Three Essays on Beef Genomics: Economic and Environmental Impacts

by

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Abstract

The successful diffusion of new agricultural biotechnologies depends on widespread producer acceptance and uptake. The assessment of the key factors that can influence producer decision making is fundamental to the understanding of the rate of uptake, the attainable rate of potential benefits and the effectiveness of different measures that can stimulate the diffusion of these innovations. This dissertation examines three related aspects of cow-calf producer decision making with regards to the uptake of genomic selection for feed efficiency in beef cattle production in Canada. Improvements in feed efficiency can have significant economic and environmental impacts on beef cattle production through the reductions in feed costs and greenhouse gas emissions. Specifically, the following objectives are addressed: (i) the evaluation of the factors affecting cow-calf producer willingness to pay (WTP) for genomically improved feed efficient bulls (ii) the assessment of how supply chain linkages can influence cow-calf producer decision making (iii) the assessment of environmental outcomes from different decisions made by cow-calf producers and the extent to which the opportunity to obtain additional revenue from these environmental externalities can influence these decisions.

In the first paper, cow-calf producers' private valuation of genomic information on feed efficiency in their bull purchase decision is assessed. The analysis is situated in a multi-trait context that accounted for both conventional and genomic breeding information and cow-calf producer heterogeneity due to attitudes and farm practices. The results indicated that willingness to pay (WTP) for genomic information is positive; cow-calf producer valuation of conventional breeding technologies is relatively higher. The results further showed evidence of heterogeneity in cow-calf

producer preferences according to characteristics such as risk perceptions, calf retention practices and familiarity with genomics.

The results of the second paper highlight the potential supply chain issues that can impact the widespread diffusion of the innovation. From the stylized industry framework outlined, the allocation of benefits from the genomic selection for feed efficiency is skewed towards feedlot operators who typically do not incur the cost of bull purchases in fragmented systems. The results suggest that in the absence of a mechanism that rewards cow-calf producers for the additional cost associated with the genomic bull, the diffusion of the innovation is likely to be slow.

The results of the third paper show that breeding for feed efficient cattle is associated with positive environmental outcomes across the three agroecological zones considered. The simulation analysis showed that these environmental benefits differ spatially and are highest when the selection for feed efficiency is combined with limits on stocking rates. While the participation in a carbon offset scheme is an additional source of revenue which can possibly change cow-calf producer incentives, the results show that revenue from the offset scheme is inadequate given the low level of emissions per farm and the examined price of carbon.

Overall, the empirical results of this study suggest that genomic selection for feed efficiency can improve the economic and environmental performance of the Canadian beef cattle industry. The potential supply chain bottlenecks and the spatial heterogeneity in cow-calf production must however be accounted for in the design of mechanisms to stimulate cow-calf producer uptake.

Preface

This thesis is an original work by Albert Boaitey. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Boards, Project Name "Producer Attitudes Towards the Adoption of Genomic Selection in Beef", No. Pro00050259, July 21, 2014.

Sections of Chapter 3 of this thesis has been published as A., Boaitey, E., Goddard, G., Hailu, and K., Poon, "Improving sustainability of beef industry supply chains," British Food Journal, vol. 118, issue 6, 1533-1552. I was responsible for the analysis as well as the manuscript composition. G.Hailu and K. Poon assisted with modelling and data analysis. E. Goddard was the supervisory author and was involved with concept formation and manuscript composition. The feed efficiency analysis in Chapter 3 has also been published as A., Boaitey, E., Goddard, S., Mohaptra, and J., Crowley, "Feed Efficiency Estimates in Cattle: The Economic and Environmental Impacts of Reranking," Sustainable Agriculture Research vol. 6, issue 3, 35-47. I was responsible for the analysis as well as the manuscript composition. S., Mohaptra and J., Crowley assisted data analysis and data respectively. E. Goddard was the supervisory author and was involved with concept formation and manuscript composition.

Dedication

To mum and dad, and all my teachers from whom I learnt everything I know

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Chapter 1 : Introduction

1.1 Feed Efficiency and Beef Cattle Production

Profitability in livestock production is influenced by cattle prices, cost of production and changes in efficiency resulting from genetic improvements in specific traits. Historically, cattle breeders have focussed on output traits such as fertility, live weight and carcass attributes, and have placed less emphasis on input traits such as feed efficiency (Arthur et al., 2001). For example, as a result of improved genetics and management, cattle dressed weights have seen significant increases. Between 1975 and 2005, the average carcass weight of steers and heifers increased by 144 pounds (steers) and 194 pounds (heifers) (McMurry, 2011). This represented a 21 and 35% increase in carcass weight in steers and heifers respectively. Growth in the average carcass weight of bulls and cows followed a similar trajectory over the 30-year period with increases of approximately 35 and 31% in bulls and cows respectively (McMurry, 2011). This emphasis on output traits has resulted in the failure to attain a balanced improvement across all traits that contribute to breeding objectives (Garrick, 2011). This is particularly true for input traits such as feed efficiency that are linked to feed intake and costs.

Feed costs constitute the single most important variable cost in beef cattle production (Hughes, 2011; Myers, 1999; Dilenzo and Lamb, 2012). As a proportion of total cost, the annual feed cost of maintaining a cow in a herd is substantial, estimated at 41-75% of total costs on a per cow basis (Hughes, 2011; Myers, 1999). These costs are even greater for feedlot operators as a result of the use of higher cost grain diets as compared to grass in cow-calf operations (Dilenzo and Lamb, 2012). Changes in feed prices also affect cattle values across the supply chain. For example, reduced margins for feedlot operators emanating from higher feed costs can lead to reduced valuation of feeder cattle, thereby transmitting lower prices to cow-calf producers upstream. As a result of this, changes in feed grain markets influence cow-calf profitability and cattle cycles (Hasbargen and Egertson, 1976). The combined effect of the influence of feed cost on cow-calf producers' own production costs and calf prices implies that improvements in feed efficiency can have significant economic implications for these producers.

Aside from the economic impacts, there are also a number of environmental outcomes from improved feed efficiency. In North America, cattle are estimated to account for 12-17% of methane emissions from human activities (Beauchemin et al., 2010). Improvements in feed efficiency are linked to improved enteric fermentation and reductions in GHG emissions (Basarab et al., 2013). As a greenhouse gas emissions abatement approach, breeding for efficient cattle can result in the attainment of desired GHG reduction goals without compromising herd size or level of production (Alford et al., 2006; Basarab et al., 2013).

1.2 What is Genomic Selection?

Prior to the availability of DNA sequence information, most of the progress in the breeding for specific traits in livestock occurred through the use of actual performance information (phenotypic data) or estimated breeding values[1] (EBVs) calculated with these phenotypes (Dekkers, 2012). These EBVs for specific traits combined information on the performance of an animal and that of its relatives (Jonas and de Koning, 2013). Molecular techniques such as marker assisted selection (MAS) use marker information in breeding. These markers identify variations in DNA sequences linked to specific traits. In genomic selection (GS), whole genome molecular data is used in estimating the genetic merit of a given animal (Goddard and Hayes, 2007). As compared to MAS, genomic selection incorporates information from thousands of markers spread throughout the

[1] A glossary of terms used in this dissertation is provided in section 5.6.

genome of an animal to estimate its genetic performance (Twine, 2010 pp. 15).The process of genomic selection can be summarized in two steps. According to Hayes (2007), the first step involves the establishment of the linkage between a DNA chromosome segment and the relevant traits in a reference or training population. This requires both phenotypic and genotypic information. In the second stage, the genomic breeding values of animals outside the training population are predicted based on their genotypic information. The uptake of genomics in livestock breeding has been facilitated by the advent of cost-effective genotyping that allows for the analysis of thousands of markers (Twine, 2010 pp. 15; Matukumalli et al., 2009).

1.3 Genomics and the Selection for Feed Efficient Cattle

Feed efficiency is moderately heritable with heritability estimates ranging from 0.16 to 0.44 (Sherman et al., 2014; Schenkel, 2004). Improvements in the trait are associated with reduced dry matter intake at equal levels of growth and body size (Basarab et al., 2013). Recent studies have identified specific DNA segments linked to the trait (Bolormaa, 2011; Sherman et al., 2014). The use of genomics can be particularly advantageous for the selection of feed efficiency for a number of reasons. The selection for the trait requires the identification of variations in feed intake within a cohort of animals. This necessitates the measurement of an individual animal's actual feed intake. The cost of measurement however, gets prohibitively expensive as cattle numbers increase. Indeed, the absence of a standardized approach for the selection for feed efficiency in the beef industry has been attributed to insufficient information on feed intake due to high measurement costs (Rolf et al., 2012). The relative advantage of the use of genomic selection is: if feed efficiency can be predicted on the basis of an animal's DNA profile information, then the cost of measuring actual feed intake in order to predict future feed performance may not be incurred[2](Pryce et al., 2014).

[2] Measuring of feed intake is required in training populations in order to establish DNA linkages.

The beef industry can thus obtain the benefit of a feed efficient herd without having to necessarily measure actual feed intake for all animals in whole herds.

Figure 1.1 shows the genetic trends in birthweight, weaning weight, feed intake and residual average daily gain. From the trends, it seems that whilst traits such as weaning weight and birthweight have seen improvement over time, the change in feed intake and residual average daily[3] gain is relatively minimal.

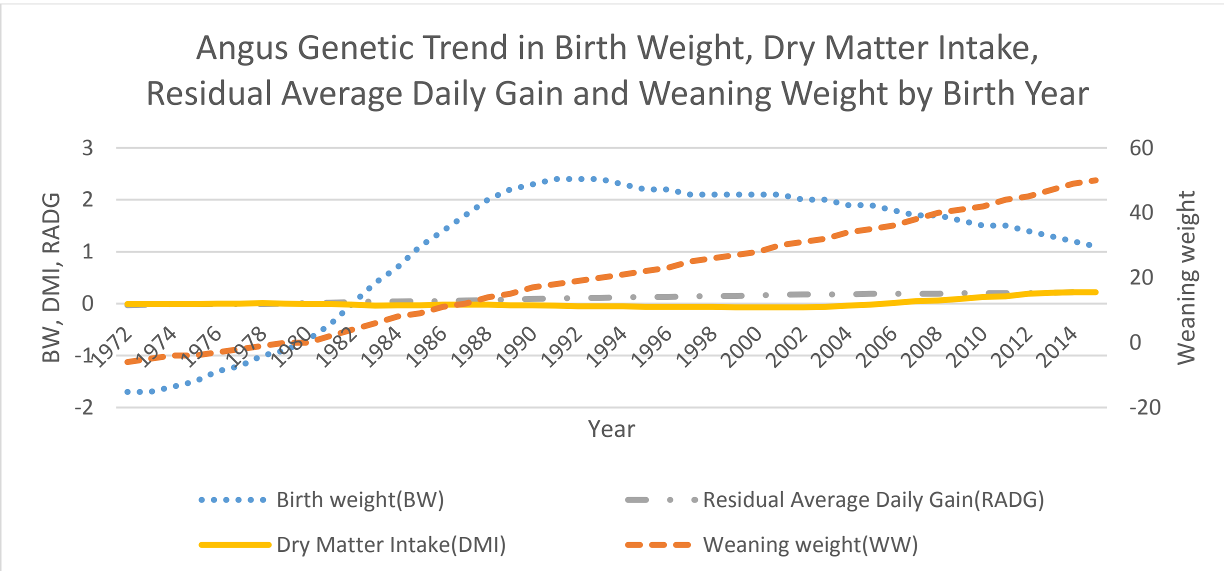

Figure 1.1: Angus cattle: Trends in selected traits (Data source: Angus Beef, 2015)

1.4 Study objectives

To enhance profitability and maintain competitiveness, cow-calf producers must make complex decisions; perhaps the most important being the breeding stock purchase decision. This decision is fundamental for the introduction of genetic improvements into the herd. By purchasing breeding stock with relatively higher genetic value as compared to culled animals, cow-calf producers increase the genetic value of their breeding stock (Melton, 1980). These improvements may be transmitted to other producers downstream through the sale of weaned calves.

[3] An alternate measure of feed efficiency.

The use of new breeding technologies such as genomics for the selection of feed efficient cattle has important implications for cow-calf producer valuation of bull traits, farm level profitability and the environmental impact of production. In spite of this, not much has been done to comprehensively address cow-calf producer decision making in the context of the use of genomics for the selection of feed efficient cattle. The few available studies on improved feed efficiency (e.g. Weaber, 2012; Alberta Agriculture and Rural Development, 2006) do not account for pertinent factors such as environmental impacts and the effect of cow-calf producer behavior. In this study, the economic and environmental impacts of genomic selection for feed efficiency on cow-calf producer decision making in Canada are examined. Specifically, the following are addressed: (i) factors affecting producer willingness to pay (WTP) for genomically improved feed efficient bulls (ii) the assessment of how supply chain linkages can influence producer decision making (iii) the assessment of environmental outcomes from different decisions made by producers and the extent to which the opportunity to obtain additional revenue from these environmental externalities can influence these decisions.

1.5 Motivation for Research

Food production systems in many countries face a complex conundrum. In less than 3 decades (2050), the global population is projected to reach 9 billion from the current 7.3 billion-an increase of almost 2 billion (UNDES, 2015). To meet this expected increase in the demand, food production must increase. The ability to meet this challenge is however, constrained by changes in land use and concerns about greenhouse gas emissions (GHG) from increased agricultural production. For livestock producers this challenge is even more peculiar. On the one hand, the demand for meat and dairy products globally, is projected to increase by approximately 60% by 2050 (Alexandratos and Bruinsma, 2012). On the other hand, livestock production, particularly bovine systems such as beef cattle are the main emitters of methane from agricultural sources (Pitesky et al., 2009). A majority of these emissions are related to digestive processes in the rumen which is associated with the efficiency with which cattle utilizes feed (i.e. enteric fermentation) (Johnson and Johnson, 1995). The adoption and use of genetic innovations (such as genomics) that enhances the efficiency of production in the cattle industry can be important in meeting the challenge of increased production with minimal environmental impact.

The benefits of production-based innovations are however, only derived if producers adopt. It cannot be simply assumed that producers would adopt these new technologies. In production systems where cattle ownership changes across the different phases of production (i.e. cow-calf, backgrounder and feedlot operator), the producer incurring the additional cost of adopting the innovation does not always receive the entire benefits. Irrespective of the overall public and industry benefits of a given innovation, particular groups of producers may be less likely to adopt if the private benefits are inadequate. Other segments of producers who care about the environment (for example) may adopt even if the direct economic benefits are low. Understanding producers' private valuation of a given innovation, the distribution of these values across the supply chain, and the effect of environmental externalities are therefore important for predicting behavior. The three papers that constitute this dissertation are an attempt to assess whether or not the beef cattle system – as is- has the appropriate characteristics to encourage adoption of innovations which create value in the supply chain and have positive environmental externalities. Insights from this study can guide policies aimed at promoting the widespread uptake of new breeding technologies by cattle producers.

1.6 Overview of the Canadian Beef Industry

Beef cattle production is an important component of the Canadian red meat industry. With a total herd of approximately 13.5 million animals, beef production is the largest single source of farm cash income in Canada (Statistics Canada, 2016a). Receipts for the sector from 1971-2015 (Figure 1.2) averaged 17% of total farm cash receipts and 40% of total receipts from livestock and livestock products (Statistics Canada, 2016a). As shown in Figure 1.2, farm cash receipts for the industry totalled $10 billion in 2015 representing a 7% increase in earnings from the previous year (Statistics Canada, 2016a).

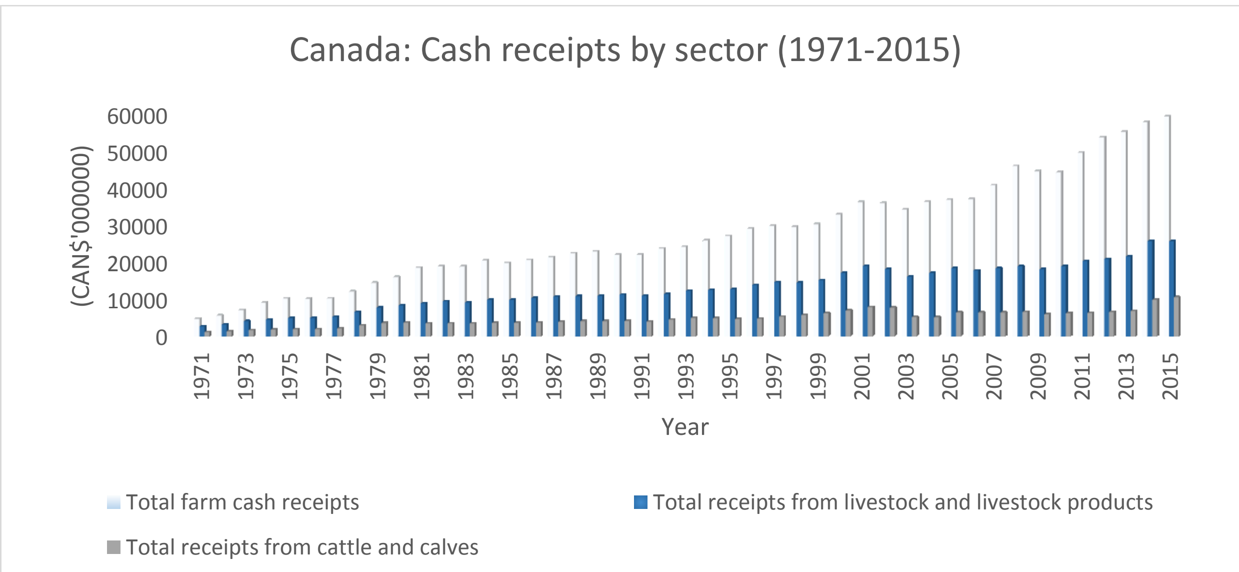

Figure 1.2: Canada, Farm Cash receipts (Data source: Statistics Canada 2016a)

The number of domestic slaughter cattle in federal and provincially inspected facilities in 2014 was approximately 2.8 million cattle, up 2.8 % from the previous year (Canadian Meat Council, 2012). Per capita beef consumption in 2016 was 25 kg (Agriculture and Agri-food Canada, 2016).

Beef consumption was higher than pork (20.90 kg) but lower than chicken[4] (32.51 kg). From Figure 1.3, the consumption of beef has been on a downward trajectory from 1980-2016.

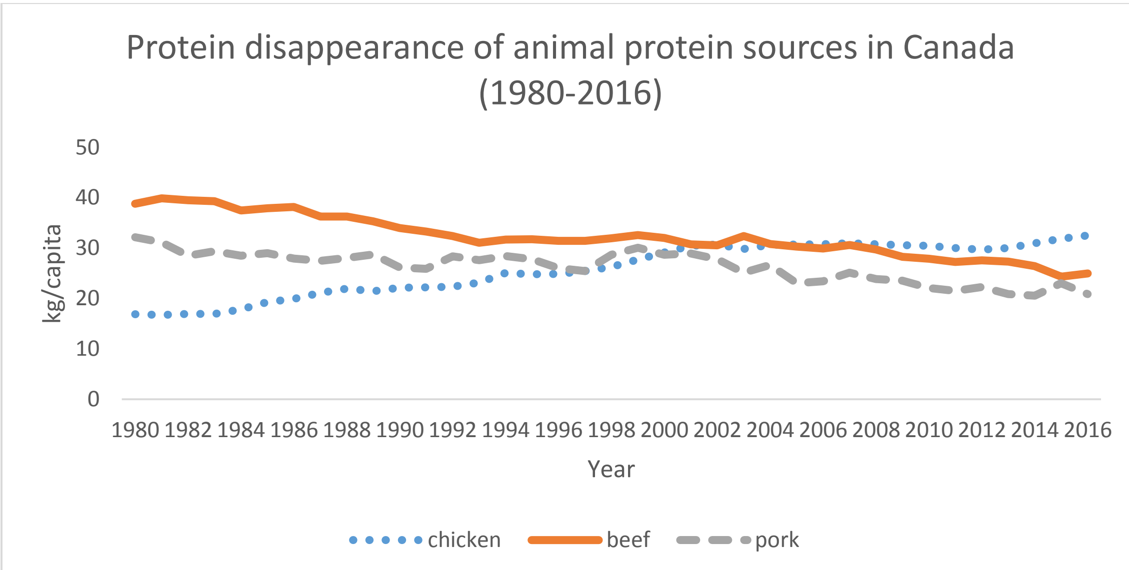

Figure 1.3: Trends in meat consumption in Canada: Beef, chicken and pork (Data source: Agriculture and Agrifood Canada, 2016)

Possible contributory factors to these changes include: changes in tastes and preferences, supply conditions, demographic factors (Kinsey and Senauer, 1996; Agriculture and Agri-Food Canada, 2005), and changes in the price of beef relative to other meat substitutes (Brester et al., 1995; Barkema and Drabenstott, 1990).

Aside from domestic consumption, a significant proportion of both live cattle and processed beef is exported to the US[5]. The former refers to the exports of fed and feeder cattle to exploit the US's relative advantage in finishing cattle and subsequent value addition (Peel, 2015; Brester and Marsh, 1999). Between 2012 and 2016, an average of about 900,000 feeder and fed cattle were

[4] Chicken kg is in eviscerated weight, pork and beef are in kg carcass weight
[5] For example in 2012 the US accounted for 75% of total exports valued at $1.21 billion.

exported to the US (Agriculture and Agri-food Canada, 2017). Other important trading partners include Japan, Russia and China. As the main market for Canadian cattle and beef products, supply conditions as well as trade policies in the US directly impact trade volumes. For example, the closure of the US border to Canadian cattle following the BSE outbreak in 2003 not only impacted Canadian exports to the US but the entire beef production system.

1.6.1 Beef Production: An Overview

Structurally, beef production comprises farm-level production and slaughter-processing segments. As the closest segment to the consumer end of the supply chain, the slaughter-processing segment transmits important market signals to producers upstream through the valuation of finished cattle. The production cycle begins with cow-calf producers. These producers supply live cattle to the feedlot/feeder sector. Historically a single industry, specialization is believed to have commenced in the early 1960's (Duboon, 1997). Further, backgrounding of beef cattle may be undertaken by cow-calf producers or a distinct segment of producers who specialize in this practise. The cow-calf sector holds a majority of Canadian cattle accounting for 70% (7 million cattle in 2016) (Statistics Canada, 2016b). Comparatively, the number of cattle on backgrounding and feedlot operations in the same period was approximately 2 million and 1.4 million for the former and latter respectively (Statistics Canada, 2016b). Figure 1.4 is a plot of Canada's beef cow inventory from 1940-2017.

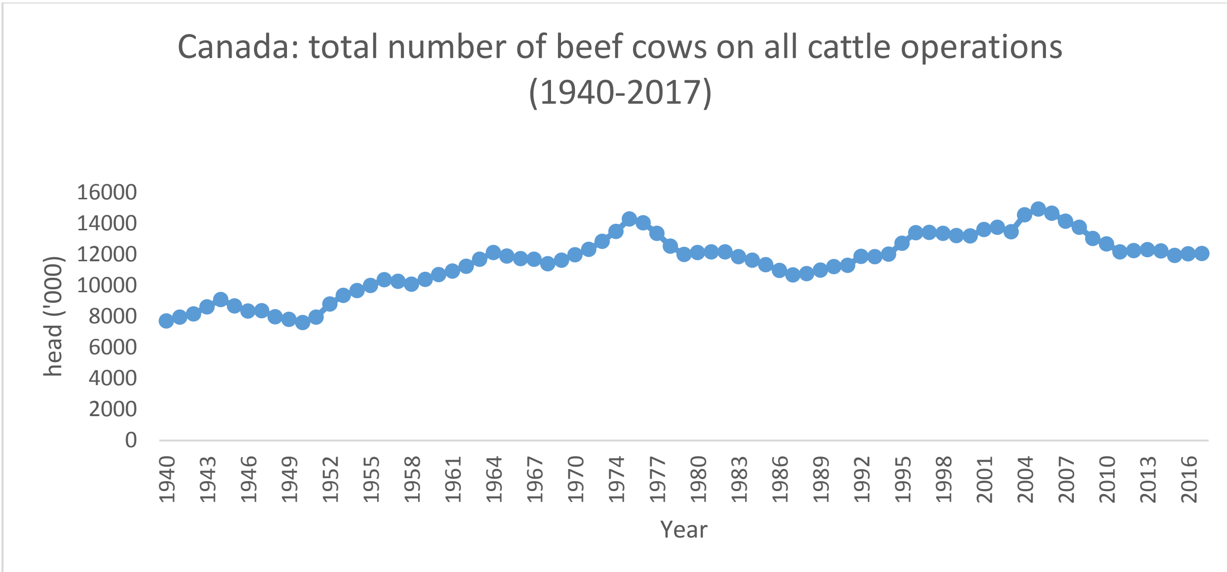

Figure 1.4: Canada: Beef cow inventory 1940-2017 (Data source: CANSIM table 003-0032)

From Figure 1.4, cattle inventory follows a cyclical pattern. These cycles typically run for 10-12 years (Canfax, 2011). Constrained by biological factors, the expansion and contraction phases that characterize cattle cycles often lag behind the relevant causative factors such as calf prices, feed price and changes in consumer demand (Canfax, 2011; Anderson et al., 1996). Herd size dynamics in the industry are mostly driven by cow-calf profitability. Cow-calf producers respond to increases in net returns resulting from high calf prices for example, by increasing the retention of heifers and reducing the culling of cows (Anderson et al., 1996). This leads to an increase in production and consequently increased inventories. All else equal, prices decline in response to increased supply- initiating a liquidation phase. This supply contraction phase continues until calf prices are restored to favorable levels (Anderson et al., 1996). The most recent cattle cycle in Canada spanned 1996-2005 and comprised of: liquidation phase (1996-1999) followed by an expansion phase (2000-5) (Canfax, 2011).

Cattle production in Canada is characterized by wide variations in scale across regions and between production segments. Cow-calf operations in Canada averaged 129 cattle and calves per operation while average feedlot capacities of 8200-8400 are not uncommon in Alberta and Saskatchewan (Canfax, 2011). From Figure 1.5, Alberta and Saskatchewan jointly account for over 60% of the total beef cow inventory in 2016 (Canfax, 2013; Statistics Canada, 2016c). Further, beef cattle production is concentrated in regions with relative land base and natural feedstuff advantages (Smith et al., 2006). For example, approximately 25% of all steers and heifers on feed in Canada are located in Lethbridge AB

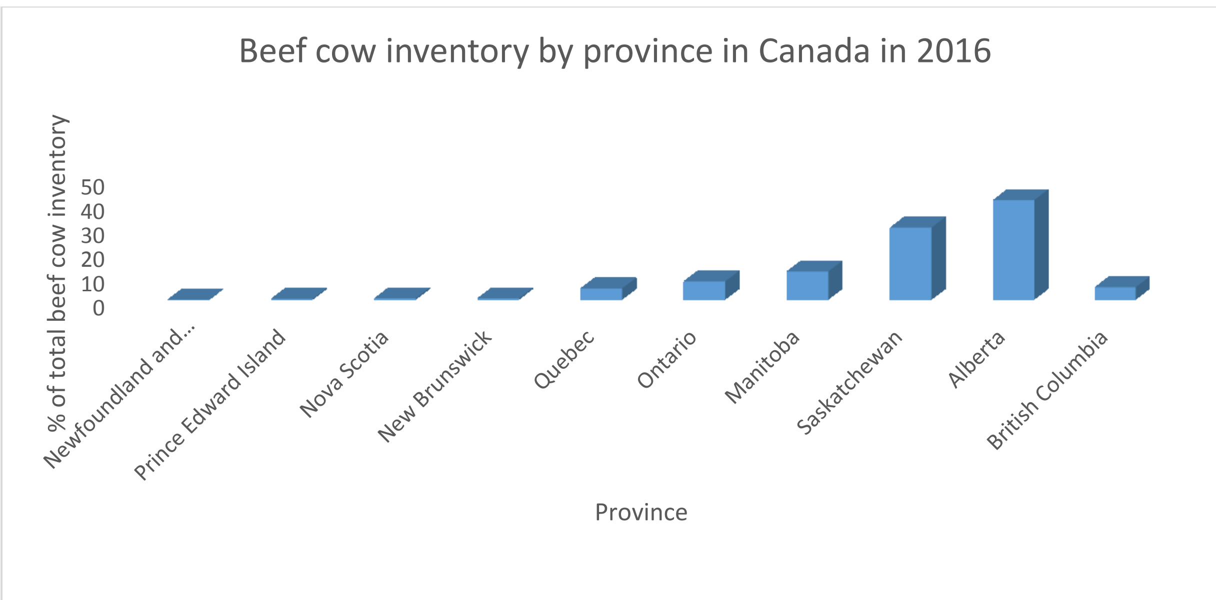

Figure 1.5: Distribution of beef cow by province (Data source: Statistics Canada, 2016c)

1.6.2 Cattle Production Cycle

The different stages of cattle production typically follows a seasonal cycle. As depicted in Figure 1.6, cows are exposed to bulls or artificially inseminated in early summer of the previous year to ensure that calving coincides with emerging spring grass the following year (Canadian Cattlemen's Association, 2013a). Cows and their newly bred calves graze on forage until fall when calves are weaned at about 550Ibs. Based on the production objectives different marketing options are pursued. Weaned calves may be retained as replacement heifers, marketed to backgrounding and feedlot operators or sold to other cow-calf operators. Backgrounding is an intermediary operation that may include both feeder and finisher operations. By providing a bridge between cow-calf operations and feedlots, backgrounding facilitates the continuous flow of finished cattle throughout the year. Weaned calves may be over-wintered on forage diets and marketed as yearlings to feedlot operators at weight of up to 900Ibs or fed to finish (Canadian Cattlemen's Association, 2013a). These feedlot operations are relatively more intensive and involve the placement of cattle on high grain diets over a period of 60-200 days until the attainment of slaughter weight of approximately 1250 Ibs (Canadian Cattlemen's Association 2013b).

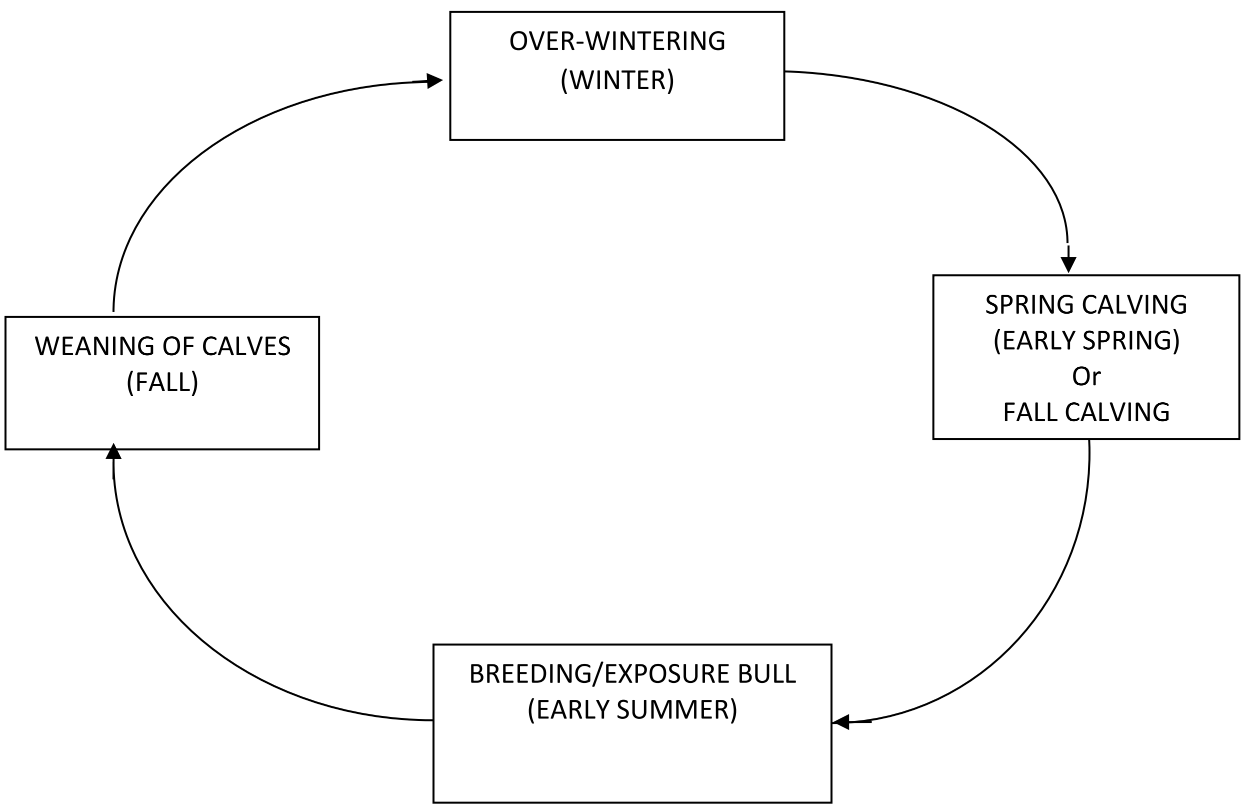

Figure 1.6: Typical cow-calf production cycle

Figure 1.7, shows the structure of the beef cattle industry and the flow of cattle through the various segments and decision makers along the supply chain. It also illustrates the key decision making points discussed in the previous sections. From Figure 1.7, cow-calf operators produce weaned calves that are marketed to backgrounders and feedlot operators or retained as replacement heifers. Cattle may be backgrounded directly to slaughter weight or marketed to feedlots for subsequent finishing. Finished cattle are slaughtered and processed for domestic and foreign markets.

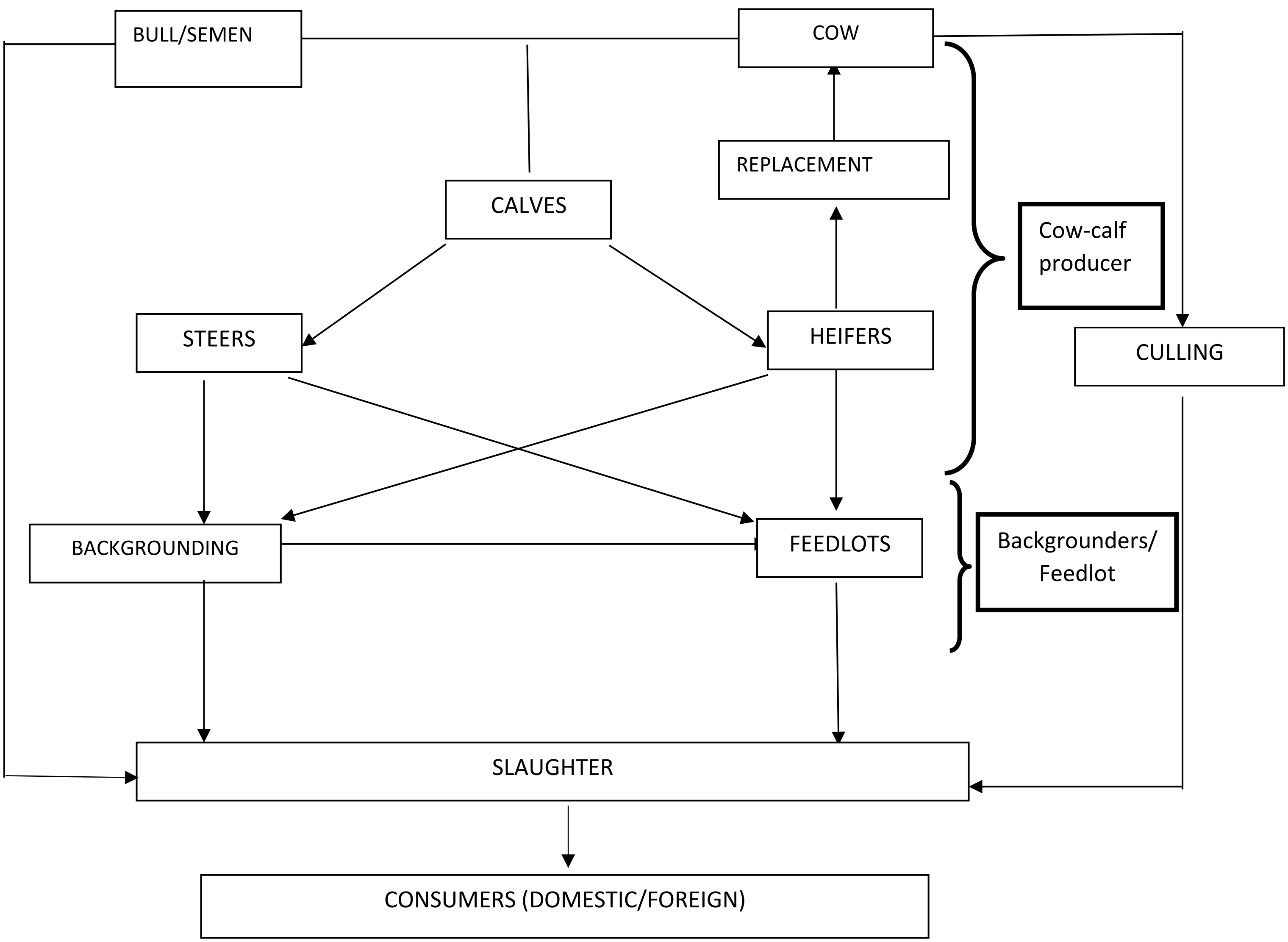

Figure 1.7: Beef production in Canada-Flow of cattle

The important role of the cow-calf producer with regards to breeding decisions is also evident. The bull/semen purchase and heifer retention decisions introduce improved genetic traits into the herd. Backgrounders and feedlot operators are impacted directly through the purchase of weaned calves. Depending on the nature of the improvements and the degree of market efficiency, these improvements are passed on to consumers through higher quality beef products or lower retail prices.

1.7 Overall Conceptual Framework

As previously discussed, this dissertation addresses three interrelated aspects of cow-calf producer decision making with regards to the use of genomic information to select for feed efficiency in beef cattle. These are namely: cow-calf producer's own private evaluation of bulls with genomic information on feed efficiency; the effect of the value distribution of feed efficient calves in the beef supply chain, and; environmental outcomes from different breeding decisions made by cow-calf producers. In this section, a general conceptual framework that illustrates the linkages between the three components is presented.

1.7.1 Genomics and Cow-calf Producer Decision Making

For the individual livestock producer, the availability of genomic information represents an additional input to facilitate decision making. With respect to breeding decisions, genomic information can be applied in two ways. Genomic information on a bull's performance for different traits can guide bull purchase decisions. The technology can also be applied in heifer retention/cull decisions. Cow-calf producers can genotype heifers to determine high performing heifers to retain. Alternatively, low performing heifers can be culled. The value of genomic information to cow-calf producers in the two decisions (i.e. bull purchase and cow replacement) is not the same. Bulls are typically used to service multiple cows. From a genetic improvement perspective, the bull purchase decision is therefore relatively more important. In this dissertation, cow-calf producer decision making relative to the bull purchase decision is addressed.

In general, breeding decisions are hierarchical. Firstly, the cow-calf producer must make the decision to retain or cull, and subsequently decide on the choice of a replacement once the former decision has been made. While a significant proportion of the extant literature has examined the former decision from the asset replacement perspective (Jarvis, 1974; Melton, 1980; Rosen, 1987), the impact of additional genomic information on cow-calf producer choice of a bull has largely not been addressed.

The asset replacement model (Perrin, 1972; Burt, 1965) provides the theoretical construct for analyzing livestock producer optimal replacement decisions. The basic premise is that asset managers act to maximize profits over time (Frasier and Pfeiffer, 1994). For beef cattle, this theory postulates that cattle are capital goods held until their cull value exceeds productive value (Jarvis, 1974). In general, cow-calf producers must decide on the proportion of the herd to market, retain for future production and future marketing, given current and expected market conditions (Rosen, 1987). These micro decision models in the aggregate determine the composition of future herds, influence market equilibria and impact other producers in the supply chain.

Despite the useful insights provided by previous studies, a number of pertinent issues related to the use of newer breeding technologies have largely not been addressed. For example, as compared to phenotypic selection, the incorporation of genomics in breeding decisions can facilitate the selection of younger bulls, reduce generation intervals and improve predictability of breeding values. Given that cattle traits differ in heritability, the issue of uncertainty is important in assessing the overall value of genomic information.

