the market can add to market depth. However, the activity of speculators can exacerbate market volatilities which can lead to decreased participation by risk averse farmers. Increasing market depth can be facilitated through the introduction of water market instruments for

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[41] Non-use traders are those that take positions in the market with no intent on diverting water for consumption or storage. Such traders would include financial speculators, the government in some cases or environmental groups that would want to maintain river flows for environmental purposes.

[42] Such externalities are pecuniary in nature and even though the welfare impacts of pecuniary externalities are not as severe as technological externalities, it is important to highlight especially in a context of a thin market. Driving volumes out of the market could lead to a collapse of the market.

which the underlying asset would be river flow volumes. Bjornlund et al. (2007) advocates that the development of economic instruments can facilitate efficient reallocation of water resources. For speculators, these instruments create price signals without interfering with the actual river flows as speculators would close out positions just before delivery is due and receive gains or incur losses based the outcome of their bet.

Water trading is a major concern of environmentalists as well as farmers. The concern is that trading activates sleeper licences. If non-use traders can participate in water trading then environmental agencies (e.g., Ducks Unlimited) can purchase rights, ensuring environmental flows while bolstering demand adding to market depth.

In this study, the irrigation district (ID) holds the largest volume of water rights. For there to be efficient trade, therefore, the ID must be a significant seller in the market. In this model, it is assumed that if the ID is unable to divert enough water based on its licence it would have enough volumes in storage to meet the short-term demand of its members and replenish reserves during the off-season. If this does not hold in reality, then the ID may choose to restrict supply to the market, creating further market price instability. It is further assumed that the ID is passive. Its only objective is to supply its members with water. However, if its mandate is to also create value for its members then the ID would find it very profitable to restrict supply, due to the inelastic nature of the demand curve, thereby dramatically increasing sales revenues.

An efficient trading platform is perhaps the largest assumption made by the ORWTM. It assumes that market prices and trade volumes are clearly communicated to participants. This would be reminiscent of trading platforms used for stocks. However, there is no online platform for efficiently communicating prices. As such, equilibrium price and volume uncertainty could translate to limited activity by irrigators.

3.5.4.3 The Effect of Water Diversion Externalities on Crop Farm Water Market Participation

The theoretical model in section 3.3.2 highlights externalities in diversion. This is crucial to the optimal decision of irrigators when irrigation water supply is scarce. In the ORWTM it is anticipated that externality effects are captured by the effect of the location of the irrigator along the banks of the river (in the case of a water sharing regime), and/or the effect of the priority of the rights held (in cases of FITFIR) on the farmer's profitability. In the base scenario, an agent's location and priority (assigned to the agent's endowed licence) impact the resulting level of profitability. Even with an efficient trading platform or a switch to a water-sharing regime, water supply and location externality effects are existent. This means that the implementation of an efficient water rights trading platform and a change in the water rights regime cannot address the problem highlighted in the theoretical model. In the determinants of water market participation models, it is observed that agents' location and/or priority affect the level of market participation of either buyers or sellers or both. This means that agents are using the market to position themselves in a way that mitigates the impact of third-party diversion effects, especially in periods of inadequate irrigation water supply. Switching the allocation regime from FITFIR to a water sharing system reduces the effect of externalities. Whenever the FITFIR regime is in effect both priority and location effects are present in crop farm market participation. However, when water sharing regime is in effect only location externalities are significant. Also, He and Horbulyk (2010) have shown the economic inferiority of FITFIR to a correlative rights system of water allocation.

While the literature arrives at the conclusion that water rights regime must be one that facilitates trade under a different water allocation regime, the same conclusion is arrived at in this thesis, although from a different perspective. In this study, the call for both efficient trading platform and a movement away from the FITIR water rights regime is based on inefficiencies generated by diversion externalities which generate volatile price signals and limits market participation. As depicted in section 3.3, diversion externalities generate uncertainties in flows and lead to sub-optimal behaviour by irrigators.

3.5.4.4 Irrigation District Revenue from Water Market Sales and Expenditure on Infrastructure Rehabilitation and Expansion.

An aside to the thesis but directly relevant to current irrigation policy in Alberta is the issue of funding for irrigation rehabilitation and expansion. In the model, the Irrigation district is the single largest seller in the market, selling more than 12000 ML per year and generating revenues of between $1.6 million $4.8 million each year. LNID is engaged in the Irrigation Rehabilitation Programme (IRP) in which open canals within the control of the district are being replaced with pipelines. These changes reduce water loss in delivery, making the system more efficient. There is a cost sharing agreement in which the government funds 75 percent of the cost of rehabilitation, and the district the remainder. In 2015, the province contributed almost $2.0 million and the irrigation district spent just over $689,000 (Lethbridge Northern Irrigation District, 2015a).

From the point of view of the provincial government, the potential revenues generated from trading rights could substantially or completely offset government spending on the IRP, saving taxpayers millions of dollars per year. From the perspective of the irrigation district, it could invest in technologies that could improve accurate metering of diversions for all its members and thereby increase water use efficiency. Finally, from the point of view of the members, the irrigation district could use some of the proceeds from sales to reduce distribution fees and offset any metering costs associated with irrigation.

3.6 Summary and Conclusion

This study set out to investigate whether the type of water rights employed by the Albertan jurisdiction influence water market liquidity and more specifically determine if the type of water rights regime affects water market participation. On the macro-scale, there are no significant differences between trade volumes across regime types with approximately 2500 ML traded each month and prices ranging from $142/ML when water is adequate to $261/ML when water is inadequate. This indicates that there are no significant effects of the regime on water market participation. What is evident from the results is that if the market operates efficiently then participation will initially decline, but by year 3 participation would start to increase and by year 6 surpass the initial levels.

Also, the study seeks to investigate explanations for the difference in perspectives of those in academia and those in industry. When there is adequate water supply, crop farmers prefer not to trade. This substantiates the perspective of some water managers in industry. However, when there are inadequate supplies, a no-trading scenario leads to a sub-optimal outcome for crop farms and livestock producers. When there is water shortage, a water sharing regime is preferred by crop farmers. This supports the perspective of academics. Therefore, water supply levels dictate whether water markets are necessary for efficient water resource allocation. In the trading scenarios, price volatility negatively affects crop farm profitability but gains from efficient water markets will not be fully eroded by volatile water prices.

In conclusion, irrigation plays an important role in southern Alberta agriculture. The FITFIR system is not superior nor is it inferior to a water sharing system. What is needed is a flexible system that accommodates a FITFIR regime with no trade in periods of adequate water supply and an efficient trading platform in which rights are traded under a water sharing regime in period of shortages. It is also found that externalities can affect irrigators' decision to participate in a water market. Also, water market volatility can negatively affect crop farm profitability. Livestock farmers who are less reliant on water for irrigation purposes (by model construct these farmers could sell all their rights and purchase feed for livestock) find the use of the water market profitable, especially under a FITFIR regime, which tends to have higher prices on average. Because crop farmers have production more closely tied to irrigation, they have fewer options regarding the use of their water rights and as a result do not fare as well with water markets as livestock farmers. Because water supplies are constantly changing, what is required is a flexible system of water allocation that adjusts to changing water conditions so that the welfare of licenced crop producers, livestock producers and the irrigation district increase in Southern Alberta.