Assuming the cow-calf producer faces the choice of two bulls, (A) and (B), such that bull A represents the generic bull whilst bull B is marketed with genomic information. A bull[6] is considered to be a conglomeration of genetic attributes (g). Based on Kerr (1984)'s specification, the generic bull's production function is given as:

$$Y_A = f[x_A^G(g), x_A^N] \qquad (1)$$

where Y is output defined as weaned calves, $x^G(g)$ refers to genetic input assumed to be primarily sourced from the bull (or semen), x^N refers to non-genetic inputs. Conversely, the production function of the genomic bull is specified as:

$$Y_B = f[x_B^G(g), x_B^N, I^G] \qquad (2)$$

where I^G is the genomic information input and the rest of the notation is same as previously defined. As observed by Kerr (1984), x^N is defined as traits contributed by for example, cows in the production process. The $x(g)$ specification of the genetic aspects of production captures the both the phenotypic form of the relevant trait (x) and the underlying genes, (g). The genetic component $x(g)$ can be extended to the multi-trait $(x_1, x_2,,, x_n)$ and multi-gene $(g_1, g_2,,, g_n)$ context without loss of generality. Ex-ante, the perceived profits from the generic bull is given as:

$$\pi_A = P_A^Y f_A[x_A^G(g), x_A^N] - wx_A^N - P_A^B(g) \quad (3)$$

where w is per unit price of the non-genetic input, P^Y is the output price and P^B is the price of the bull defined as a function of its genetic profile. In the case of the genomic bull, Babcock (2000)'s approach is used to account of the uncertainty in the genetic input [7]. The profits from the

[6] Or semen in the case of artificial insemination.
[7] For simplicity the uncertainty in breeding with respect to the generic bull is ignored.

genomic bull is at a higher level of productivity f^H and a prior probability p_0 that the genomic information is accurate is given as:

$$\pi_B^H = P_B^Y f_B^H[x_B^G(g^H), x_B^N, I^G] - wx_B^N - P_B^B(g) - w^G \qquad (4)$$

where w^G is the additional cost of the genomic bull. It holds that at $(1-\rho_0)$ the bull is of lower productivity f^L, in which case profit is equivalent to:

$$\pi_B^L = P_B^Y f_B^L[x_B^G(g^L), x_B^N, I^G] - wx_B^N - P_B^B(g) - w^G \qquad (5)$$

The cow-calf producer selects the genomic bull if:

$\rho_0(\pi_B^H) + (1-\rho_0)(\pi_B^L) > \pi_A$; π_A otherwise. Stated this way, the producer maximizes expected profit specified as:

$$\begin{aligned}\tilde{\pi} \quad & \begin{Bmatrix} \rho_0\left(P_B^Y f_B^H[x_B^G(g^H), x_B^N, I^G] - wx_B^N - P_B^B(g) - w^G\right) + \\ (1-\rho_0)\left(P_B^Y f_B^L[x_B^G(g^L), x_B^N, I^G] - wx_B^N - P_B^B(g) - w^G\right) \end{Bmatrix} \\ & + (1-\phi)\left\{P_A^Y f_A[x_A^G(g), x_A^N] - wx_A^N - P_A^B(g)\right\} \qquad (6)\end{aligned}$$

The cow-calf producer expresses positive values for the extra genomic information ex-ante and chooses the genomic bull ($\phi = 1$) if the expected profits weighted by the accuracy of the informational input from the genomic bull (B) exceed the forgone profits from the generic bull (i.e. the opportunity cost from not selecting the generic bull). For a marginal change in the genetic input (g), this is equivalent to:

$$\rho_0 P_B^Y f_B^{'H} x_B^{'G} + (1-\rho_0) P_B^Y f_B^{'L} x_B^{'G} - P_B^{'B}(g) - [P_A^Y f_A^{'} x_A^{'G} - P_A^{'B}(g)] > 0 \qquad (7)$$

In the context of the bull replacement decision, the role of new DNA based informational tools such as genomic information is to increase the likelihood of the selection of higher productive bulls i.e. a shift from A to B in Figure 1.8. This can be extended to genomic information on specific traits. Further, there may be a category of cow-calf producers who attached value to the reduced

GHG emissions from feed efficient cattle due to, for example, higher environmental attitude/awareness. For this segment of producers, improved environmental quality can be considered as an environmental input in the profit function (Bocksteal and McConnell, 2017, page 299). Assuming the profits from more feed efficient cattle is $\pi^G(x, y, p)$, and $\pi^R(x, y, p)$ is profit from regular calves, where: x denote inputs, y is output and p is price. If environmental quality improves from say q^0 to q^1 as a result improved feed efficiency, then the benefit to the cow-calf producer from this change is equivalent to: $\pi^G(q^1) - \pi^R(q^0)$.

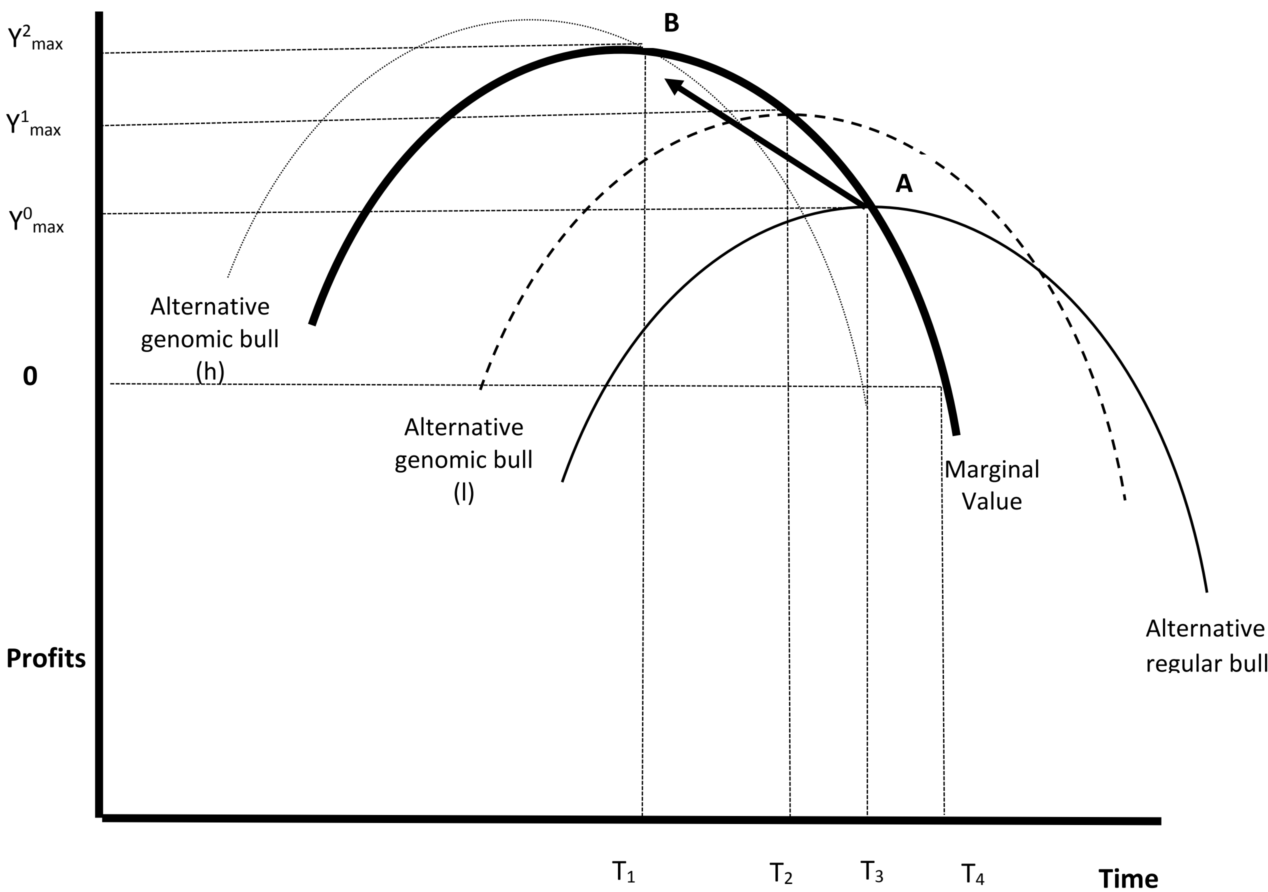

Figure 1.8: Bull replacement decision in the presence of bulls with genomic information (adapted from Groenendaal et al., 2004)

Within this decision making framework the impact of improved genomic technologies may vary across cow-calf producers based on factors such as: in age, income, farm size, risk preferences and attitudes. These factors can impact cow-calf producer willingness to pay (WTP) for genomic information. Additionally, management practices such as calf retention strategies may be impact the decision to purchase bulls with genomic information on feed efficiency. These ownership strategies are marketing decisions with respect to the sale of weaned calves (Pope et al. 2011, Franken et al. 2010). Cow-calf producers can sell calves to backgrounders or directly to feedlot operators or retain calves till slaughter age. Feed efficiency may affect these dynamics through its impact on feed costs. It is also plausible that cow-calf producers may retain calves till higher weights in order to internalize the benefits of any reductions in feed if downstream producers do not offer appreciable values for weaned calves. In the context of the conceptual model presented above, cow-calf producer heterogeneity can be incorporated using the approach outlined in Koundouri et al. (2006). This involves adjusting the bull production specification and the resulting profit and utility functions by individual specific characteristics. The first paper in this dissertation addresses cow-calf producer preferences for genomic information in their bull purchase decision. A theoretical model that accounts for multiple traits, cow-calf producer heterogeneity and different sources of bull performance information is developed. Outcomes of the model are evaluated with data from a national survey of cow-calf producers in Canada.

Paper two is centered on the value allocation to cow-calf producers from the sale of feed efficient calves and the impact this can have on the incentive to purchase bulls with higher merit for feed efficiency. The bull purchase decision by the cow-calf producer is an important investment decision from which the producer may receive improved net returns from the sale of calves. This investment-price of the bull (P_B^B in the conceptual model) should yield these net returns over the useful life of the bull. Equation 5 can be extended intertemporally to include the stream of net returns from the purchase of the genomically improved bull. The return on this investment is revenue from the sale of calves with specific attributes inherited from the bull i.e. P^Y in the conceptual model. For example, if a bull produces calves with superior carcass or growth attributes cattle feeders would pay a higher price for these calves if the market for these attributes is well-defined. The case of feed efficiency is peculiar in a number of different respects. First, value signalling in cattle markets is output-oriented. Feed costs are relatively higher for feedlot operators as compared to cow-calf producers who make the bull purchase decision. The former is therefore more likely to derive greater benefits from improvement in feed efficiency. This notwithstanding, whether or not the relative benefit obtained by cow-calf producers through improved feed efficiency is sufficient to stimulate uptake has not be previously addressed. The potential role of market and non-market interventions in stimulating uptake has not been also been examined. This can be in the form of the payment of a differential price for higher feed efficient calves by cattle feeders. The non-market interventions can be the form of a cost underwriting scheme. In paper 3, a number of the supply chain considerations are addressed. A stylized industry model that accounts for different adoption behaviors and production segments is developed.

Further, the potential environmental benefits of improved feed efficiency have been noted (Nkrumah et al. 2006). In the context of the theoretical model presented in section 1.4, the bull's underlying genetic attributes, $x(g)'s$ may affect the environmental performance of its offspring. Assuming that these environmental benefits are attainable (per animal basis), breeding feed efficient cattle produces a positive externality (reductions in methane emissions) that accrues to society. From a private perspective, cow-calf producers may be able to trade these reductions on carbon markets (such as the Alberta Offset Credit System) for additional revenue. This implies extending equation 5 to account for this potential revenue effect. It cannot however, be simply assumed that these producers would respond to these additional incentives. As feed efficiency improves, feed intake per cow reduces and stocking rates may in fact increase. Also stocking rates differ across agroecological zones due to differences in climatic factors and forage yields[8]. This implies that although emissions per head may be reduced, changes in overall emissions are indeterminate (increase/decrease/stay the same). The spatial differences in climatic effects within one province also imply the incentives for different cow-calf producers may vary depending on their location. Paper three addresses the combination of cow-calf producer decision making linked to environmental outcomes, the opportunity to change herd feed efficiency through selective breeding and the impact of carbon offset markets. Figure 1.9 is a summary of key aspects of the three papers that make-up this dissertation.

1.8 Organization of Thesis

Chapter 2 addresses cow-calf producer preference for genomic information on feed efficiency in their bull purchase decisions. The assessment of the supply chain issues identified and their impact on decision making is presented in Chapter 3. In Chapter 4, the environmental impact of the selection for feed efficient cattle is examined. This analysis is done within the context of cow-calf producer participation in the carbon offset scheme in Alberta. In the final chapter of this dissertation (Chapter 5), a summary of the results, implications, limitations and suggested directions for future research are presented.

[8] Equation 1 and 2 can also be adjusted to account for different (spatial) weather effects.

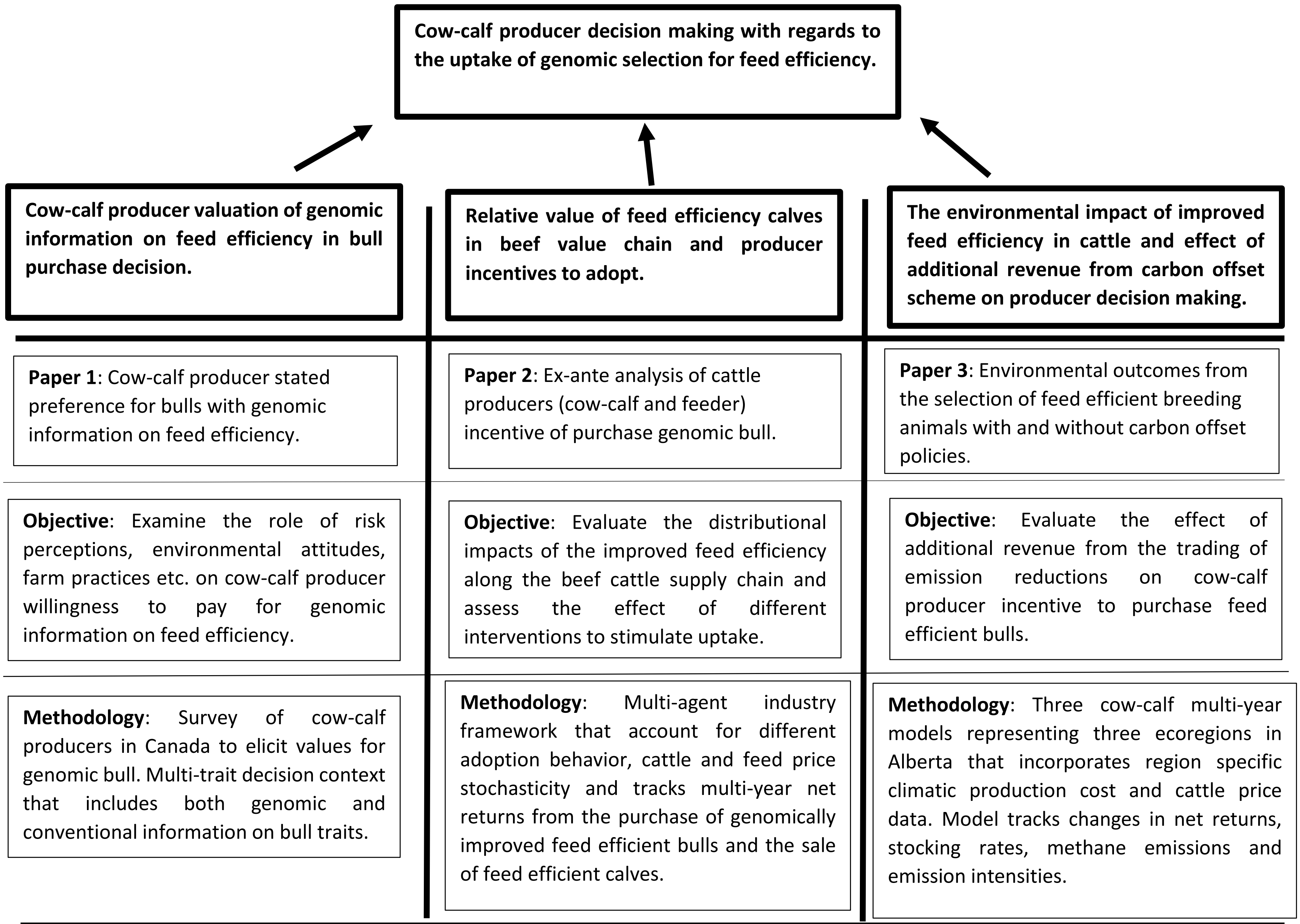

Figure 1.9: Overview of conceptual framework and research objectives

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Chapter 2 : Cow-Calf Producer Willingness to Pay for Genomic Information on Feed Efficiency

2.1 Introduction

Cow-calf producers face a complex decision in their choice of a bull to purchase for breeding as the attributes inherited from the bull by its progeny impact directly on both productivity and profitability. The vertical interdependencies along the beef cattle supply chain ensure that the impacts of this decision extend to other segments of the supply chain i.e. backgrounders and feedlot operators. The potentially important implications of this decision notwithstanding, the actual productivity of the bull for different traits as determined by its genetic make-up and the degree to which these genes can be expressed, is uncertain at the time of purchase.

To reduce this uncertainty, multiple sources of information on a bull's traits and performance are provided by bull sellers to cow-calf producers. These include the bull's own performance information, otherwise referred to as simple performance measures (SPMs), expected progeny differences[9] (EPDs), relatively new DNA profile information and hybrid measures such as the combinations of EPDs and DNA information [10](Dhuyvetter et al., 1996; Vanek et al., 2008; Vestal et al., 2013). It is not uncommon for two bulls to differ in the level of a given trait and for each bull, in the level of the trait according to different sources of information.

Further, heterogeneity in cow-calf producer preferences can also impact their valuation of bull traits. These producers may have different valuations for the same bull based on differences in their understanding of the information provided, production goals, and farm practices. Furthermore, the potential uncertainties and lack of familiarity with newer breeding tools such as

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[9] A statistical measure of the future performance of a bull.
[10] So-called genomically enhanced EPDs

genomics implies that cow-calf producer risk perceptions may have an important role in their preferences for specific kinds of breeding tools.

While the preferences for bull traits by livestock producers are well-known, little has been done to evaluate cow-calf producer preferences for feed efficiency or DNA related information in bull purchase decisions. More importantly, the role of cow-calf producer heterogeneity in the preferences for genetic information has not been addressed. With the additional genomic information, these producers now have to interpret information from traditional breeding values in addition to genomic breeding values within the context of their own idiosyncratic characteristics. This makes the issue of heterogeneity in preferences is important.The objective of this chapter is to examine preferences for genomic information on feed efficiency by cow-calf producers in Canada. The specific objectives include:

1. Develop a conceptual framework that accounts for uncertainty in the accuracy of genomic information, multiple informational traits and producer heterogeneity to analyze cow-calf producers' preferences for genomic information in their bull purchase decision.
2. Evaluate the role of factors such as risk perceptions, familiarity with genomics and calf retention practices on producer willingness to pay (WTP) for genomic information on feed efficiency.

2.2 Contribution of Study

Recent advances in agricultural biotechnology especially in the area of production-based DNA innovations hold significant promise for livestock production. Cow-calf producers are the primary agents for the diffusion of these innovations in beef cattle production. In this regard, understanding the preferences of producers is important as the decision to adopt or not determines whether any potential benefits are obtained. Most of the existing literature on cattle producer preferences for bull traits focus on conventional sources of information and output traits (Walburger, 2002; Dhuyvetter et al., 1996; Chvosta et al., 2001). The use of DNA breeding technologies such as genomic selection and the direct selection for feed efficiency is relatively new in beef cattle production. By evaluating cow-calf producers' preferences for feed efficiency in their bull purchase decision, this paper extends the literature on cattle producer valuation of bull traits. Further, by considering the effect of different sources of heterogeneity in preferences, this paper provides insights into the effect of different factors that might influence the rate of uptake by cow-calf producers.

The rest of the paper is organized as follows; section 2.4 is a discussion of the relevant literature. The conceptual framework is presented in section 2.5. The empirical framework and data sources are described in sections 2.6 and 2.7 respectively. The results of the empirical analysis are reported in section 2.8. The discussion of results is presented in section 2.9. Section 2.10 concludes the paper.

2.3 Literature Review

The literature review presented in this section provides an overview of livestock producer valuation of different traits in their seed stock purchase decisions. Consistent with the focus of this study, most of the studies reviewed relate to cattle producer valuation of bull traits. The section ends a summary of key outcomes of previous studies and contributions of the present study.

2.3.1 Livestock Producer Valuation of Breeding Stock

Numerous studies have evaluated livestock producer preferences for different production traits. These studies can be broadly classified into two based on methodology i.e. revealed or stated preference methods. Revealed preference approaches such as hedonic price models have been used to estimate implicit values for bull traits by cattle producers (Dhuyvetter et al., 1996; Chvosta et al., 2001; Walburger, 2002; Jones et al., 2008; Vanek et al., 2008; McDonald et al., 2010; Vestal et al., 2013). The empirical application of these models typically involve the regression of the price of a bull on selected traits that capture actual or expected performance or both (Dhuyvetter et al., 1996; Turner et al., 2004; Chvosta et al., 2001; Holt et al., 2004). The implicit value of any given trait is its coefficient in the hedonic price function (Ladd and Martin, 1976)

Walburger (2002) derived implicit values for consumption, production and reproductive traits for bull buyers (breeders) in Alberta. Birthweight, sale weight, average daily gain (ADG), scrotal size and ultrasound measures such as back fat and ribeye were considered. Highly heritable traits such as scrotal circumference associated with other reproductive traits had positive significant marginal values. Breeders tended to prefer bulls with wider scrotal circumference and would pay \$62.34-216.71 for a unit centimeter increment. Less desirable traits such as birth weight[11] were discounted by buyers. A major weakness of Walburger (2002) study was the failure to directly account for the productivity of a bull's future progeny. Other studies account for future performance through the inclusion of expected progeny differences (EPD). Expected progeny differences are estimates of the performance of future progeny of a bull for various traits by combining information from an animal's own performance and that of its relatives (Dhuyvetter et al., 1996; Chvosta et al., 2001).

Dhuyvetter et al. (1996) estimated a hedonic price model for 1,700 bulls comprising 7 breeds of cattle. Bulls' physical and genetic characteristics, performance attributes and marketing factors were considered. Specifically, attributes such as breed, color, bull's own birth weight EPD and a binary variable denoting whether or not a particular bull was pictured in the sale catalog were included in the hedonic regression model. By incurring the extra cost of featuring bulls in catalogs,

[11] Associated with calving difficulties

sellers were deemed to be providing signals about the quality of the bull. The study reported varying effects of performance and physical attributes on bull prices across the different breeds. For example, birthweight EPD was found to be a significant determinant of prices for 3 out of the 7 breeds and ranged from a discount of 4.4 to 4.6% for each increase in EPD. Bulls featured in catalogs commanded premiums of up to 28% as compared to those without pictures. Chvosta et al. (2001), extended the model used by Dhuyvetter et al. (1996) to include output and input price expectation. These were captured as futures contract prices for feeder cattle and corn for the former and latter respectively. Chvosta et al. (2001) found that both EPDs and simple production measures significantly affected cow-calf producer valuation of bulls. These results were consistent across different cohorts of animals.

Despite the straightforward derivation of implicit values from hedonic models, a number of weaknesses persist. One of the main concerns is collinearity between bull traits (Vanek et al., 2008; McDonald et al., 2010; Vestal et al., 2013). To circumvent this, some studies (e.g. Vanek et al., 2008; McDonald et al., 2010) have defined composite traits. The interpretation of implicit values elicited for these transformed traits however tends to be complex. Further, the use of data pooling methods that combined both stated and revealed preference data has been suggested (Vestal et al., 2013). This is not applicable in the absence of well-defined markets or in instances where actual behavior is inherently difficult to observe. For example, implicit values for genomic information on feed efficiency cannot be estimated with hedonic price models because of the absence of actual bull purchase data related to the trait.

2.3.1 Stated Preference Approaches

In the absence of data on revealed preferences, stated preference methods can be used to evaluate livestock producer preferences. Within the stated preference literature, livestock valuation studies can be classified into: conjoint analysis (e.g. Sy et al., 1997; Harrison et al., 2004) and choice experiments (Olynk et al., 2012; Roessler et al., 2008; Scarpa et al., 2003; Tano et al., 2003 Birol et al., 2006; Ruto et al., 2008).

Conjoint analysis (CA) relies on individual judgment of products in the estimation of the marginal contribution of specific product characteristics to overall preference rating (Sy et al., 1997). Individuals express preferences through the ranking of alternative bundles. Sy et al., (1997) evaluated producer preferences for different cattle attributes using conjoint analysis approach. Preferences of breeders, cow-calf producers and feedlot operators for traits including: calving ease, weaning weight, conformation, feed efficiency and temperament, were evaluated. Respondents evaluated bulls and steers based on a preference scale. Additionally, producer profiles were interacted with attributes to derive group specific marginal values. For instance, while the average producer valued steer slaughter weight of 1400 Ibs at $0.24, relative marginal values for cow-calf and feedlot operators were -$0.035, and $0.044 respectively. Tano et al., (2003) assessed producer valuation of cattle in southern Burkina Faso using a conjoint analysis. The study reported higher preferences for bulls with high fertility, disease resistance and rapid weight gain.

A number of weaknesses have been identified with the use of CA as a preference elicitation mechanism. Louviere et al., (2010) noted that the CA approach is based on numerical response to factorial manipulation of factor levels and not necessarily preference behavior. Further, individuals in CA rank instead of choosing specific alternatives (Louviere, 1988). In contrast to conjoint analysis, a discrete choice experiment (CE) approach is more consistent with preference behavior as individuals choose specific alternatives amongst a number of options (Louviere et al., 2010; Louviere, 1988). This ensures consistency with random utility theory (Adamowicz et al., 1998). Further, the multiple attribute dimension of CE models enables the evaluation of trade-offs between attributes (Lusk et al., 2003). The use of CE models is however, not problem-free and has a number of weaknesses such as the sensitivity of outcomes to experimental design and cognitive difficulties linked to the complexity of the choice tasks presented to respondents[12] (Hanley, 2001).

Roessler et al. (2008) assessed hog producer preference for pig breeding values in Vietnam. Results indicated high valuation of both adaptive and performance traits in hog breeding decisions. Implicit values for increases in live weight, litter size, feed purchase requirements were VND[13] 1300, VND 3300 and VND 25,200 respectively. Scarpa et al. (2003a) contrasted the performance of stated and revealed preference methodologies in the estimation of values for cattle in Kenya. Unlike Tano et al. (2003), Scarpa et al. (2003a) considered breeds instead of specific traits. Estimated breed values compared well in both CE and hedonic price models. Ruto et al. (2008) reported values for genetic attributes of indigenous cattle in Kenya using a latent class model (LCM). Implicit value estimates were characterized by significant differences in the magnitudes and signs indicating substantial heterogeneity across the three segments identified.

2.3.2 Cattle Producer Valuation of Genetic Information

The literature on cattle producer valuation of genetic information has focused largely on the value of using genetic markers in the marketing of cattle or in selecting feeder cattle for placement in feedlots (DeVuyst et al., 2007; Lusk, 2007; Lambert, 2009; Thompson et al., 2014; Thompson et al., 2016). Most of these studies relate to genetic information on the leptin genotype (Lusk, 2007; DeVuyst et al., 2007; Lambert, 2009). Using data on 1,668 cattle in a feedlot, Lusk (2007) found that the value of genetic information on the leptin genotype was significantly higher in selection

[12] A number of measure are undertaken to address some of these potential pitfalls in this study

[13] [1USD=VND16,300]

(~$23) as compared to choosing the optimal days on feed (~$3/head for steers; $1/ head for heifers). Qualitatively, these results were similar to those reported in Lambert et al., (2009). These outcomes are also consistent with more recent studies (e.g. Thompson et al. 2014). In the case of Thompson et al. (2014) genetic information was in the form molecular breeding values (MBVs). Although the value of genetic information was positive ($1-13) it was lower than the cost of testing ($40/head). This suggests that cattle feeders may be less likely to pay the additional cost of acquiring genetic information. As noted by Thompson et al., (2014) genetic information may be more valuable in breeding and selection decisions as compared to sorting of feeder cattle or in the determination of days on feed. In cattle production, the bull purchase decision by cow-calf producers contributes significantly to the genetic make-up and performance of the herd. While WTP for different aspects of cow-calf production has been evaluated (Norwood et al., 2006; Schumacher et al., 2012; Pope et al., 2011), no previous studies have looked at cow-calf producer preference for genomic information on feed efficiency. Evidence from phenotypic assessment of feed efficiency indicate that producers undervalue the trait relative to its actual economic value (McDonald et al., 2010; Brimlow and Doyle, 2014). It has also been suggested that cow-calf producers place higher values on a bull's expected productivity as compared to its actual traits as the true value of a bull is the extent to which it is able to pass on desirable traits to its offspring (Jones et al., 2008). Vestal et al. (2013) examined cow-calf preferences for DNA marker information on output traits by cow-calf producers. The study found that preference for genetic information was generally weak amongst the sample of respondents. This study extends the existing the literature in several different respects. First, as shown in the literature review, little has been done to elicit cow-calf producer preferences for input traits such as feeding efficiency using stated preference methods. Second, the analysis of cattle producers' preferences for feed efficiency in the few cited cases have been limited to phenotypes. This is partly due to the fact that the direct selection for feed efficiency is relatively new in cattle breeding as breeders have historically focused on output traits. In this study, conventional (EPDs) and genomic information on feed efficiency are included in the analysis. This approach allows for the evaluation of cow-calf producer preferences for different sources of information on the same trait in their bull purchases. Preferences for output traits such as birthweight are also elicited. Third, this study also examines the role of different sources of heterogeneity- knowledge about genomics, risk perceptions and farm practices on cow-calf producer willingness to pay (WTP) for genomic information on feed efficiency.

2.4 Conceptual Framework

The conceptual framework developed to evaluate cow-calf producer preference for genomic information on feed efficiency is based on Kerr (1984)'s characterization of the beef producer's production function with respect to the incorporation of a genetic input. Koundouri et al. (2006)'s approach is used to account for heterogeneity in the utilization of the genetic input. The cow-calf producer's production function is defined as:

$$Y = f[(h(\alpha), x^G(I^G), x^N)] \qquad (1)$$

where $h(\alpha)$ is a measure of the efficiency with which a cow-calf producer uses genetic resources defined as a function of individual specific characteristics[14] α, x^G is the genetic input, x^N is the non-genetic input and I^G is information on the genetic input. It is assumed that the genetic input is sourced from the bull (Kerr, 1984). All else equal, for any two cow-calf producers with different α, say α_1 and α_2:

[14] Both observable and non-obsevable

$$f[(h(\alpha_1), x^G(I^G), x^N)] \neq f[(h(\alpha_2), x^G(I^G), x^N)] \qquad (2)$$

The *ith* producer's utility can be specified as:

$$U = U[pf(h(\alpha), x^G(I^G), x^N) - wx^N - rx^G(I^G)] \qquad (3)$$

Given, I^G, the actual realization of x^G and Y is unknown at the time of purchase. The price of weaned calves[15] which is the main source of revenue for cow-calf producers is denoted as p. The unit cost of the non-genetic input is w and r is the cost of the genetic input. The producer has information on the accuracy of I^G which can be considered as the prior probability of achieving different states of x^G. In the dichotomous case, it is assumed that x^G has two potential outcomes- x_H^G and x_L^G with probability ρ_H and ρ_L respectively. The two states x_L^G and x_H^G denote low and high performance respectively. It follows that:

$$[(h(\alpha), x_H^G(I^G), x^N)] > [(h(\alpha), x_L^G(I^G), x^N)] \qquad (4)$$

The cow-calf producer's action set [a_i] comprises the option to purchase the genetic input with genetic information [$a = 1$] or otherwise [$a = 0$]. The expected utility from purchasing the genetic input with the additional information ($a = 1$) is given as:

$$\begin{aligned} EU^1 = {} & \rho_H U[pf(h(\alpha), x_H^G(I^G), x^N) - wx^N - rx^G(I^G)] \\ & + \rho_L U[pf(h(\alpha), x_L^G(I^G), x^N) - wx^N - rx^G(I^G)] \end{aligned} \qquad (5)$$

[15] The inclusion of the price of calves also links the analysis of cow-calf producers' private valuation of genomic bulls to the supply chain analysis conducted in Chapter 3.

For simplicity, assume that $\rho_L = (1-\rho_H)$. Alternatively, the expected utility at some probability ρ_0 from the decision to purchase the genetic input with conventional information (I^c) is given as:

$$EU^0 = \rho_0 U[pf(h(\alpha), x^G(I^c), x^N) - wx^N - rx^G] \qquad (6)$$

Consistent with the value of information theory (Babcock, 1995), the value of genetic information v_i is the difference between EU^1 and EU^0 with the payment for the additional information being optimal for all $EU^1 > EU^0$. In the context of equation 5, the value of information depends on the level of accuracy of the information provided (ρ), costs (r), the price of calves (p) and characteristics of the cow-calf producer $h(\alpha_i)$. In this framework, factors such as heritability of the trait is assumed to influence the accuracy of the genetic input.

Under certainty and assuming perfect competition, the value of the genetic input can be derived as a marginal value in equation 3 (Kerr, 1984). Under the assumption that the information input is an additional attribute, a hedonic model approach can be used (e.g. Kerr, 1984). Under uncertainty, the value of information can be examined from a number of perspectives. For example, the expected value of information can be considered as the difference in certainty equivalent (CE) with and without the additional information [16](Lambert et al., 2009). Further, the expected value of information can also be referred to as the demand value or the Willingness to pay (WTP) value (Lawrence, 1999, p.90).

The role of cow-calf producer heterogeneity is particularly important in a multi-trait context with multiple sources of information about bull traits. A cow-calf producer's utility from the genetic input composed of multi-traits can be specified as:

[16] CE is defined as the monetary outcome that yield the same utility as expected utility over different distributions of outcomes.

$$U(x^G) = U[(x_i^g(I_i^g), x_j^g(I_j^g), \ldots, x_k^g(I_k^g), h(\alpha_i), p, \rho)] \qquad (7)$$

where $x_i^g, \ldots, x_k^g$ are the constituent traits for example, feed efficiency, birth weight etc. and, $I_i^g, \ldots, I_k^g$ represent the corresponding information on the traits. In the context of the cow-calf producer's breeding decision three sources of heterogeneity are identifiable. First, preferences may vary by trait, for example, weaning weight versus feed efficiency. Additionally, for any given trait there is heterogeneity in the valuation of the trait based on cow-calf producer and farm characteristics. Cow-calf producers may also differ in their valuation of different sources of information on the same trait i.e. genetic versus conventional. These sources of heterogeneity are categorized as trait, individual and technology respectively. Figure 2.4 is an illustration of the different sources of heterogeneity and how they relate to the cow-calf producer's breeding decision.

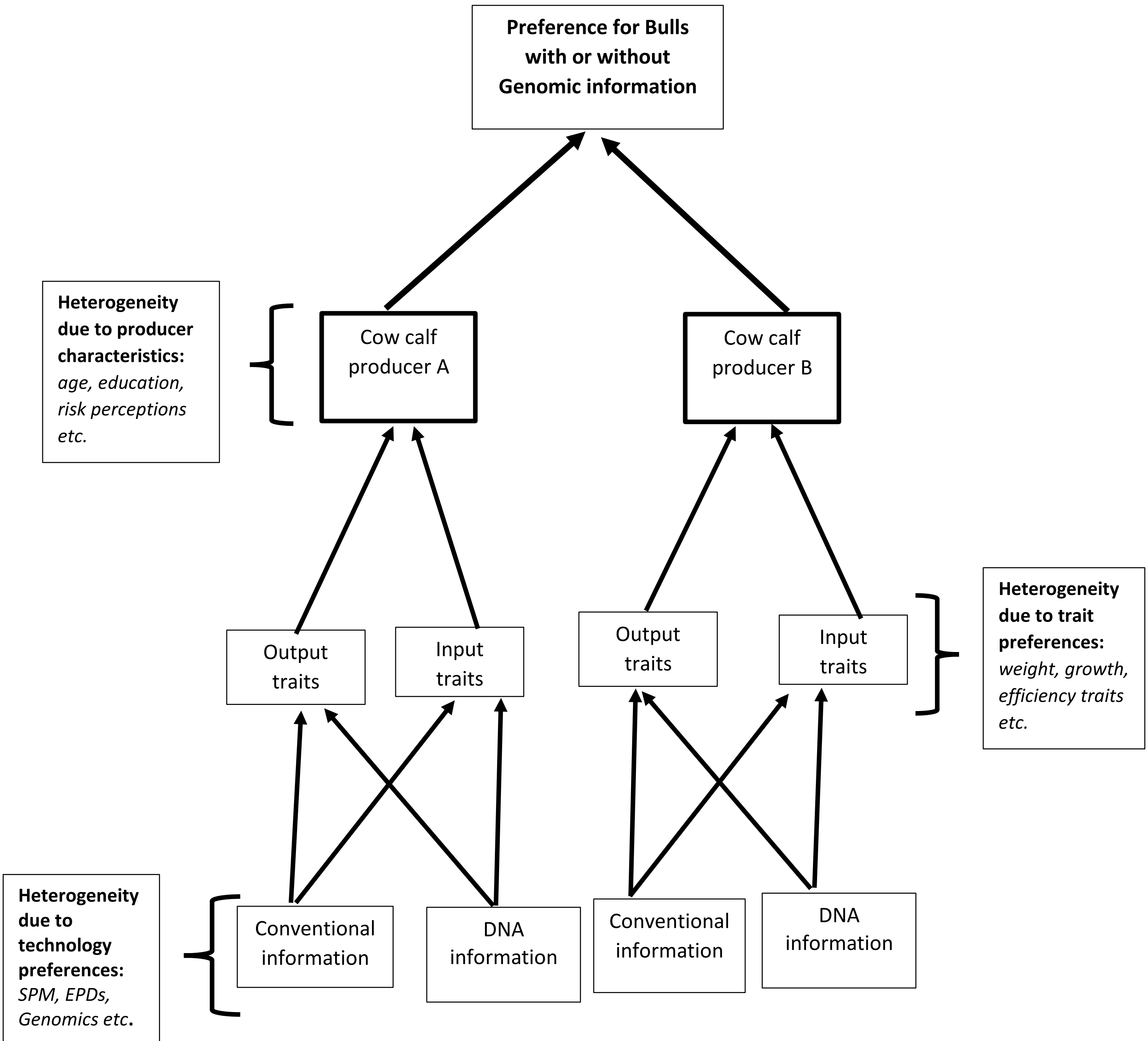

Figure 2.1: Schematic representation of theoretical model

2.4.1 Role of Producer Heterogeneity in the Uptake of New Technologies

Given the potentially important role of cow-calf producer heterogeneity in the uptake of genomic information on feed efficiency identified in the conceptual model, on overview of the role of different producer characteristics in farmer adoption decision making is discussed in this section.

The decision to adopt a particular innovation is influenced by a number of economic and non-economic factors. The effect of these factors differ on the basis industry, product and production characteristics (Ward et al., 2008). A survey of the expansive literature on farmer decision making suggests that factors such as farm size, human capital, risk perceptions and farm income also impact on producer behavior. A number of these factors are interrelated in terms of their impact on decision making. Notable amongst them is the relationship between income (for example) and farm size. Large farms tend to be high revenue operations due to relatively higher sales and scale economies. These larger operations are management intensive requiring significant proportions of producers' time. This links farm size to off-farm employment and income. Evidence from previous studies suggest a negative relationship between off-farm employment and farm size (McNamara and Weiss, 2001). Further, the propensity to adopt is dependent on the requisite level of management of the relevant technology. Fernandez-Comejo (2007) notes that smaller size operators are more likely to adopt management saving technologies as these optimize their on-farm time allocation. Empirical analysis of herbicide tolerant (HT) soybean adoption support this notion (Fernandez-Comejo et al., 2007).