3.6.1 Discussion of the Key Limitations of the Model

Agent-based models are very data intensive. If data are not available at the agent level, then assumptions are made about the distribution of missing data that reflect the mean or range of data which are either available at an aggregate level or indicated by the literature. The values are sampled from the assumed distributions and assigned to the respective agents. Ideally, one would make several sample draws for each variable for each agent and have the model simulated over each sample draw. However, computer processing power and considerable runtime only allow for a single draw of values. Such variables include the land size of farmers, the level of relative risk aversion of farmers and farmer's speed of adjustment to water market variables. If the actual values for these variables vastly differ from the model, then results could be different from those presented in this thesis.

In this model, other licence holders do not engage in the water market. For trade to be meaningful within the model, crop farmer agents are required to seed their entire crop land within a given crop year. If a farmer is expecting a drought the farmer would seed less water thirsty crops if the priority on the licence held is low. If the farmer is able to leave land fallow or even choose to irrigate more valuable crops and have the others grow based on dryland farming, then losses due to crop moisture deficiency could be mitigated. The current ORWTM model is not able to accommodate farmers' seeding adjustment based on expected moisture, although that could be captured in future work.

The model also assumes that if moisture available for crops are low and irrigation volumes are inadequate to meet the requirements for all crops, then water is uniformly distributed across crops and hence yield losses would be uniform with moisture deficiency. However, in reality farmers may choose to disproportionately irrigate higher value crops and leave lower valued crops as dry land crops, which would result in smaller losses due to moisture deficiencies. Nevertheless, the ORWTM is modelled conservatively and the results serve as an upper bound for losses that could be incurred from moisture deficiencies.

In the ORWTM under the FITFIR regime when water is traded, priority is not tied to the volume traded. This assumption is made because of the increased complexity and significant runtime that would be required to model the transfer of priority. Furthermore, if the priority is transferred, a standardised approach to trading water rights would be inappropriate as rights would be heterogeneous. Use of an alternate means of market clearing and allocation would significantly increase model runtime. Nevertheless, if rights are tied to the seniority, it would not perhaps be difficult see the significant price spreads between high priority rights and low priority rights. This would be even more beneficial to the Irrigation district who hold most of the volume and are quite senior in priority.

Not much is known about what drives irrigator water demand and supply of water rights in Alberta. In this thesis an attempt is made at simulating a few possibilities as to what could drive intra and inter-seasonal water demand and supply. Assumptions are made regarding an irrigators speed of adjustment to market equilibrium but very little is known about irrigators speed of adjustment. This speed of adjustment does significantly impact the markets ability to clear and hence if this speed of adjustment assumption is not nearly representative of the actual adjustment then the equilibrium prices and volumes could differ significantly.

3.6.2 Future Work

Currently, only farmers and the irrigation district can trade in the simulated market. In the future, it is hoped to expand model capabilities to incorporate water market availability for all agent types in the water market. This would require detailed information of the other agents. This study makes a comparison between the FITFIR and a water sharing regime. In the future, comparisons can be made with other regimes. For example, the current FITFIR regime could be compared to a People-First regime (Section 3.2.1.4). Current legislation does not allow for non-use agents to trade rights. What would be the effect on market performance if non-use participants are added to the model? Would speculators drive prices upwards, pricing agricultural producers out of the market or would the sheer number of speculators stabilize prices in the market and foster more trade? Finally, risk aversion levels of the participants are exogenous and fixed over time. If this assumption are to be relaxed, would market decisions change? These are some questions that could be explored in future work.

4.0 Conclusion

4.1 Recap of Thesis Objectives

This thesis examines the value of two input risk mitigation strategies in the context of Albertan agriculture. The aim is to assess the economic value of adopting risk mitigation strategies. This is explored in two distinct papers. The first paper explores the value to Albertan hog farmers of adopting nutrient identification technologies. The second paper investigates the role of trade water price volatility, water volume supply uncertainty and water allocation regime on water market participation, and the ensuing economic effects on southern Albertan crop and livestock producers.

4.2 Summary of Methods and Key Findings

The first paper utilises a joint mathematical programming and simulation approach to assess the value of increased knowledge about protein content of feed in three feedstuffs to Albertan hog farmers. Two models are estimated to determine the value of NIRS technology, a full information model and an incomplete information model. In the full information model, which mimics the adoption of NIRS, 1000 protein levels are sampled from a normal distribution, then for each draw, a mathematical programming least cost rations model is estimated. Under imperfect information, a linearized chance constrained programming model is used to capture farmers’ awareness of the uncertainty in nutrient content. Decision makers are assumed to adjust for the nutrient quality risk by employing margins of safety in their diet formulation. The difference in cost between the models of certainty and uncertainty yields the cost savings of adopting NIRS technology. In situations where the actual protein level in the diet is less than what is required in the uncertainty model, the difference in the protein intake is inputted into a model predicting the change in lean dressed carcass weight. The lean dressed carcass weight loss is monetized as the difference in premiums that could be earned under NIRS feeding strategies (optimum premiums) and premiums earned without NIRS. These premium penalties are added to the cost savings for adopting NIRS.

To evaluate the feasibility of investment in NIRS technology, the daily cost savings per animal is aggregated to the annual cost savings per farm. The cost savings are compared to the procurement cost of the NIRS machine and annual maintenance costs over the estimated life-span of the machine. The analysis is done for average sized farm and a large sized farm. There are also two modes of investment- desktop NIRS machine or the process NIRS machine.

Based on results, investment in information-increasing technologies creates value to Albertan hog farmers. Farmers could generate more than $5 per hog in feed cost savings per year. For the average 70 sow/ 1630 head Albertan farm this amounts to savings of almost $7,300 per year and for a larger 500 sow/11920 head farm savings could be approximately $56,000 per year. NIRS investment could generate as much as $700,000 in NPV benefits for a large Albertan 500 sow operation when only crude protein content is variable in wheat, barley and peas. There is also evidence to suggest that it is feasible for large-scale operators to invest in the process NIRS technology, but it is still not economically feasible for average-sized Albertan farms to invest in the inline systems. However, investment in sample testing units is feasible for both average-sized and large-sized farms.

The second study investigates the effect of irrigators' risk responses to water market price variability and water supply uncertainty on their water market participation. Additionally, the resultant effects on their profitability (net feed cost in the case of livestock producers) are assessed.

An agent-based model is constructed to simulate economic cropping decisions of farmers and their subsequent irrigation decisions from the Oldman River in Alberta under alternative water right regimes. There are six agent-types in the model: riparian crop farms, dairy farms, beef cattle farms, an irrigation district who services non-riparian crop farms with water and all other licences (a classification that comprise individuals or firms that have licences to divert water from the Oldman River but does not fall under the above sub-groups). Riparian farms use an optimization protocol to determine their crop mix and water demand/ supply functions. Non-riparian farms also use an optimization protocol and their estimated annual water demand is communicated to the irrigation district who first meet their demand then trade a fraction of the surplus in the market.

It is assumed that the market operates for six months of the growing season. Agents modify the bid function every month depending on crop moisture requirements (which is a function of random precipitation and crop mix, estimated budget for buyers, rights remaining for sellers). Bids are updated using an adaptive expectations framework. For each month the market clears, unused diversion rights are re-allocated among riparian farmers. At the end of an irrigation season, gross margins for all farms (feed costs for livestock farms) are tallied considering the farmers' ability to irrigate lands as required. Its effect on yield, the purchase costs of water rights and the revenue generated from water sales are all computed.

When river flows are adequate, it is most profitable for crop farmers to abstain from the water market. Due to the relatively high price of water and the relatively low cost-savings generated by growing feed, livestock producers choose to buy their feed and sell their rights. Their net cost is always lower under an efficient trading market. However, a FITFIR regime is always preferred because of the relatively higher prices for which water rights can be sold.

In comparing regimes, mean water market trade volumes and price are not considerably different. However, regardless of the water supply level, the water sharing regime exhibits slightly less volatile trade prices and volumes, lower average prices and greater average trade volumes than FITFIR. There is clear evidence that water price risk affects crop farm participation under FITFIR regime, under both adequate and inadequate water supply, but only affects crop farm participation under water shortage in a sharing regime. It is observed that farmer agents use the market under a water sharing regime as a means of reducing risk exposure supporting the notion of Calatrava and Garrido (2005a). It is also evident that a shift to a water sharing regime will expose farmers to reduced externality effects.

4.3 Effect of Input Risk Management Policies on Albertan Agricultural Producers Competitiveness

This thesis concludes with a brief discussion of policy recommendations regarding input risk management in agriculture. Results from both studies suggest that there can be significant value for agricultural firms when they employ input risk management strategies. While the first study outlines the value of investing in technology that reduces input quality risk, the second highlights the value of having the flexibility of a market to trade inputs. The final discussion here highlights the possible role of government in reducing risk in the agricultural industry.

Most privately-owned firms will adopt technology that will improve productivity or reduce costs. However, industries in which margins are quite narrow, it may be difficult to divert resources to research the viability for investment in new technologies. This is an avenue in which government and agricultural associations can assist. Government and agricultural associations may choose to fund research into the viability of new technologies and make information available to farmers who can then make the decision to invest.

For markets to be viable and be used as a means of risk reduction for farmers, market information needs to be transmitted transparently. The current system of water trading involves significant transaction costs. This include search costs (finding someone with coinciding wants in a multi-unit setting is very difficult) or the cost in wait time to have a trade approved. The government is in a position to facilitate an efficient market. A web-based market could be constructed, reporting daily prices and trade volumes. This transparency would encourage farmers to participate in water markets especially in periods of water shortages.

From the study, it is apparent that water trading may not always lead to better economic performance of irrigators- when flows are adequate, trading is found to be less profitable than no trading. This means that flexibility in the system of allocation could facilitate effective water risk management by irrigators. The government may be in the best position to institute a system in which FITFIR is used in period of surplus water supplies but will switch to a more efficient system such as water sharing when water supplies are inadequate.

In this thesis, two examples in which the management of input risk creates value to agricultural producers are shown. It is also indicated that all stakeholders in the input market benefit from greater transparency. As domestic producers increasingly compete with global producers, it is important that not only efficiencies in production are exploited but that cost efficiencies are also explored. Established centralized institutions such as the government and irrigation districts can play significant roles in the timely dissemination of information such as new technologies that reduce costs, or in the implementation of an efficient market platform for trading water.

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Appendices

Appendix A. Chapter 2 Appendix

Table A.1 Nutrient Content in Feedstuff

	Nutrient Levels (% of diet on an as-fed basis)										
Ingredient	NE (Kcal)	CP	Crude Fat	Lysine	Threonine	Methionine	Cystine	Tryptophan	Sodium	Calcium	Phosphorus
Barley	2,327	11	2.1	0.4	0.4	0.2	0.3	0.1	0.0	0.1	0.4
Wheat	2,472	14	1.8	0.4	0.4	0.2	0.3	0.2	0.0	0.1	0.5
Canola Meal	2,351	35	10.0	1.6	1.2	0.6	0.8	0.3	0.1	0.7	1.2
Ground corn	2,672	8	3.5	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.3
Oat groats	2,720	14	5.9	0.5	0.4	0.2	0.2	0.2	0.1	0.1	0.4
Peas	2,419	22	1.2	1.6	0.8	0.2	0.3	0.2	0.0	0.1	0.4
Soybean Meal	2,087	48	6.6	3.0	1.9	0.7	0.7	0.7	0.1	0.3	0.7
Wheat DDGS	1,847	37	5.3	0.7	1.1	0.5	0.6	0.4	0.3	0.2	0.9
Fish meal	2,351	63	9.7	4.6	2.6	1.7	0.6	0.6	0.8	4.3	2.9
Whey powder	2,797	76	0.8	6.9	4.8	1.7	1.8	1.6	0.9	0.6	0.4
Salt									39.5	0.3	
Vitamin premix		5	3						0	12	0
L-methionine	855	58				99					
L-lysine HCL	697	95		79							
L-threonine	608	73			99						
Poultry fat	7,361		29								
Canola oil	7,554		7								
Limestone									0	36	0
Potassium chloride									1	0	
dicalcium phosphate									0	25	19
Magnesium oxide										2	

	Nutrient Levels									
Ingredient	Magnesium (%)	Potassium (%)	Zinc MG/KG	Copper MG/KG	Selenium MG/KG	vitamin A (kIU/KG)	vitamin D3 (kIU/KG)	vitamin E (kIU/KG)	Phytase FTU	Xylanase U/KG
Barley	0.1	0.4	28.1	5.4	0.1	4.1		7.4		
Wheat	0.2	0.5	31.0	3.0	0.3	0.4		11.6		
Canola Meal	0.5	1.2	72.0	5.4	1.1			13.4		
Ground corn	0.1	0.3	16.5	3.4	0.1	0.8		11.7		
Oat groats	0.1	0.4		6.0						
Peas	0.1	1.0	23.0	9.0	0.4	1.0		0.2		
Soybean Meal	0.3	2.2	48.8	15.1	0.3	0.2		0.1		
Wheat DDGS	0.4	1.1	80.0	57.0	0.4	3.5				
Fish meal	0.1	0.6	89.0	8.0	1.6			5.0		
Whey powder	0.1	2.0	9.9	6.6	0.1			0.3		
Salt	0.0									
Vitamin premix (‘000)			200	30	0.6	10,000	2,000	100	4,600	5,600
L-methionine										
L-lysine HCL										
L-threonine										
Poultry fat										
Canola oil										
Limestone	2	0								
Potassium chloride	0	51								
dicalcium phosphate	1	0								
Magnesium oxide	55	0								