Human capital often proxied by producers' level of education has been studied extensively in the adoption literature (Soule et al., 2002; Khanna, 2001; Wu and Babcock, 1998; Dorfman, 1996: Fuglie and Bosch, 1995). Education is often considered simultaneously with age. Higher education is assumed to improve one's perceptiveness of the benefits of innovation, whilst age influences producers planning horizon. Younger more educated farmers tend to be more likely to adopt innovative practices (Feder and Umali, 1993). This is however, technology specific. For example, as compared to conventional breeding, genomic breeding can increase the rate of improvements in traits at a faster rate. All else equal, this increased productivity may be perceived as reduction in the planning horizon within which desired outputs of bulls are attained. This can make the technology potentially appealing to older farmers generally regarded as having a shorter planning horizon and being less likely to adopt such technologies.

2.5.1.1 Risk Perceptions and Producer Decision Making

As production function altering factors, there is a degree of uncertainty related to the impact of new technologies ex-ante (McDonald et al., 2010). Considering that the bull purchase decision is an investment decision with uncertain outcomes, producer risk perceptions are an important consideration. Agricultural producers are generally regarded as risk averse although heterogeneity in risk perceptions is not uncommon (Rat-Aspert and Fourichon, 2010). Further, as shown in the conceptual model, cattle breeding is characterized by an inherent degree of uncertainty. This is dependent on heritability of the relevant trait and accuracy of breeding technology. Improvements in these traits can reduce yield uncertainty and attenuate production risks. This implies that the trade-off between perceived inherent risk of the breeding technology and its production risk reducing capabilities is a key driver of WTP.

Elliot et al. (2013) examined the determinants of beef reproductive technology adoption amongst a sample of cow-calf producers in Missouri. Significant determinants of the adoption of artificial insemination and estrus synchronization included operation type, producer risk and management practices. Pope et al. (2001) evaluated the determinants of cow-calf producer retained management decisions. Perceptions about price risk significantly influenced calf retention- producer with lower perceptions of price risk were found to be more likely to market calves at heavier weights.

Other studies (e.g. Pope et al., 2011) have use these multi-item approaches. Pope et al. (2011) evaluated the impact of cow-calf producer risk preferences on retained ownership. Producer risk preferences were defined as scores from the weighted combination of responses to a set of risk related questions. Risk averse producers were found to be more likely to market calves at weaning; implying a lower tendency to engage in value added practices given the risk involved.

Although risk aversion generally reduces the propensity of farmers to adopt different production practices, there is evidence to suggest that that the reverse may hold in some instances (Tsur et al., 1990). For example, when risk aversion results in a higher valuation of future returns, risk averse producers may exhibit greater propensity to adopt new technologies with the potential to reduce future risk (Feder and Umali, 1993).

Kim et al. (2005) examined the determinants of adoption of best management practices (BMPs) amongst by cow-calf producers in Lousiana. Risk preferences were elicited using the so-called risk attitude measurement instruments (RAMI) (Fausti and Gillespie, 2006). Specifically, producers compared their likelihood of making investment decision to their peers. In general, risk was negatively related to the adoption of capital intensive BMPs with uncertain outcomes. This implied that producers discounted the productivity enhancing impacts of these BMPs given their costs. A major weakness of the approach in the Kim et al. (2005) study was the use of a single construct to measure risk preferences. Pennings and Gracia (2001) noted that multi-item approaches were ideal for the effective elicitation of risk preferences.

Two main approaches to the measurement of risk perceptions have been identified in the extant literature. These are namely the elicitation of responses to Likert type risk scales in surveys (e.g. Goodwin and Schroeder, 1994) and the use of lotteries (e.g. Pennings and Smidts, 2003; Lusk and Coble, 2005). The latter approach is based on the expected utility theory. A respondent is presented with the choice between two outcomes- a certain outcome and a lottery. The lottery typically has two payoffs, each with an attached probability. The respondent is presented with multiple choice situations. In each scenario the level of the certain outcome is varied up the point where the individual is indifferent between the pay-off from the certain outcome and the lottery (Pennings and Smidts 2003). The certainty equivalents are mapped onto a preference ordering with a utility function and the individual's risk attitude measure is estimated as a coefficient of the utility function (Pennings and Smidts 2003; Franken et al. 2014). In the survey approach, individuals are presented with a number of tasks including self-assessment and hypothetical gambles and asked to report their risk preferences over a given range. The risk scenarios can be defined to include different dimensions of risk and decision making contexts. Psychometric scales for risk preference elicitation are relatively easy to implement and adaptable to different risk contexts. This notwithstanding, questions about its theoretical consistency have been raised (Lusk and Coble, 2005). In a study of hog producers, Pennings and Smidts (2000) found that preferences elicited with psychometric scales were better predictors of intent whilst the lottery approach tended to perform better at predicting actual behaviour. Risk preferences elicited with these two approaches were however positively correlated. In contrast, the findings of Dohmen et al. (2001) and Franken et al. (2014) suggest that scale-type measures were more effective. In fact, Dohmen et al. (2001) found that risk preferences measured with psychometric scales represented a reliable predictor of actual behavior.

2.5.1.2 Effect of Management Practices

Management practices undertaken by producers can also impact on their valuation of new technologies. One such practice is retained ownership of cattle. Cow-calf producers typically have the option of maintaining ownership of their calves beyond the conventional sale point (at weaning). Figure 2.1 (Feuz and Wagner, 2012) illustrates the ownership and marketing possibilities available to the cow-calf producer. Without a well-defined market for specific traits, cattle may only benefit from calves with higher merit for these traits through retained ownership. This suggests that the producers in the practice of retaining calves beyond weaning may have higher valuation for improvements in these traits as compared to others.

Retaining ownership of calves through later stages of production has been suggested as a means to addressing perennial low and volatile returns in cow-calf production (Pope et al., 2011, Franken et al., 2010). This increased marketing flexibility allows producers to capture a greater share of management inputs such as genetic improvement (Feuz and Wagner, 2012; White et al., 2007). Lawrence (2002) noted that retained ownership facilitates genetic improvement by allowing the flow of direct information feedback to the genetic decision maker. Carlberg and Brown (2001) analyzed the net returns under six possible alternative retained ownership practices amongst cow-calf producers in Saskatchewan over a 20- year period. Retaining cattle till finishing yielded highest net return i.e. $24/head. In a comparison of 22 calf crops (1983-2004), Lawrence (2002) found that calves retained through finishing yielded the highest net returns ($57/head) when compared to calves sold at weaning (-$2/head), backgrounding ($2/head) or after backgrounding and finishing ($48/head). These possibilities for increased net returns notwithstanding, calf retention may expose the cow-calf producer to price and non-price risks (Schroeder and Featherstone, 1990).

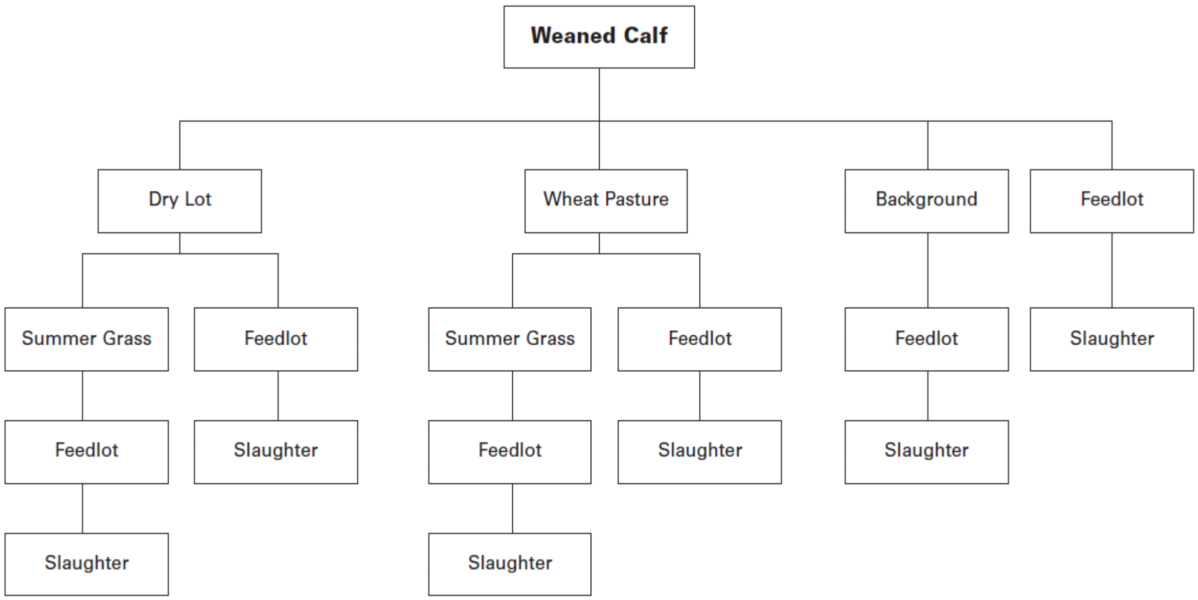

Figure 2.2: Retained Ownership Alternatives in Beef Cattle (Source: Feuz and Wagner, 2012)

2.5.1.3 The Role of Environmental Attitudes

In addition to profit maximizing goals, producers may be motivated by social and environmental goals. Bond et al. (2011) observed that public concerns as well as attempts at gaining wider consumer acceptance can influence a number of production decisions. For example, cow-calf producers may raise cattle using more environmentally friendly production practices if they perceive that a significant segment of consumers attached higher values to cattle with a lower carbon footprint or if there are public concerns about greenhouse gas (GHG) emissions from beef production systems. This is in addition to the effect of a producer's own environmental attitudes and awareness.

Two opposing pathways to reducing the environmental impact of agricultural production have been identified. These are namely the "agroecological" and technology based intensive farming approaches (Fairweather and Campbell, 2003). A hybrid approach, the so-called sustainable intensification (Tillman et al., 2011) unifies aspects of both intensive and agroecological concepts. Genomic selection for feed efficient cattle by cow-calf producers can be categorized under the latter approach.

In general, the importance of considering the environmental attitudes of producers in their adoption decisions is underscored by the following: 1.) the increased awareness by consumers of the environmental attributes of agricultural products; 2.) attitudes and worldviews are significantly more mutable than other psychological variables; 3.) producer decision making regarding environmentally sustainable practices often entails trade-offs with competing economic objectives (Gillespie et al., 2007); and 4.) understanding the relationship between attitudes and behaviour is necessary for inducing behavior modification and the prediction of behavioural change (McEachern and Willock, 2004).

A number of psychological models have been proposed in the social psychology literature to explain the causal linkage between attitudes and behavior. These include the theory of planned behavior (Ajzen, 1991), the value belief norm theory (Stern, 2000) etc. Amongst these theories, the theory of planned behavior (TPB) is perhaps the most prevalent.

The TPB (Figure 2.2) centralizes the role of intentions and perceived behavioral control as direct determinates of behaviour (Ajzen, 1991). More generally, beliefs about the expectations of others (normative beliefs), beliefs regarding the likely consequences of behavior (behavioral beliefs) and the beliefs about the presence of control factors (control beliefs) jointly determine behavior. Stated this way, an individual may have a higher propensity to engage in particular behavior if he is: favorable disposed to it, the behavior is perceived as socially acceptable and has a lower attendant cost (Bamberg, 2003). These beliefs tend to have a degree of context specificity. As noted by

Bamberg (2003), general attitudes such as pro-environmental attitudes indirectly impact on intentions and behavior through their effect on behavioral beliefs, norms and control beliefs. Pro-environmental attitudes are however latent. Consequently, a number of scales have been developed measure these attitudes. An endorsement of a particular scale is assumed to indicate a given environmental orientation.

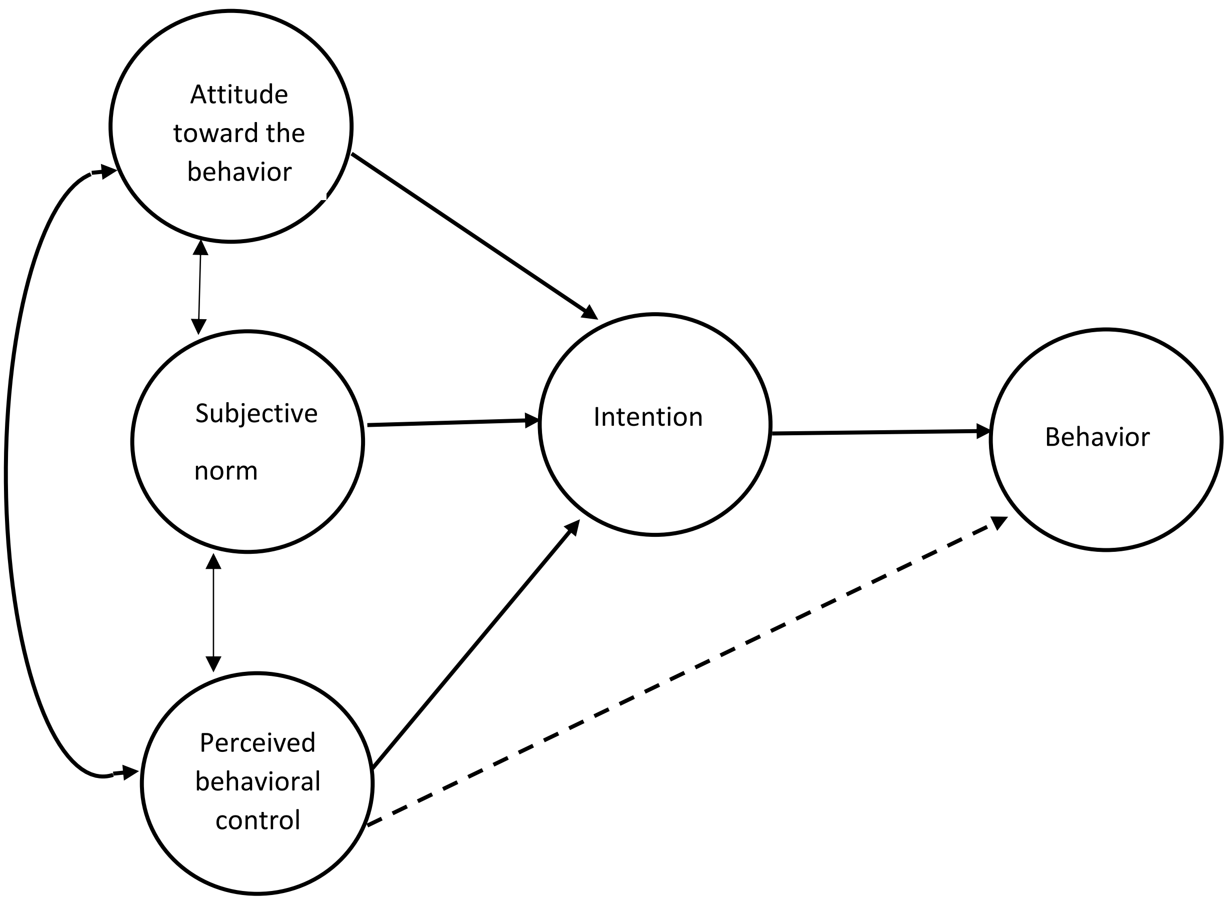

Figure 2.3: The Theory of Planned Behavior (Ajzen, 1991)

Little is known about the effect of environmental attitudes on WTP for breeding technologies by cow-calf producers in Canada. Previous studies of the environmental attitudes of Canadian farmers, found higher attitudes amongst younger and more educated farmers (Filson, 1993). Understanding environmental attitudes and preferences is crucial for the accurate prediction of technology adoption in instances where these attitudes are relevant (Bond et al., 2011).

The New Ecological Paradigm (NEP) scale (Dunlap, 2000) and the New Human Interdependence Paradigm (Corrallo-Verdugo et al., 2008) represent popular[17] multi-item scale instruments used for measuring environmental attitudes. The NEP scale comprises 15 statements each rated on the basis of a 5-point Likert type scale ranging from (1) "strongly disagree" to (5) "strongly" agree. The current 15-item scale represents a revision of the initial 12-item scale developed by Dunlap and Van Liere (1978). The NEP scale comprises subthemes related to an ecological world view: (i) the limits of growth; (ii) the possibility of an ecocrisis; (iii) fragility of nature's balance; (iv) anti-anthropocentrism; and (v) rejection of human exemption from biophysical limits (Dunlap, 2000). As evident from the different components, the NEP is pro-ecocentric-reinforces the notion that nature should be conserved for its intrinsic value. In contrast to the NEP, the NHIP scale (Corral-Verdugo et al., 2008) addresses the interdependence of humans' use of nature (anthropogenic view) and nature's intrinsic value (ecocentric view). In other words, the NHIP construct assumes that human development and conservation of nature are not mutually exclusive. The five Likert–type NHIP scale measures beliefs about the usefulness of nature and the intergenerational effects of the current utilization of natural endowments.

While an endorsement of these environmental paradigms is important, perhaps the more relevant question is the degree to which these environmental values capture disposition towards pro-environmental behaviour (Corral-Verdugo et al., 2008). Although inconclusive (Vogel, 1996),

[17] The former more so than the latter.

available evidence suggests that higher environmental values (or attitudes) are linked to: the acceptance of climate change policy (Nilsson et al., 2004); water conservation practices (Corral-Verdugo et al., 2008) etc.

A number of studies have addressed the relationship between environmental attitudes and WTP in environmental decision making. Majority of these studies evaluate the effect of environmental attitudes on non-use values for endangered species and other resources (Aldrich et al., 2007; Meyerhoff, 2006; Kotchen and Reiling, 2000; Cooper et al., 2004).

Approaches to modelling attitudinal variables include: cluster analysis (CA), including attitude scores in latent class models (LCM) and more elaborate methods such as integrated choice and latent variable (ICLV) models (Aldrich et al., 2007; Hess and Beharry-Borg 2011; Morey et al. 2008). Although, the deterministic nature of the cluster approach has been criticized (Thacher et al., 2005; Morey et al. 2008), other studies have found the approach to be comparably to the LCM. Aldrich et al., (2007) observed that results from two approaches were comparable in an assessment of the effect of environmental attitudes on non-use values for the protection of endangered bird species. Another relevant attitudinal variable is environmental risk perception. An individual's environmental risk perception is linked to his preferences for specific risk management strategies (Pootinga et al., 2002). These perceptions are associated with views on nature described by the so called "myths of nature": nature benign, nature ephemeral, nature tolerant, and nature capricious (Steg and Sievers 2000). The myths of nature are linked to the following worldviews: i.) egalitarianism (nature ephemeral); ii.) hierarchism (nature tolerant); iii.) individualism (nature benign); and iv.) fatalism (nature capricious) (Hoogstra-Klein et al., 2012).

As discussed in Steg and Sievers (2000), individuals with nature benign views hold the belief that nature is resilient. These individuals have lower risk perceptions about the environment.

Additionally, individuals in this category have a strong preference for the use of new technologies to solve environmental problems. In contrast, the nature ephemeral myth is characterised by high environmental concerns based on the notion that environmental resources are highly depleted. Proponents of this viewpoint ascribe to behavioral change as the means to conserve natural resources. Between these two are the fatalist and nature tolerant myths. Individuals in the latter category have an intermediate view of environmental risk and believe that nature is robust up to a certain threshold. The fatalist view is less systematic and considers natural outcomes as random. This viewpoint prefers stringent control mechanism (Steg and Sievers, 2000). Figure 2.3 is a summary of the myths, the underlying worldviews and preferences for the different environmental risk management strategies.

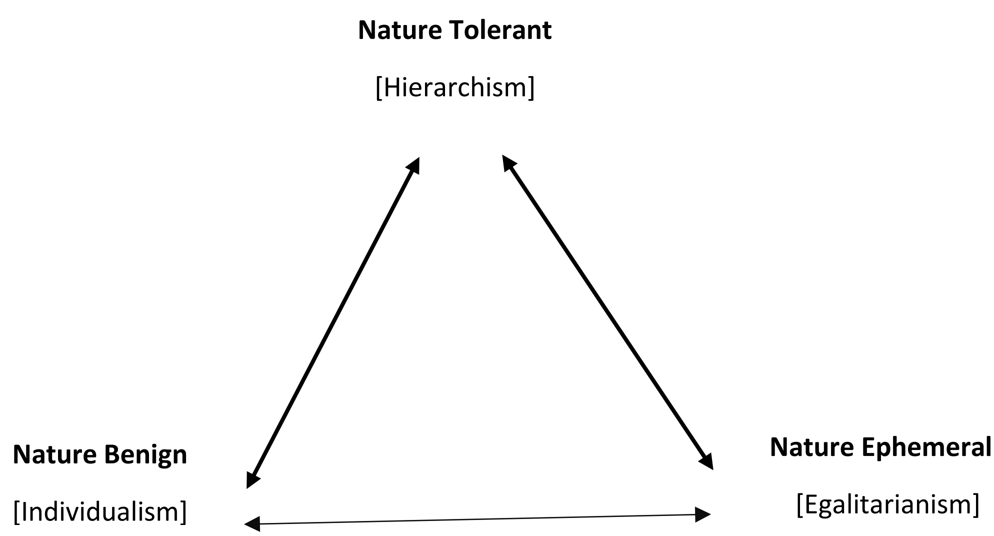

Figure 2.4: Myths of Nature and Preferences for Solution Strategies
(Adapted from Pootinga et al. 2002)

A number of studies have applied this framework to examine environmental risk concerns in different contexts (Hoogstra-Klien et al., 2012; Steg and Sievers, 2000; Pootinga et al., 2002). Matin et al. (2012) found an inverse relationship between egalitarianism (nature ephemeral) and support for the use of nanotechnology in food package amongst a sample of Canadian respondents. In the study of car use in Holland, Steg and Sievers (2000) also found that nature ephemeral beliefs were associated with higher problem awareness and stronger preference for environmental policy measures as compared with nature benign beliefs. Further, Pootinga et al. (2002) addressed the linkage between nature myths and environmental risk management strategies amongst a sample of Dutch respondents. The results indicated that respondents with nature benign beliefs preferred market orient strategies as compared to government regulated approaches (as was in the case of nature ephemeral views). In the present study, environment risk perceptions are addressed in the context of cow-calf producer stated preference for the use of genomic information in the selection of feed efficient cattle. An overview of the empirical approach used in the present analysis is discussed below.

2.5 Empirical Framework

Based on the conceptual framework discussed in section 2.4 and assuming a multi-attribute preference space (Lancaster 1966, Scarpa et al. 2003a; Scarpa et al. 2003b; Roessler et al. 2008), cow-calf producers preferences for genomic information on feed efficiency is assessed in the context of the bull purchase decision. The bull is the genetic input (x^G in the conceptual model) and comprises three traits i.e. feed efficiency, weaning weight and birth weight. The three traits denote the $x_i^g,...,x_k^g$ in the conceptual model. Each of these traits are represented by conventional estimates of expected performance ($I_i^c,...,I_k^c$) as the actual performance of the bull is not known with certainty at the time of purchase. It is implicitly assumed that informational traits are significantly correlated with traits they measure (Thompson et al., 2016). In this study, conventional traits are measured as expected progeny differences (EPDs). This represents the case of the absence of genetic information in the conceptual model. Additionally, two feed efficiency traits are included- genomic information on feed efficiency and accuracy of feed efficiency EPD. The latter represents the reliability associated with the conventional trait while the former is the new genetic input (I^g).The ith cow-calf producer's random utility U_{iq} from the qth bull given a set of S bull alternatives is given as:

$$U_{iq} = V_{iq} + \varepsilon_{iq}, \quad \forall_q \in S \qquad (8)$$

where:

U_{iq} = random utility of the qth bull for individual i ;

V_{iq} = deterministic component of utility;

ε_{iq} =random component of utility.

V_{iq} the deterministic component of utility is defined as:

$$V_{iq} = f(X_{iq}; \beta) \qquad (9)$$

where β is the parameter vector and X_{iq} is the traits of qth bull and the characteristics of the ith producer. A utility maximizing producer facing the choice of any two bulls q and z would choose q over z if $U_{iq} \geq U_{iz}$, the probability of choosing of the producer's choice is given as:

$$\Pr(q) = (U_{iq} \geq U_{iz} \quad \forall_z) \qquad (10)$$

In the random parameter logit (RPL) specification β is assumed to vary over all i respondents i.e. β_i with density $f(\beta_i / \theta)$; θ denotes the parameters of the distribution (Train, 1998). If errors ε_{iq} are assumed to be extreme value, the probability conditional on the i cow-calf producer's choosing the q bull given the S bull choices (Hensher and Greene, 2001):

$$L_{iq} = \frac{e^{\beta_i^{'} X_{iq}}}{\sum_S e^{\beta_i^{'} X_{iq}}} \qquad (11)$$

In relation to the meaning of β_i , Train (1999) noted that :

Agent-specific coefficients β_i *represent that agent's tastes. The researcher does not observe, and cannot estimate, the coefficients for each agent but knows that the coefficients vary in the population, with density f. For example, the coefficients may be distributed normally in the population, with mean* θ_1 *and variance* θ_2 *. In this case, the goal is to estimate the mean and variance of tastes in the population.*

In contrast to the RPL, the standard multinomial logit (MNL) model assumes homogeneity in preferences i.e. β is fixed across the sample of respondents. In this paper, two specifications of the random parameter logit model are estimated. First, the base model which includes only bull attributes. The second specification included the interaction of individual specific characteristics with bull traits. This is to allow for preferences to vary across individuals. As a comparison, standard MNL models with both bull attributes and individual interaction terms are also reported. The relevant conditional indirect utility expressions are:

$$U_{iq} = \beta_1 \mathrm{P}_{Bull} + \beta_2 WW + \beta_3 FE_g + \beta_4 FE_{con} + \beta_5 AccFE_{con} + \beta_5 BW + \varepsilon_{iq} \qquad (12)$$

$$\begin{aligned} U_{iq} = {} & \beta_1 \mathrm{P}_{Bull} + (\beta_2 + B_3 * indiv) * WW + (\beta_4 + \beta_5 * indiv) * FE_g + (\beta_6 + B_7 * indiv) * FE_{con} \\ & + (\beta_8 + \beta_9 * indiv) * AccFE_{con} + (\beta_{10} + \beta_{11} * indiv) * BW + \varepsilon_{iq} \end{aligned} \qquad (13)$$

where P_{Bull} is the price of the bull, WW is weaning weight EPD, BW is birth weight EPD, FE_{con} is the feed efficiency EPD, FE_g is genomic information on feed efficiency, $AccFE_{con}$ is the accuracy of the feed efficiency EPD, $indiv$ is individual producer characteristics and ε_{iq} is the error term. The individual producer characteristics include socio-demographic characteristics (age, gender, education, income), farm characteristics (herd size, number of best management practices, use of artificial insemination) and other characteristics (knowledge about science and technology). In the RPL estimation, the random coefficients of the bull attributes: WW, BW, FE_g, FE_{con}, $AccFE_{con}$ and FE_g follow a normal distribution. The price of the bull is assumed fixed. The mean coefficient estimates in the RPL model are reported with their respective standard deviations. The models are estimated by maximum simulated likelihood using Halton draws. The analysis is conducted in NLOGIT 9 (NLOGIT, 2009).

2.5.1 Willingness to pay calculation

In the base estimates, Willingness to pay (WTP) for the kth trait is estimated (Ding et al. 2015):

$$WTP_k = -\frac{\beta_k}{\beta_p} \qquad (14)$$

where β_k is the estimated coefficient of the kth trait and β_p is the coefficient on price. For the estimates with individual specific characteristics, willingness to pay for the kth trait is calculated as (Kallas et al. 2007):

$$WTP_k = -\frac{(B_k + \beta_i * indiv)}{B_p} \qquad (15)$$

where β_i is the coefficient estimate on the individual specific characteristics. Equations 14 and 15 are used to estimate WTP for both MNL and RPL models (Nahuelhual et al., 2004). With price assumed fixed in the RPL specification, the WTP for each trait takes the same distribution as coefficient estimates in the RPL model but this is only for the basic model with no other than attribute explanatory variables). Consistent with the conceptual framework, three sources of heterogeneity in producer preference for feed efficiency are examined. Differences in the valuation of the trait is measured as the difference between WTP for feed efficiency EPD and the weaning weight and birthweight EPDs. The technology specific-effect is captured by the difference between the WTPs for feed efficiency and genomic information on feed efficiency. Lastly, the distribution of WTP by environmental attitudes, risk attitudes and retained management practices is also reported.

2.6 The Cow-calf Producer Survey

Producer stated preference for genomic information on feed efficiency was evaluated with data from a Canadian national survey of cow-calf producers conducted in 2013. Other traits included in the choice experiment were feed efficiency EPD, birthweight EPD, weaning weight EPD and the accuracy of feed efficiency EPD. The choice of the feed efficiency traits is consistent with the objectives of the study. Previous bull valuation studies have also found birthweight and weaning weight EPDs to be important in cow-calf producer bull purchases (McDonald et al., 2010; Brimlow and Doyle, 2014). The survey began with a series of questions about cow-calf producer demographics and farm characteristics. This also included questions regarding knowledge about the technology, number of BMPs on farm, AI use and risk perceptions. The second section of the survey was the choice experiment. The choice sets were preceded by questions evaluating producers' current level of knowledge about the use of genomic information in selection. A description of the traits included in the choice sets was also provided. The final section of the survey consisted of questions on environmental attitudes as measured by the two attitudinal scales i.e. the New Ecological Paradigm (NEP) scale (Dunlap et al. 2000) and the New Human Interdependence Paradigm (NHIP) (Corral-Verdugo et al. 2008). Additionally, questions on trust in a number of organizations (veterinarians, breed societies, research organizations and government authorities) were asked.

Respondents were drawn from a national producer database administered by Ipsos Agriculture and Animal Health. The company contacted producers and provided them with access to the on-line survey, which was housed on the server at the University of Alberta. Each respondent received a token payment of CAD$50. Based on the available financial resources for this study, we recruited 250 cow-calf producers. The sample size reported in this study is typical of on-line producer surveys (e.g. Ochieng and Hobbs, 2016), and comparable to Vestal et al. (2013). It is much higher than other reported producer CE studies (Breustedt et al., 2008; Gallardo et al., 2015; Vassalos et al., 2016).

2.6.1 Experimental Design

In the selection of bull traits to include in the choice experiment a number of measures were taken to mitigate the effects of a number of the identified weaknesses associated with choice experiment (Hanley et al. 2001). For example, to overcome any potential cognitive difficulties associated the complexity of the choice task, the number of attributes included in the choice experiment was limited to important weight and growth traits. Four traits with three levels, one trait with two levels, one trait with five levels and an opt-out option translates into $(3\times3\times3\times3\times5\times2)^2 \times1$ possible hypothetical bull profiles. The inclusion of the "neither option" makes the choice scenarios more realistic and ensures that respondents do not make forced choices. An orthogonal (array) design approach in SAS was used to reduce these choices to 36 bull profiles. These were arbitrarily divided into sets of six choices and producers completing the survey online were randomly provided with one of the six set of questions to answer. For each of these traits, producers were provided with a short explanation of the trait and its potential selection outcomes. An example of this for weaning weight is shown below:

Weaning weight EPD: Measured in pounds (lbs) the higher EPDs are desirable. Assuming two bulls: bull A has a weaning EPD of +30 lb. and bull B has a weaning EPD of +20 lb. If you randomly mate these bulls in your herd, you could expect bull A's calves to weigh, on average, 10 lb. more at weaning than bull B's progeny (30 - 20 = 10).

With the exception of genomic information on feed efficiency, the traits of the bull included in the choice experiment were defined as expected progeny differences (EPDs). Usually, expressed as pounds (lbs) below or above the breed average, these EPDs predict the future performance of a bull's offspring (Dhuyvetter et al. 1996). The traits were defined as follows:

Genomic information on feed efficiency: This trait indicates the presence of information about genes that directly influence the efficiency of feed utility by the weaned calves produced by the bull. Genomic information on feed efficiency is a 1-0 dummy variable; 1 if genomic information is available and 0 otherwise.

Birth weight EPD: Birth weight EPD is a maternal EPD that indicates differences in the expected weight of calves produced by a bull at birth. If two bulls A and B have a birth weight EPD of +2 and +6 respectively, the calves produced by the bull B would be expected to weigh on average 4 pounds more than those of A. Heavier birth weights are associated with increased difficulty at calving and possible death of calves and cows (Herring 1996). Consequently, lower birth weights are desirable. A calf birthweight of about 6-7% of a dam's weight is considered ideal (Walters, 2013). The levels[18] used for this trait in the present study are: +10, +20 and +30.

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[18] Levels of all the traits were set after an extensive review of bull catalogues and consultation with experts

Weaning weight EPD: Weaning weight has been noted to be a trait of major economic importance in cow-calf breeding decisions as the weaned calf is the primary output of the cow-calf producer. High weaning weight EPDs are associate with high weaning weight of calves produced by the bull-A bull with a weaning weight of EPD of +20 would produce calves 10 pounds heavier at weaning as compared to a bull with an EPD of +10 (Greiner 2009). Three levels were specified for this trait: -5, 0 and +5.

Feed efficiency EPD: Feed efficiency EPD[19] captures the performance of the bull's progeny in terms of feed utilization. In the present study higher values of this EPD are associated with improved feed utilization in weaned calves born by a given bull. The inclusion of this trait allows for the comparison of the trade-off the cow-calf producer makes between the new technology (genomics) and conventional measure (EPD) with respect to feed efficiency. The levels of feed efficiency investigated were: -0.09, +0.1 and +0.22.

Accuracy of feed efficiency EPD: The accuracy of the feed efficiency EPD is a measure of the reliability of the feed efficiency i.e. how close the predicted EPD is to the "true" EPD of the bull which is unknown. Reported as percentage, higher percent accuracies denote higher reliabilities. The levels of accuracy examined were namely: 30, 40, 50, 60 and 75%.

Price of the bull: This represents the purchase price of the bull. This represent the cost of the bull (P_i^B) in the conceptual model. Three levels of bull prices i.e. \$1500, \$5500 and \$9000 were specified in the survey. Table 2.1 presents a summary of the traits and levels.

Table 2.1: A summary of traits used in choice experiment

Traits	Levels.
Genomic information on feed efficiency	1= if bull has genomic information. Otherwise=0.
Birth weight EPD(Ibs)	+10, +20, +30
Weaning weight EPD (Ibs)	-5,0, +5

[19] It must be noted that the incorporation of direct measures of feed efficiency into conventional breeding tools is ongoing.

Feed efficiency EPD (Ibs)	-0.09, +0.1, +0.22
Accuracy of feed efficiency EPD (%)	30,40,50,60,75
Price(CAN$/bull)	$1500, $5500, $9000

As shown in Table 2.2, the choice set comprised two actual bull profiles and a “no option”.

Table 2.2: Example of choice set used in the study

Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	No	Yes	I wouldn’t buy either of these types of Bulls
Birth weight EPD(lbs)	20	10	
Weaning weight EPD(lbs)	0	0	
Feed efficiency EPD(lbs)	-0.09	0.22	
Accuracy of Feed efficiency EPD (%)	50%	60%	
Price of Bull(CAN$)	$1,500	$5,500	
I would buy	□	□	□

2.6.2 Incorporating Environmental Attitudes

Two environmental attitudinal variables i.e. the New Ecological Paradigm (NEP) scale (Dunlap 2000) and New Human Interdependence Paradigm (NHIP) scale (Corrallo-Verdugo et al. 2008) are included in the analysis. Incorporating these attitudes requires a number of assumptions. Firstly, it assumed that latent environmental attitudes as measured by these attitudinal scales capture a tendency to engage in pro-environmental behaviour. In other words, respondents with higher NEP and NHIP scores are likely to make pro-environmental choices. The second issue relates to how respondents are assigned to different attitudinal segments based on their scores. Scores may be aggregated and selected aggregates used as boundaries to denote attitudinal categories (e.g. Choi and Fielding 2013). This approach is however arbitrary and is not supported by a consistent theoretical underpinning. Conversely, more conceptually consistent approaches such clustering approach can be used (e.g. Aldrich et al., 2007).

In this study, a cluster analysis approach is implemented to segment the cow-calf producers sampled. A number of clustering procedures (e.g. hierarchical methods, k-means procedure) are available. Attitudinal clusters in the present study are derived based on a hierarchical clustering approach, specifically a Ward's method applying Euclidean distance as the distance (or similarity) measure (Aldrich et al., 2007).

The Ward's method (Ward 1963), an agglomerative[20] clustering procedure, forms clusters by minimizing the sum of squared deviations from a given cluster mean. The total within-cluster error sum of squares (E) is minimize such that (Everitt et al. 2011):

$$\min \sum_{m=1}^{g} E = \sum_{m=1}^{g} \sum_{l=1}^{n_m} \sum_{k}^{p} \left[x_{mlk} - (\frac{1}{n_m}) \sum_{i=1}^{n_m} x_{ml,k} \right]^2 \quad (15)$$

where l, m, k subscripts are the individual, cluster and attitudinal score identifiers respectively. x_{mlk} is the value of the kth attitudinal scale score(NEP and NHIP) for the lth individual in the mth cluster. In this form, group membership in CA is deterministic.

Following the approaches used in previous studies (Matin et al. 2012; Poortinga et al. 2000; Steg and Sievers 2000), statements that capture the different beliefs (myths of nature) were also presented to respondents. Specifically, these beliefs about environmental risk are captured in the following (Steg and Sievers 2000, p. 258):

" we do not know whether environmental problems will magnify or not"(nature capricious); " we do not need worry about environmental problems, because in the end these problems will always

[20] Groups are merged at each stage of clustering according to clustering criterion

be resolved by technological solutions"(nature benign); "the environmental problems are running out of control, but the government should dictate clear rules about what is and what is not allowed"(nature tolerant); and " the environmental problems can be only controlled by enforcing radical changes in human behaviour and in society as a whole"(nature ephemeral)."

Cow-calf producers were categorised in a particular belief subset based on the choice of one of the four statements presented.

2.6.3 Measuring Risk Attitudes

The measurement of risk preferences is complex and often context specific (Franken et al., 2014). As an attitudinal variable, a person's risk preference is not directly observable ex-ante and can only be deduced from actual behaviour. Behaviour in turn varies under different circumstances. In this regard, the different approaches to measuring risk and the performance of these metrics remains contentious in the literature (Pennings and Smidts, 2000; Dohmen et al., 2001; Franken et al., 2014; Anderson and Mellor, 2009).

In this study, multiple psychometric scales are used to elicit different aspects of producer risk attitudes. Following previous work on cow-calf producer risk attitudes by Pope et al. (2008) different aspects of risk such as: experience and knowledge, speculative risk, and guaranteed versus probable risk are measured. In addition to these, responses to other aspects of risk i.e., risk in farming decisions, health, finances and general decision making were also elicited (see questions 35, 37, 38, 39, 48 in Appendix 5A). Pope et al. (2011) aggregated scores from the different risk scales into a single risk score. In this study, the attitudinal scores of farmers on the different risk measures are reported. Further, the distribution of WTPs for bull traits by the general risk attitude scores are reported (Table 2.3). A similar approach is used for the other attitudinal variables examined. This approach to analyzing the role of attitudes follows Aldrich et al. (2007).

Table 2.3: General risk measurement scale

In general, would you say that your behavior and the decisions you take are:								
1	2	3	4	5	6	7	8	9
Not at all risky	Not risky	Very little risk	Slightly risky	Moderately Risky	Risky	Very risky	Extremely risky	More than extremely risky
☐	☐	☐	☐	☐	☐	☐	☐	☐

2.6.4 Measuring other Producer Characteristics

Cow-calf producer knowledge about genomic information was assessed using a self-reported scale. Respondents were asked, "How would you describe your current level of knowledge about the use of genomic information in selection/breeding?" Responses were coded as, "1=Not at all familiar" to "4=Very Familiar". A similar approach was used to assess cow-calf producer level of knowledge about science and technology.

Additionally, the effect of practices such as retained management and the number of BMPs on the probability of choosing a bull with genomic information on feed efficiency was also addressed. The former represents an avenue for cow-calf producers to integrate further down the supply and extract value for traits with less defined market values. Producers in the sample were asked about the frequency at which they retain cattle till finishing. Responses were coded in order of increasing retention such that: "Never =1"; "Seldom=2"; "Sometimes=3"; "Often=4"; and; "Always=5". A BMP score representing an aggregate measure of the number of different BMPs undertaken on the farm by cow-calf producers is included in this analysis. These selected practices were obtained from the Alberta Cow-calf Audit (AAFRD, 1998).