Source: NRC (NRC, 1998, 2012)

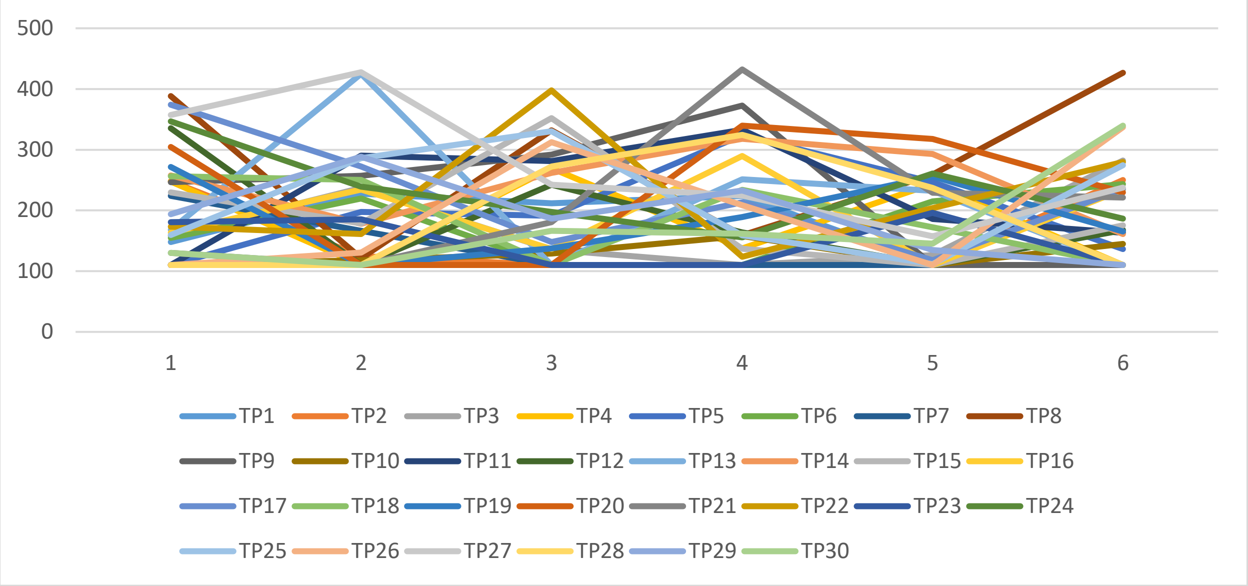
Table A.2 Sample Western Hog Exchange Hog Carcass Grading Grid

Yield Class	Lean Yield %	0 - 67.9 kg	68 - 72.9 kg	73 - 77.9 kg	78 - 82.9 kg	83 - 87.9 kg	88 - 92.9 kg	93 - 97.9 kg	98 - 102.9 kg	103 - 107.9 kg	108 - 111.9 kg	112 - 116.9 kg	117 - 999 kg
1	64.3 - 100	10	10	50	75	95	95	100	100	100	100	100	50
2	63 - 64.29	10	10	50	75	95	103	109	109	107	105	100	50
3	61.8 - 62.99	10	10	50	75	95	108	113	113	111	107	100	50
4	60.7 - 61.79	10	10	50	75	95	110	116	116	113	109	100	50
5	59.6 - 60.69	10	10	50	75	95	110	116	116	113	109	100	50
6	58.6 - 59.59	10	10	50	75	95	109	114	114	111	108	95	50
7	57.7 - 58.59	10	10	50	75	95	103	109	109	107	105	90	50
8	56.9 - 57.69	10	10	50	60	85	95	104	104	95	90	80	50
9	56.1 - 56.89	10	10	50	60	70	90	95	95	90	80	70	50
10	0 - 56.09	10	10	50	60	60	70	70	70	70	60	60	50

Source: Western Hog Exchange (2014)

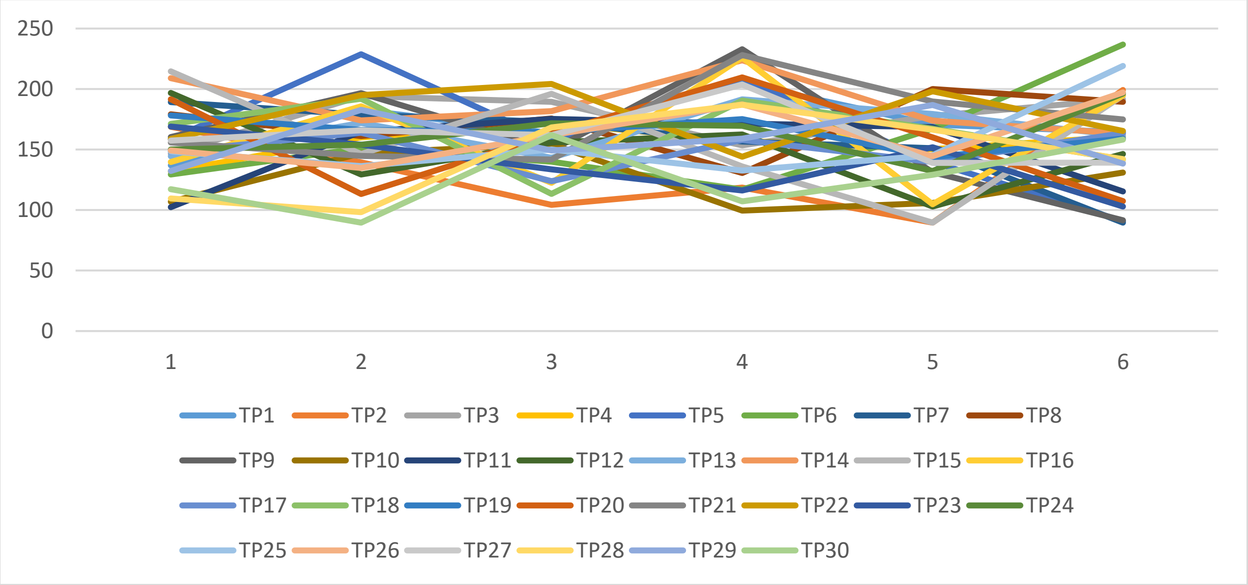
Appendix B. Chapter 3 Appendix

Figure B.1 Estimated Price Paths for Non-Feed Wheat



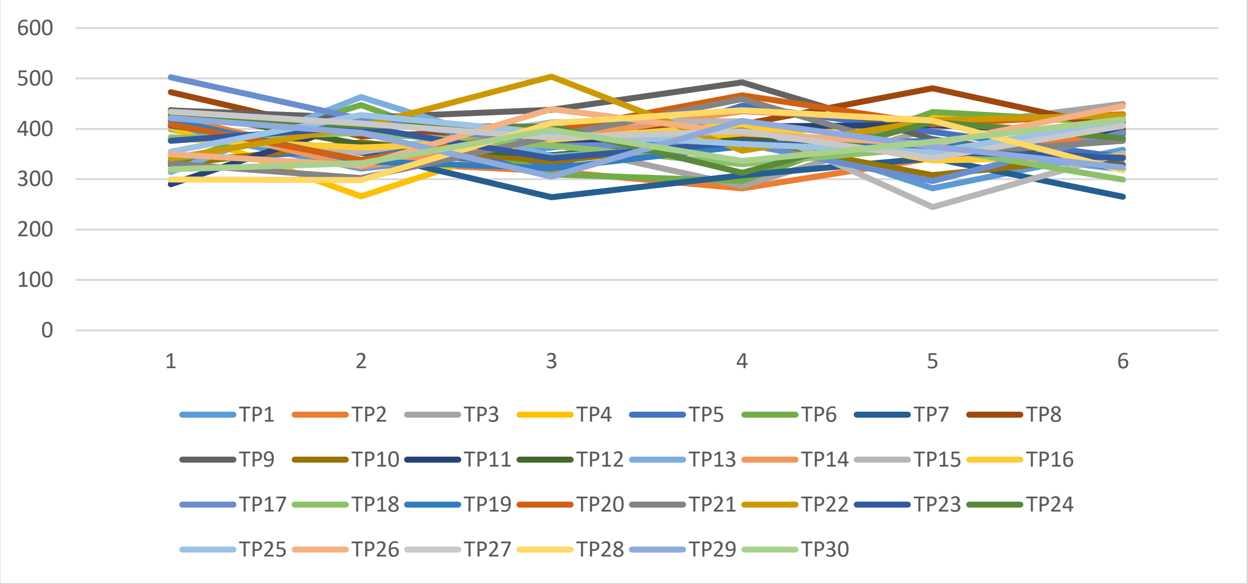
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.2 Estimated Price Paths for Non-Feed Barley



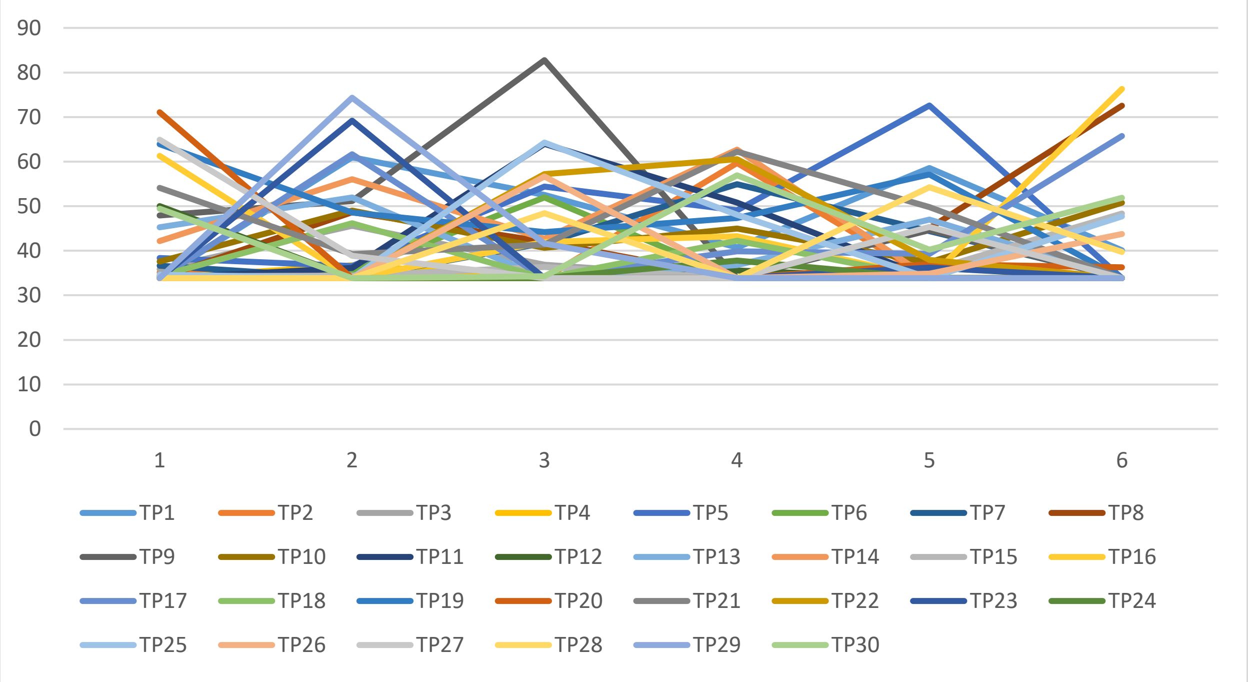
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.3 Estimated Price Paths for Canola



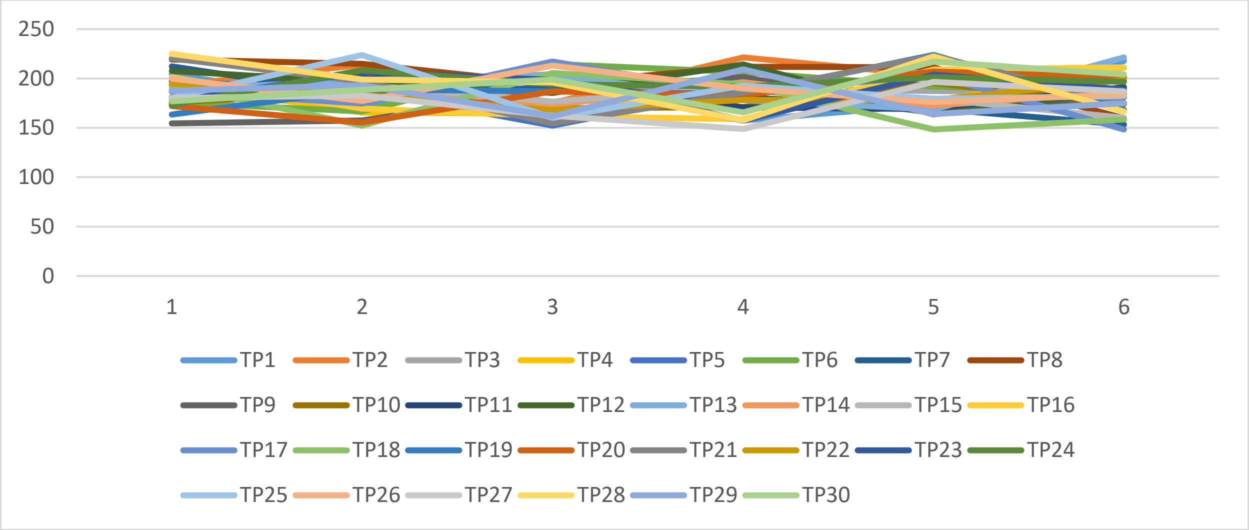
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.4 Estimated Price Paths for Sugar Beet