In general, higher weaning weight, feed efficiency and accuracy of feed efficiency EPDs and the presence of genomic information are hypothesized to have a positive effect on the probability of purchasing a given bull. Conversely, cow-calf producers are expected to discount bulls with higher birthweight EPDs. Specific to genomic information on feed efficiency, it is hypothesized that cow-calf producers in the practice of retaining weaned calves beyond weaning will have a higher likelihood of choosing a bull with genomic information on feed efficiency as compared to those that sell at weaning. As compared to traditional measures of a given bull's productivity (say EPDs), the premium paid for a bull with genomic information can be considered as a form of value addition. For feed efficiency, the saving on feed costs, which represents primary return on this investment increases the longer cattle are retained. This is expected to be reinforced by the absence of a well-defined market for feed efficient calves by feeders at the present time. Similarly, it is expected cow-calf producers with higher best management practice score (BMP) will have higher probability of purchasing a bull with genomic information on feed efficiency. Knowledge of science and technology is also hypothesized to have positive effect on WTP for genomic information on feed efficiency. A priori, the effect of a cow-calf producer's level of knowledge about the use of genomics in breeding is indeterminate - Producers' level of knowledge about genomics can have a positive relationship on their valuation of genomics if this knowledge reinforces positive perceptions about the technology. Conversely, the relationship can have a negative effect. The effect of risk preferences is also likely indeterminate, since there could be two identifiable but opposing effects. First, as a newer technology, risk averse cow-calf producers may discount the technology due to uncertainties about its effectiveness. Alternatively, increasing the feed efficiency of the herd, may constitute a production risk reduction strategy; attenuating the effects of feed price risk, for example. This may hold true for the other feed efficiency related traits as well. Implicitly, the trade-off between perceived inherent risks of the breeding technology and its production risk reducing capabilities will determine the relationship between risk perceptions and preference for bulls with genomic information on feed efficiency. It is also hypothesized that farmers in the practise of using Artificial Insemination (AI) would have higher probability of purchasing bulls with genomic information. The widespread use of AI in other livestock sectors such as dairy cattle has been linked to the higher levels of uptake of genomic technologies (Taylor et al., 2016).

Older farmers tend to be less likely to adopt new technologies as a result of their relatively shorter planning horizon (Elliot et al., 2013). Technology adoption studies in dairy cattle (e.g. Khanal and Gillespie, 2013) found evidence of a higher propensity to adopt newer technologies amongst younger farmers. It is therefore hypothesized that age (AGE) will negatively impact cow-calf producers' valuation of genomic information. The effect of farm size (SIZE) on producer adoption has been linked with economies of size impacts. For cattle breeding, this effect can be significant. A bull purchased by a cow-calf producer typically services multiple cows implying that the cost per unit cow of the cost of improvements in the bull may be lower for larger scale producers as compared to small farms. In other words, a producer with a larger size herd would have a higher probability of purchasing bull marketed with genomic information on a given trait vis-à-vis one without. The effect of income is expected to be similar to that of farm size. The impact of education on cow-calf producer's decision toward the incorporation of new product and process inputs of production occurs in a number of ways: directly through the better understanding of the impacts of these new inputs; and indirectly through the ability of producers to acquire additional information (Wozniak, 1993). A producer's level of education positively impacts the adoption of new technology through the ability to apply the technology appropriately (achieve higher returns) and acquire additional information (Wozniak, 1993). Evidence of the effects of gender on technology adoption is mixed. Studies, mostly in developing country contexts find that a higher propensity to adopt amongst male producers (Ragasa, 2012). It is likely that this effect is technology and context specific. In the present study the effect of gender is indeterminate a priori.

With respect to the effect of environmental attitudes, it is hypothesized that cow-calf producers with a higher NHIP scores will have higher WTP for genomic information as compared to those with lower scores. This is primarily because the NHIP ascribes to the sustainable use of natural resources by humans and the use of technologies such as genomics in breeding for feed efficient cattle is consistent with this concept. In contrast, the effect of pro-NEP is not straightforward. On the one hand cow-calf producers may value the environmental impact of a feed efficient. On the other hand, they may perceive the use of genomics as enhancing intensification and affecting nature's intrinsic value. The impact of the NEP attitudinal variable on WTP for genomic information on feed efficiency depends on which of these two effects dominate. Additionally, it is expected that cow-calf producers with stronger perceptions about environmental risk (strong nature ephemeral beliefs) will have higher WTP as compared to those with nature benign beliefs.

2.7 Results

2.7.1 Descriptive Analysis of Survey

Data from a nationwide survey of cow-calf producers was included in the analysis. In total responses from 246 producers were used[21]. The frequency distributions of responses to questions on producer characteristics (age, level of education, gender, location), farm characteristics (number of cows, income from cattle operations, cost of composition) and production practices (best management practices, retained ownership, bull/semen sourcing) is first presented.

The geographical distribution of the cow-calf producers in the sample was consistent with the distribution of cow-calf production across Canada. As shown in Figure 2.5, Alberta (34%) and

[21] Missing values were not systematic across the entire survey. Missing values for specific questions meant that respondents were excluded accordingly.

Saskatchewan (26%) jointly account for 60% of the total number of respondents. The proportion of producers in Ontario and Manitoba was 22 and 17% respectively.

The mean age of cow-calf producers sampled was approximately 52 years. Two percent (2%) of producers in the sample were younger than 30 years whilst 5% of producers were 70 years and older. Producers in the sample were predominantly male comprising approximately 86% of respondents, whilst 14% of respondents were female.

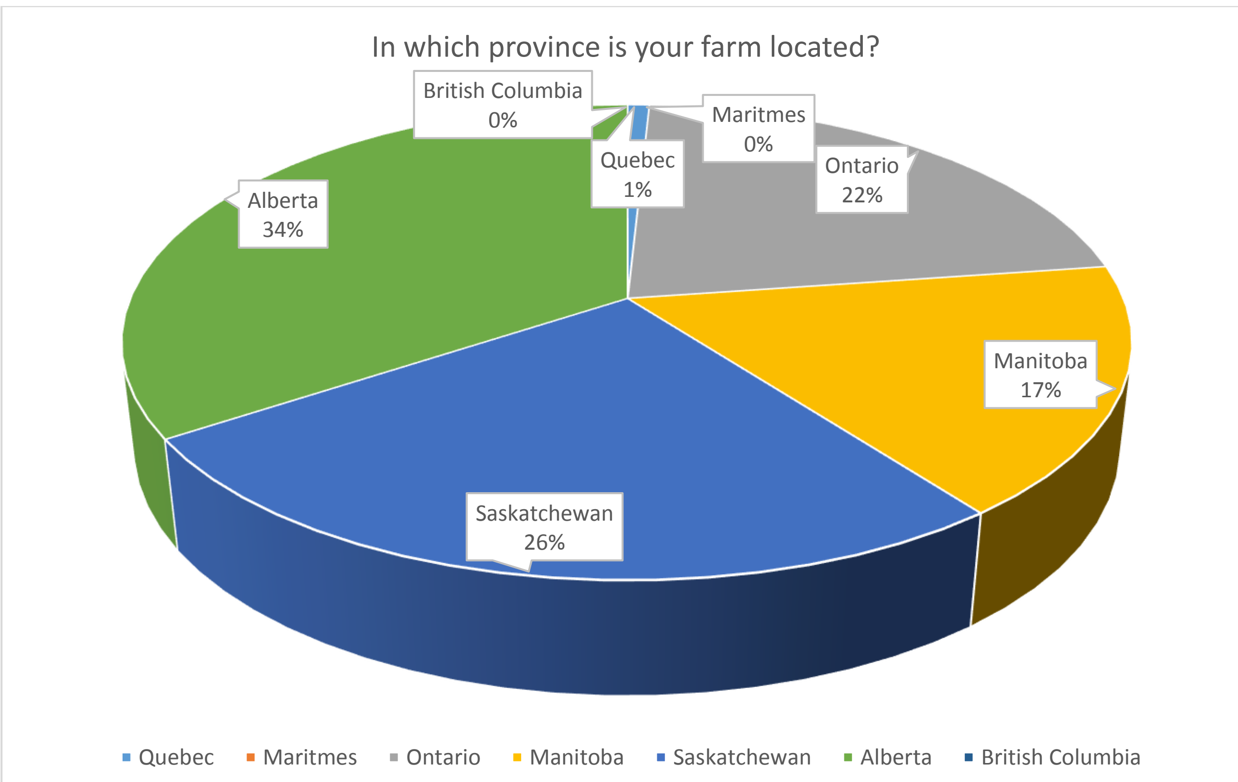


Figure 2.5: Location of farm in Canada (Source: Author's own)

Over half of the producers in the sample had at least post-secondary education –higher than 12 years of school. The level of education varied by gender with a higher proportion (64%) of female producers attaining post-secondary education as compared to male producer (56%). Figures 2.6 and 2.7 show the distribution of producers by educational attainment.

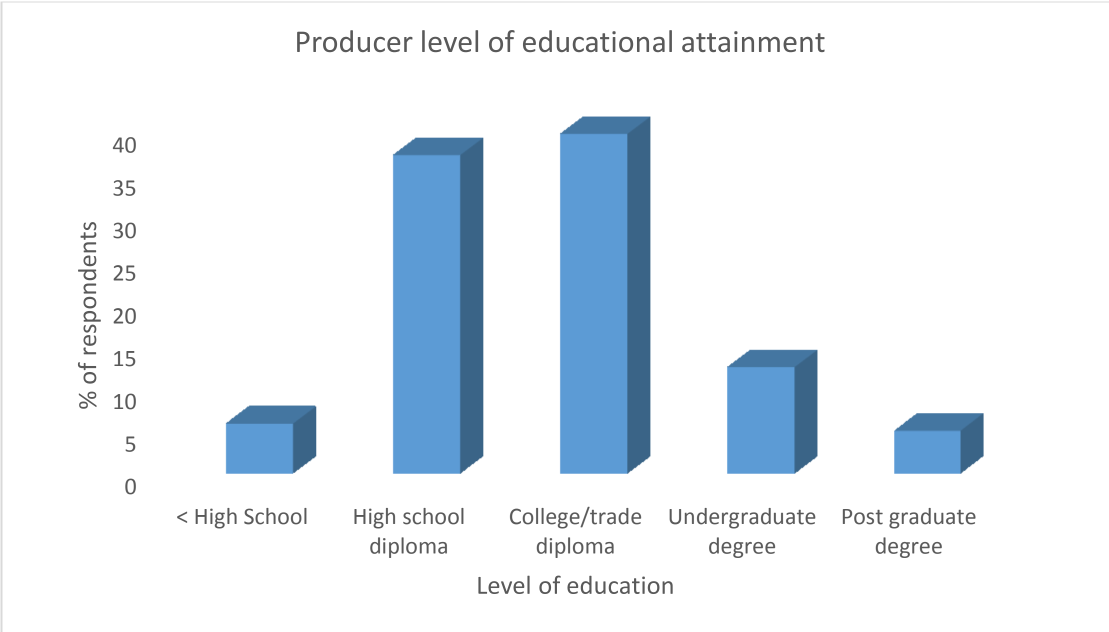


Figure 2.6: Cow-calf producer level of education attainment (Source: Author’s own)

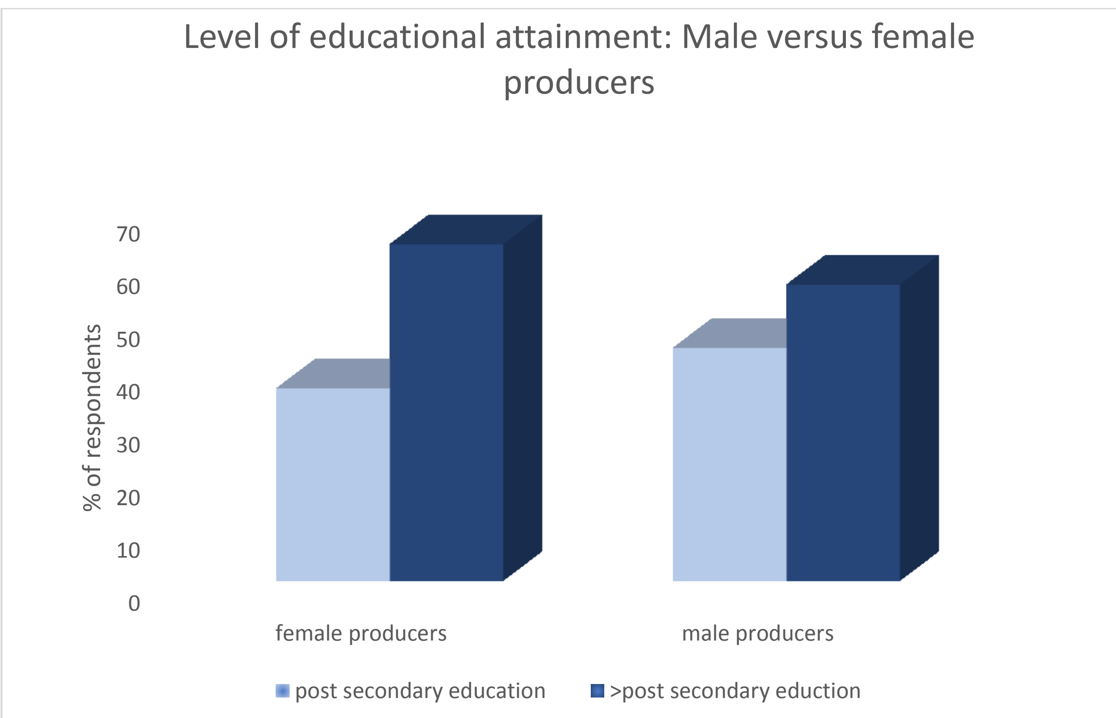


Figure 2.7: Cow-calf producer level of educational attainment by gender (Source: Author’s own)

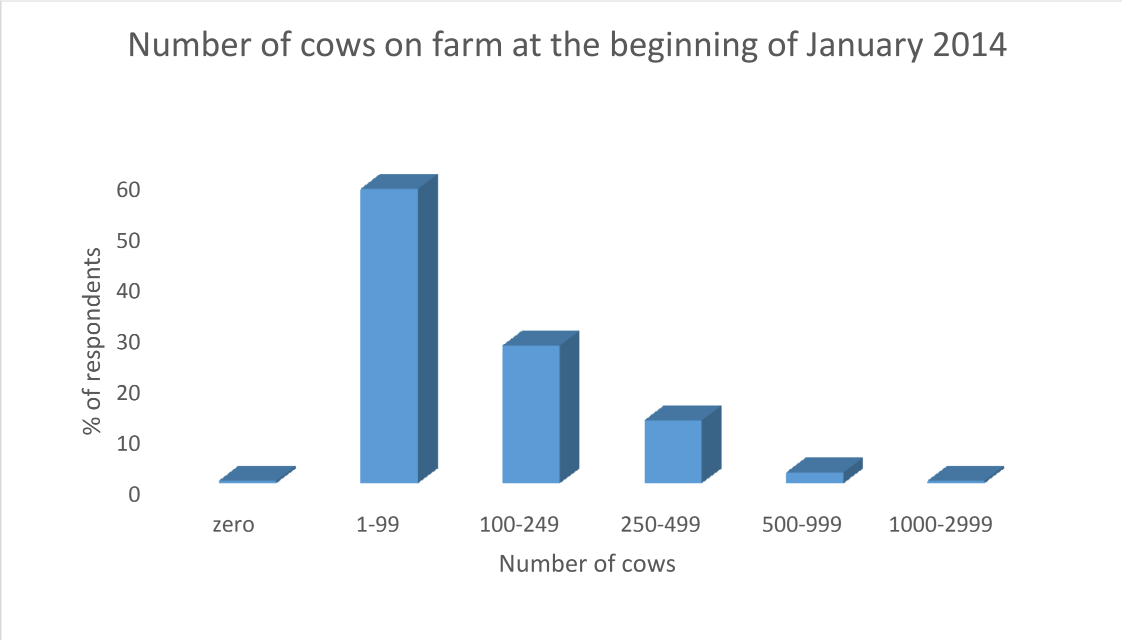


Figure 2.8: Number of cows on farm in 2014 (Source: Author's own)

The mean number of cows on farm was approximately 131 cows (Figure 2.8). The corresponding percentage of sales from cattle operations ranged between 20% and 100% with a mean of 49.5% (Figure 2.9). This implies that the predominant practise of cow-calf producers in the sample was mixed farming.

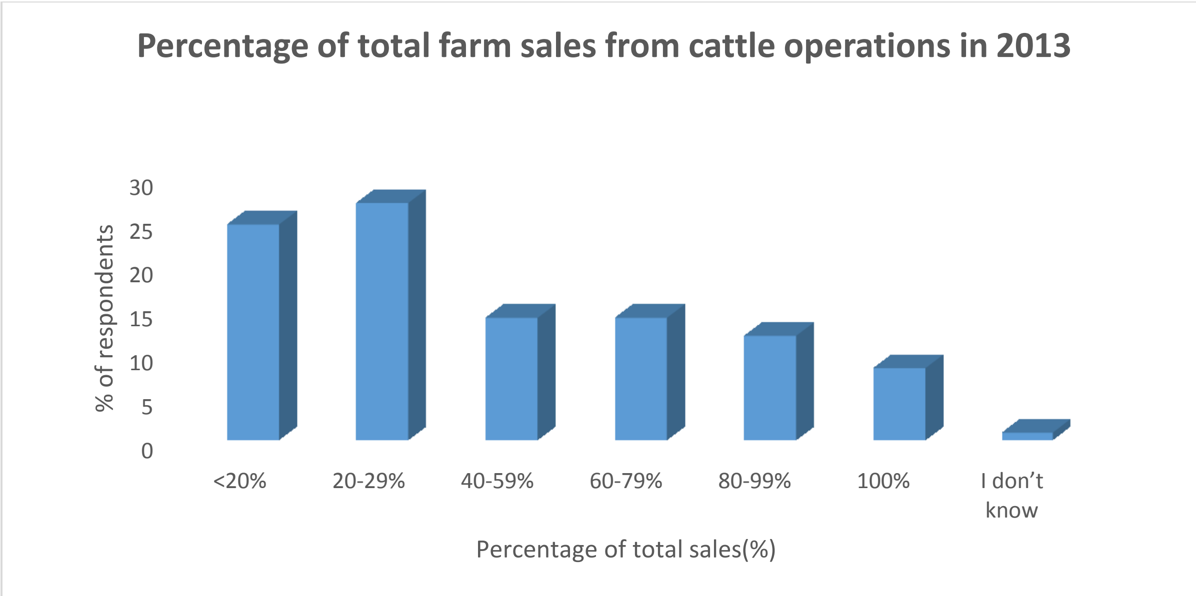


Figure 2.9: Proportion of total farm sales allocable to cattle production (Source: Author's own)

2.7.2 Overview of Farm Practices

Figures 2.10-2.12 capture the distribution of different production practices amongst the sample of cow-calf producers. The relevant practices include retained management practices and on-farm best management practices (BMPs).

A number of BMPs undertaken on cow-calf operations was also examined. These practices were adapted from 1998 Alberta cow-calf audit (Alberta Agriculture and Rural Development 1998). Common practices identified amongst producers included vaccination of cows (90%), selecting of wintering sites as manure management (64%), fencing of riparian areas (39%), feed management practices (66%) and rotational grazing (Figure 2.10).

A BMP score was created as an aggregate measure of the number on farm BMPs undertaken. Figure 2.11 shows the distribution of the BMP scores across the survey respondents. It is evident that most cow-calf producers undertook multiple BMPs on their farm; approximately 87% respondents undertook at least four BMPs.

Figure 2.10: Cow-calf producer: Best management practices (Source: Author's own)

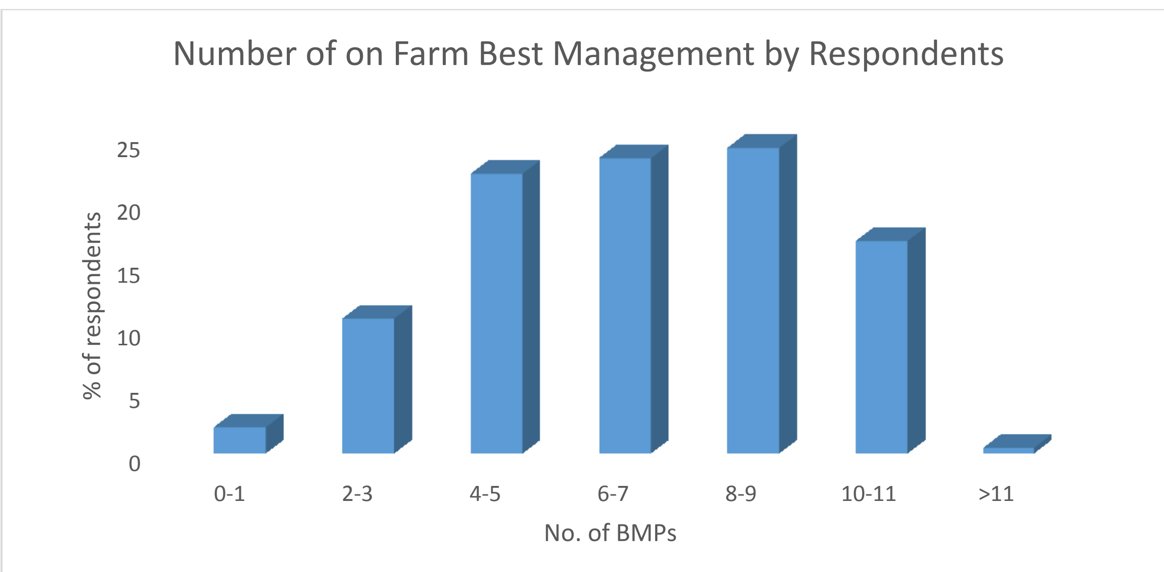


Figure 2.11: Cow-calf producer: Best management practices (Source: Author's own)

Producers in the sample were also asked about the frequency at which they retain cattle till finishing. Specifically, cow-calf producers were asked, “How often do you retain steers through to finishing and then sell them?” Responses were coded in order of increasing retention such that: “Never =1”; “Seldom=2”; “Sometimes=3”; “Often=4”; and; “Always=5”. The mean estimate of the calf retention variable = 1.96 over the range of 1 (minimum)-5 (maximum). Figure 2.12 shows the distribution of producers according to the frequencies of calf crop retention.

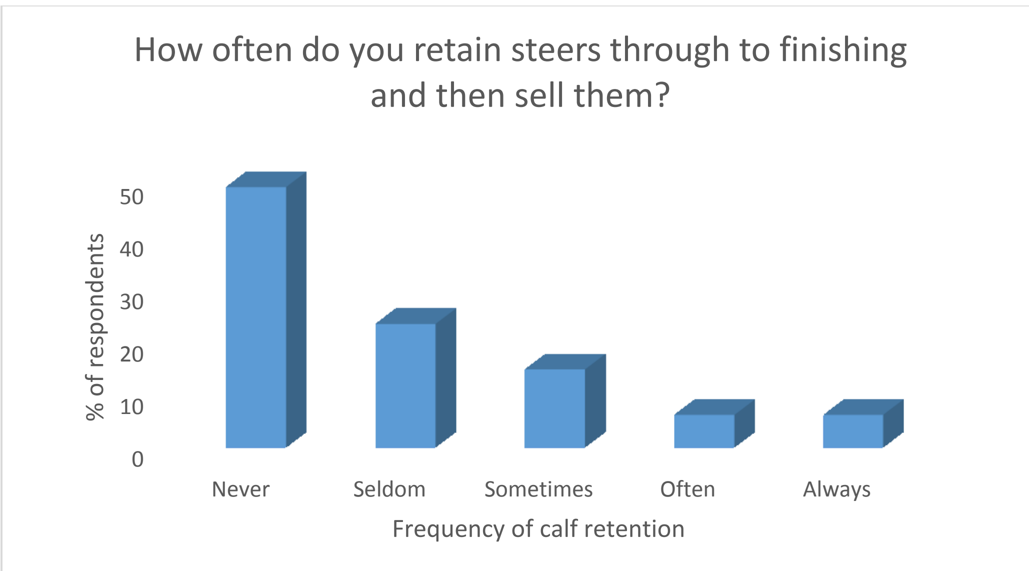


Figure 2.12: Cow-calf producer retained ownership of cattle (Source: Author’s own)

From Figure 2.12, it is evident that the retained ownership of steers to finishing is not a common practise amongst sample respondents. Approximately 50% of respondents reported that they “never” retained cattle till finishing. Alternatively, 12% of respondents reported “often” and “always” marketed steers after finishing. The distribution of producers also indicate that producers behave strategically in the marketing of steers-38% reported that they “sometimes” and “seldom” marketed their steers after finishing. This perhaps shows that the calf retention decision may also be dependent on prevailing market conditions.

Table 2.5 is a summary of selected demographic characteristics of cow-calf producers sampled in this study and those reported in the Census of Agriculture (CoA) in Canada for 2011. The mean reported farmer age was approximately 52 years, marginally lower than the 55 years reported in the CoA 2011 (Statistic Canada, 2012c). Over 50% of respondents in this study had at least secondary education; this estimate is also consistent with the 51.6% reported in the CoA 2011 for agricultural producers (all commodities) in Canada (Statistic Canada, 2012d) In contrast, the proportion of male farmers (86%) in this study was higher than 73% reported in the 2011 Census of agriculture. The latter estimate is however for all farmers in Canada (Statistics Canada, 2012e). The average herd size amongst the sample of producers in this survey is comparable (130.79) to that reported in the Census (129) (Statistics Canada, 2012a). From the geographical distribution of respondents, our survey is bias towards to producers in the three Prairie Provinces i.e. Alberta, Manitoba and Saskatchewan. In terms of share of production, these three provinces cumulatively account for 82% of cow-calf production in Canada with Alberta and Saskatchewan making up the bulk of this (Canada Beef, 2016). To the extent that comparison of these datasets is possible, it seems that the present sample is reasonably representative although it over selects for male and younger producers on average.

Table 2.4: Summary statistics of variables included in the analysis

Variable	Description	Mean	SD	MIN	MAX
Size	Number of cows on farm in 2013	130.79	162.56	0.00	2000.00
Income	Total revenue from cattle sales in 2013($‘000).	130.73	321.77	0.00	3500.00
Age	Age of producer (Years)	51.87	10.81	25.00	70.00
Education	Highest level of education attained (Years).	13.36	2.10	8.00	18.00
Male	Gender of producer, 1=male; 0=female.	0.86	0.34	0.00	1.00
BMP	Number of best management practices	6.72	2.66	0.00	12.00
Risk perception	In general, would you say that your behavior and the decisions you take are:	Not risky (9.54%); Slightly risky (53.52%); Moderately risky (36.10%); Extremely risky (0.83).			
AI	% Expenditure on Artificial Insemination in 2013.	0.60	1.95	0.00	15.00
Science and Technology	Level of knowledge about scientific and technological developments. 1=Not at all informed;2=Not very informed;3=Somewhat informed;4=Very informed	2.85	0.58	1.00	4.00
Location of farm	% of respondents in a given province as a % of total number of respondents	AB (34%); SK (26%); BC (0%); MT (0%); QB (1%); ON (22%); MB (17%).			
Retained ownership	How often do you retain steers through to finish?	Never (49.38%); Seldom (23.46%) ; Sometimes (14.81%); Often (6.17%); Always (6.17%).			
Knowledge of genomics	Describe your current level of knowledge about the use of genomic information in selection/breeding?	Not at all familiar (18.93%); Not very familiar (36.21%); Somewhat familiar (39.09%); Very familiar (5.76%)			

Note: AB=Alberta; SK=Saskatchewan; BC=British Columbia; MT= Maritimes; QB=Quebec; ON=Ontario; MB= Manitoba.

Table 2.5: Summary of comparison of means between our survey and the Census of Agriculture

Variable	This study	Census of Agriculuture 2011
Size	130.79	149.00[a]
Income	130.73	211.98[b]
Age	51.87	55.00
Education	50.00%	51.60%[d]
Male	0.86	0.73
Location of farm	AB (34%); SK (26%); BC (0%); MT (0%); QB (1%); ON (22%); MB (17%)	AB (26%); SK (18%); BC (7%); MT (4%); QB (14%); ON (24%); MB (9%)

Note :[a] average number of cattle and calves per farm; [b]mean income estimated total gross receipts farm for agriculture producers in Canada.; [d] 51.6% of farm operators had completed post-secondary education.

2.7.3 Analysis of Attitudinal Variables

The responses to the NEP statements are reported in Tables 2.6 to Table 2.8. To ensure consistency in pro-environmental orientation. The eight odd numbered statements were scored as: "Strongly disagree" =1, "Mildly disagree" =2, "Unsure" =3, "Mildly agree"=4, and "Strongly agree"=5. The seven even numbered responses were scored in the reverse.

Table 2.6: New Ecological Paradigm (NEP) scale item response frequencies and descriptive statistics

Do you agree or disagree	**SD**	**MD**	**U**	**MA**	**SA**	**Mean**
1. We are approaching the limit of the number of people the earth can support(*EARTHCAP*)	15.77%	19.50%	35.27%	17.01%	12.45%	2.91
2.Humans have the right to modify the natural environment to suit their needs(*modifyenv*)	16.32%	30.13%	23.43%	25.94%	4.18%	3.28
3. When humans interfere with nature it often produces disastrous consequences(*interf*)	5.83%	18.33%	22.92%	35.00%	17.92%	3.41

4. Human ingenuity will insure that we do NOT make the earth unlivable(*ingenuity*)	10.79%	19.50%	32.78%	31.54%	5.39%	2.99
5. Humans are severely abusing the environment(*abusingenv*)	6.69%	21.76%	27.19%	32.22%	12.13%	3.21
6. The earth has plenty of natural resources if we just learn how to develop them(*sufresour*)	6.61%	14.46%	23.97%	41.32%	13.64%	2.59
7. Plants and animals have as much right as humans to exist(*righttoexist*)	7.53%	15.48%	24.69%	38.49%	13.81%	3.36
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations(*strongbalance*)	8.68%	30.99%	37.19%	19.42%	3.72%	3.21
9. Despite our special abilities humans are still subject to the laws of nature(*lawsofnature*)	0.84%	3.35%	22.59%	46.86%	26.36%	3.95
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated(*ecolcrises*)	8.71%	14.52%	36.51%	28.22%	12.03%	2.80
11. The earth is like a spaceship with very limited room and resources(*spaceship*)	9.58%	23.33%	29.17%	29.58%	8.33%	3.04
12. Humans were meant to rule over the rest of nature(*humrule*)	14.17%	31.25%	29.17%	18.33%	7.08%	3.27
13. The balance of nature is very delicate and easily upset(*delicatebalance*)	3.32%	13.28%	22.82%	44.40%	16.18%	3.57
14. Humans will eventually learn enough about how nature works to be able to control it(*controlblance*)	20.25%	22.73%	35.54%	18.60%	2.89%	3.39
15. If things continue on their present course, we will soon experience a major ecological catastrophe(*ecolcatastrphe*)	14.46%	21.07%	39.26%	17.36%	7.85%	2.83

Note: SD= Strongly disagree, MD=Mildly disagree, U=Unsure, MA=Mildly agree, SA=Strongly agree. Even numbered statements are coded in reverse such that 'SD'=5, 'MD'=4, 'U'=3, 'MA'=2, and 'SA'=1.

Table 2.6 is a summary of means and response frequencies to the multi-item NEP scale. The frequencies of responses vary widely across the different statements indicating heterogeneity in environmental attitudes within the sample of respondents. Respondents showed higher levels of disagreement with even numbered statements as compared the odd numbered statements. Most respondents were "Unsure" about the possibility of an ecocrises (statements 10 and 15), rejection of exemptionalism (statements 4 and 14) and the balance of nature (statement 8). The strongest pro-environmental values were associated with statements 9 and 13. With the exception of these, responses tended to be evenly distributed. From the overall pattern of responses, it is evident that while cow-calf producers were concerned about the delicate balance of nature, they were unsure about the possibility of an eco-crises or catastrophe.

As shown in Table 2.7 the direction of the distribution of frequencies for the NEP is comparable to other studies. Pro-environmental orientation in the present study however tended to be lower (see support of for statements 3,5,7,9 and 13). These differences are not unexpected as environmental attitudes typically differ across samples.

Table 2.7: Comparison of distributional frequencies for NEP reported in different studies

NEP item	This study			Choi et al. (2013)			Dunlap al. (2000)		
	AG	US	DA	AG	US	DA	AG	US	DA
1. *Earthcap*	29.46	35.27	35.27	56.19	28.20	15.61	52.90	21.00	26.10
2. *Modifyenv*	30.12	23.43	46.45	21.27	20.97	57.66	32.60	9.20	58.20
3. *Interf*	52.92	22.92	24.16	83.47	11.79	4.74	82.30	4.00	13.70
4. *Ingenuity*	36.93	32.78	30.29	67.04	19.76	13.21	31.30	21.50	47.20
5. *Abusingenv*	44.35	27.19	28.45	87.21	10.57	2.22	86.60	2.60	10.80

6. *Sufresour*	54.96	23.97	21.07	52.47	25.68	21.85	59.30	11.30	29.40
7. *Righttoexist*	52.30	24.69	23.01	68.71	23.54	7.75	76.90	4.70	18.40
8. *Strongbalance*	23.14	37.19	39.67	23.84	32.80	43.36	8.50	11.30	80.20
9. *Lawsofnature*	73.22	22.59	4.19	62.20	24.50	13.31	90.90	5.40	3.70
10. *Ecolcrises*	40.25	36.51	23.23	11.69	23.79	64.52	21.80	13.80	64.40
11. *Spaceship*	37.91	29.17	32.91	57.84	29.02	13.14	74.30	7.50	18.20
12. *Humrule*	25.41	29.17	45.42	20.20	24.75	55.05	33.90	8.20	57.90
13. *Delicateblance*	60.58	22.82	16.60	65.02	24.60	10.92	78.70	5.90	15.40
14. *Controlbalance*	21.49	35.54	42.98	38.71	34.17	27.12	23.30	24.20	52.50
15. *Ecolcatastrphe*	25.21	39.26	35.53	82.90	13.78	3.32	65.30	16.90	17.80

Note: AG includes mildly agree and strongly agree, U is Unsure, DA includes strongly disagree and mildly disagree.

Conversely, patterns of convergence in disagreement to a number of statement items were evident. Across the three studies, disagreement to the NEP items was strongest for statements 2, 8, 12 and 14. The observed frequencies were however, lowest in the present study as compared to the other cited studies. The only exception being statement 14 i.e. “Humans will eventually learn enough about how nature works to be able to control it”- 42.98% of respondents in disagreed, as compared to 52.50% in Dunlap et al. (2000) and 27.12% in Choi and Fielding (2013).

Table 2.8: Alpha estimate NEP scale

Number of items in the scale	15
Scale reliability coefficient (α)	0.83

The Cronbach’s alpha statistic (Cronbach, 1951) based on responses to the 15 statements in the NEP scale is approximately 0.83(Table 2.8). This estimate in the present study is equivalent to

Dunlap et al. (2000) ($\alpha = 0.83$), and Kotchen and Reiling (2000) ($\alpha = 0.83$). It is higher than the reliability coefficient reported in Cooper et al. (2004) ($\alpha = 0.72$) and Choi and Fielding (2013) ($\alpha = 0.70$). An α estimate of at least 0.70 is generally considered as an adequate indicator of internal consistency (Cooper et al., 2004).

2.7.4 Analysis of NHIP Scale

The five item Likert-type scale NHIP scale was also used to elicit environmental attitudes. Responses ranged from 1 (strongly disagree) to 5 (strongly agree). The distribution of response frequencies to the NHIP scale is reported in Table 2.9. Respondents showed stronger support for statements 2 and 3- "Human beings can enjoy nature only if they make wise use of its resources" and "Human progress can be achieved only by maintaining ecological balance" respectively. In contrast, respondents expressed the highest levels of disagreement for statements 4 and 5. The proportion of respondents who disagreed (SD and MD) were 30% (statement 4) and 28% (statement 5). This suggests that cow-calf producers in the sample expressed higher support for values bordering on the "functional dependence" between human development and nature as opposed to the inter-temporal dependence between current and future utilization of resources.

Table 2.9: NHIP scale item response frequencies and descriptive statistics

Do you agree or disagree	SD	MD	U	MA	SA	Mean
1.Human beings can progress only by conserving nature's resources	2.06%	13.17%	25.51%	39.92%	19.34%	3.62
2. Human beings can enjoy nature only if they make wise use of its resources	1.67%	6.67%	18.75%	42.50%	30.42%	3.94
3. Human progress can be achieved only by maintaining ecological balance	1.24%	6.61%	25.62%	46.28%	20.25%	3.78

4. Preserving nature at the present time means ensuring the future of human beings	10.79%	19.50%	32.78%	31.54%	5.39%	3.74
5. We must reduce our consumption levels to ensure well-being of the present and future generations	6.69%	21.76%	27.20%	32.22%	12.13%	3.61

Note: SD= Strongly disagree, MD=Mildly disagree, U=Unsure, MA=Mildly agree, SA=Strongly agree.

Unlike the NEP scale, few studies have reported alpha coefficients for the NHIP scale. The estimate in this study ($\alpha = 0.86$, Table 2.10) is comparable to Vandermoere et al. (2011) ($\alpha = 0.88$) and exceeds Corral-Verdugo et al. (2008) ($\alpha = 0.78$).

Table 2.10: Alpha estimate NHIP scale

Number of items in the scale	5.00
Scale reliability coefficient	0.86

2.8.5 Analysis of Environmental Risk Perceptions

Environmental risk perceptions amongst the sample of cow-calf producers in the study were also examined. Respondents were asked to select one out of four statements (myths of nature) most consistent with their views about nature (Figure 2.13).

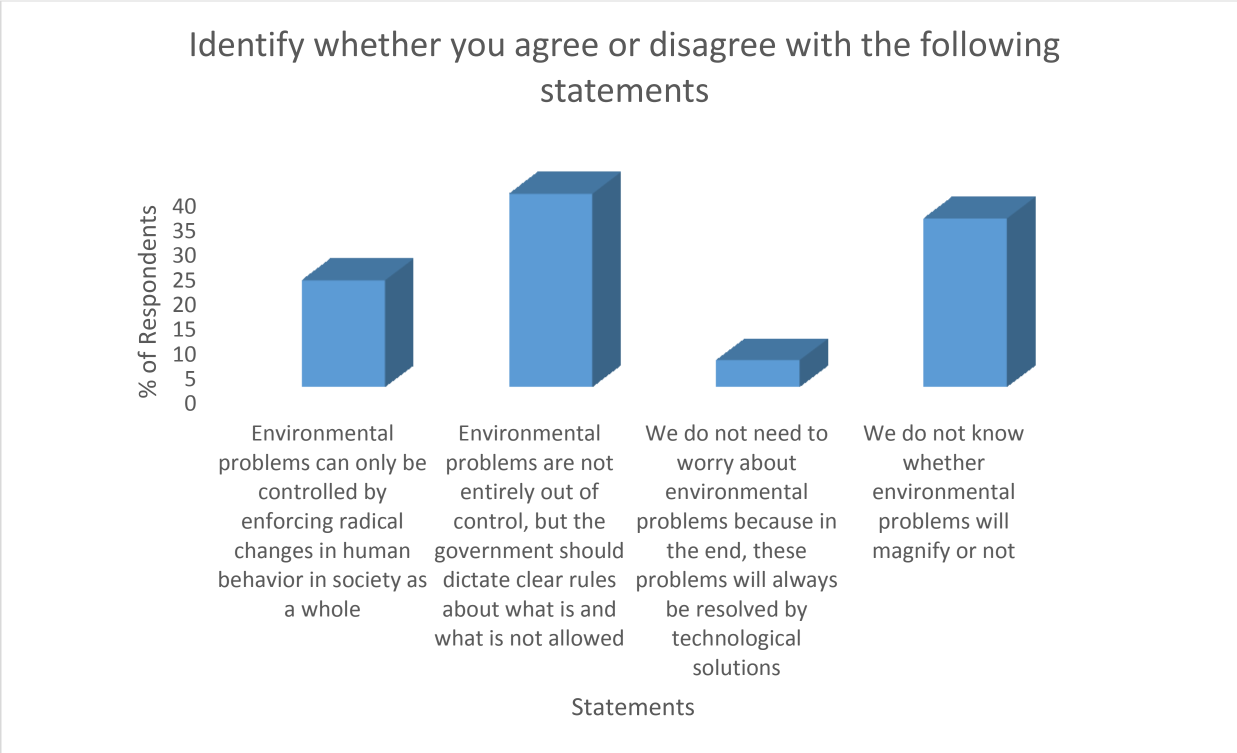


Figure 2.13: Distribution of responses to statements on environmental risk perception (Source: Author's own)

Most respondents in the sample (39%) subscribed to the nature tolerant view. Only 5.39% agreed that nature was robust and resilient (nature benign views). The nature ephemeral view was subscribed to by approximately 22% of respondents whilst 34.02% held the nature capricious viewpoint. From these responses, it seems that cow-calf producers agree that environmental problems exist. The general consensus is that these problems can be managed by effective regulation. Further, cow-calf producers showed a considerable degree of uncertainty regarding the future aggravation of current environmental problems (nature capricious viewpoint).