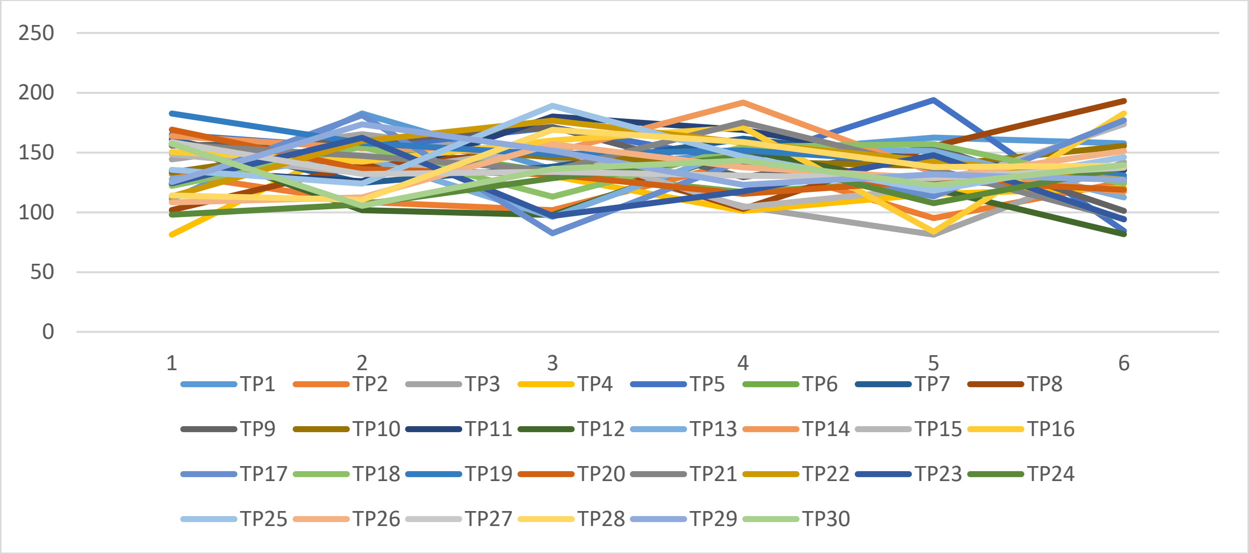
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.5 Estimated Price Paths for Potato



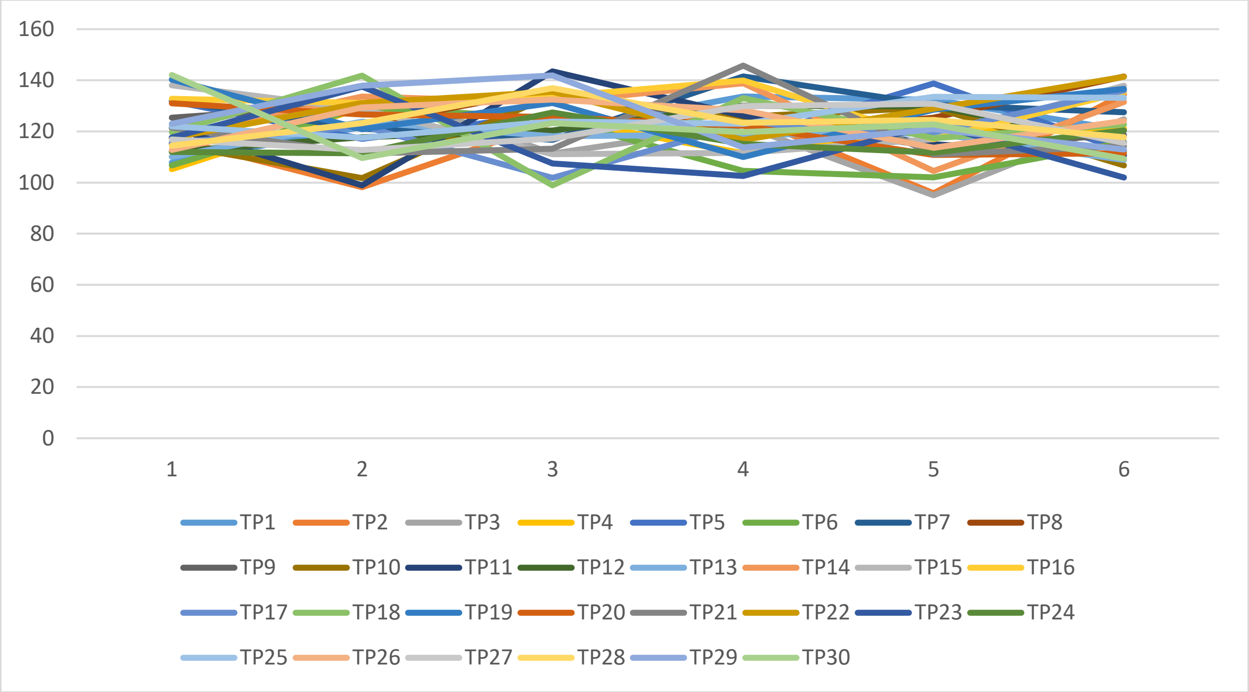
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.6 Estimated Price Paths for Feed wheat



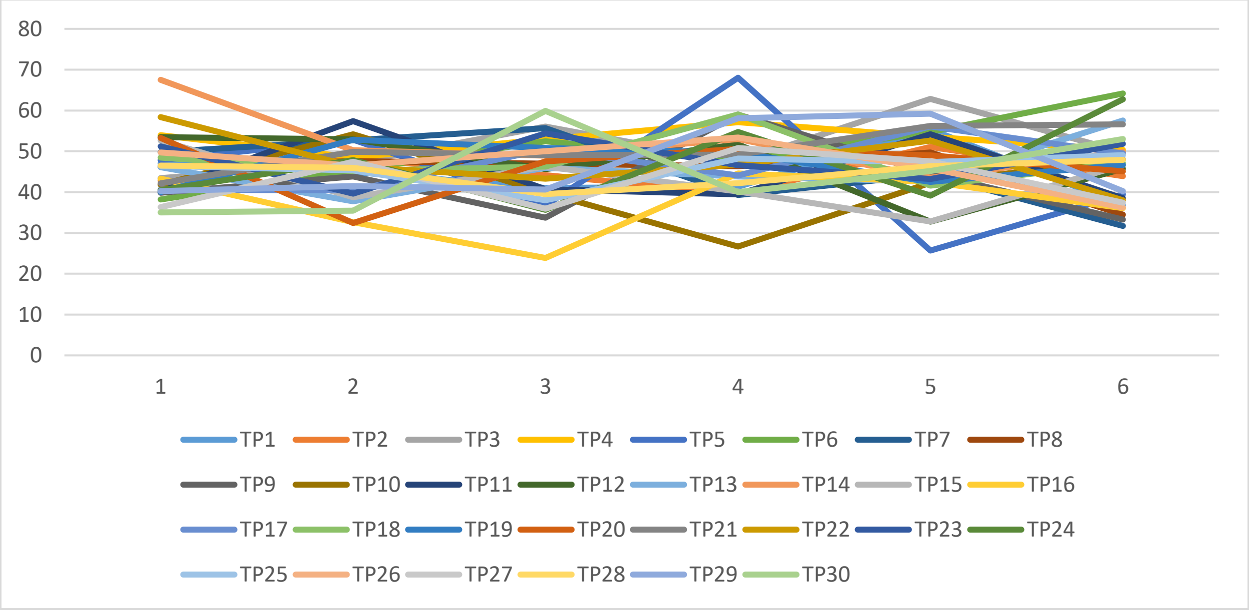
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.7 Estimated Price Paths for Feed Barley



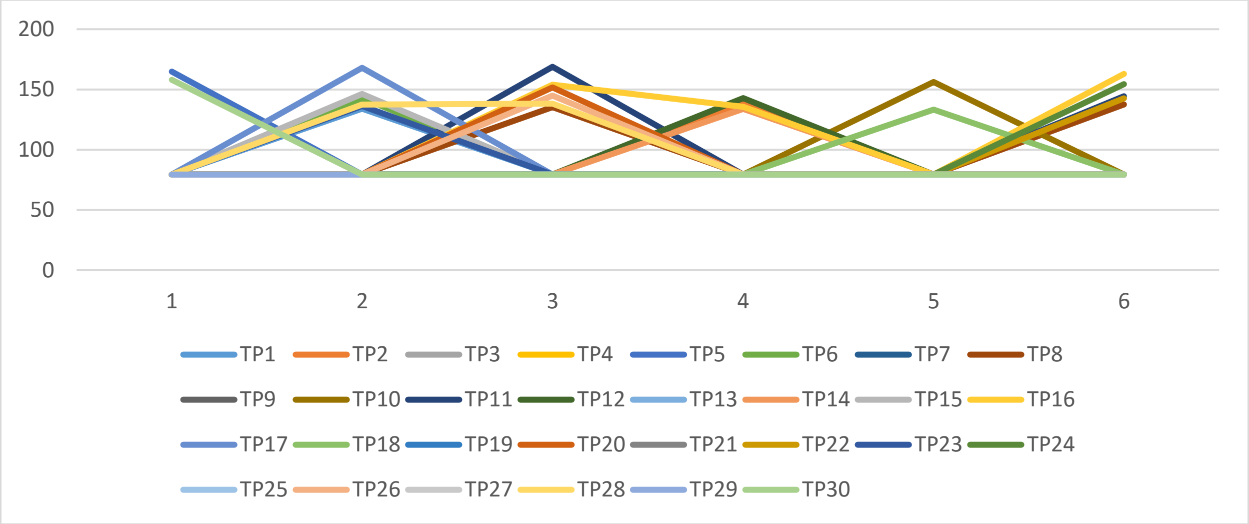
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.8 Estimated Price Paths for Barley Silage



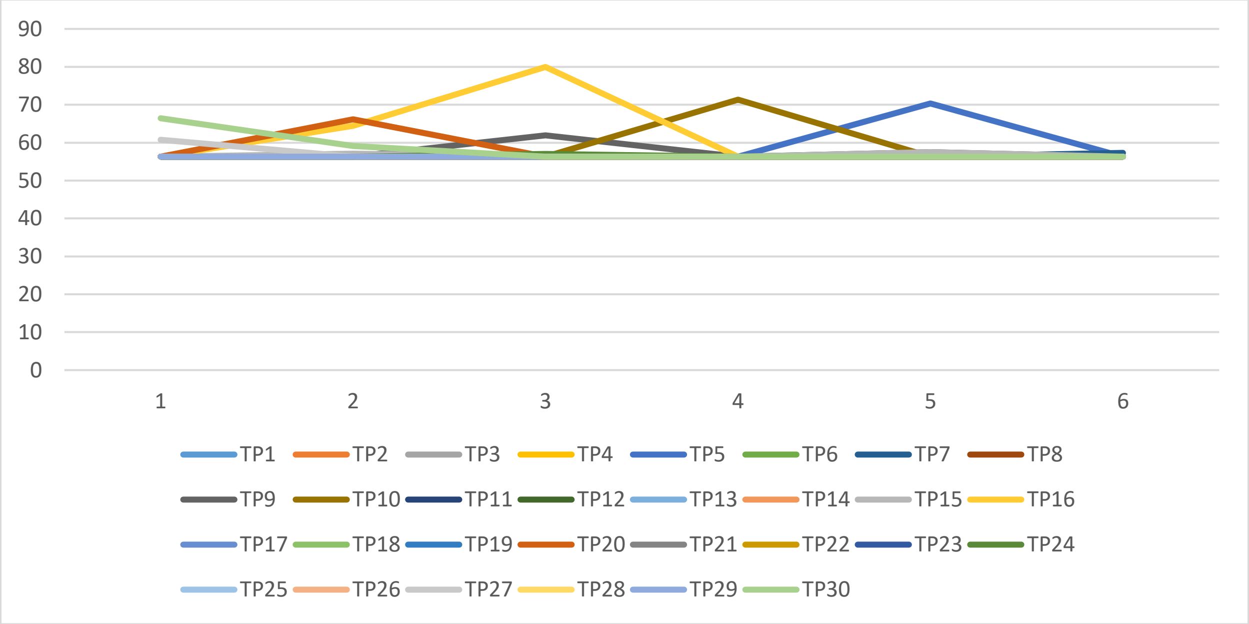
Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.9 Estimated Price Paths for Alfalfa Hay



Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Figure B.10 Estimated Price Paths for Mixed Hay



Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Table B.1 Historical Crop Price Series used in SUR Estimation