Table 2.11: Comparison of distributional frequencies for environmental risk perceptions reported in different studies

Myths of Nature	This study	Steg and Sievers (2000)	Matin et al. (2012)	Poortinga et al. (2000)
The environmental problems can only be controlled by enforcing radical changes in human behaviour and in society as a whole (nature ephemeral).	21.58%	47%	50%	22.80%
The environmental problems are not running out of control, but the government should dictate clear rules about what is and what is not allowed (nature tolerant).	39.00%	26%	32%	48.90%
We do not need to worry about environmental problems because in the end, these problems will always be resolved by technological solutions (nature benign).	5.39%	9%	4.00%	2.20%
We do not know whether environmental problems aggravate or not (nature capricious).	34.02%	18%	14.00%	26.10%

Table 2.11 shows the distribution of respondents in the present study as compared to previous studies using then same metric. The distribution of responses is similar to Poortinga et al. (2000) but differs from Matin et al. (2012). Matin et al. (2012) found strong nature ephemeral views (50%) in a survey of the Canadian public. This may indicate divergence in perceptions of environmental risk in public as compared to producers. The commonality in all the studies reported is the low support for nature benign views.

2.7.6 Analysis of Risk Attitudes

Tables 2.12-2.19 is a summary of the results of the analysis of the different self-reported risk perception scales included in the study. A number of these scales were adapted from a previous study of cow-calf producer risk attitudes in Kansas by Pope (2008). Respondents were first asked about how their neighbours would describe their risk taking behavior (denoted RISKEXP) as it relates to their farm management practices (Table 2.12). Most respondents (54.13%) reported that they were willing to take risk after adequate research. Approximately 40% of respondents are "Cautious" whilst 4.55% reported that they would avoid risk. Very few respondents (1.65%) reported that they were "Real gamblers". These frequencies are largely identical to Pope (2008), the notable exception being that a lower proportion of respondents in the present study were in the "Cautious" category.

Table 2.12: Risk taking attitude: Frequencies of responses

	RISKEXP
Statement	In your farm/ranch management, how would your neighbours describe your risk taking behaviour?
Options:	Frequencies[1]
A risk avoider	4.55%
Cautious	39.67%
Willing to take risks after adequate research	54.13%
A real gambler	1.65%

[1]Responses were coded 1-4 in the direction of increasing risk seeking behavior

Respondents were also asked about different loss or gain scenarios related to the marketing of weaned calves. As reported in Table 2.13, respondents showed the propensity to assume a considerable level of risk; 40.42% preferred the third most risky outcome ($65/calf return best; $35/calf loss case). In contrast, 25% respondents chose the certain outcome. A similar pattern of responses was reported in Pope (2008). The risk preferring attitude in this instance may be a result of the familiarity with calf-crop marketing due to the frequency at which this activity is undertaken.

Table 2.13: Frequency of responses to loss or gain scenarios

	RISKS
Statement	Given the best and worst case potential outcomes from marketing your weaned calves, which net return/loss prospect would you most prefer?
Options:	Frequencies[1]
$20/calf return best case; $0/calf loss worst case	25.00%
$35/calf return best case; $20/calf loss worst case.	18.75%
$65/calf return best case; $35/calf loss worst case.	40.42%
$100/calf return best case; $75/calf loss worst case	15.83%

[1]Responses were coded 1-4 in the direction of increasing risk seeking behavior

Table 2.14 is a summary of cow-calf producer responses to questions assessing other dimensions of risk- speculative risks and gambles. Cow-calf producers in the sample tended to prefer investments with a lower degree of uncertainty in returns. Compared to Table 2.13, it seems producers are willing to assume more risk in the marketing of weaned calves as compared to general investment decisions.

Table 2.14: Frequency of responses: Investment risk

	Responses[1]					
Statement	Nothing	$1000	$10,000	$50000	$1000,000	>$100,000
-Your trusted is putting together an investment with the two possible outcomes: 50 times initial investment/best case scenario and nothing in the worst case scenario. Your friend estimates the chances of success to be 20%. How much would you invest?	51.02%	31.43%	13.06%	2.04%	1.63%	0.82%
-If your trusted and banker each conclude that the chances of success in the above question is 60% instead of 20%, how much will you invest.	19.01%	26.03%	37.60%	12.40%	2.48%	2.48%

[1]Responses were coded 1-6 in the direction of increasing risk seeking behavior

Additionally, respondents were more risk tolerant regarding general and farming decisions as compared to financial and health matters. Most respondents reported that would assume "moderate risk" with respect to the former as against "very few risk" in the case of the latter (Table 2.15). In the rest of the analysis, the self-reported general risk attitude scale is used as measure of risk attitude.

Cow-calf producer level of awareness and knowledge of the use of genomics in cattle breeding was also evaluated. A significant proportion of respondents were unfamiliar with the use of genomics-55% reported being "not at all familiar" or "somewhat familiar". Approximately 39% of respondents reported being "somewhat familiar" whilst 8% were very familiar with the technology. Most of the respondents in the sample used natural service as showed by the low proportion of total expenditure on AI (~1%).

Table 2.15: Frequencies of responses: Risk attitudes in different decision making context

Type of decision making context	Not at all risky	Not risky	Very few risky	Slightly risky	Moderately risky	Risky	Very risky	Extremely risky	More than extremely risky
General	4.58	5.00	29.17	24.17	30.83	5.42	0.83	-	-
Farming	2.90	3.32	26.14	27.39	34.85	4.15	1.24	-	-
Finances	3.33	6.67	30.83	30.42	22.50	5.42	0.83	-	-
Health	5.80	8.71	34.02	21.99	20.33	5.81	2.07	0.83	0.41

Note: Responses were coded 1-9 in the direction of increasing risk seeking behavior

2.7.7 Conditional and Random Parameter Logit Estimates

The focus of this study is cow-calf producer valuation of genomic information on feed efficiency and the effect of producer attitudes and farm practices on this WTP. Consequently, the analysis is centred on cow-calf producer choice of different bull profiles described previously. Both conditional logit (CL) and random parameter logit (RPL) with and without socio-demographic interaction terms are estimated. The corresponding WTP estimates are derived in accordance with equations 21 and 22.

Table 2.16 shows the estimates of the CL and RPL base models. These models only include the traits of the bull as covariates. The RPL model was estimated under the assumption that all the traits i.e. genomic information, birthweight EPD, weaning weight EPD, feed efficiency EPD and accuracy of feed efficiency EPD followed a normal distribution. The price of the bull was assumed to be non-random.

In general, the signs of the parameter estimated were consistent with a priori expectation. Cow-calf producers preferred bulls with genomic information on feed efficiency and higher feed efficiency EPDs. In contrast, producers tended to discount bulls with higher birthweight EPDs. This is unsurprising as high birthweights are associated with calving difficulties and calf mortality.

Given that these expected progeny differences (EPDs) represent an estimate of the performance of the bull's progeny it can be deduced that producers prefer bulls that produce feed efficient calves and lower birthweights. The parameter estimates of both the weaning weight EPD and the accuracy of the feed efficiency EPD were positive but not significant. Further, the sign of the coefficient of the bull price indicates that cow-calf producers prefer lower cost bulls. The significance of the standard deviation of the random components in the RPL specification indicates that the including the mixing structure was appropriate.

Table 2.16: Estimates of results: Base conditional and random parameter logit estimates

Bull traits	Model 1: CL		Model 2: RPL	
	Coefficient	SE	Coefficient	SE
Price	-0.20D-03***	(0.00)	0.28D-03***	(0.00)
Genomic info.	0.41***	(0.14)	0.52***	(0.17)
Birthweight EPD	-0.03***	(0.01)	-0.04***	(0.01)
Weaning weight EPD	0.07	(0.07)	0.10	(0.08)
Feed Efficiency EPD	1.98***	(0.40)	2.33***	(0.48)
Acc. of Feed Efficiency EPD	0.01	(0.02)	0.02	(0.02)
Neither	0.06	(0.90)	-0.15	(1.07)
Standard deviations of random parameters				
Genomic info.			0.55	(0.28)
Birthweight EPD			0.08***	(0.01)
Weaning weight EPD			0.16***	(0.03)
Feed efficiency EPD			1.22*	(0.74)
Acc. of Feed efficiency EPD			0.03***	(0.00)
LL	-1307.81		-1210.48	
R^2	0.14		0.23	
Number of obs.	1428		1428	

Note: ***, **, * indicate significance at the 1%, 5%, and 10% significance level, respectively.

To account heterogeneity generated by demographics and farm practices etc. these variables were interacted with the bull traits. As evident from Table 2.17 these farm/farmer characteristics do in fact affect cow-calf producer valuation of bull traits.

Table 2.17: Conditional and random parameter logit estimates including cow-calf producer socio-demographics terms and farm practices

Bull traits	Model 3: CL		Model 4: RPL	
	Coefficient	SE	Coefficient	SE
Price	- 0.22D-03***	(0.00)	-0.28D-03***	(0.00)
Genomic info.	-0.04	(1.04)	-0.29	(1.19)
Birthweight EPD	0.08	(0.06)	0.14*	(0.09)
Weaning weight EPD	0.31*	(0.16)	0.33	(0.23)
Feed Efficiency EPD	0.62	(3.94)	1.87	(4.50)
Acc. of FE EPD	0.03	(0.03)	0.04	(0.04)
Neither	-0.05	(0.07)	-0.04	(1.11)
Genomic information				
Age	0.01	(0.01)	0.01	(0.01)
Size	-0.16D-03	(0.00)	0.26D-03	(0.00)
Male	0.17	(0.31)	0.16	(0.37)
Income	0.36D-03	(0.00)	0.20D-03	(0.00)
Education	-0.02	(0.05)	-0.03	(0.07)
AI	0.22***	(0.07)	0.26***	(0.08)
Science & Tech	-0.22	(0.20)	-0.14	(0.22)
BMPs	0.09**	(0.04)	0.08	(0.05)
Birthweight EPD				
Age	-0.72D-03	(0.00)	-0.14D-02*	(0.00)
Size	0.12D-04	(0.00)	-0.55D-04	(0.00)
Male	-0.24D-02	(0.02)	-01	(0.03)
Income	-0.78D-04**	(0.00)	-0.95D-04*	(0.00)
Education	-0.30D-02	(0.00)	-0.42D-02	(0.00)
AI	-0.78D-02**	(0.00)	-0.01**	(0.01)
Science & Tech	-0.02*	(0.01)	-0.02	(0.02)
BMPs	0.45D-02*	(0.00)	0.41D-02	(0.00)
Weaning weight EPD				
Age	-0.22D-02	(0.00)	-0.20D-02	(0.00)
Size	-0.43D-04	(0.00)	-0.38D-04	(0.00)
Male	-0.77D-02	(0.00)	0.01	(0.07)
Income	-0.43D-04	(0.00)	-0.11D-04	(0.00)
Education	-0.02*	(0.01)	-0.02*	(0.01)
AI	0.01	(0.01)	0.01	(0.01)
Science & Tech	0.28D-02	(0.03)	-0.14D-02	(0.04)
BMPs	0.01*	(0.01)	0.01	(0.01)
Feed efficiency EPD				
Age	-0.03	(0.04)	-0.05	(0.04)
Size	-0.20D-02	(0.00)	-0.28D-02	(0.00)
Male	0.62	(1.10)	0.38	(1.29)
Income	-0.27D-03	(0.00)	-0.23D-03	(0.00)
Education	-0.04	(0.20)	-0.11	(0.24)

AI	-0.03	(0.22)	0.05	(0.26)
Science & Tech	0.69	(0.73)	0.72	(0.83)
BMPs	0.25	(0.16)	0.36*	(0.19)
Acc. feed efficiency EPD				
Age	-0.22D-03	(0.00)	-0.27D-03	(0.00)
Size	-0.54D-05	(0.00)	0.17D-04	(0.00)
Male	-0.62D-02	(0.01)	-0.93D-02	(0.01)
Income	0.36D-04***	(0.00)	0.49D-04***	(0.00)
Education	0.70D-03	(0.00)	0.50D-03	(0.00)
AI	-0.15D-03	(0.00)	0.40D-03	(0.00)
Science & Tech	0.19D-02	(0.00)	0.38D-02	(0.01)
BMPs	-0.26D-02**	(0.00)	-0.25D-02*	(0.00)
Standard deviations of random parameters				
Genomic info.			0.33	(0.24)
Birthweight EPD			0.08***	(0.01)
Weaning weight EPD			0.14***	(0.06)
Feed efficiency EPD			1.29*	(0.66)
Acc. of Feed efficiency EPD			0.03***	(0.00)
LL	-1207.59		-1116.93	
R^2	0.18		0.26	
Number of obs.	1428.00		1428.00	

Note: ***, **, * indicate significance at the 1%, 5%, and 10% significance level, respectively.

From the CL model estimates (Model 3 Table 2.17), higher levels of AI usage and number of BMPs were associated with a stronger preference for bulls with genomic information on feed efficiency. This is consistent with a priori expectation. Knowledge about science and technology did not seem to have any effect on preference for genomic selection as were age, gender, education and income. Comparatively, the effect of these variables on preferences for the other feed efficiency related traits was mixed. While the sociodemographic and production related variables had no effect on preferences for the feed efficiency EPD, higher levels of income positively impacted the probability of a cow-calf producer selecting a bull with higher accuracy of feed efficiency EPD values. Farmers who reported undertaking more BMPs however, discounted bulls with higher accuracy values. In some sense, the accuracy of the feed efficiency EPD is a measure of the degree of confidence that can be attached to the feed efficiency EPD, and it seems cow-calf producers do not perceive this as a "value addition".

With respect to the other bull traits, cow-calf producers who reported higher levels of income discounted the birthweight EPD. The effect of AI and knowledge about science and technology on preferences for bulls with higher birthweight EPDs was also negative. Conversely, cow-calf producers with higher BMPs expressed relatively lower disutility for bulls with high birthweight EPDs scores. Higher weaning weight EPD values had a positive impact on the producer preference for bulls although more educated producers discounted the trait. The effect of BMPs on producer preference for bulls with higher weaning weight EPD values was positive.

With few exceptions, the RPL model estimates (model 4, Table 2.17) were similar to the CL estimates. For example, as compared to the CL, the coefficient estimate of birthweight EPD was positive and significant in the RPL. Older farmers tended to discount the birthweight EPD whilst the number of BMPs had a positive impact on the probability of a cow-calf producer choosing a bull with a higher feed efficiency EPD score. For genomic information on feed efficiency, the effect of the AI variable was robust in both the RPL and CL regression estimates.

Based on the coefficient estimates from reported in the Tables 2.16 and 2.17 and following equations 21 and 22, mean WTPs for the different cattle traits were estimated (Table 2.18). Willingness to pay for the feed efficiency EPD was rescaled by 100 to ensure a common basis with the other traits. A similar approach was used to rescale the genomic information trait to ensure that the feed efficiency traits were comparable on a per unit basis.

As evident from the WTP estimates, cow-calf producers discounted birthweight- the range of mean WTP was $143.60 to -150.74. Willingness to pay for genomic information on feed efficiency was positive and ranged from $18.84 to 19.34. Willingness to pay for the more conventional feed efficiency EPD ranged from $84.51-93.74.

Table 2.18: Estimates of willingness to pay for the different bull traits

Bull Trait	CL	95% Confidence Interval	RPL	95% Confidence Interval
		Estimates based on model without interaction terms		
Genomic info. ($/ cwt)	19.34***	[6.01,32.67]	18.84***	[6.62,31.06]
Birthweight EPD ($/bull per lbs. increase)	-143.60***	-200.72, --86.48]	-150.74***	[-220.72, -80.77]
Weaning Weight EPD ($/bull per lbs. increase)	346.29	[-304.37,996.95]	371.27	[-227.43, 969.94]
Feed Efficiency EPD ($/ cwt)	93.74***	[56.27, 131.20]	84.50***	[48.85,120.16]
Accuracy of FE EPD ($/bull per % increase)	64.07	[-94.78,222.91]	62.15	[-82.59,206.89]
	CL	95% Confidence Interval	RPL	95% Confidence Interval
		Estimates based on model with demographic and farm characteristics		
Genomic info. ($/ cwt)	18.84***	[6.62,31.06]	19.70***	[7.11,32.29]
Birthweight EPD ($/bull per lbs. increase)	-150.74***	[-220.72,-80.77]	-180.91***	-256.58, -105.23]
Weaning Weight EPD ($/bull per lbs. increase)	371.26	[-227.43,969.94]	299.40	[-311.95910.74]

Feed Efficiency EPD ($/ cwt)	84.51***	[48.85,120.16]	88.81***	[52.39,125.23]
Accuracy of FE EPD ($/bull per % increase)	62.15	[-82.59,206.89]	77.08	[-71.50,225.66]

2.7.8 Likelihood Ratio Test of Model Significance

In the rest of this paper, the distribution of WTPs by different risk perceptions, retained cattle ownership practices and knowledge about genomic information is examined. To select the appropriate model for this, a likelihood (LR) ratio test of model significance was implemented to assess whether the additional interaction terms significantly improved model fit. For each of the CL (models 1 versus 3) and RPL (models 2 versus 4). As shown in Table 2.19 the null that the addition of the extra interact terms did not significantly improve model fit is strongly rejected (χ^2_{40} =63.69). On the basis of this and the significance of the standard deviation terms in the RPL model, we proceed to use the estimates of the RPL with interaction terms for the rest of the analysis.

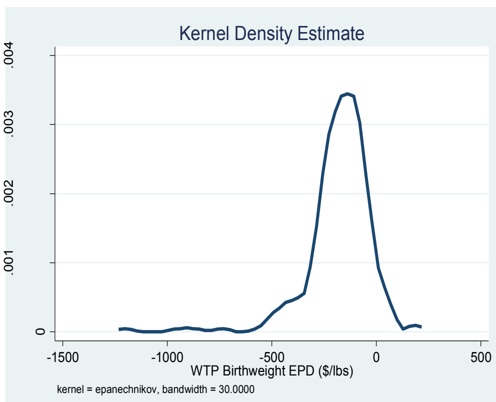
Table 2.19: Results of likelihood ratio test of model significance

	Test statistic	# of restrictions
Conditional Logit		
Base model vs. model with interaction terms	200.44***	40
Random Parameter Logit		
Base model vs. model with interaction terms	187.10***	40

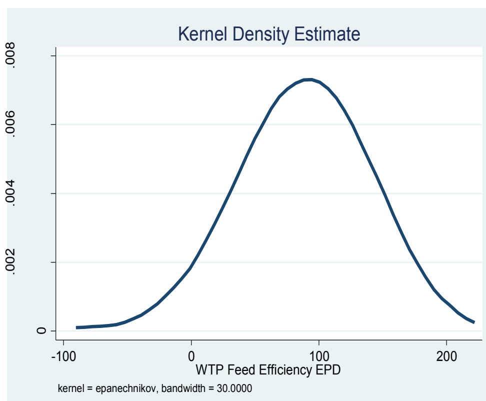
Note: ***, **, * indicate significance at the 1%, 5%, and 10% significance level, respectively

2.7.9 Kernel Distribution of Willingness to Pay for Bull Traits

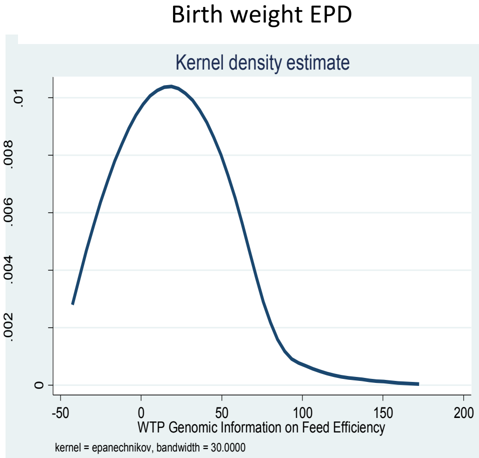
Kernel density estimators were plotted to examine the WTP for the three traits with significant WTP. With the exception of birth weight, cow-calf producers generally had positive willingness to pay for all the other traits (Figure 2.14). The distribution of WTP for the feed efficiency EPD was generally normally distributed with slightly negative skewness (-0.65). In contrast, WTP for genomic information on feed efficiency more positively skewed. Willingness to pay for birthweight EPD was negatively skewed.



Birth weight EPD



Feed Efficiency EPD



Genomic information on feed efficiency

Figure 2.14: Kernel density distribution of bull traits

2.7.10 The Effect of Attitudes and Knowledge on Willingness to Pay for Bull Traits

Figures 2.15-2.20 show the distribution of WTP for the feed efficiency EPD and Genomic information on feed efficiency by environmental risk perception (Figure 2.15), NEP scale (Figure 2.16), NHIP scale (Figure 2.17), knowledge about genomics (Figure 2.18), retained ownership (Figure 2.19) and risk attitudes (Figure 2.20). The results suggest a strong evidence of preference heterogeneity as WTPs differed widely across these attitudes and within sample for a given attitudinal variable. Despite being measures of the same trait, the effect of the different attitudes on WTP for the feed efficiency related traits were not necessarily identical across all the attitudinal variables examined.

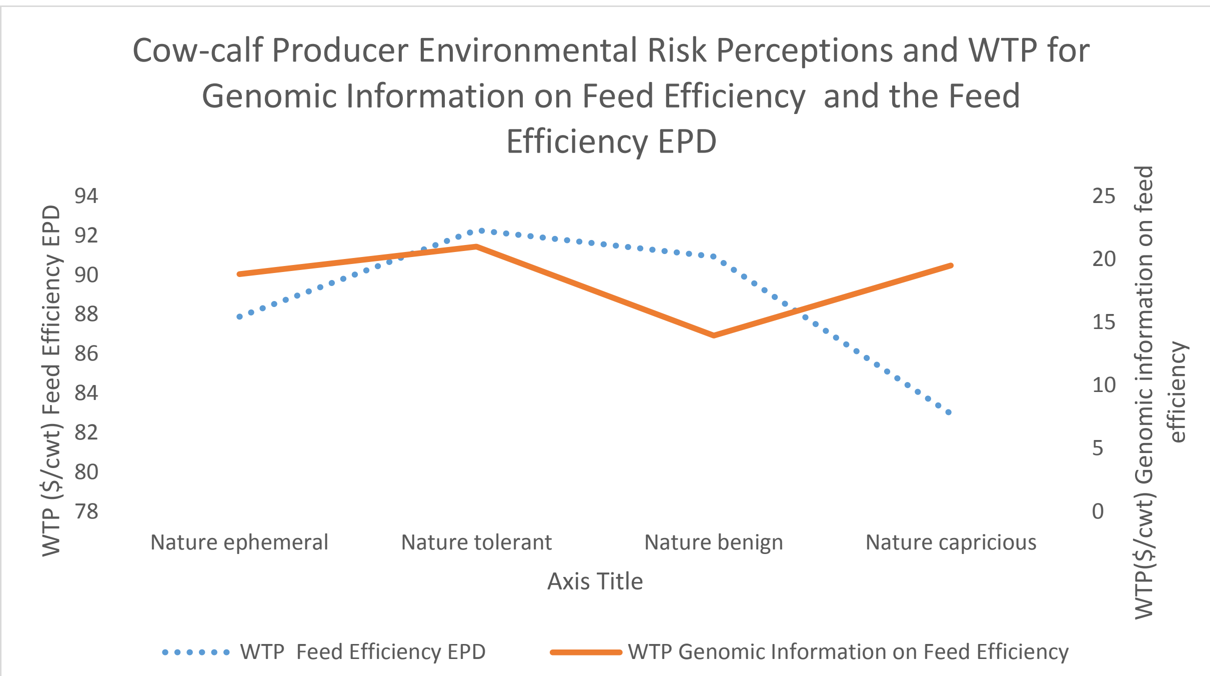


Figure 2.15: Effect of environmental risk perception on WTP for feed efficiency related traits (Source: Author's own)

Figure 2.15 shows the distribution of WTP for the feed efficiency related traits by environmental risk perception scores ("myths of nature"). Mean WTP for genomic information was highest for respondents with the nature tolerant view ($20.99) and lowest for those with the nature benign view ($13.94). Respondents with nature tolerant views have an intermediate view of environmental risk and believe that nature is robust up to a certain threshold. In comparison, individuals with nature benign views have low environmental risk perceptions and believe that nature is resilient. In the case of feed efficiency EPD, WTP was also highest ($92.27) for cow-calf producers with nature tolerant views. Producers with nature capricious category views reported the lowest WTPs for the feed efficiency EPD ($82.95). Given that most respondents in the survey had nature tolerant views, the link between WTP for genomic information on feed efficiency in particular and these myths of nature suggests that producers associate the use of the technology with moderate environmental risk reduction. Mean WTP was however not significantly different between the two polar views on nature (nature benign versus nature ephemeral views) and the feed efficiency related traits (Table 2.20).

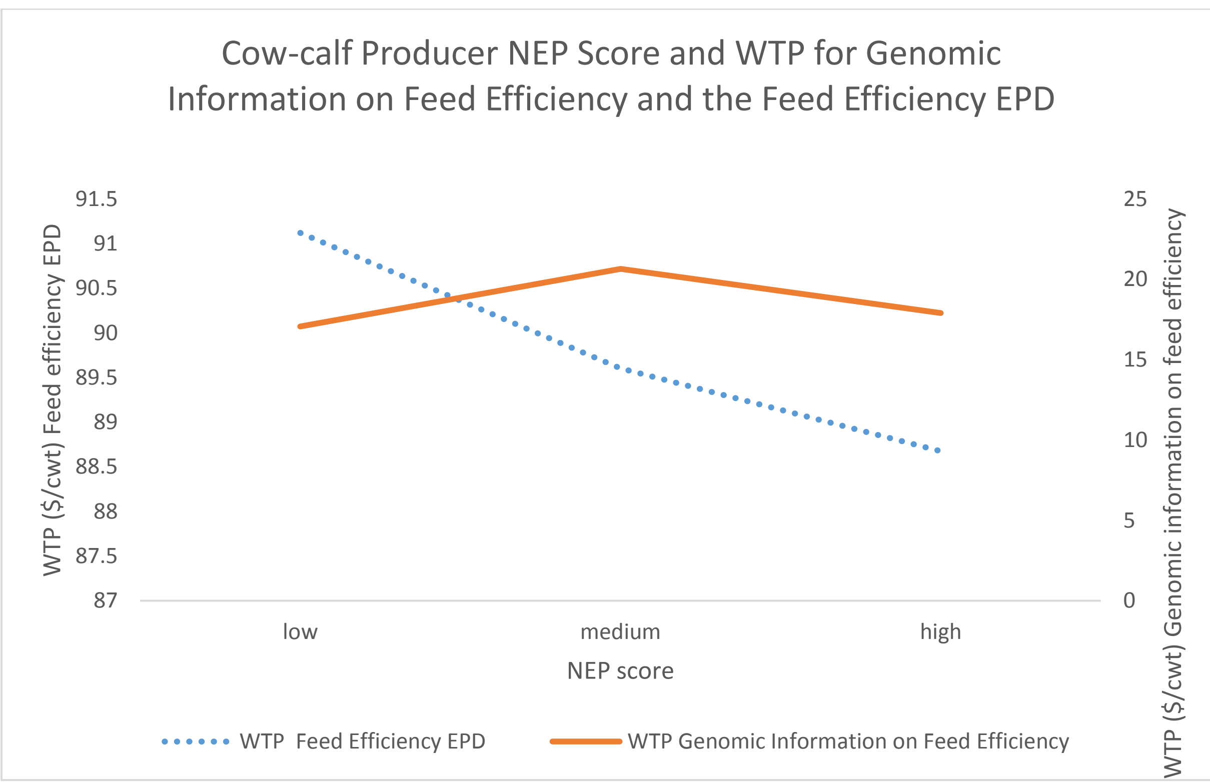


Figure 2.16: NEP scores and WTP for feed efficiency related traits (Source: Author's own)

The two environmental worldviews (NEP and NHIP scales) had opposing effect on WTP for genomic information on feed efficiency and the feed efficiency EPD (See Figures 2.16 and 2.17 respectively). High NEP scores were associated with high WTP for genomic information and low WTP for the feed efficiency EPD. In contrast to relationship between respondents' WTP and their NEP score, the relationship between the NHIP scores and the two feed efficiency related traits was positive. These differences in WTPs for the high and low categories of the NEP and NHIP attitudes were however not significantly different (see Table 2.20).

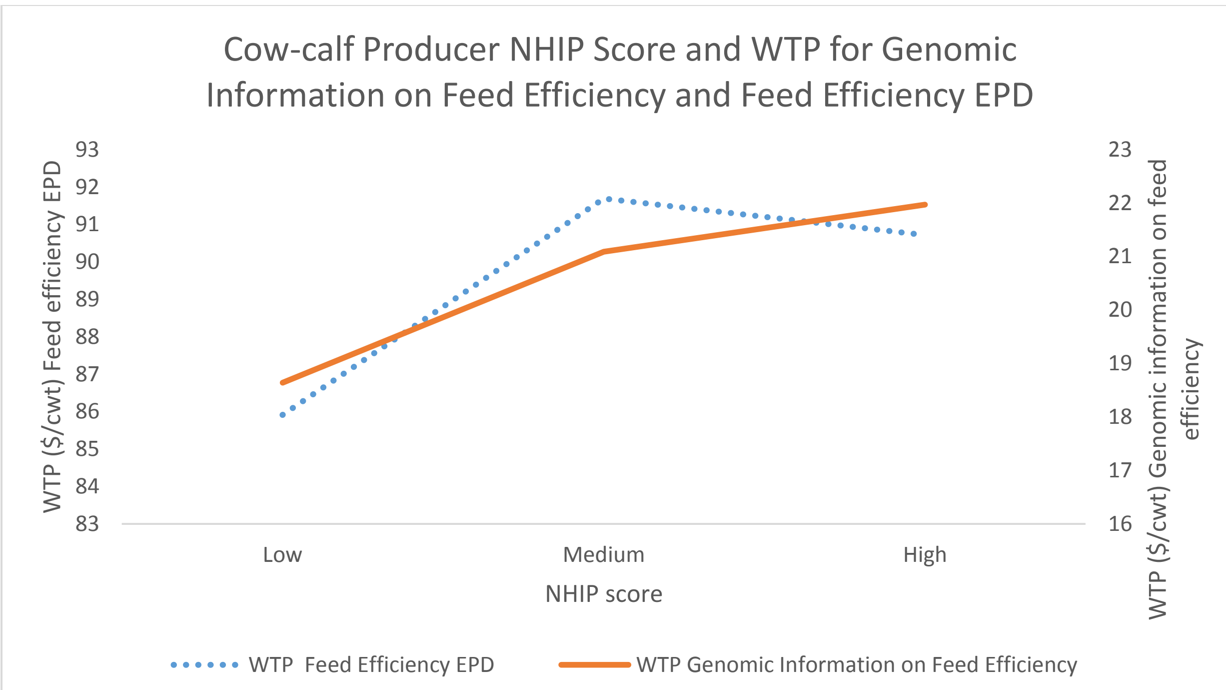


Figure 2.17: NHIP scores and WTP for feed efficiency related traits (Source: Author's own)

In addition to environmental attitudes, the effect of risk attitudes on cow-calf producer WTP for genomic information on feed efficiency and the feed efficiency EPD was also analyzed. As showed in Figure 2.18, Producers in the highest self-reported risk attitude[22] category expressed

[22] Risk scores were re-categorized into 4 categories.

significantly higher WTP ($138.51) for the feed efficiency EPD as compared to those in the lowest category ($50.16). Willingness to pay for genomic information on the trait was also significantly higher in the higher risk category as compared to cow-calf producers who reported preferring low levels risk. The mean WTP genomic information on feed efficiency for the low and high risk categories were $15.28 and $20.71 respectively.

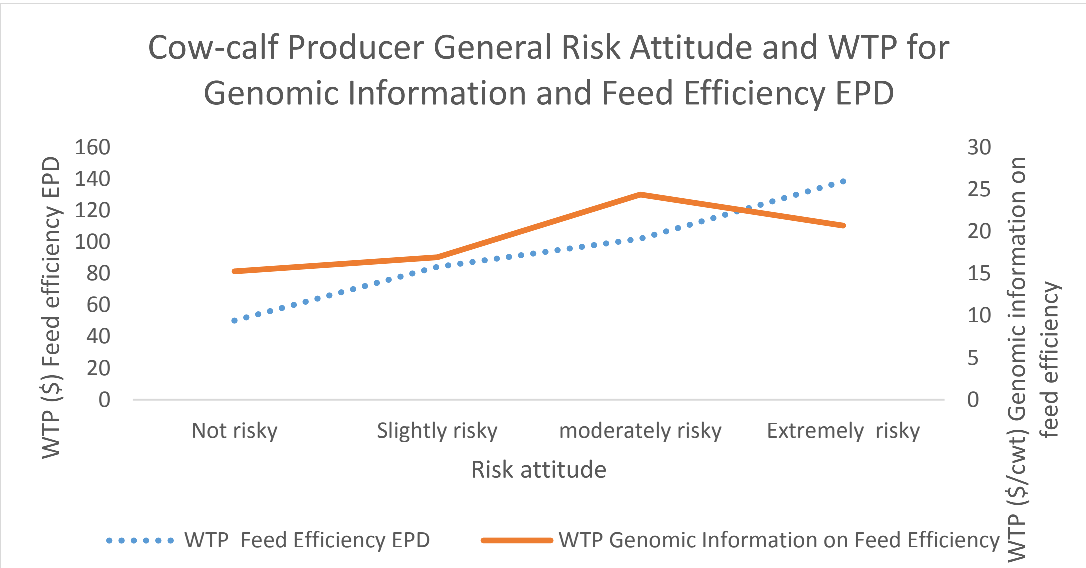


Figure 2.18: Cow-calf producer risk attitude and WTP for feed efficiency related traits (Source: Author's own)

The effect of knowledge about genomic information on cow-calf producers WTP was also evaluated. As shown in Figure 2.19, WTP for genomic information on feed efficiency was positively related to the knowledge about the use of genomics in cattle selection. Cow-calf producers who were most familiar with genomics attached significantly higher values ($40.67) to the trait as compared to $16.07 by producers least knowledgeable about the use of the technology. Similar outcomes were observed for the feed efficiency EPD.

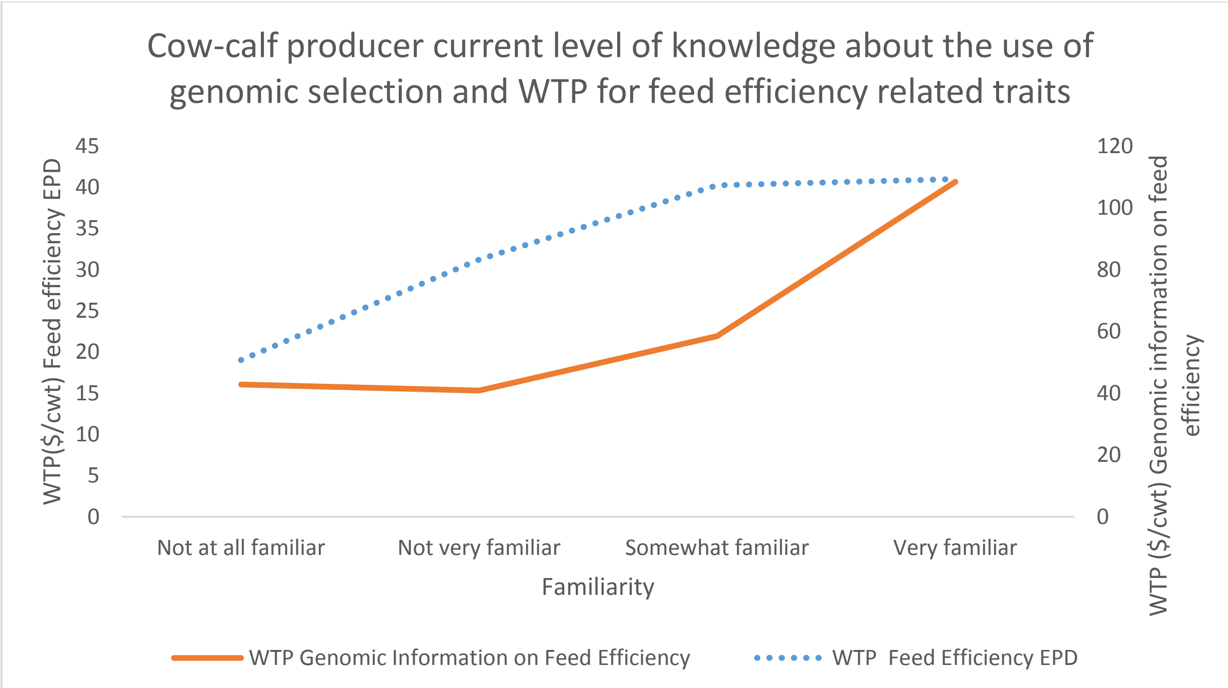


Figure 2.18: Effect of knowledge of Genomics on feed efficiency related traits (Source: Author's own)

From Figure 2.20, there seems to be a systematic positive relationship between WTP for genomic information on feed efficiency and calf retention practices. The segment of cow-calf producers in the practice of retaining calves till slaughter age expressed significantly higher WTP ($30.94) as compared to those that marketed calves at weaning ($18.38). In comparison, the relationship between calf retention practices and WTP for the feed efficiency EPD is less clear. Producers in the high calf retention category had marginally higher WTP ($84.87) as compared to those in the low frequency category ($82.54). The difference in WTP was however, not significantly different.

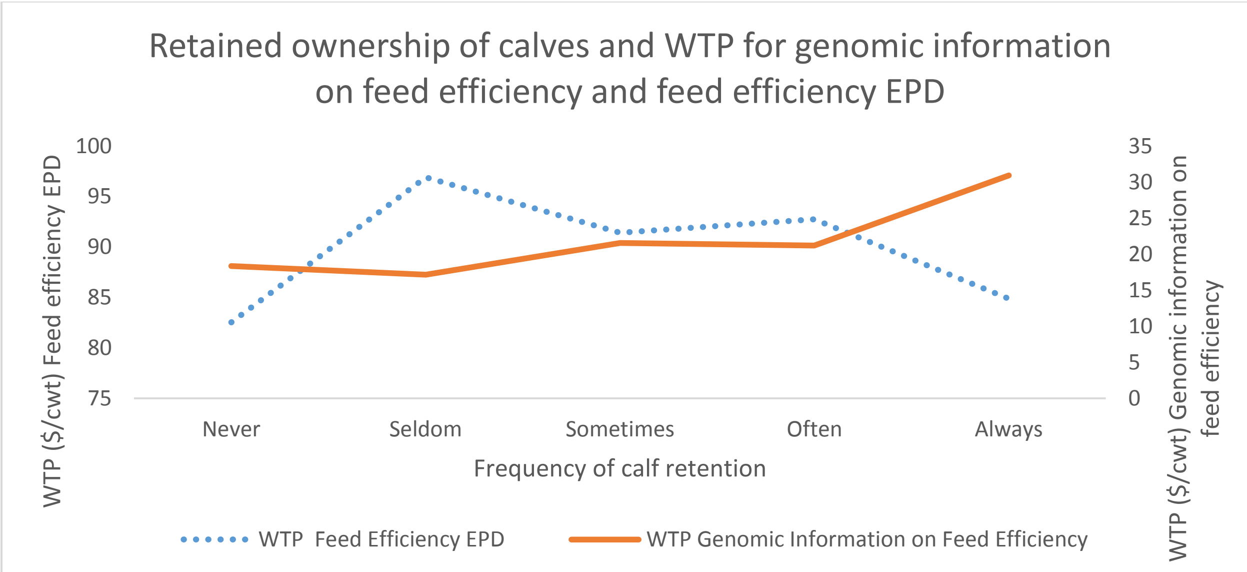


Figure 2.19: Retained ownership practices and willingness to pay for feed efficiency related traits (Source: Author's own)

Table 2.20 is the summary of the t-test of significance of mean difference in WTP for the different attitudinal, farm production practices and knowledge variables examined[23].

Table 2.20: Effect of attitudes and knowledge variables on willingness to pay for feed efficiency related cattle traits

Attitude	WTP ($) for Genomic Information on Feed Efficiency	WTP ($) for Feed Efficiency EPD
NEP Score		
High NEP Score	20.64 (n=14)	88.67(n=14)
Low NEP Score	17.06 (n=56)	91.12(n=56)
	t-Stat=2.10	t-Stat=2.11
NHIP Score		
High NHIP Score	21.97(n=67)	90.71(n=67)
Low NHIP Score	18.64(n=122)	85.91(n=122)
	t-Stat =1.97	t-Stat =1.98
Environmental Risk Perception		
Nature Ephemeral	18.81(n=52)	87.87(n=52)
Nature Benign	13.94(n=13)	90.93(n=13)

[23] The table section 2.11 is an RPL model that includes the attitudinal variables.

	t-Stat = 2.06	t-Stat = 2.10
General Risk		
Not Risky	15.28(n=23)	50.16(n=23)
Risky	24.32(n=89)	138.51(n=89)
	t-Stat =2.00**	t-Stat = 2.04***
Frequency of calf retention to finishing		
Never	18.38(n=120)	82.54(n=120)
Always	30.94(n=15)	84.87(n=15)
	t-Stat = 2.12*	t-Stat = 2.10
Knowledge about the use of genomics		
Not at all familiar	16.07(n=46)	50.75(n=46)
Very familiar	40.67(n=14)	109.32(n=14)
	t-Stat = 2.09***	t-Stat = 2.05***

Note T-test of significance of means was conducted between the highest and lowest indicators in each category. ***, **, * indicate significance at the 1%, 5%, and 10% significance level, respectively

2.7.11 Cow-calf producers who opt-out

In this section, the characteristics of respondents who choose the opt-out option in all six choice tasks are compared with those who chose at least one of the choices presented. Cow-calf producers in the opt-out category make-up about a tenth of the entire sample. Overall, respondents in the opt-out category were almost identical to those in the opt-in category. This notwithstanding, they tended to be older and more educated. Farm size and income were higher in the opt-in category despite not being significantly different.

Table 2.21: Profile of cow-calf producers that opted-in and out of the choice task

Variable	Opt-in	Opt-out	t-critical
Age	51.35	56.35	2.05**
Income (‘000)	131.79	125.07	2.01
Farm size	122.72	211.09	2.07
Education	13.28	14.09	2.05*
Gender	0.86	0.91	2.05
Number of BMPs	6.70	6.87	2.05
Observations	219	23	

Note: ***, **, * indicate significance difference in means at the 1%, 5%, and 10% significance level, respectively

2.8 Discussion

The results of this study indicate that cow-calf producers attach positive significant values to feed efficiency as showed by the positive WTPs for the feed efficiency EPD and Genomic information on feed efficiency. The mean WTP[24] for the feed efficiency EPD \$84.51 is lower than the value for the same trait (i.e. \$319) reported by McDonald et al. (2010) for a unit improvement in feed efficiency but higher than the \$59.49 reported in Brimlow and Doyle (2014). Although positive, mean WTP (\$18.84) for genomic information on feed efficiency was lower than for the feed efficiency EPD. Mean WTP for increased accuracy of the feed efficiency of EPD was however not significant.

The significant role of genomic information in this study is contrary to the results of Vestal et al. (2013). This is however not unexpected as the sample of respondents and the context of the two studies are not identical. This paper focussed on WTP pay for genomic information as it pertains to a specific trait whilst Vestal et al. (2013) examine the value of DNA profile information (markers) in a more generic context. The results from these studies may suggest that cow-calf producers attached significant values to trait specific information and to genomics as compared to other DNA related sources of information.

Mean WTP estimate for birthweight EPD (-\$197.33) in this study was higher than the Brimlow and Doyle (-\$117.65), Jones et al. 2008(-\$139.06 to -\$128.78) and Vestal et al. (2013) (-\$106.20- -\$73.65) but lower than McDonald et al. 2010's estimate (-\$543.00). Further, the present estimate for the trait was within the range (-\$287 to -\$98) estimated by Vanek et al. (2008). Considering that a number of the reported studies used actual bull auction data, the comparability of the estimates of these different studies with that of the present study may indicate that cow-calf

[24] Based on the estimates of the RPL with farm and farmer interaction terms.

producer preference for birthweight is relatively stable. The mean estimated value for the birthweight EPD was also higher than the -$38.03 to -$68.05 range estimated by Walburger (2002) in a study of implicit prices for bulls in Alberta. Walburger (2002)'s estimates were for actual bull traits and not EPDs. The difference between Walburger (2002)'s study and the present analysis value may be point to the fact that producers attach higher values to expected productivity as compared actual traits (Jones et al. 2008). The WTP for weaning weight was not significant. It is not uncommon for weaning weight to be expressed as a ratio of weight or age and the presence of both birthweight and weaning weight as individual traits may have accounted for the insignificance of the latter. Previous studies (e.g. McDonald et al. 2010) reported a WTP for birth for yearling weight EPD[25] of approximately $101.

The results of this study are generally consistent with outcomes of previous studies that show that cow-calf producers have a stronger preference for output traits. In the present study, this outcome is supported by the estimates of WTP for feed efficiency ($89.26) as compared to birthweight (-$197.33) for example. This result is not unexpected, as birthweight is associated with calf mortality and therefore directly beneficial to the cow-calf producer whose main source of revenue is from the sale of weaned calves. In contrast, the direct benefit of improved feed efficiency to the cow-calf is less clear. Although the integration of measures of feed efficiency in traditional selection tools is nascent, the higher WTP for the feed efficiency EPD as compared to genomic information for the same trait may be partly due to increased familiarity with EPD based performance measures. The relative values attached to the two feed efficiency related traits may also indicate that cow-calf producer are willing to pay extra for genomic information on feed efficiency as an additional source of information. The results further suggest that in the presence of both genomic

[25] a transformed trait

information on feed efficiency and the feed efficiency EPD, producers place a limited value on the accuracy of the feed efficiency EPD. It is plausible that producers consider the additional genomic information trait as enhancing the certainty of the feed efficiency EPD therefore making the accuracy trait redundant. The results of this study also provide evidence to support the notion that preference for a bull's characteristics differ across different producer socio-economic attributes. This notwithstanding, environmental attitudes as measured with the NEP and NHIP attitude scales generally had a limited impact on WTP for genomic information on feed efficiency and the feed efficiency EPD.

The largest category of cow-calf producers hold a nature tolerant view i.e. that, "Environmental problems are not entirely out of control, but the government should dictate clear rules about what is and what is not allowed". This category of producers also expressed the highest WTP for both genomic information on feed efficiency the feed efficiency EPD. Although WTP for the polar myths of nature (nature ephemeral and nature benign) was not significantly different, the dominance of the risk tolerant view, may have significant implications for role of government or external agencies (cattle producer groups, industry associations etc.) in the promotion of the adoption of genomics for the selection of feed efficient cattle.

Retained management of cattle was associated with positive WTP for genomic information on feed efficiency. This outcome is consistent with a priori expectation, as the additional investment in genomics can be viewed as a "value add" activity by the cow-calf producer. By retaining calves till finishing, producers are internalizing the entire benefit of the genomic bull as well-defined markets for feed efficient calves do not exist. This highlights the potential impact of supply chain considerations on producer WTP. The risk perceptions of respondents are positively related to both the Genomic information on feed efficiency and the feed efficiency EPD. Also, producers who reported being more knowledge about genomic selection for feed efficiency expressed significantly higher WTP for genomic information on feed efficiency as compared to those who reported lower levels of familiarity.

2.9 Conclusions

This paper examined cow-calf producer WTP for genomic information on feed efficiency in a multi-trait context using data from a nationwide survey of cow-calf producers in Canada. The results of the study show a stronger producer preference for traits directly linked to profitability i.e. birthweight as compared to feed efficiency related traits. This notwithstanding WTP to pay for the genomic information on feed efficiency and feed efficiency EPD is positive and significant indicating that positive demand may exist for the breeding technology. Additionally, it can also be gleaned from the results of this study that the co-existence of "low" and high tech" breeding applications i.e. EPDs and genomics, can be feasible as most of the factors examined had a similar effect on the two traits. Efforts are currently on-going to develop hybrid measures which combined both EPDs and genomics- so-called "Genomically-enhanced EPDs". Our study did not however evaluate preferences for these hybrid measures. This can be a fruitful area for future research.

The limited role of the environment environmental attitudes on WTP for genomic information on feed efficiency and the feed efficiency EPD may suggests that that cow-calf producers do not link the selection of feed efficient cattle to the environmental impact of cattle production. It may be that cow-calf producers are unclear about the effectiveness of the use of the technology on environmental outcomes or perceive that cattle production in general, does not have significant negative impacts on the environment. Majority of the cow-calf producers in the sample hold the nature tolerant viewpoint which is a more conservative view of environmental risk.

The lower values attached to feed efficiency may also be an outcome of the issue of the alignment of incentives within the beef cattle supply chain. Indeed, the significant effect of cattle retained management practices on WTP for genomic information on feed efficiency and the relative importance of the feed efficiency related traits as compared to the output trait examined support this conclusion. In an industry where output is valued on the latter traits it is not surprising that cow-calf producers may be less willing to invest in technologies related to so-called "feedlot" traits. In this regard, a useful extension to the present study will be the comparison of the value of genomic information related to more conventional traits such as birthweight and genomic information on feed efficiency. It seems the issue of the distribution of benefits along the value chain and increased familiarity with the technology would be key determinants of future uptake. Future studies examining feedlot cattle operators' preference for genomic information on feed efficiency related traits, will not only put the current estimates in context but facilitate the comparison of preferences for the same trait by different producers along the beef cattle supply chain. Further, future studies can incorporate the accuracy of genomic information in the experimental design. This will allow for the assessment of the value cow-calf producers attach to the accuracy of the trait. In the current study, the focus was on whether or not producers valued the availability of genomic information and not the degree of confidence per se.

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2.11 SUPPLEMENTARY RESULTS

Table 2.21: Random parameter logit estimates including producer demographics and environmental attitudes

Model 4: RPL

Attribute	Coefficient	Standard error
Price	-0.29D-03***	0.25D-04
Genomic info.	-0.48	1.41
Birthweight EPD	0.14	0.10
Weaning Weight EPD	0.18	0.26
Feed Efficiency EPD	-0.81	5.49
Accuracy of FE EPD	0.04	0.05
Neither	-1.11	1.22
Birth weight EPD		
Age	0.61D-03	0.88D-03
Size	0.36D-03	0.11D-03
Male	- 0.01	0.03
Income	0.11D-03**	0.55D-04
Education	-0.01	0.01
BMP	1.93D-03	3.96D-03
Science & Technology	-0.03*	0.02
AI	0.01**	0.01
MYTH1	0.07**	0.03
MYTH2	-0.01	0.02
MYTH3	-0.03	0.05
NHIP	0.03	0.10
NEP 1	-0.01*	0.01
NEP 2	0.01*	0.01
Weaning weight EPD		
Age	-0.13D-02	0.23D-02
Size	0.15D-03	0.28D-03
Male	0.08	0.08
Income	-0.80D-04	0.90D-04
Education	-0.73D-02	0.01
BMP	0.02**	0.01
Science & Technology	-0.04	0.05
AI	0.02	0.01
MYTH1	0.12	0.08
MYTH2	-0.01	0.06
MYTH3	0.12	0.13
NHIP	0.01	0.02
NEP 1	-0.02	0.01

NEP 2	-0.02	0.02
Feed Efficiency EPD		
Age	-0.03	0.05
Size	0.50D-03	0.01
Male	0.99	1.68
Income	0.20D-03	0.20D-03
Education	-0.51D-03	0.29
BMP	0.39*	0.22
Science & Technology	0.73	0.96
AI	0.05	0.28
MYTH1	0.08	0.14
MYTH2	0.70	2.68
MYTH3	-0.90	0.12
NHIP	0.19	0.34
NEP 1	0.16	0.32
NEP 2	-0.66	0.41
Genomic Information		
Age	0.02	0.01
Size	0.75D-03	0.16D-03
Male	0.07	0.44
Income	0.75D-03	0.15D-02
Education	0.01	0.07
BMP	0.08	0.06
Science & Technology	-0.24	0.25
AI	0.29***	0.09
MYTH1	-0.07	0.46
MYTH2	-0.31	0.33
MYTH3	-0.24	0.70
NHIP	0.05	0.09
NEP 1	-0.07	0.08
NEP 2	0.16	0.10
Accuracy of FE EPD		
Age	-0.50D-03	0.39D-03
Size	0.25D-04	0.49D-04
Male	-0.02	0.02
Income	0.53D-04**	0.21D-04
Education	0.51D-03	0.22D-02
BMP	0.31D-02*	0.17D-02
Science & Technology	0.77D-02	0.89D-02
AI	-0.11D-03	0.01
MYTH1	-0.02	0.01
MYTH2	-0.01	0.01
MYTH3	-0.01	0.02
NHIP	-0.20D-02	0.27D-02
NEP 1	0.22D-02	0.24D-02
NEP 2	-0.23D-02	0.33D-02

Standard deviations of random parameters

Genomic info.	0.40	0.25
Birthweight EPD	0.10***	0.02
Weaning Weight EPD	0.15***	0.03
Feed Efficiency EPD	1.82	1.32
Accuracy of FE EPD	0.03***	0.04
LL ratio	-960.91	
Number of obs	1428	
R^2	0.28	

Note: ***, **, * indicate significance at the 1%, 5%, and 10% significance level, respectively. Standard errors are given in parenthesis.

Chapter 3 : Adoption of Genomic Selection for Feed Efficiency in Beef Cattle Production Systems: An Ex-ante Analysis[26]

3.1 Introduction

The development and uptake of new technologies in agriculture has been an important contributor to increased productivity in both crops and livestock (Sunding and Zilberman, 2001). For livestock producers, the advent of the so-called *omic* technologies that allow producers to determine the quality of breeding animals based on their DNA profile, holds significant promise for the selection of a wide array of complex traits. For traits such as feed efficiency which are difficult to measure, the benefits of selecting cattle based on their DNA profile for the beef industry is enormous. The industry can obtain the benefit of a feed efficient herd i.e. lower feed costs and greenhouse gas emissions, without necessarily incurring the prohibitively high cost of measuring actual feed intake for a large cohort of cattle.

Cow-calf producers, are key agents if the use of genomic information in selective breeding is to have any effect on beef supply chains and/or a positive return to public investment in the technology. Irrespective of the overall public and industry benefits of a given innovation, cow-calf producers are unlikely to adopt if the private incentives are insufficient. For innovations relating to input traits, the issue of incentive alignment is crucial for a number of reasons. First, cattle ownership changes across the different phases of production as cattle move along the supply chain

[26] Earlier sections of this chapter has been published: Boaitey, A., Goddard, E., Mohapatra, S., and Crowley, J. (2017). Feed Efficiency Estimates in Cattle: The Economic and Environmental Impacts of Reranking. Sustainable Agriculture Research 6(2):35-47. Goddard, E., Boaitey, A., Hailu, G., and Poon, K. (2016). Improving sustainability of beef industry supply chains. British Food Journal, 118(6):1533-1552.

(i.e. cow-calf, backgrounding and finishing), one segment of producers (i.e. cow-calf producers) typically makes breeding decisions that affect the characteristics of animals that are subsequently fed by other agents and slaughtered by later participants in the supply chain. Cow-calf producers may incur the additional costs of using genomic bulls in their breeding strategy and benefits of traits like feed efficiency are realized further down the supply chain (feedlots for example). Second, beef cattle markets are output-oriented (Grier, 2005), which suggests that value signalling with respect to traits not directly linked to live weight, dressed weight or carcass quality may be currently weak or non-existent.

In this paper, a number of these highlighted supply chain issues are examined. A theoretical model of cow-calf producer choice of a bull in a multi-agent industry framework is developed. Key outcomes of the model are assessed using a multi-year stochastic optimization model. Based on evidence from a study by Kessler (2014), cow-calf producers are segmented into two groups- potential adopters and non-adopters of genomically selected bulls. The former decides whether they wish to purchase higher priced genomic bulls and produce higher feed efficient calves under different market conditions. The latter has no interest in genomically selected bulls and chooses to produce regular calves, with normal variation in feed intake across the animals. These calves, from both suppliers, are marketed to cattle feeders, who face the choice of a heterogeneous set of calves differentiated by their feed efficiency profiles. A number of scenarios under which cow-calf producers may adopt is also evaluated. These include: the payment of premium for feed efficient calves by feeders or the institution of cost-share subsidy programs.

This paper provides critical insights into producer incentive to adopt input oriented innovations in fragmented production systems in which points of uptake and realization of benefits differ. The contribution of this paper is unique as the distribution of value from input related innovations and the role of private incentives in the uptake of genomics by cow-calf producers have not be previously addressed.

The rest of the chapter is organized as follows; section 3.3 is an overview of the relevant literature. The theoretical framework is presented in section 3.4. Sections 3.5 and 3.6 describe the empirical framework and data sources. Results and discussion are captured in sections 3.7 and 3.8. The conclusions of the study are reported in section 3.9.

3.2 Literature Review

3.2.1 Agriculture Technologies and Producer Decision Making

The development and uptake of agricultural technologies involves a variety of actors (farmers, innovators), institutions (private sector, research organizations, governments) and actions (Caiazza et al., 2014). Based on the innovation systems approach, Spielman et al., (2016) identified three interrelated components of agricultural innovations- discovery, development and delivery (Figure 3.1). The discovery process describes the initiation of the scientific component of the innovation (Hall, 2004). The development stage marks the translation of the science into the actual technology and the subsequent commercialization. Delivery describes the diffusion of the technology (Spielman et al., 2016). This process refers to the adoption decisions by individual agents and the overall market uptake. The diffusion of innovations depends on the decision of primary agents to adopt. The uptake of new technologies is impacted by profitability (Griliches, 1957; Adrian et al., 2005), public and market based support measures (Stoneman and Diederen, 1994).

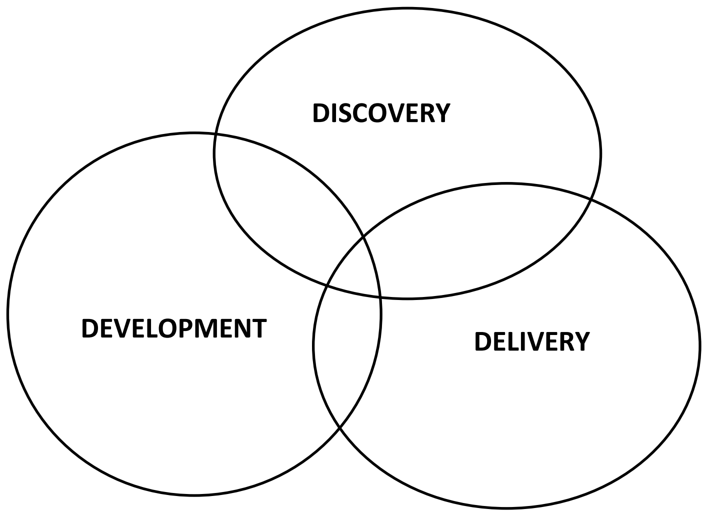

Figure 3.1: Technology uptake from discovery to diffusion (Spielman et al., 2016)

Several studies have evaluated farmer adoption decisions (see Federer and Umali, 1993). These studies can further be categorized as either ex ante or ex post. Ex-ante assessments are particularly suited for policy design in the case of new technologies in which behavior is inconsistent with existing policies or difficult to observe (Purvis et al., 1995).

Another strand of research has examined the issue of uncertainty about the returns and cost of technology adoption decisions (Purvis et al., 1995; Isik, 2004; Carey and Zilberman, 2002). Isik (2004) examined the impact of cost-share subsidy policy uncertainty on farmer adoption of technologies that reduce non-point pollution. The results of the simulation were consistent with the outcomes of the theoretical model- uncertainty regarding government policy did impact on adoption decisions. Isik (2004) also found that expectations regarding the introduction of punitive measures (fines) had a positive impact on the incentive to adopt. Evidence from studies (e.g.

Lalman and Smith, 2002) that have examined the adoption of management practices such as health programs and calf pre-conditioning by cow-calf producers show that the producers are incentivized by the ability to obtain premiums from other producers in the supply chain. Given that these programs directly impact output-reduced death loss, morbidity and carcass quality, value signalling with respect to these practices may less ambiguous as compared to input traits. The incentive to adopt even in these cases may be weak if existing premiums do not reflect the full value of the investment (Dhuyvetter, 2004).

3.2.2 Structure of Beef Cattle Supply Chain in Canada

The Canadian beef industry is a complex system that involves different participants (see Figure 3.2). The structure of this system has implications for the diffusion on innovation. Value is ultimately determined by consumers located at the end of the supply chain (Schroeder, 2003). These values are expressed through the price paid by these consumers for beef with different attributes. Further up the supply chain are breeders who determine the genetic make-up of breeding stock and cow-calf producers who make the decision on the type of bulls and cows to purchase in response to value signalling at the retail end. Between consumers and cow-calf producers are a host of intermediaries each adding incremental value to the product (beef) as it moves through the chain. The production segment of the beef value chain is comprised of cow-calf producers, backgrounders and feedlot operators (Figure 3.2).

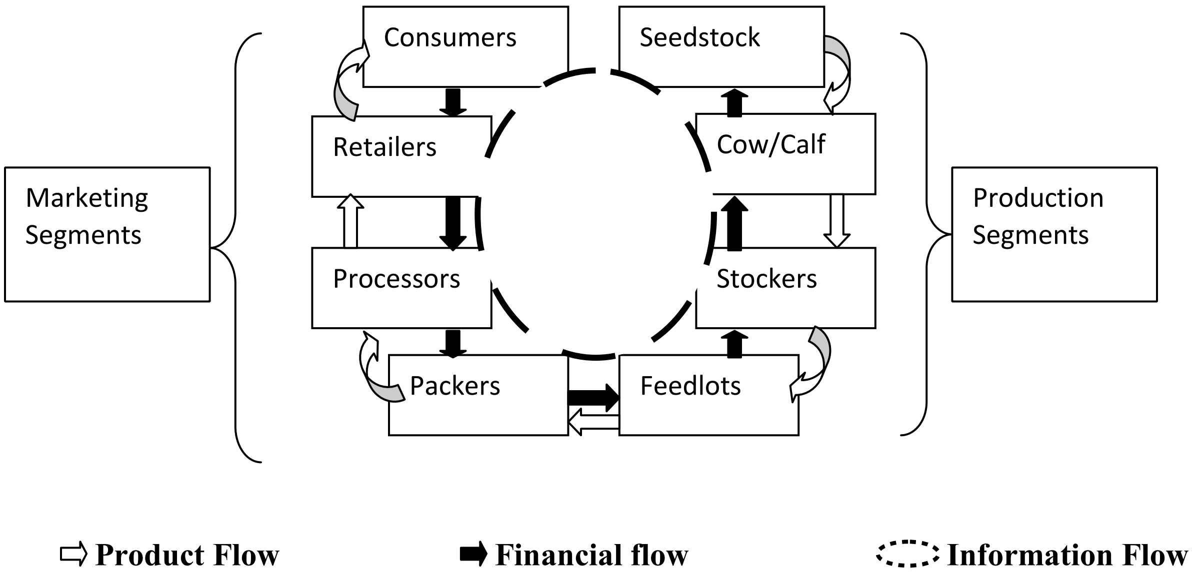

Figure 3.2: Information, product, and financial flows in beef industry (Source: Schroeder, 2003)

In addition to the fragmentation in production, the degree of concentration increases as one moves further down the supply chain. As evident from Figure 3.3, the structure of the supply chain in Alberta (for example) is such that a large atomistic cow-calf production segment supply cattle to a relatively concentrated feeding segment.

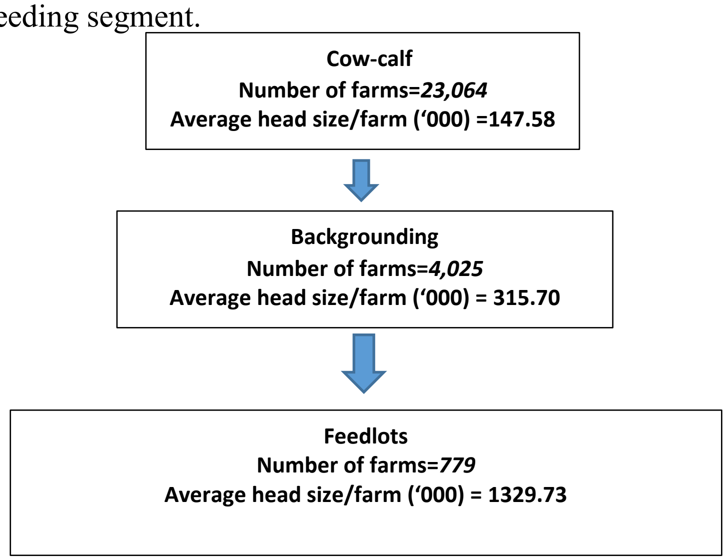

Figure 3.3: Alberta cattle inventory by farm type 1995-2014 (Agriculture and Agrifood Canada, 2015)

In general, the feedlot segment is dominated by large specialized operators co-existing with a number of relatively smaller size operations (Canadian Cattlemen's Association, 2017). Over time, reductions in the number of feeding operations have occurred whilst the average number of cattle per farm has increased (Figure 3.4 and 3.5). As shown in Figure 3.4, between 1995-2012 the average number of farms in western Canada, reduced from approximately 2000 to 730 farms, whilst the average herd size increased (543-1502 cattle/farm) over the same period (Figure 3.5).

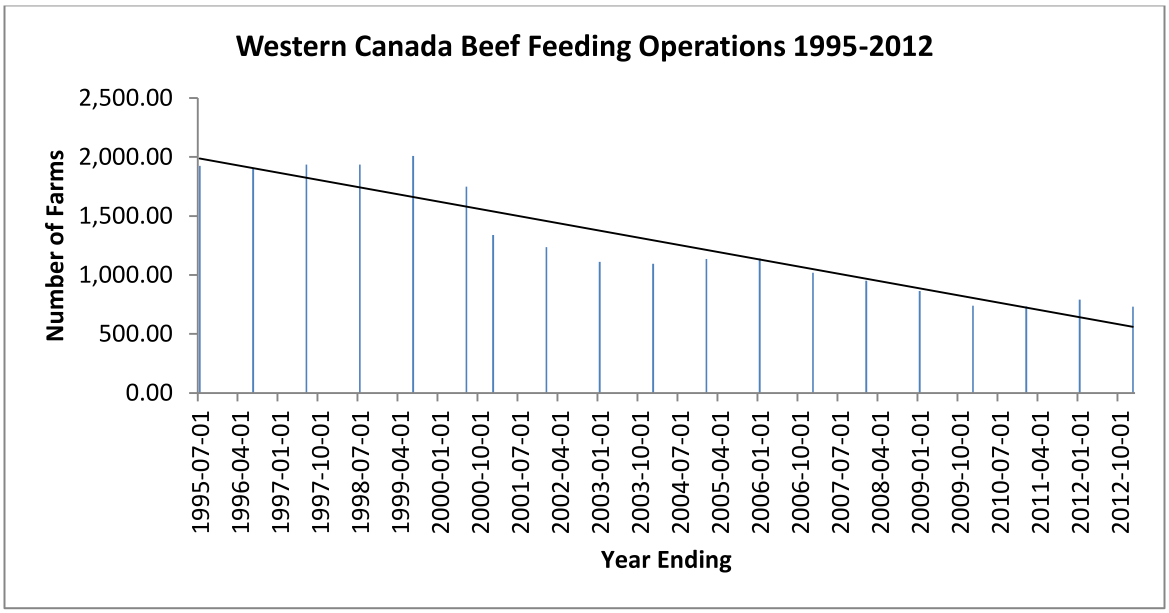

Figure 3.4: Western Canada: Number of feeding operations (Data: Statistics Canada, 2013)

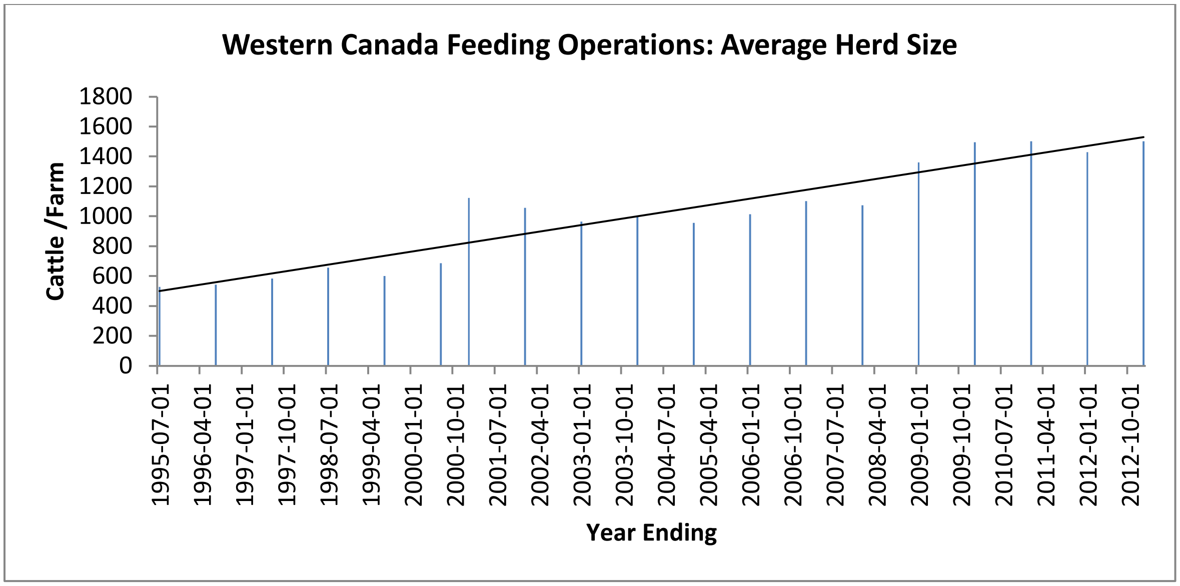

Figure 3.5: Western Canada Feeding Operations: Average herd size (Data: Statistics Canada, 2013)

In 2011, the composition of bulk capacity in Alberta and Saskatchewan consisted of finishing operations of head capacity; 1,000-5000(16%), 5001-10,000(19%); >10,001(65%) (Canfax, 2013). Moreover, over 50% of slaughter weight cattle in Alberta was produced by fewer than 20 feedlots (Beef Industry Alliance, 2009).

Additionally, the meat packing sector in western Canada is highly concentrated. For example, the two major beef packing firms i.e. JBS (4,000 head/day) and Cargill (4,500 head/day), have a combined capacity processing capacity of about 8500/head of cattle per day (Wingrove, 2012; Cargill, 2017). This notwithstanding, available empirical evidence suggests the absence monopsony power in the input market for fed cattle (Rude et al., 2011). This is partly due the existence of excess capacity in beef packing (Anderson et al., 2002).

An aspect of the market structure of beef cattle production that is likely to reinforce the emphasis on output traits is the use of captive supply arrangements by packers. This backward integration into the feeding segment through captive supplies may have direct implications for value signalling and innovation as packers place greater emphasis on carcass related traits.

Captive supply arrangements comprise the use of fed cattle purchased (Ward et al., 1998): i.) from packer owned feedlots; and, ii.) by exclusive marketing arrangement or forward contracts.

The concerns about these captive supply arrangements are driven by two interrelated factors. First, there has been a shift towards increased concentration in beef packing with a few firms processing the large proportion of cattle (Rude et al., 2011). Captive supplies can be an avenue for these packers to behave opportunistically and manipulate prices. Second, captive supplies can also result in the thinning of fed cattle (terminal) markets and lead to phenomenon where the cash market becomes the "lemon market" (Ward et al., 2007). This can dampen prices for fed calves in the spot market. The former effect has been the focus of several studies.

Although results of these studies (e.g. Zhang and Sexton, 2000; Ward et al., 1998; Schroeter and Azzam, 2004) are mixed, the general consensus is that a negative relationship exists between the existence of this market arrangement and fed calves price although this tends to be small (Ward et al., 1998; Schroeter and Azzam, 2004). Little has been done in the Canadian context with regards to captive markets. Anecdotal evidence suggests Canada is similar to the US given the degree of integration between the two markets (Ward et al., 2007).

3.2.3 Stimulating the Diffusion of Genomics: The Case of the Irish Data Genomics Programme

In addition to these market considerations, government can play an important role in the diffusion of agricultural innovation (Zilberman and Sunding, 2001; McVittie et al., 2009). This may become necessary if for example, the benefit of the innovation has "public good" characteristics such as the environmental benefits (Zilberman and Sunding, 2001; McVittie et al., 2009). Or when initial investments are required to stimulate uptake (Zilberman and Sunding, 2001).

Ireland has recently launched a Beef Data Genomics Programme (BDGP) with the objective of collecting data information on selected beef cattle. Key features of the programme are highlighted in Figure 3.6 below. Under this cost share program, beef farmers receive payments (subsidies) for genotyping their cattle (Department of Agriculture, Food and the Marine 2016). This facilitates the establishment of a comprehensive genetic database for genomic selection in the beef cattle herd with the overarching goal of improving feed efficiency, reducing greenhouse gas (GHG) emissions and increasing the genetic quality of the entire national herd (Department of Agriculture, Food and the Marine, 2016). The program spans a 6-year period (2015-2020) with a budget of approximately £300 million. Summarily, beef farmers enrolled in the program are required to genotype their cows, meet the requisite cattle reporting and replacement requirements and complete the Carbon Navigator- an on-farm management tool that estimates the environmental improvements from key production practices. The regulatory functions under the scheme are performed by the Irish Cattle Breeding Federation (ICABF) and Department of Agriculture, Food and the Marine (DAFM). The regulators select the cattle to be genotyped, make payment, provide training and ensure compliance.

According to the DAFM (2016), 29,770 producers initially applied to the program. In terms of cattle inventory this represents a little over half a million animals i.e. 560,000 animals. Recent reports however, indicate that about 4,278 farmers (15%) had withdrawn from the program citing difficulties in meeting the stringent requirements of the scheme (Moran, 2016). The Irish model is an example of the potential role of government in the diffusion of genomic selection for feed efficiency in beef cattle.

BEEF FARMER OBLIGATIONS:

- Tag and register calves with regulator with 27 days of birth. Provide information on sires and complete calving survey.
- Six-year commitment to the scheme.
- Complete yearly surveys on herd (calves, bulls and cows) and provide herd performance (e.g. milk, docility, functionality, reasons for culling) information.
- Provide tissue samples of selected animals to laboratories for genotyping.
- Replacement strategy:
  Males-one bull on farm (if renting bulls) should be rated 4-5 stars based on the Euro star rating (a selection index) by June 2019.
  80% AI must be from 4-5 star bulls by June 2016
  Females-20% of cows genotyped must be rated 4-5 stars by 2018. This should increase to 50% by 2010.
  Replacement heifers purchased on bred should be 4-5 star on Euro star index.
- Complete carbon navigator.

REGULATORS FUNCTIONS:

- Select animals to be genotyped each year
- Ensure farmer compliance to the requirements of the scheme through inspections and imposition of penalties for non-compliance.
- Bears the cost of the scheme- payments for compliance, training, carbon navigator services

PAYMENT MECHANISM:

- Payment to beef farmers calculated on a per hectare basis=
  $$\frac{Number\ of\ eligible\ producing\ calf\ in\ given\ year}{stocking\ rate = 1.5}$$
- Rates:
  -£142.50/ha for 1st 6.66 ha
  - £120/ha for each eligible hectare
- Other
  -Number of animals selected each year should be at least 60% of cows on farm
  -Genotyping cost must not exceed 15% of the value of the scheme.

Figure 3.6: A Summary of the key features of the Irish beef data Genomics programme

3.2.3.1 Environmental Externalities and Subsidy payments

Another justification for the implementation of a subsidy scheme to incentive cow-calf producers to adopt genomic selection for feed efficiency is issue of market failure with respect to environmental externalities. Market failures arise when private markets are unable to operate efficiently due to the presence of externalities, products with public good characteristics etc. (Field, 2008, pp.118-120). For beef cattle production in particular, the issue of environmental externalities from breeding decisions is particularly relevant. On the one hand, cattle production is a significant source of greenhouse gas emissions (GHG) from enteric fermentation sources (Beauchemin et al., 2010; Beauchemin et al., 2011). On the other hand, the breeding for feed efficient cattle is associated with reduced GHG emissions and improvements in environmental quality that accrues to society (Alford et al., 2006). The decision to purchase bulls with genomic information is however, a private decision for which the cow-calf producer only internalizes his own private benefits, i.e. reductions in feed costs. The producer may not adopt if these benefits are low relative cost despite the potentially higher overall social benefits. A cost share programme financed by government can therefore represent an avenue to pay for the social benefits of the innovation and incentivize producers to adopt.

Alternatively, a GHG emission reduction tax ($/$Co_{2\ eq}$) payable by other producers along the beef supply chain such as feedlot operators, who may benefit from higher feed efficiency can be instituted. Such a mechanism can address other forms of market failure specific to beef genetic management such as misalignment in incentives, potential free-rider behavior etc. (Elliott, 2013). The revenue accrued from the scheme can be used to subsidize the cost of genomic bulls purchased by cow-calf producers.

3.2.4 Feed Efficiency: Measurement and Selection

Feed efficient cattle consume less feed per unit measure of beef produced. Commonly used estimates of feed efficiency include feed conversion ratios (FCR) (Brody, 1945) and residual feed intake (RFI) (Koch et al., 1963). Although extensively used in the past, the former is less favored in recent times as result of unfavorable correlations between FCR and its component traits (Nkrumah et al., 2004; Archer et al., 1999). Residual feed intake (RFI), estimated as the difference between actual animal feed intake and predicted feed intake, is the prevalent measure of feed efficiency across the different livestock production systems (Koch et al., 1963; Archer et al., 1999; Rauw et al., 2006). Differences in RFI capture variations in the efficiency with which individual animals utilize feed for maintenance and production; lower RFI values are more desirable since they imply more efficient conversion of feed into meat and lower costs (Johnson et al., 1999). Empirically, predicted feed intake has been predominately estimated as a linear regression of actual animal feed intake on a set of covariates such as average daily gain (ADG), mid metabolic body weight (MBW) and measures of meat composition such as back fat (Hoque et al., 2009).

Previous studies (e.g. Arthur et al., 2001a; Herd and Bishop, 2000; Basarab et al., 2003) have examined residual feed intake for different categories of beef cattle. This residual portion of feed intake forms the basis for identifying relatively more efficient-cattle with lower (negative) RFIs. It has been suggested that RFI could represent variations in metabolic processes which determine feed efficiency (Brelin and Brannang 1982; Korver, 1988). As errors from the regression of covariates that capture size and growth, residual feed intake is phenotypically independent of these production traits. Arthur et al. (2001a) in a study of feed efficiency in Angus cattle, estimated a linear regression model of feed intake on metabolic weight and ADG controlling for group and sex effects. The study found evidence of genetic and phenotypic independence between RFI and component traits. This implies that selecting for RFI is unlikely to affect ADG and MWT, thus allowing for comparisons across cattle that differ with respect to these component traits.

Herd and Bishop (2000) assessed the existence of genetic variation in RFI in young bulls and the phenotypic and genotypic relationships between RFI and other important production traits such as mature cow size. The predicted feed equation was estimated as a linear regression of feed intake (FI) on MBW and ADG. Archer (1999) estimated RFI as residuals from the linear regression of feed intake on ADG and MMWT. In an attempt to capture possible heterogeneity across animals resulting from gender and treatment, separate models were estimated for each gender within each test cohort. Arthur et al. (2001b) examined genetic and phenotypic relationships between different feed efficiency and growth measures in young Charolais bulls. Heterogeneity was restricted to year effects. In the case of Meyer et al. (2008), separate expected feed intake regression models were estimated for pregnant and open females in a classification of RFI in grazing beef cows. Basarab et al. (2003) in a study using data from 176 steers, analyzed the relationship between residual feed intake, daily gain and other measures such as body size and composition. The study found evidence of the possibility of re-ranking cattle based on efficiency from the different linear models used.