Time ID	SW	MB	CAN	SB	PO	FW	FB	BS	AH	MH
1980	227.69	160.89	325.21	77.45	118.33	164.64	133.57	34.90	91.31	86.28
1981	202.21	125.63	305.36	52.37	116.30	177.53	141.28	36.91	77.14	86.05
1982	199.30	107.55	331.88	66.42	114.06	178.37	125.26	32.73	78.12	93.68
1983	211.31	141.88	462.99	47.33	138.20	167.72	113.83	29.74	92.29	100.28
1984	182.08	138.92	392.69	35.15	120.83	172.91	130.82	34.18	121.31	92.72
1985	163.46	123.17	353.07	53.43	117.17	184.36	149.53	39.07	155.26	130.14
1986	152.60	115.95	321.00	63.93	227.62	182.96	139.39	36.42	173.14	143.08
1987	213.99	127.58	492.45	86.70	273.39	152.13	124.91	32.63	131.29	127.92
1988	243.20	167.86	431.40	59.22	203.92	169.32	122.01	31.88	127.04	100.43
1989	177.16	133.57	340.81	57.64	195.84	180.04	134.60	35.17	138.27	89.99
1990	157.63	121.05	377.65	61.90	239.21	187.89	137.19	35.84	127.78	97.92
1991	178.10	131.23	404.93	58.47	213.58	169.33	126.73	33.11	120.51	100.65
1992	179.81	135.31	450.30	62.50	275.77	151.02	128.26	33.51	138.66	102.11
1993	193.27	120.79	493.00	66.13	276.82	124.80	123.11	32.16	158.62	113.1
1994	243.40	138.18	494.48	60.96	207.13	132.34	115.22	30.10	146.79	97.15
1995	227.16	167.88	403.62	47.40	194.49	161.68	130.60	34.12	114.38	76.63
1996	158.74	123.95	418.32	44.07	155.66	179.62	151.75	39.65	109.65	87.83
1997	173.28	144.40	456.91	58.40	203.03	151.90	135.65	35.44	173.96	107.59
1998	170.32	131.15	427.84	41.80	212.90	150.14	133.81	34.96	150.6	106.26
1999	171.30	141.67	357.08	49.72	252.01	154.45	133.10	34.77	147.59	114.48
2000	190.52	149.70	355.35	47.85	221.92	153.35	137.05	35.81	183.62	123.69
2001	200.55	172.54	374.55	60.47	224.15	157.94	159.95	41.79	211.79	132.58
2002	196.21	168.46	377.66	39.63	205.97	172.92	171.87	44.90	165.43	146.46
2003	171.53	145.82	381.42	47.15	185.95	172.97	147.22	38.46	134.29	132.65
2004	178.72	142.95	410.66	53.28	200.57	147.94	129.39	33.81	127.48	99.02
2005	180.56	140.16	375.22	64.50	248.17	124.62	129.93	33.95	144.02	105.38
2006	167.11	144.37	379.60	56.44	240.37	136.99	132.36	34.58	120.44	91.54
2007	184.82	165.81	374.78	43.24	172.63	160.10	153.05	39.99	96.25	67.57
2008	221.43	161.96	382.74	35.29	169.20	175.02	151.59	39.61	94.47	59.78
2009	197.46	152.17	395.83	39.90	194.17	151.29	131.39	34.33	120.8	95.63
2010	188.68	148.96	418.07	52.75	209.16	157.23	143.92	37.60	95.82	111.96
2011	183.33	160.00	441.67	44.60	184.54	164.27	152.07	39.73	80.37	62.42
2012	197.67	186.05	441.86	42.71	169.68	197.60	178.26	46.57	105.91	53.11
2013	211.74	185.74	419.76	37.70	187.99	191.26	167.26	43.70	127.33	57.89
2014	208.91	167.13	399.26	47.11	236.29	164.72	146.78	38.35	151.25	87.57

Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Table B.2 Price Forecast Correlation Comparison

	SW	MB	CAN	SB	PO	FW	FB	BS	AH	MH
	Correlation of Average Crop Prices used in the simulation									
SW	1.00									
MB	0.61	1.00								
CAN	0.68	0.46	1.00							
SB	0.37	0.24	0.06	1.00						
PO	-0.12	-0.23	-0.04	-0.03	1.00					
FW	0.42	0.43	0.10	0.78	-0.34	1.00				
FB	0.28	0.33	0.02	0.54	-0.26	0.65	1.00			
BS	-0.12	0.24	0.02	-0.33	0.19	-0.36	-0.41	1.00		
AH	0.10	-0.01	0.01	0.29	-0.02	0.34	0.28	-0.25	1.00	
MH	0.01	0.03	-0.03	-0.03	-0.04	0.03	0.01	-0.01	0.02	1.00
	Historical Correlation of Crop Prices 1980 -2014									
SW	1.00									
MB	0.48	1.00								
CAN	0.27	0.11	1.00							
SB	0.09	-0.44	0.06	1.00						
PO	-0.15	-0.03	0.38	0.32	1.00					
FW	-0.10	0.13	-0.38	-0.31	-0.54	1.00				
FB	-0.15	0.56	-0.22	-0.49	-0.17	0.54	1.00			
BS	-0.15	0.56	-0.22	-0.49	-0.17	0.54	1.00	1.00		
AH	-0.22	0.00	0.05	0.13	0.54	-0.27	0.06	0.06	1.00	
MH	-0.30	-0.40	-0.11	0.36	0.33	-0.22	-0.18	-0.18	0.67	1.00

Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Table B.3 Cholesky Decomposition of Price Shocks

	SW	MB	CAN	SB	PO	FW	FB	BS	AH	MH
SW	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MB	0.67	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAN	0.47	-0.17	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB	-0.14	-0.47	0.15	0.86	0.00	0.00	0.00	0.00	0.00	0.00
PO	-0.12	-0.23	0.20	0.52	0.79	0.00	0.00	0.00	0.00	0.00
FW	-0.08	0.51	-0.20	-0.14	-0.37	0.74	0.00	0.00	0.00	0.00
FB	-0.17	0.60	-0.14	0.00	-0.27	0.37	0.62	0.00	0.00	0.00
BS	-0.17	0.60	-0.14	0.00	-0.27	0.37	0.62	0.00	0.00	0.00
AH	-0.16	0.12	-0.14	0.20	0.23	-0.28	0.30	0.07	0.82	0.00
MH	-0.34	-0.12	-0.18	0.21	0.15	-0.20	0.23	-0.17	0.53	0.60

Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Table B.4 Price forecast coefficients SUR model

	SW	**MB**	**CAN**	**SB**	**PO**	**FW**	**FB**	**BS**	**AH**	**D.MH**
1 Period Lag	0.46	0.43	0.61	0.38	0.05	0.74	0.65	0.65	0.82	0.33
2 Period Lag	-0.08	-0.04	-0.05	0.02	-0.07	-0.17	-0.16	-0.16	-0.28	-0.38
Constant	109.70	82.50	166.01	27.24	188.34	64.87	65.36	17.08	56.39	-2.47

Source: AF(2009, 2015b, 2016d), (2015b), Laate (Laate, 2013), Statistics Canada (2016a, 2017), AAFC (2015), UDMDriect Service (2016), MAFRD (2015), BoC (2018).

Appendix C. ORWTM ABM NetLogo Code

The link below takes you to the author’s website where the ABM Simulation code is published.

https://sites.google.com/s/0B2YgCzr0fReWTE5oMmladjRUdVE/p/0B2YgCzr0fReWaUZSNjJzMzhGbW8/edit?authuser=1

Appendix D. Stata Panel Regression Code and Regression Results

The link below takes you to the author’s website where the Stata code is published.

https://sites.google.com/s/0B2YgCzr0fReWTE5oMmladjRUdVE/p/13grZq8K0LiMeKhuuXufAlKcVubVjCuqK/edit?authuser=1

The link below takes you to the author’s website where the descriptive statistics for regressions are published.

https://sites.google.com/s/0B2YgCzr0fReWTE5oMmladjRUdVE/p/1lTtwRm93giSURnpqwigd1NrrY_MLkpZY/edit?authuser=1

The link below takes you to the author’s website where the full regression results are published.

https://sites.google.com/s/0B2YgCzr0fReWTE5oMmladjRUdVE/p/1InJ_DLx1s_QtE4OolbA486lCUMrujch9/edit?authuser=1