As evident from the literature, models used in RFI estimation are predominately linear and assumptions about heterogeneity have been largely unsystematic. In an industry where treatment effects, pen, trail and year effects vary widely across cohorts and between different levels of operations, assumptions about these effects can have a significant impact on the consistency of modeling procedures. Even more importantly, the incorporation of these estimates into selection indices brings to the fore the inter-temporal dimensions of the present issue. In other words, efficiency rankings based on incorrect empirical models may affect selection decisions that ultimately determine characteristics of future herds. For a trait such as feed efficiency that impacts significantly on profitability, these effects can be significant. Additionally, these potential impacts may further vary across the different sectors within the livestock industry as a result of differences in maintenance requirement. For example, an estimated 60-65% of feed in the mature cow herd is used to meet maintenance requirements suggesting considerable benefits from improved efficiency (Arthur et al., 2005).

Studies (e.g. Robinson, 2005a; Robinson 2005b; Berry and Crowley, 2013) have evaluated aspects of RFI estimation. Robinson (2005a) examined the impact of errors in covariates in the context of residual feed intake estimation. Errors in covariates were found to be a significant source of bias in the resulting coefficient estimates. Approaches such as inverse regression were suggested as a means of correcting for the effect of these errors (Robinson 2005a). Robinson (2005b) compared different estimates of weight gain using feed efficiency data.

Berry and Crowley (2013) noted possible nonlinear relationships between feed intake, ADG and MWT amongst diverse populations and animals with inferior genetic merit for these traits. Boaitey et al. (2013) found evidence of considerable sensitivity of feed efficiency estimates to assumptions pertaining heterogeneity between animals and within cohorts.

3.2.5 Improving Feed Efficiency in Beef Cattle

Improvements in feed efficiency in beef cattle can be attained in multiple ways. These include: through selection, nutrition, the use of growth promotants and management practices (see Table 3.1 for a summary). Evidence from multiple programmed feeding experiments (Plegge, 1986; Zinn, 1986; Hicks et al., 1990) of cattle in different phases of production report improvements in feed efficiency of 2-8%. The inclusion of higher levels of concentrate in feed particularly in finisher diets is also associated with higher feed conversion rates. Meyers (1999) reported a 25%

increment in feed efficiency from cattle fed 90-100% concentrate as compared to 60% concentrate diets. The use of growth promotants such as implants, ionophores and beta-agonists is associated with higher levels of feed efficiency (4-23%). In addition to these, evidence from other studies (Myers et al. 1999; Schoonmaker et al. 2004; Barker-Neef et al., 2001) that examined the effect of management practices on the feed efficiency report a negative relationship between weaning time and feed efficiency. In general, feed efficiency is higher (9-8%) in early weaned calves. The reported rate of improvement in feed efficiency from selection (i.e. 0.75-1%) is relatively low in magnitude as compared to the other practices outlined. However, genetic change is per year and is cumulative and permanent.

3.2.6 Cattle Producer Decision Modelling

Successful breeding in beef cattle is depended on accurate and timely application of genetic information. Theoretically, this is amendable to conjectures from the value of information literature (Byerlee and Anderson, 1976; Baquet et al., 1976; Babcock, 1990; Hennessy et al., 2004). The value of information being the difference in profits with and without the additional informational input (Babcock, 1990).

A producer places a given herd on feed if the herd's expected value at the end of the feeding period exceeds costs. The main cost components are feeder cattle price and expected feeding cost (Bullock and Logan, 1970). This decision making process is complex as the key drivers (performance and market characteristics) of profitability tend to be uncertain. Time usually defined as days of feed is a variable of significance in feeding operations impacting profits in a number of ways. These include effects on cost of feeding, rate of daily gain and meat quality (Williams and Ladd, 1977).

Table 3.1: Summary of selected approaches to increasing feed efficiency in beef cattle

Approach		Improvements in feed efficiency	Type of cattle	Reference
Selection	Select for feed efficiency (low RFI)	0.75-1% per year improvement in feed efficiency	Calves	Basarab et al. (2013)
		1.247 kg/day (< feed intake) divergence in feed efficiency from high and low RFI bulls	Calves	Arthur et al. (2001d)
Nutrition and growth promotants	Restricted and Programmed feeding (Galyean, 1999)*	2.6% (At 96% ad libitum-fed) 2.7% (At 92% ad libitum-fed)	Finishing cattle	Plegge (1986)
		4.3% (intake based on projected gain)		Zinn (1986)
		8.4% (At 82% ad libitum-fed)		Hicks et al., (1990)
	Diet Concentration	Gain: Feed ratio 0.19 (concentrate) 0.18 (pasture)	Finishing phase	Myers (1999)
		Feed efficiency: 25%> (90-100% concentrate diet) versus (60% concentrate diet)	Finishing phase	(Fluharty et al., 2000)
	Growth Promotants	8.8% (implants) 3.6% (Ionophores) 12.6% (Beta-agonists)	Feedlot cattle	Lawrence and Ibarburu (2007)
		Gain: Feed ratio 0.24 (cattle raised with growth promotants) 0.18 (cattle raised without growth promotants)	Feedlot cattle	Cooprider et al., (2011)
		Gain: Feed ratio 0.17 (Implanted steers) 0.15 (Non-implanted steers)	steers	Wileman et al., (2009)
		14% 23%	Steers in growing phase Steers in finishing phase	Berthiaume et al., (2006)
Management practices	Weaning age	Gain: Feed ratio 0.20 (90 days);0.18 (152 days); 0.16 (215days)	Steer calves	Myers et al., 1999
		Feed conversion ratio (FCR) 9-8% (103 days)	Steer calves	Barker-Neef et al., (2001); Schoonmaker et al., (2002)

Notes: *meta-analysis of different studies; different units of the magnitudes of reduction limits comparability

Bayesian decision (Bullock and Logan 1970; Williams and Ladd, 1977; Eidman et al., 1967) and optimization models (Lusk, 2007; DeVuyst et al., 2007) have been used in the analysis of producer behavior in finishing operations. In the former, experimental information is combined with a prior information to develop conditional posterior probabilities for the occurrence of particular states of nature (Bullock and Logan, 1970). The latter applies to optimization approaches in the selection of optimal days on feed or profits.

Weaber and Lusk (2010) analyzed the economic value of marker assisted selection for improvements in beef tenderness. These markers consist of numerous single nucleotide polymorphisms (SNPs). Weaber and Lusk (2010) implemented a Monte Carlo simulation model of marker-assisted selection coupled with an economic model of beef supply. The beef supply system comprising feeder, slaughter, packer and retail sectors. By linking the selection to the entire supply chain, changes in the level and distribution of economic benefits for the different market segments were derived. Although the bull-heifer selection strategy was found to be suboptimal, the bull-only selection strategy yielded significant economic benefits estimated at $7.6billion. Feeder cattle suppliers obtained the highest proportion of benefits (49%) as compared to customers (31%), retailers (10%), Packers (3%) and feedlot operators (7%).

Another strand of research has evaluated different aspects of beef production systems (Crews et al., 2006; Okine et al., 2000; Fox et al., 2001; Archer and Barwick, 1999). A common limitation in a significant proportion of these studies is the seeming lack of rigour in the modelling of economic variables i.e. feed costs, cattle prices, feed prices etc. With regards to feed efficiency, previous studies have addressed the impact of improved feed efficiency and metabolizable energy on feed costs and net returns (Okine et al., 2000; Fox et al., 2001). Other studies have looked at the effect of the inclusion of feed efficiency in selection indexes (Crews et al., 2006), and the impact of the measurement of the trait on profits (Archer and Barwick, 1999).

Crews et al., (2006) combined information from both steers and yearlings to develop an index that can be used to select for feed efficiency in yearling bulls in a multi-trait context. In addition to residual feed intake (RFI), the 3-trait selection index developed in the study included average daily gain (ADG) and body weight (BW). The estimated criterion weights for the component traits in the index were: -10.29 (RFI), 24.79 (ADG) and -0.009 (BW)-with the negative value for RFI implying that lower feed intake is more desirable.

Archer and Barwick (1999) examined the economic feasibility of the recording and inclusion of feed efficiency in breeding schemes using a gene flow model. The study evaluated the production of steers for two markets: a high value export market; and a lower value domestic market. Given the measurement costs, breeding for feed efficiency was more profitable in the high value market (Archer and Barwick, 1999).

Okine et al., (2000) compared the savings in feed cost resulting from the 5% increase in feed efficiency with an equivalent percentage increase in growth. The analysis was based on actual performance data of a cohort of steers feed to 560 kg from an initial placement weight of 250 kg over a 200-day feeding period. The results showed that improvements in feed efficiency had a greater impact on costs than the increases in the rate of growth. Savings in the former was approximately $18/head in the in the later as compared to the $2/head (Okine et al., 2000). The direction of the effect of improvements in feed efficiency was similar to that of Fox et al. (2001). Fox et al., (2001) found that a 10% increase in the efficiency of metabolizable energy resulted in a 43% increase in profits. Okine et al. (2000)'s approach did not however, consider a number of factors that can affect net costs such as stochastic cattle prices. Further, using a static single period perspective limits the understanding of the producer's decision which is often intertemporal- it is not uncommon for cattle producers to trade-off losses in one period for profits in another. A number of these identified weaknesses also persisted in Fox et al., (2001)'s study.

Exton et al., (2000) evaluated the economic benefit from investing in the bulls with genetic superiority for feed efficiency for beef cattle grazing and finishing systems in southern Australia. Annual rate of improvement in the seed stock was approximately 0.6% and 0.3% in the seed stock and calves respectively. Discounted net returns per cow was approximately \$6.95. It was further estimated that feedlot producers can pay about \$2/cow as premium for feed efficient calves. The total value to the southern Australian cattle sector over a 25-year period at a 30% rate of adoption was \$210 million. Whilst providing useful insights, Exton et al. (2000)'s analysis does not account for price stochasticity in cattle prices.

This paper extends the existing literature by comprehensively addressing cow-calf producer incentive to purchase bulls with genomic information on feed efficiency using a stylized industry model. The model accounts for two types of cow-calf producers and two feeders. This segmentation accounts for two-types of behavior- adopting and non-adopting. This framework also allows for the evaluation of different scenarios under which uptake can be stimulated.

3.3 Theoretical Framework

Consider two types of cow-calf producers (A and B) that are identical in all aspects of production. Each producer supplies a portion of the market of weaned calves to feeders. It is assumed that producer of the type. A faces a discrete choice of two bulls: a regular bull and a genomic bull. It is further assumed that the genomic bull produces more feed efficient calves. The producer's profit function is given by:

$$\pi^A = P^A u^A - c(H, u^A) - (1-\phi^A) m F^A(u^A, H, \psi^A) - P_B - \alpha \qquad (11)$$

where P^A is the price of weaned calves, u^A is the number of weaned calves marketed, $c(H,u)$ is the non-feed related costs such as labour and capital, $(1-\phi^A)$ is the probability that cattle is feed efficient, m is the unit cost of feed, $F^A(u^A,H,\psi)$ is total feed consumed, H is the number of cows, ψ is the feed efficiency parameter, P_B is the price of the bull and α is the additional cost of the bull attributable to technology. Alternatively, a cow-calf producer could choose to purchase a regular bull without genomic information and produce regular calves. The expected profit, π^B from the regular bull is defined as:

$$\pi^B = P^B u^B - c(H,u^B) - (1-\phi^B) m F^B(u^B,H,\psi^B) - P_B \qquad (12)$$

It is assumed that if A chooses the genomic bull then $\phi^A > \phi^B$ and[27] $\frac{\partial F^A}{\partial \psi^A} < \frac{\partial F^B}{\partial \psi^B}$. The latter term indicates that feed intake is lower in A, because of higher feeder efficiency (ψ). The difference between ϕ^A and ϕ^B capture the difference in the accuracies of genomic and conventional breeding technologies and degree of pass through of savings in feed efficiency between the progeny of genomic and conventional bulls. The producer chooses bull A if:

$$P^A u^A - c(H,u) - (1-\phi^A) m F^A(u,H,\psi) - P_B - \alpha > P^B u^B - c(H,u) - (1-\phi^B) m F^B(u,H,\psi) - P_B \qquad (13)$$

This implies that the additional value for feed efficiency (α) will be paid by the producer under the condition that:

$$(P^A u^A - c(H,u) - \phi^A m F^A(u,H,\psi) - P_B) - (P^B u^B - c(H,u) - \phi^B m F^B(u,H,\psi) - P_B) > \alpha \qquad (14)$$

[27] In general, $\frac{\partial F}{\partial \psi} < 0$

This implies that the additional value of higher feed efficient bull (α) will be paid by the producer under the condition that:

$$(P^A u^A - c(H,u) - (1-\phi^A) mF^A(u,H,\psi) - P_B) - (P^B u^B - c(H,u) - (1-\phi^B) mF^B(u,H,\psi) - P_B) > \alpha \quad (15)$$

This is equivalent to:

$$(P^A u^A - P^B u^B) + m[(1-\phi^B) F^B(u,H,\psi) - (1-\phi^A) F^A(u,H,\psi)] > \alpha \quad (16)$$

All else equal, this is true if $P^A > P^B$ is positive. This means that the decision to pay extra for the genomic bull depends on the difference in relative value between calves produced by genomic bulls and those from regular bulls $(P^A u^A - P^B u^B)$ and relative cost savings $m[(1-\phi^B) F^B(u,H,\psi) - (1-\phi^A) F^A(u,H,\psi)]$ .The second term is likely to have a lower effect on the incentive to pay as cows/calves are typically raised on pasture with supplemental feeding done mostly in the winter. Which suggests that in the absence of premiums for feed efficient calves, the cow-calf producer may have limited incentive to purchase the feed efficient bull.

In the case of the cattle feeder (say feedlot operator), weaned calves represent an input to production of slaughter weight steers and heifers. Given the option to purchase a particular category of calves, the cattle feeder will purchase only feed efficient calves if profits from growing the feed efficient cattle exceeds that of the regular cattle:

$$P^s x^s - P^A u^A - (1-\phi^A) mF^A(u,\psi) - c_f(H,u) > P^s x^s - P^B u^B - (1-\phi^B) mF^B(u,\psi) - c_f(,u) \quad (17)$$

where P^s is the price of cattle at finishing, and x^s is the number of cattle finished. The value to the cattle feeder is driven by:

$$[(1-\phi^B) mF^B(u,\psi) - (1-\phi^A) mF^A(u,\psi)] > (P^A u^A - P^B u^B) \quad (18)$$

In reality however, cattle feeders typically source calves from multiple sources. The resulting profit for the producers:

$$P^s x^s - P^A u^A - (1-\phi^A) mF^A(u,\psi) - c_f(u) - P^B u^B - (1-\phi^B) mF^B(u,\psi) - c_f(u) \qquad (19)$$

Where P^s is the price of cattle at finishing, x^s is the number of cattle finished, P^A and P^B are the prices of weaned calves, u^A and u^B are the number of weaned calves purchased, and $c_f(u)$ is non-feed related costs. Feeders have the incentive to pay a uniform price i.e. $P = P^B < P^A$ and earn profit:

$$P^s x^s - Pu^A - (1-\phi^A) mF^A(u,\psi) - c_f(u) - Pu^B - (1-\phi^B) mF^B(u,\psi) - c_f(u) \qquad (20)$$

This is because all else equal:

$$P^A u^A + P^B u^B > Pu^A + Pu^B \qquad (21)$$

Which suggests that feeders are better-off paying a uniform price for both feed efficient and regular calves if the uniform price is below the differentiated price paid for calves. These outcomes are more evident when the feeders profit function (π^F) is optimized. Assuming that the categories of cattle are the only inputs of production in the cattle feeders production function[28]. Also letting ($1-\phi^A$) $= k^A$ and ($1-\phi^B$) $= k^B$ for simplicity, the profit is given by:

$$\pi^F = P^s x^s(u^A, u^B) - P^A u^A - k^A mF^A(u,\psi) - P^B u^B - k^B mF^B(u,\psi) \qquad (22)$$

The first order condition (FOC) with respect to u^A :

$$\frac{\partial \pi^F}{\partial u^A} = P^s \frac{\partial x^s(u^A, u^B)}{\partial u^A} - P^A - k^A m \frac{\partial F^A(u,\psi)}{\partial u^A} = 0 \qquad (23)$$

[28] Ignoring non-cattle related costs for simplicity.

Similarly, maximizing profit with respect to the regular calves is:

$$\frac{\partial \pi^F}{\partial u^B} = P^s \frac{\partial x^s(u^A,u^B)}{\partial u^B} - P^B - k^B m \frac{\partial F^B(u,\psi)}{\partial u^B} = 0 \qquad (24)$$

Equation 23 and 24 respectively can be written as:

$$P^s \frac{\partial x^s(u^A,u^B)}{\partial u^A} - k^A m \frac{\partial F^A(u,\psi)}{\partial u^A} = P^A$$

$$P^s \frac{\partial x^s(u^A,u^B)}{\partial u^B} - k^B m \frac{\partial F^B(u,\psi)}{\partial u^B} = P^B$$

Since $\frac{\partial F^B(u,\psi)}{\partial u^B} > \frac{\partial F^A(u,\psi)}{\partial u^A}$ the feeder should pay a higher price for the more feed efficient cattle. It follows that optimal profit $\pi^{F*}(u^{A*},u^{B*})$ is obtainable at the profit maximizing

It follows that optimal profits are obtainable at the profit maximizing $u(u^{A*},u^{B*})$ derived from the FOC.

The points A and B represents optimality for u_A and u_B respectively (Figure 3.7). It is also evident from Figure 3.7, that the cattle feeder has an incentive to pay $P^B = P < P^A$ and move towards point *c* as he attains the higher value of the feed efficient herd without paying the additional cost. On the supply side, it seems unlikely that the cow-calf producer will adopt genomic innovations related to feed efficiency in the absence of a premium for feed efficient calves.

Given the additional environmental benefits of improved feed efficiency, the additional cost attributable to genotyping (α) can be offset with a subsidy[29].

[29] Similar to the IDG programme described in section 3.3.3

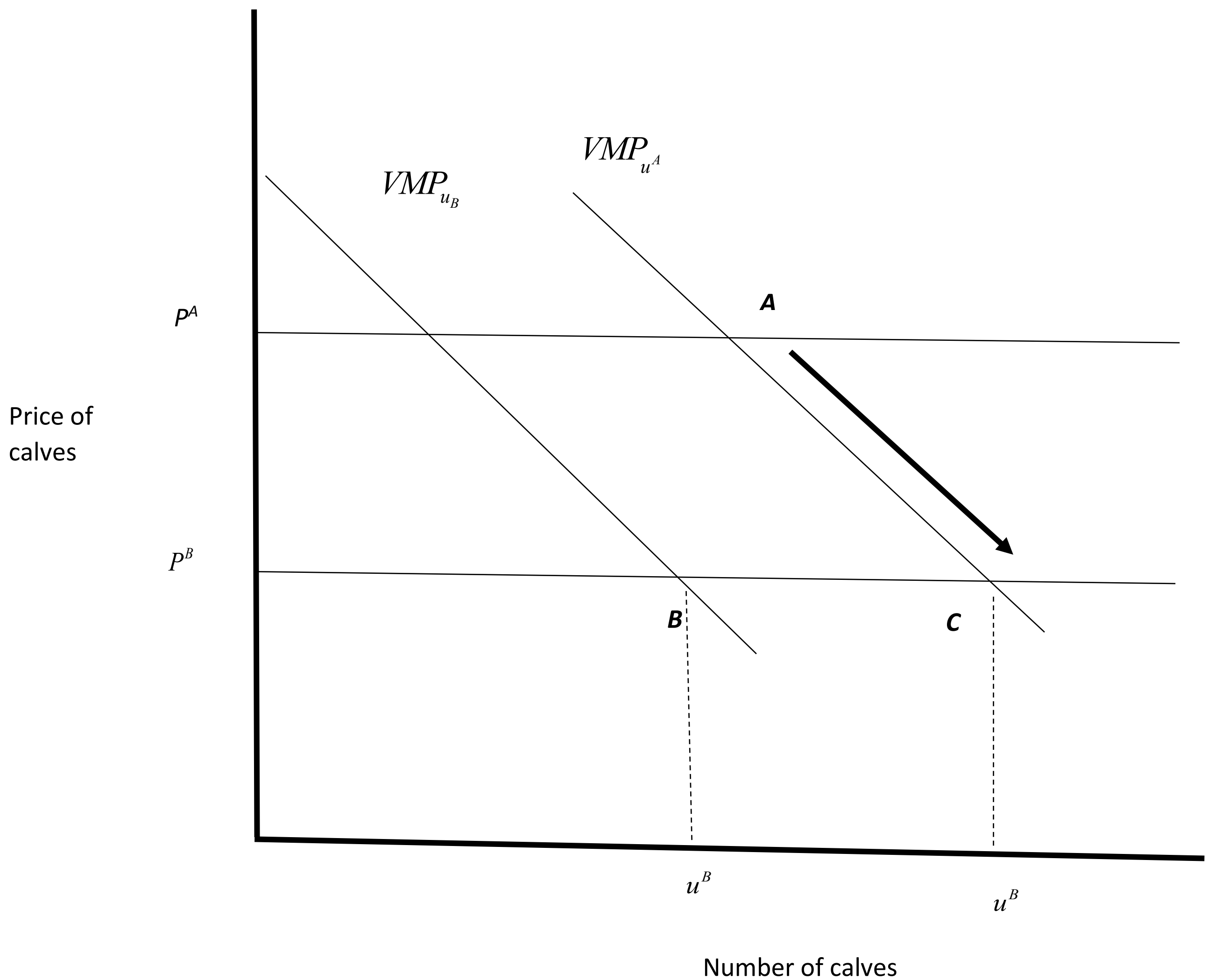

Figure 3.7: Schematic representation of first order conditions

3.3.1 Comparative Statistics

To address the impact of change in the price of weaned calves (P^A) and (P^B) respectively, let

$\frac{\partial x^s(u^A,u^B)}{\partial u^A} = x^s_{u^A}$, $\frac{\partial F^A(u,\psi)}{\partial u^A} = F^A_{u^A}$, $\frac{\partial x^s(u^A,u^B)}{\partial u^B} = x^s_{u^B}$ and $\frac{\partial F^B(u,\psi)}{\partial u^B} = F^B_{u^B}$. Rewriting

Equations 23 and 24 as:

$$\frac{\partial \pi^F}{\partial u^A} = P^s \frac{\partial x^s(u^A,u^B)}{\partial u^A} - P^A - k^A m \frac{\partial F^A(u,\psi)}{\partial u^A} = 0$$

$$\frac{\partial \pi^F}{\partial u^B} = P^s \frac{\partial x^s(u^A,u^B)}{\partial u^B} - P^B - k^B m \frac{\partial F^B(u,\psi)}{\partial u^B} = 0$$

Differentiating with respect to P^A and P^B at the optimal u^A and u^B produces:

$$P^s \frac{\partial x^s_{u_A}(u^{A*},u^B)}{\partial u^A}\frac{\partial u^A}{\partial P^A} - 1 - k^A m \frac{\partial F^A_{u_A}(u^{A*},\psi)}{\partial u^A}\frac{\partial u^A}{\partial P^A} = 0 \qquad (25)$$

$$P^s \frac{\partial x^s_{u_B}(u^A,u^{B*})}{\partial u^B}\frac{\partial u^B}{\partial P^B} - 1 - k^B m \frac{\partial F^B_{u_B}(u^{A*},\psi)}{\partial u^B}\frac{\partial u^B}{\partial P^B} = 0 \qquad (26)$$

This implies that:

$$\frac{\partial u^A}{\partial P^A} = \frac{1}{\left[P^s \frac{\partial x^s_{u_A}(u^{A*},u^B)}{\partial u^A} - k^A m \frac{\partial F^A_{u_A}(u^{A*},\psi)}{\partial u^A} \right]} < 0 \qquad (27)$$

$$\forall\ P^s > 0, k^A, m > 0, \frac{\partial x^s_{u_A}(u^{A*},u^B)}{\partial u^A} < 0, \frac{\partial F^A_{u_A}(u^{A*},\psi)}{\partial u^A} > 0$$

Equation 27 still holds if $\frac{\partial F^A_{u_A}(u^{A*},\psi)}{\partial u^A} < 0$ as long as $\left| P^s \frac{\partial x^s_{u_A}(u^{A*},u^B)}{\partial u^A} \right| > \left| k^A m \frac{\partial F^A_{u_A}(u^{A*},\psi)}{\partial u^A} \right|$.

An equivalent result is obtainable for P^B:

$$\frac{\partial u^B}{\partial P^B} = \frac{1}{\left[P^s \frac{\partial x^s_{u_A}(u^A, u^{B*})}{\partial u^B} - k^B m \frac{\partial F^B_{u_B}(u^{B*}, \psi)}{\partial u^B} \right]} < 0 \qquad (28)$$

Under the assumption that feed efficient calves have a higher productivity with respect to feed as compared to the regular calves i.e. $\frac{\partial F^A_{u_A}(u^{A*}, \psi)}{\partial u^A} > \frac{\partial F^B_{u_B}(u^{B*}, \psi)}{\partial u^B}$, $\frac{\partial u^B}{\partial P^B} > \frac{\partial u^A}{\partial P^A}$. This suggests that the impact of a change in calf prices is lower for the feed efficient herd as compared to one comprised of regular calves.

3.4 Empirical Approach

To evaluate aspects of the theoretical model presented in 3.3, a stylized industry model is developed. The model comprises of cow-calf producers and feeders. The former, is defined to include two types of cow-calf producers -A and B. Each cow-calf producer also produces forage to meet herd feed requirements and breeds calves for sale. Cow-calf producer A is assumed to make a decision regarding the choice of a genomic or regular bull. The decision is the type of bull to purchase given the cost of the bull and the feed efficiency profile of its progeny. Cow-calf producers of the type B represent the segment of the market that will not adopt the technology. Kessler (2014) identified a segment of producers who opposed the idea of the use of newer DNA technologies in cattle breeding. This categorization is also consistent with adoption behavior identified in previous studies such as Bishop et al., (2010). The resulting supply of calves in the present model comprises both genomic and regular steers and heifers. Given the heterogeneity in the supply of calves, the cattle feeder (type A) decides which type of weaned calf to purchase. The purchase weight of calves is assumed to be 550 lbs. This is also the sale weight for the cow-calf producers. The cattle feeder initially feeds a backgrounder diet until the animals are 750 lbs before placing the cattle on a finisher diet. Cattle are marketed at a finished weight of 1225 lbs (Brown and Carlberg, 2001). Figure 3.8 is a schematic representation of the model. A detailed description is provided below.

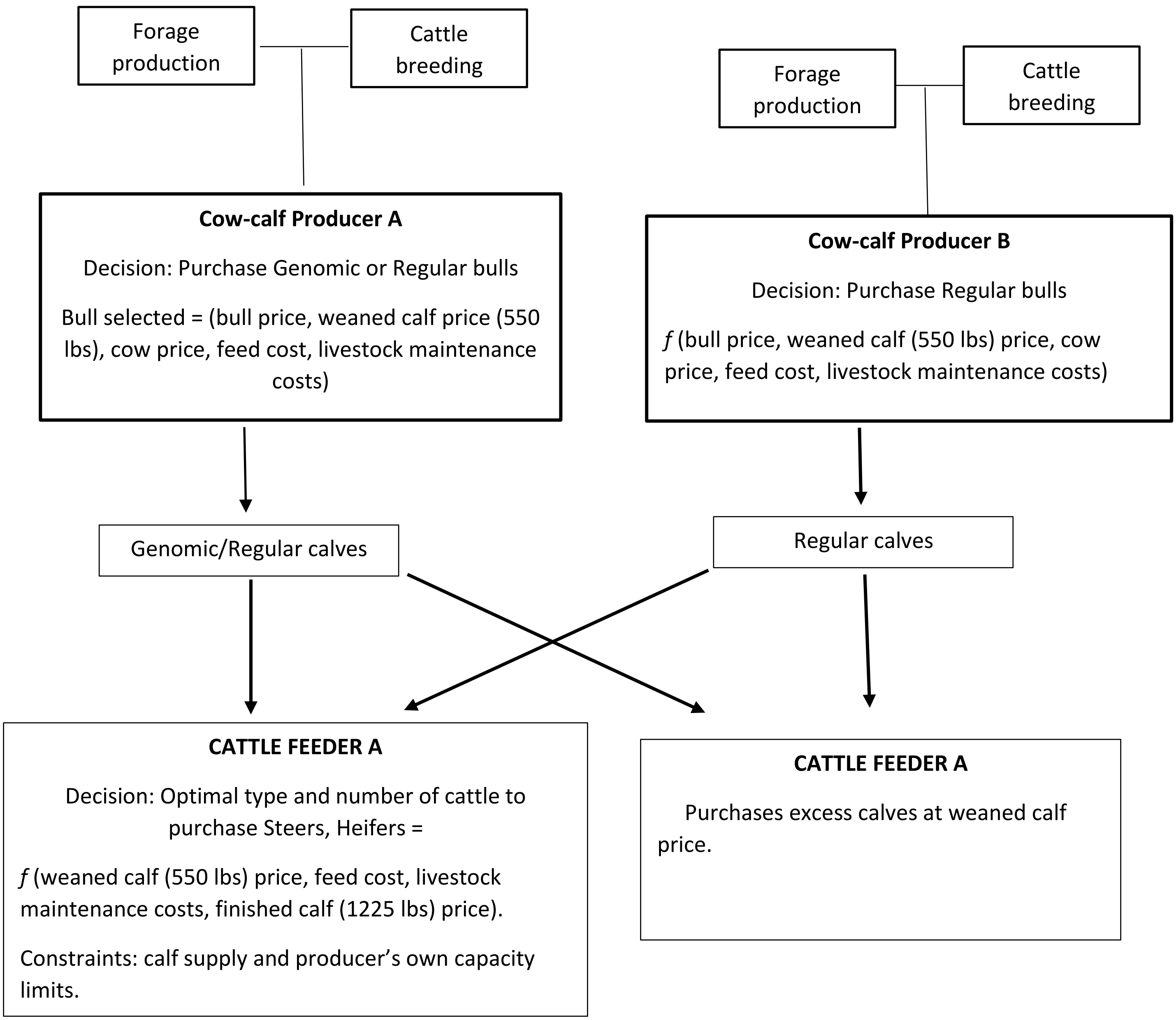

Figure 3.8: Schematic representation of empirical approach

3.4.1 Biological model

The biological component of the model describes the breeding relationships (equations 1-44) in the cow-calf segment. The number of cattle produced by category, retained, purchased and culled is tracked in this section. The beginning cow herd inventory drives the production of calves and the breeding aspects of production. The farm herd is initiated by the number of cows exposed to bulls. The number of bulls is determined by the bull-cow ratio. Cow exposure and conception rates determine the number of pregnant cows. From these conceptions, the number of offspring calved and weaned is derived from the calving and weaning rates. The resulting calf crop is segregated into steers and heifers based on the steer-heifer ratio. A proportion of heifers is retained for breeding to augment the cowherd for the subsequent period. Weaned steers produced and the remaining heifers are marketed in addition to the culled bulls and cows.

These identities are similar for the two types of cow-calf producers (A and B) considered. The main difference being the type of the bull purchased i.e. genomic or regular bulls, and the feed efficiency profile of the resulting progeny (steers and heifers) of the bull. For tractability, the producer subscripts are suppressed.

3.4.2 Bull herd

The beginning bull inventory ($Bull_{0t}$) is given as:

$$bull_{0t} = \frac{cow_{0t}}{\gamma} \qquad (29)$$

where cow_{ot} is the cow beginning inventory and γ is the bull- cow exposure ratio. A proportion of the existing inventory of bulls is purchased in each time period to maintain a stable bull herd.

$$bull_{p_t} = bull_{ot} * \theta_{cull}^{B} \qquad (30)$$

where $bull^{i}_{pt}$ denotes the number of bull of the ith type of bull purchased and θ^{B}_{cull} is the bull culling rate. If the genomic bull i.e. $bull^{g}_{pt}$ maximizes net returns, the cow-calf purchases genomic bulls and produces genomic calves. Alternatively, the producer purchases regular bulls ($bull^{r}_{pt}$) if net returns are maximized with regular bulls. The number of bulls sold ($bull_{st}$) is given as:

$$bull_{st} = bull_{ot} - \frac{cow_{wt}(1-\theta^{c}_{\exp} * \theta^{c}_{con}) + heif_{wt}(1-\theta^{h}_{\exp} * \theta^{h}_{con})}{\gamma} \quad (31)$$

where $\theta_{\exp}$ and θ_{con} denote the exposure and conception rates for cows(c) and heifers (h), cow_{wt} is the number of wintered cows and the $heif_{wt}$ is the number of wintered heifers. The bull inventory for the next period ($bull_{t+1}$) is:

$$bull_{t+1} = bull_{ot} - bull_{pt} - bull_{st}$$

3.4.3 Cow herd

The cowherd drives the bull inventory through the bull-cow ratio. The initial cowherd is denoted as cow_{0t} .Cows purchased (cow_{pt}):

$$cow_{pt} = cow_{ot} * \theta^{c}_{R} \quad (32)$$

where θ^{c}_{R} is the cow replacement rate. The number of cows (cow_{st}) sold in each period is given as:

$$cow_{st} = cow_{ot} + cow_{pt} + heif_{tt} - cow_{dt} \quad (33)$$

where $heif_{tt}$ is heifers transferred in and cow_{dt} is cow loss through death or home use:

$$cow_{dt} = \lambda_D^c * (cow_{ot} + cow_{pt} + heif_{tt}) \qquad (34)$$

where λ_D^c is the death rate. The number of pregnant cows (cow_{pregt}) is estimated from the available cow herd and the exposure and conception rates:

$$cow_{preg_t} = (cow_{ot} + cow_{pt} - cow_{st} - cow_{dt}) * \theta_{con}^c * \theta_{\exp}^c \qquad (35)$$

3.4.4 Bred heifers

The breeding heifer subsection of the model is comprised of heifer: beginning inventory ($heif_{0t}$), purchased ($heif_{pt}$) transferred in ($heif_{tt}$) and culled heifers ($heif_{ct}$). Based on the heifer inventory, the number of pregnant heifers is estimated as ($heif_{pregt}$):

$$heif_{pregt} = (heif_{pt} + heif_{tt} + heif_{ct}) * \theta_{con}^H * \theta_{\exp}^H \qquad (36)$$

Heifers unable to conceive (open heifers) ($heif_{ot}$) are culled:

$$heif_{opt} = (heif_{pt} + heif_{tt} + heif_{ct}) * (1 - \theta_{con}^H) \qquad (37)$$

Cows wintered (cow_{wt}) for each period is derived as:

$$cow_{wt} = cow_{ot} + cow_{pt} + heif_{tt} - cow_{dt} - cow_{st} \qquad (38)$$

Equation 38 also captures the cow-herd for the next period i.e. $t+1$:

3.4.5 Calf-bearing Females

The number of calf-bearing females is derived from the number of pregnant cows and heifers and their respective calving and weaning rates:

$$calff = (cow_{pregt} * \theta_{CR}^C * \theta_W^c) + (heif_{pregt} * \theta_{CR}^H * \theta_w^H) \qquad (39)$$

3.4.6 Production stock

The production stock comprises weaned heifers and steers. The number of weaned steers ($steer_t$) produced by the cow-calf producer for sale is derived from the number of calf-bearing females ($calff_t$) and the steer-heifer ratio (φ):

$$steer_{mkt} = calff_t * \varphi \qquad (40)$$

The weaned heifer sold ($heif_{Mkt}$) is the difference between heifers transferred ($heif_{it}$) and heifers transferred out ($heif_{0t}$):

$$heif_{mkt} = heif_{tt} - heif_{ot} \qquad (41)$$

where heifers transferred in is:

$$heif_{tt} = calff(1-\varphi) \qquad (42)$$

Heifers transferred out ($heif_{ot}$) is given as:

$$heif_{ot} = heif_{tt} * \theta^{H}_{\exp} \qquad (43)$$

It follows that the total calf crop ($calfmkt$) marketed each year is the sum of steers ($steer_{mkt}$) and heifers ($heif_{mkt}$).

3.4.7 Animal Purchases

In addition to bulls each cow-calf producers of each type is assume to purchase regular cows and bred heifers. The portion of production cost attributable to cattle purchases is given as:

$$PP_{totalt} = cow_{pt} * cowprice_t + heiff_{pt} * heifprice_t + bull_{pt} * bullprice_t \qquad (44)$$

The total non-feed production costs ($PDcst$) attributable to expenses such as veterinary and medicine is derived by multiplying the cowherd by the cost per unit herd.

Total revenue for each period from the sale of ith type of cattle cow-calf producers is estimated as:

$$revenue_t = bull_{st} * selP_{Bt} + heiff_{st} * selP_{ht} + cow_{st} * selP_{ct} + calfmkt * selfP_{clft} \qquad (45)$$

where $bull_{st}$ the number of bulls sold, $calfmkt$ is the number of weaned calves, $heiff_{st}$ is the number of heifer sold and the cow_{st} is the number of cows sold, $selP_{it}$ represent the sale prices for the ith type of cattle.

Cattle (cows and bulls) in the cow-calf segment are assumed to be fed barley silage and alfalfa hay in the winter. Cattle graze on pasture i.e. tamed and native pasture after the winter months. As shown in Figure 3.8, the feed requirement is assumed to be met through on-farm feed production. In other words, crop acreage for cow-calf segment of the model is assumed to be driven by cattle feed requirements. Crop acreage ($acre$) for the ith feed required to meet herd feed intake requirements is estimated as:

$$acre_i = \frac{TFEED_i}{yield_i} \qquad (46)$$

where:

$$TFEED_i = FEED_i * DOF \qquad (47)$$

$TFEED_i$ is total feed required, $yield_i$ is the yield of the *ith* feed and DOF is days on feed.

The feed cost for each cow-calf producer is estimated as the feed crop establishment cost required to meet the feed acreage requirement of the herd:

$$FEDcst = acre_i * w_i \qquad (48)$$

where w_i is the cost of inputs.

The net returns for each period is specified as:

$$\pi = revenue_t - PP_{total} - PDcst - FEDcst \qquad (49)$$

The net returns to feeders (π_t^F) is specified as:

$$\pi_t^F = P^F * calf^F - FEDcst^F - PDcst^F - PP^F \qquad (50)$$

where P^F is the price of calves at finished weight, $calf^F$ is the number of calves finished, $FEDcst^F$ is the feed cost of the cattle feeder, $PDcst^F$ is non-feed related production cost in the feeding phase and PP^F is the purchase price of weaned calves. Following Awada et al., (2015), a discount factor of 5% is assumed. The discount factor captures the expected returns available on the market and the opportunity cost to the decision maker (Ross et al., 2013). It also represents the rate at which future and current returns are traded off – higher discount rates indicate a stronger preference for current consumption relative to the future (Miller, 2002; Ross et al., 2013; Damodaran, 1997).

The discounted net returns for each production segment is given as:

$$\text{Cow-calf} = \sum_{t=1}^{25} \frac{\pi_t}{(1+r)^t} \qquad (51)$$

$$\text{Feeders} = \sum_{t=1}^{25} \frac{\pi_t^F}{(1+r)^t} \qquad (52)$$

3.4.8 Price Modelling Approach

Cattle and feed prices are modelled to account for stochasticity. Inflation-adjusted prices are assumed to follow an autoregressive (AR) process[30]. Multiple tests- Akaike's information criteria (AIC), Final prediction error (FPE), Schwarz's Bayesian information criterion (SBIC), Hannan and Quinn information criterion (HQIC) and likelihood ratio (LR) tests- are used determine the lag order of the price series. The estimation is done in STATA 14 (StataCorp, 2013). As showed in tables 3A4 and 3A5 in Appendix 3A, the optimal lag length for feed crops and livestock prices are three and one periods respectively.

A seemingly unrelated regression (SUR) (Zellner, 1962) approach is used to allow for contemporaneous correlation in errors between the individual price equations within the system. Following Miller (2002), cattle prices[31] in the cow-calf segment are estimated as a system comprising steer (550 lbs), heifer (550 lbs), culled cow and bred heifer prices:

$$P_{550}^{S} = \alpha_0 + \alpha_{S550} P_{550t-1}^{S} + \varepsilon_t^{S550} \qquad (53)$$
$$P_{550}^{H} = \alpha_0 + \alpha_{H550} P_{550t-1}^{H} + \varepsilon_t^{H550} \qquad (54)$$
$$P^{cc} = \alpha_0 + \alpha_{cc} P_{t-1}^{cc} + \varepsilon_t^{cc} \qquad (55)$$
$$P^{BD} = \alpha_0 + \alpha_{BD} P_{t-1}^{BD} + \varepsilon_t^{BD} \qquad (56)$$

where P_{550}^{S} is 550 lbs steer price, P_{550}^{H} is the 550 lbs heifer price, P^{BD} is the bred heifer price and P^{cc} is the culled cow price. A similar approach is used to estimate the feed price equations in the feeder cattle segment:

$$P^{B} = \alpha_0 + \alpha\ P_{t-1}^{B} + \alpha\ P_{t-2}^{B} + \alpha\ P_{t-3}^{B} + \varepsilon_t^{B} \qquad (57)$$
$$P^{W} = \alpha_0 + \alpha\ P_{t-1}^{W} + \alpha\ P_{t-2}^{W} + \alpha\ P_{t-3}^{W} + \varepsilon_t^{W} \qquad (58)$$
$$P^{F} = \alpha_0 + \alpha\ P_{t-1}^{F} + \alpha\ P_{t-2}^{F} + \alpha\ P_{t-3}^{F} + \varepsilon_t^{F} \qquad (59)$$
$$P^{BS} = \alpha_0 + \alpha\ P_{t-1}^{BS} + \alpha\ P_{t-2}^{BS} + \alpha\ P_{t-3}^{BS} + \varepsilon_t^{BS} \qquad (60)$$

---

[30] A KPSS test for stationarity failed to reject the null of that the series were stationary (Table 3A7 Appendix 3).

[31] The weight subscripts represent the upper boundary of the cattle weight category for each of the series.

where P^B is price of feed barley, P^F is the price of forage, P^W is the price of feed wheat, is the P^{BS} price of barley silage. Following Twine (2016), fed cattle prices are estimated together with the feed barley price. This is to allow for correlation in errors between the feed and cattle prices. The heifer (900 lbs) and steer (900 lbs) prices is estimated as a function of lagged own price, current and lagged 900+ lbs and the current barley price:

$$P_{900}^{S} = \alpha_0 + \alpha_{Bt} P_t^B + \alpha_{S9} P_{900t-1}^{S} + \alpha_{S9+} P_{900+}^{S} + \alpha_{S9+} P_{900+t-1}^{S} + \varepsilon_t^s \quad (61)$$
$$P_{900}^{H} = \alpha_0 + \alpha_{Bt} P_t^B + \alpha_{H9} P_{900t-1}^{H} + \alpha_{H9+} P_{900+}^{H} + \alpha_{H9+} P_{900+t-1}^{H} + \varepsilon_t^H \quad (62)$$
$$P^{B} = \alpha_0 + \alpha_{Bt} P_t^B + \alpha_{Bt1} P_{t-1}^{B} + \alpha_{Bt2} P_{t-2}^{B} + \alpha_{Bt3} P_{t-3}^{B} + \varepsilon_t^B \quad (63)$$

A key aspect of in the forecasting of prices relates to incorporation of the error structure of the individual prices. Given the systems approach used in this paper errors correlations are accounted using the approach described in Hull (2007, pp. 363), errors are calculated as:

$$e_1 = x_1 \quad (64)$$
$$e_2 = \rho x_1 + x_2 \sqrt{1-\rho^2} \quad (65)$$

where x's are random draws distributed as $N(0,1)$ and ρ is the correlation in errors between the variables. The errors in the *ith* case are obtained from solving for α in the following:

$$e_i = \sum_{k=1}^{k=i} \alpha_{ik} x_k \quad (66)$$
$$\sum_k \alpha_{ik}^2 = 1 \quad (67)$$
$$\sum_k \alpha_{ik} \alpha_{jk} = \rho_{i,j} \quad (68)$$

The errors derived using the approach above is scaled by their standard deviation and incorporated in their respective equations.

The cow-calf producer type A faces the choice of two bulls producing calves with different feed efficiency profiles. An integer programming specification is used to analyze cow-calf producer A decision (equation 52) due to its discrete nature. A similar approach is used to analyze feeder A decision with respect to the selection of weaned calves once the bull purchase decision has been made by cow-calf producer A. Optimization models of this structure using traditional solvers then to be complex because of the uncertainty in certain components of the model. In this paper, the *RISKoptimizer* tool in @risk (Palisade, 2015) is used. This solver allows for the derivation of optimal solutions in the presence of uncertainty. The optimizer employs a genetic algorithm (GA) search process. Although, all the price series included in the model are stochastic, a fixed seed value was set to obtain a unique set of prices and allow for the comparisons between the estimates under the different scenarios evaluated. Simulation analysis is used to assess the effect of the different policy scenarios. We also use the *Goal-seek* tool to find the level of subsidy or price increment at which the cow-calf producer switches from the regular to the genomic bull. A 25-year period is assumed.

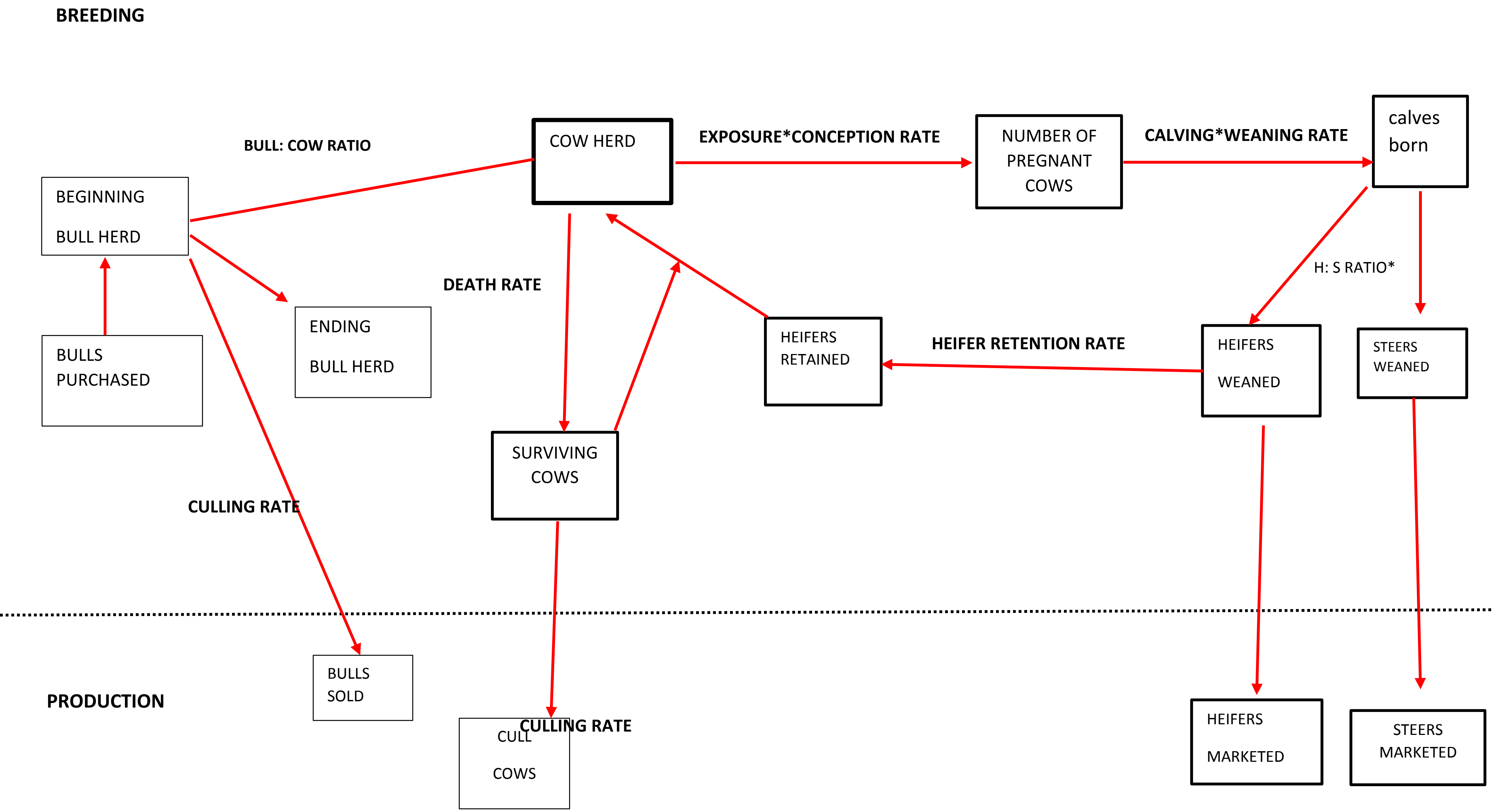

Figure 3.9: Cattle breeding and production

3.5 Data and Data Sources

Data from multiple sources are used to estimate the empirical model outlined in the previous section. The cow-calf segment is calibrated with values obtained from the Agri$Profit -a survey of cow-calf producers in Alberta (2008-2010) (Alberta Agriculture and Rural Development, 2012). Data on forage and feed barley yields are obtained from crop yield data published in the Alberta Agriculture Statistics Yearbook 2010. Information on feed requirements and entry and exit weights for the feeding phase of the model were obtained from the Alberta beef cow-calf manual (Alberta Agriculture and Food, 2008). Data on overwinter feeding cost of cows and the feeding phase (i.e. backgrounding and finisher) is obtained from AARD (2004) and the Feedlot Investment Risk Simulation (FIR$T) decision making tool. Data on breeding performance, initial herd composition, culling, exposure, conception and weaning rates are from the Agri$profit survey. This is in addition to data on herd management cost and grazing requirements. Bull price data on 18,935 transactions from 2006-2014 were collated from a regional cattle auction outlet (Figure 3.10). This data comprises sales in different locations across western Canada. Based on this data, price of the regular bull is assumed to follow a triangular distribution with the following parameters: a minimum value of $2000; a maximum of $12000 and a mode of $4000. Based on estimates from on-going trials, the price of the regular bull is adjusted by $450 to derive the price of the genomic bull (Guenther, 2016). Lower levels of increment were also tested. Other cattle and crop price data (1976-2014) used in the forecasting model were sourced from the Statistics Division of Alberta Agriculture and Rural Development. The monthly data series were converted to annual averages. To ensure the comparability of multi-year discounted cash flow estimates, the nominal prices were adjusted for inflation using the Consumer Price Index (All products) for each corresponding year (Statistics Canada, 2015). Cattle price and feed prices are assumed to be stochastic. Based on the coefficient estimates of prices estimated using a Seemingly Unrelated

Regression (SUR) approach, the distribution and the correlations between the error terms, a price forecasting model is developed for livestock (550 lbs steers and heifers, cull cows, bred heifers, cull bull, 900lbs steers and heifers) and feed crop prices (wheat, barley, forages, barley silage). Following Fennessey et al. (2013), we assume a reduction in feed intake in genomic bulls of -0.0043(kg/Dry matter/day). Based on estimates by Alford et al., (2006), higher rate of improvements in bulls are also tested (i.e. -0.43/kg/Dry matter/day) in the model. The transmission of feed efficiency from selected bulls and cows to calves is estimated as the average of the parent bull and cow's feed efficiency. These improvements are also obtained by cattle feeders if the genomic bull is purchased by the cow-calf producer through the change in the feed intake requirement of the weaned calves.

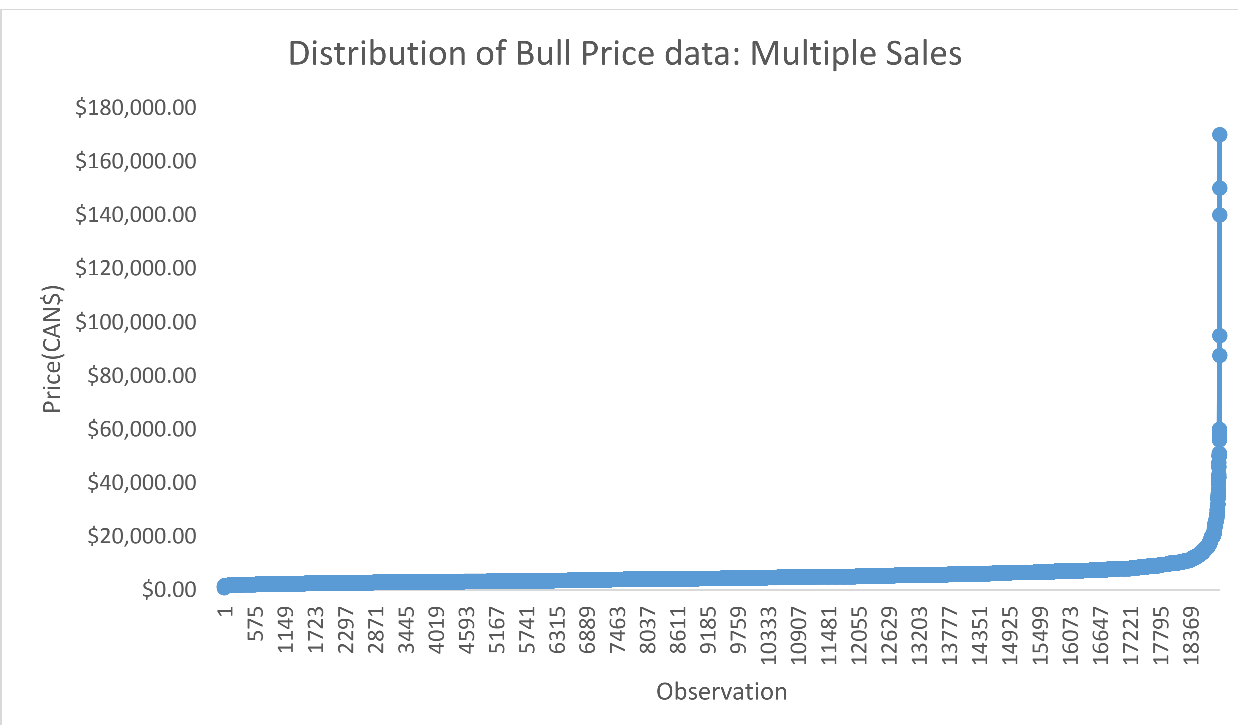

Figure 3.10: Trends in bull purchase prices (2006-2012) (Source: Author's own)

3.6 Results

The analysis of the value to producers of genomic improvements in feed efficiency is preceded by a description of the different prices series incorporated in the forecasting model. Table 3.2 is the summary of the crop and livestock prices for the cow-calf and finisher components of the model. With respect to the feed crop prices, the mean price ($/tonne) of feed barley and barley silage were $158.15 and $41.30 respectively. Feed wheat price averaged $179.82; ranging from a high of $330.17 to a low of $95.13. The mean forage price over the 38-year period was $41.30.

Table 3.2: Descriptive statistics of feed crop and livestock prices

Feed crop prices ($/tonne)				
Variable	Mean	Std. Dev	Min	Max
Wheat	179.82	58.63	95.13	330.17
Barley	158.15	42.88	98.06	268.31
Forages	92.35	31.27	51.07	158.13
Barley silage	41.30	11.20	25.70	70.15
Cow-calf segment Cattle prices ($/cwt)				
Steer (550 lbs.)	108.76	27.26	73.41	142..95
Heifer (550 lbs)	105.57	24.65	73.30	136.53
Cull cows	58.07	20.12	19.76	110.21
Bred heifers	65.76	17.73	40.31	115.61
Cull Bull	77.96	29.78	19.83	169.69
Feeding phase Cattle prices ($/cwt)				
Steer (900 lbs)	103.64	15.96	92.52	145.72
Heifer (900 lbs)	101.71	7.30	93.14	117.46

In general, cattle prices differ by gender and weight. Heifers tended to be valued lower than steers for any given weight category. The negative relationship between cattle price and weight is evident. For example, while the average price ($/cwt) for 550 lbs steer was $108.76 that for 900 lbs was lower i.e. $103.64. Similarly, the 900 lbs heifer price ($101.71) was lower than of the 550lbs heifers (105.57). This inverse relationship reflects a price slide in cattle prices.

The results of the Seemingly Unrelated Regression (SUR) equation are reported in Tables 3A11-3A13 in Appendix 3A. Table 3A11 is a summary of the estimates for the crop price series. Overall the estimated R^2 for the feed crop prices ranged between 0.68-0.80. The estimated coefficients were significant at the 1% level. The coefficient of the lagged price was positive and significant whilst the sign of the coefficient in the second period was the opposite[32].

Similarly, the SUR regression estimates for the cattle prices are reported in Tables 3A12 and 3A13. The coefficients of prices in the cow-calf segment were significant at 1% significance level. The effect of lagged prices for each series was positive and significant.

The estimates (Table 3A13) for the feeding segment included and the cost of feeding (barley price). Consistent with a priori expectation the barley price was negative and robust across the on the heifer and steer prices whilst the 900+ lbs steer price was positive. The lagged coefficient of the price was significant at the 1% level. This outcome suggests that cost of gain (feed prices) has a negative effect on cattle prices. Conversely, expected value of gain (900+ lbs steer price) had a positive effect on feeder cattle prices.

3.6.1 Stochastic Multi-year Integer Optimization Results

The approach used in this study is to first simulate the baseline scenario for the different producer categories analyzed in this study. The baseline scenario represents net returns[33] in the absence of the technology, i.e., genomically selected feed efficiency bulls. Under this scenario, both cow-calf producers purchase regular bulls and produce regular calves. Each feeder purchases a proportion of the calves produced. Table 3.3 presents a summary of the distribution of net returns for each segment of production. Calves are assumed to be marketed to feeders at 550 lbs and finished at 1225 lbs. Mean net returns per cow by producer type was approximately: \$47.07 (cow-calf A); \$47.07 (cow-calf B); \$142.10 (feeder A); and; \$142.10 (feeder B).

---

[32] A Breusch- Pagan test (Breusch and Pagan, 1980) was conducted which showed that correlation in the errors was significant.

[33] Mean net returns are obtained after 10,000 iterations.

Table 3.3: Baseline scenario: Absence of genomic bulls

Producers	Mean ($)	Max ($)	Min ($)
	Returns/cow[34]		
Cow-calf type A	47.07 (22.88)	113.86	-28.07
Cow-calf type B	47.07 (22.88)	113.86	-28.07
Feeder A	142.10 (30.59)	236.82	49.47
Feeder B	142.10 (30.59)	236.82	49.47
	Average returns		
Cow-calf type A	13517.91 (6567.06)	32702.60	-8065.58
Cow-calf type B	17430.63 (6092.74)	32702.60	-8065.58
Feeder A	30378.26 (6533.11)	50619.92	10606.74
Feeder B	30378.26 (6533.11)	50619.92	10606.74

Note: Standard deviation in parenthesis.

Consistent with the mean net returns per head estimates, average net returns in the feeder category were higher (i.e. $30378.26) than that of cow-calf producers (i.e. $13517.91).

A higher priced (more feed efficient) genomic bull is subsequently introduced and stochastic integer optimization model is estimated. Given the choice of a higher cost but more feed efficient bull and a regular bull, cow-calf producer A chooses the type of bull that maximizes net returns.

[34] Net returns for cattle feeders are reported in $/calf

This decision is discrete i.e. “1= genomic bulls” versus “0= status quo (regular bulls)”. Consistent with the assumed segmentation in cow-calf producers, the non-adopting cow-calf producer (cow-calf B) purchases regular bulls and produces regular calves. If the genomic bull is optimal in the case of A, both genomic feed efficient calves (heifers and steers) and regular calves (heifers and steers) are available to feeders.

At an additional cost of $450/bull, the increase in net returns from reduced feed costs obtained from the purchase of the genomic bull is lower than the cost. As showed in Table 3.4, the mean net returns of cow-calf producer A reduces by $1.64 relative to the base scenario. This is equivalent to a reduction of approximately 3.5 %. As a result, the optimal bull choice is the regular bull. In the absence of the genomic bull, net returns are identical to the base scenario (Table 3.3).

Table 3.4: Cow-calf producer net returns at an additional genomic bull price of $450

Producers	Mean ($)	Max ($) Returns/cow	Min ($)
Cow-calf type A	45.43 (22.86)	112.14	-29.64
Cow-calf type B	47.07 22.88	113.86	-28.07

Note: Standard deviation in parenthesis

3.6.2 Assessment of Possible Interventions

Given the potential benefit of genomic improvement in feed efficiency to the beef cattle industry, alternate options that can stimulate uptake are examined. Three scenarios are assessed. These are: (1) a cost share subsidy scheme; (2) payment of a differential price by cattle feeders for genomic calves; and; (3) more feed efficient bulls.

First, the level of subsidy that would induce cow-calf producers to purchase the genomic bull is addressed. Several bull price thresholds were evaluated and the lower boundary of the level of subsidy that causes the cow-calf producer A to switch from a regular to a genomic bull was derived (see Figure 3.11 for the proportion of genomic breeding stock with the purchase of genomic bulls).

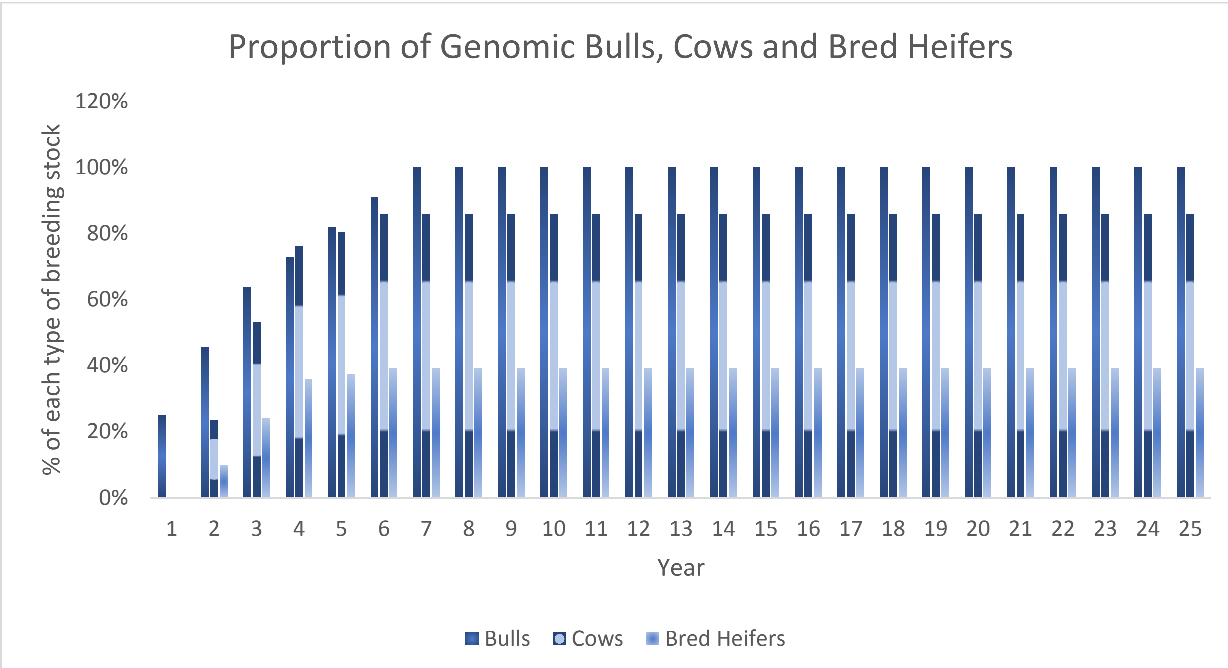

Figure 3.11: Changes in the proportion of Genomic breeding stock in each type of cattle over a 25-year period (Source: Author's own)

The switch to genomic bulls occurred when the price differential between the two bull types is at most \$130. This means that government has to incur a cost of \$320/bull if the current cost differential is \$450. In other words, this represents the level of cost underwriting that would induce the cow-calf producer (type A) to purchase bulls with genomic information on feed efficiency. Figure 3.12 shows the production of the different type of calves. With the purchase of genomic bulls, four types of calves are available to feeders – genomic and regular heifers and steers. Feeder A selects the optimal mix of calves that maximizes the producer's returns (see Figure 3.12).

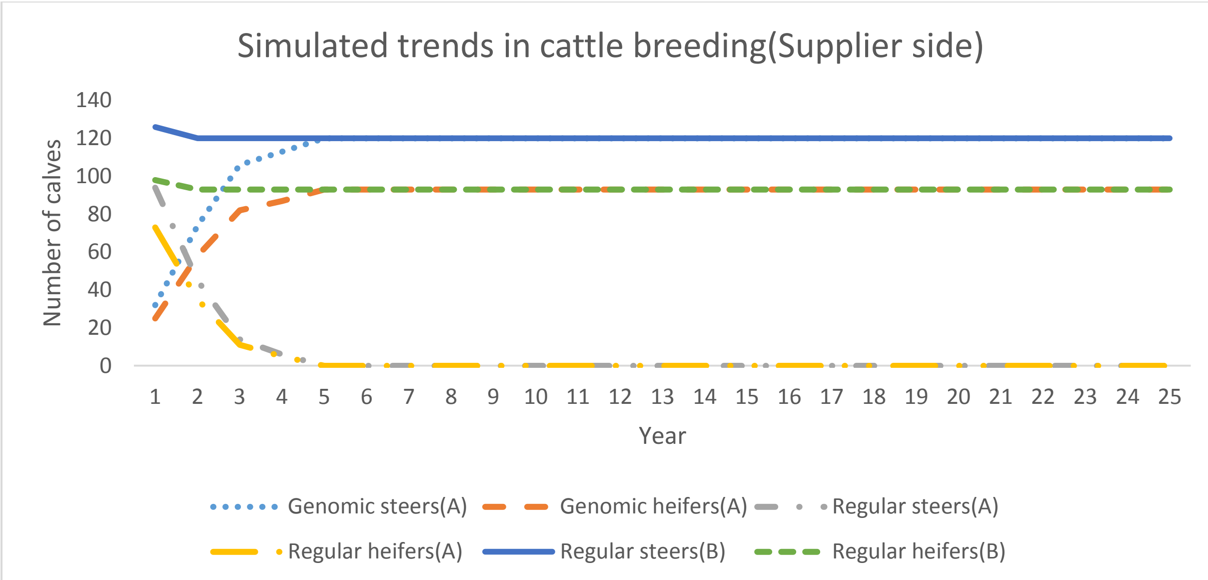

Figure 3.12: Production of calves by type over a 25-year period (Source: Author's own)

The cow-calf segment obtains a net benefit of \$0.24/cow whilst the benefit to feeder A is much higher, i.e., \$2.39/calf (Table 3.5). As showed in Figure 3.13, feeder A mainly selects a high proportion of genomic steers and complements this with genomic heifers and regular steers. As shown in the historical price summaries, weaned steers tend to be more expensive at the input end, but commands higher price at finished weight. Expectedly, mean net returns obtained by feeder B is lower than that of feeder A. In aggregate, genomic improvements in feed efficiency increases net returns of cow-calf producers by 0.50% as compared to 2.4% in the feeder segment.

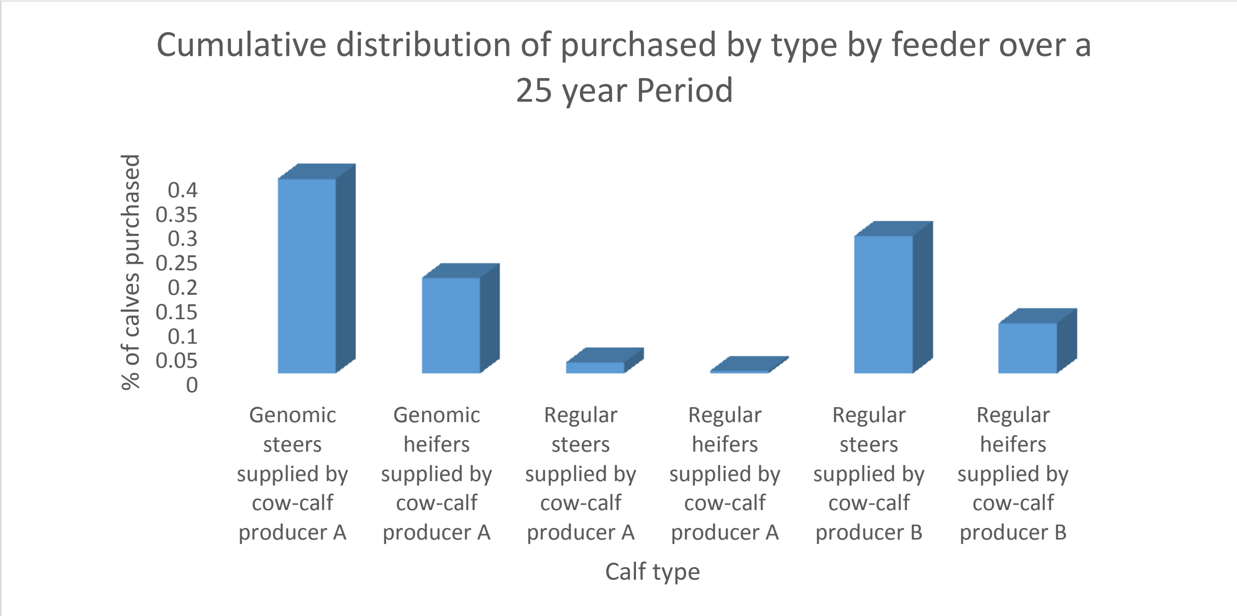

Figure 3.13: Calves purchased by type (Feeder A) (Source: Author's own)

Table 3.5: Estimated net returns under a subsidy scheme for genomic bulls

Producers	Mean ($)	Max ($)	Min ($)	Change in mean ($)	Change in mean by segment ($)	Change in mean by segment (%)
		Returns/cow				
Cow-calf type A	45.31 (22.86)	144.03	-27.75	0.24	0.24	0.50%
Cow-calf type B	47.07 (22.88)	113.86	-28.07	0.00		
Feeder A	152.36 (30.80)	246.56	59.97	10.26	2.39	2.39%
Feeder B	135.24 (30.60)	230.57	42.29	-6.86		

Note: Standard deviation in parenthesis

Alternatively, this outcome can be achieved through market based measures. Considering the higher benefit of a feed efficient herd to the cattle feeding segment, feeders can pay a higher price for genomic calves. The *Goal Seek* tool in @risk (Palisade Corporation, 2015) is used to find the price level that would cause cow-calf producers to switch to genomic bulls. In the absence of a subsidy, the payment of an additional \$0.90/calf induces the cow-calf producers to purchase genomic bulls. As summarized in Table 3.6, the net benefit to the cow-calf sector is ~ \$0.26/cow. By paying a higher differential price for feed efficient calves, net returns obtained by feeder reduces to \$0.83 from the \$2.39. This represents 65% reduction in the extra net returns as compared to the scenario under which feeders pay a uniform price for both genomic and regular calves.

Table 3.6: Estimated net returns when feeders pay a higher price for genomic calves

Producers	Mean (\$)	Max (\$)	Min (\$)	Change in mean (\$)	Change in mean by segment (\$)	Change in mean by segment (%)
		Returns/cow				
Cow-calf type A	47.33 (22.86)	114.04	-27.73	0.26	0.26	0.55%
Cow-calf type B	47.07 (22.88)	113.86	-28.07	0.00		
Feeder A	150.75 (30.80)	245.06	58.37	8.65	0.83	0.58%
Feeder B	134.28 (30.60)	229.62	41.33	-7.82		

Note: Standard deviation in parenthesis.

The results reported in Tables 3.5 and 3.6 are based on the assumption that the rate of improvement obtainable from the feed efficient bull is -0.0043(kg/DM/Day). To assess the impact of more feed efficient bulls on the incentive to adopt, a higher rate of improvement of -0.43 kg/DM/day (Alford *et al.*, 2010) is assumed. In the conceptual model, this is synonymous to the effect of an increase in ψ . At this rate, the choice of the genomic bull becomes optimal even at a price differential of \$450.Change in mean net returns is positive for both cow-calf producers who adopt and the feeder segment (Table 3.7). Consistent with the previous estimates, the relative value is much higher for feeders as compared to cow-calf producers.

Table 3.7: Estimated net returns for higher feed efficient genomic bulls

Producers	Mean ($)	Max ($)	Min ($)	Change in mean ($)	Change in mean by segment ($)	Change in mean by segment (%)
		Returns/cow				
Cow-calf type A	48.42 (22.86)	115.13	-26.64	1.35	1.35	2.87%
Cow-calf type B	47.07 (22.88)	113.86	-28.07	0.00		
Feeder A	154.57 (30.78)	248.85	62.38	12.47	5.61	3.95 %
Feeder B	135.24 (30.60)	230.57	42.29	-6.86		

Note: Standard deviation in parenthesis.

Based on the results of the alternative scenarios, the demand for genomic feed efficient bulls by cow-calf producer is derived (Figure 3.14). This is based on assumed improvements in feed efficiency of 0.0043(kg/DM/Day). The upper part of the chart shows the incremental cost in the price of genomic bulls and lower section shows the actual demand at these costs. As derived previously, demand for genomic bulls is approximately zero if the additional costs as compared to the price of regular bulls exceeds $450. The demand has a kink at an additional cost of $130/bull, indicating the point at which the producer switches to the genomic bull. The demand curve has a "Z" shape depicted by A-B; B-D; D-E. The introduction of a cost share scheme results in a downward slopping demand curve (line A-C) with government bearing the incremental costs (line B-C). This same outcome is derived if the feeder pays for the additional bull cost through the payment of a higher price for genomic calves as compared to regular calves. At higher rates of improvements in feed efficiency, the demand for genomic bulls feasible without subsidy by government or without higher prices for genomic calves at the additional cost of $450 and this is showed by line F-C. Over time, higher prices for genomically selected feed efficient bulls may result from competitive demand for the trait and further analysis is necessary of the breakeven price for cow calf producers to invest in the bull at multiple levels of bull costs. These outcomes may also change as the cost of the technology reduces over time.

3.6.3 Impact of Changes in Calf and Feed Barley Prices

In this section, the sensitivity of net returns to changes in 550 lbs calf price, finished cattle price, feed barley price and changes in finished weight are examined. The assessment of the impact of changes in price also allows for the evaluation of key outcomes of the theoretical model- a feed efficient herd ameliorates (increases) the impact of negative (positive) input and output price changes. The four scenarios previously analyzed are reported – base scenario, subsidy payments, payment of a higher price by feeders and the effect of more feed efficient bulls. The limits of the price are set at the maximum (high) and minimum (low) historical price levels respectively.

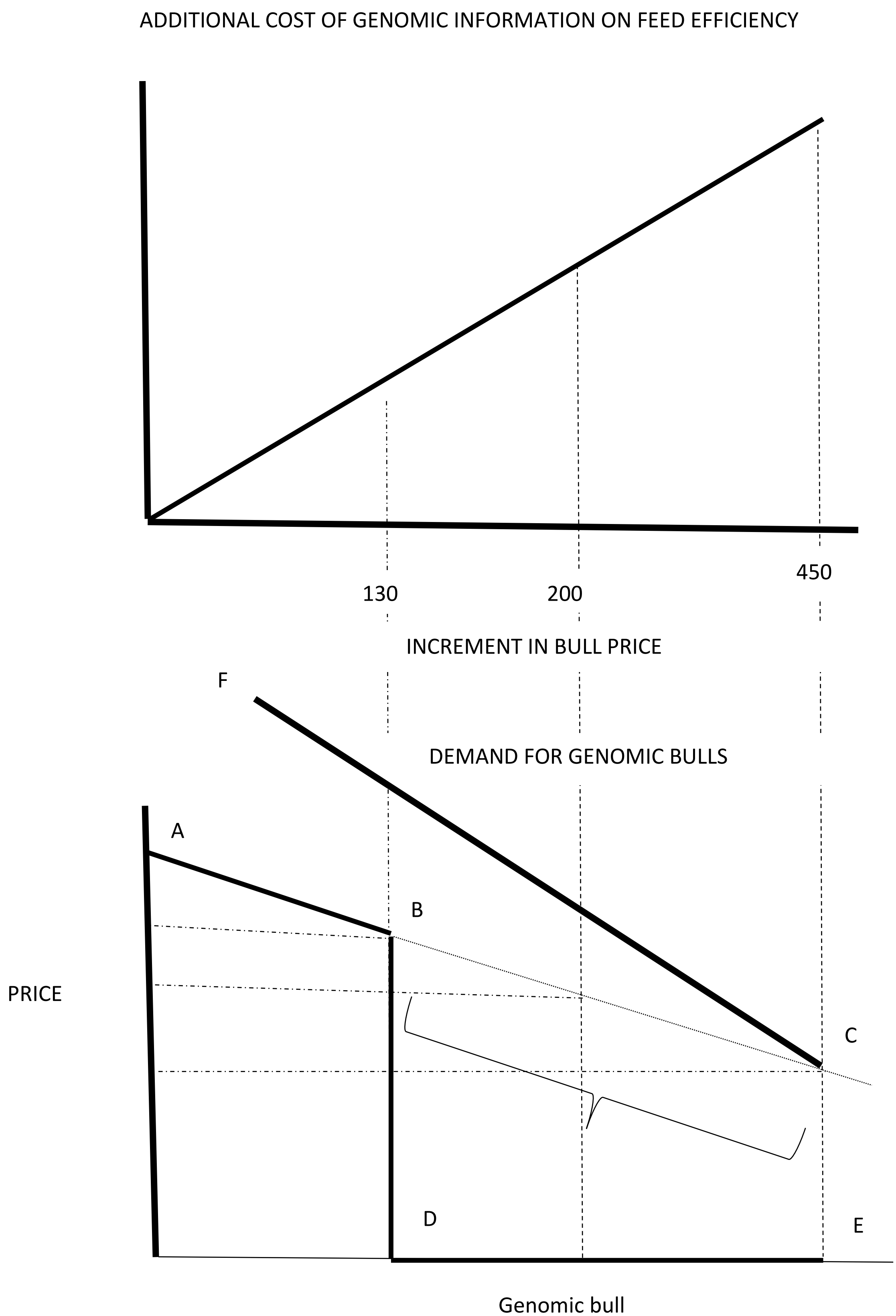

Figure 3.14: Demand for genomic bulls under different scenarios

3.6.4 The Effect of Changes in Cattle Price

The results presented in section 3.7.2 assumes 550 lb calf price of $108.18/cwt and $104.91/cwt for steers and heifers respectively. These calves represent the output of the cow-calf segment and the primary source of revenue for these producers. For feeders, weaned calves are inputs. The effect of changes in calf price on profits at the feeding phase is therefore opposite to that of cow-calf producer.

At the minimum price of $73.41/cwt (steers) and $73.30 (heifers), the net returns of cow-calf producers is $107.98. The corresponding mean value for feeders is $249.59 (Table 3.8). The introduction of genomic bulls under a subsidy scheme results in an increment of $0.26/cow (0.78%) and $3.40/calf (2.11%) for cow-calf producers and feeders respectively. Mean net returns of the latter reduces to $0.84/calf (0.52%) under the scenario where a higher price is paid for feed efficient calves. Consistent with previous estimates, higher levels of improvement in feed efficiency further increases the difference between cow-calf producer and cattle feeder net returns. Mean net returns increase by $1.36 (cow-calf) and $5.61 (feeders) relative to the base scenario.

The effect of higher calf prices is also examined. A comparison of Tables 3.8 and 3.9 shows the effect of high and low calf prices on both cow-calf and feeder net returns. As evident from the baseline scenarios, net returns for cow-calf producers is ~ 80% higher at maximum price calf prices when compared with the minimum price. The inverse is observable for feeders ~ 40% reduction in net returns for feeders. This reflects the relative importance of changes in calf price on the profits of cow-calf producers.

Under a subsidy scheme, net returns of cow-calf producers increase by ~ 0.40%. A similar result is obtained under the scenario where a differential price is paid for feed efficient calves. Cow-calf net returns increase by about 2% when the assumed improvement in feed efficiency is sufficiently high.

Table 3.8: Sensitivity of cattle producer net returns to changes in 550 lbs price (minimum)

	Cow-calf A	Cow-calf B	Feeder A	Feeder B
Base scenario				
Min	-30.46	-30.46	60.01	60.01
Max	107.98	107.98	249.59	249.59
Mean	33.13	33.13	160.85	160.85
Subsidy scheme for genomic bulls				
Min	-30.14	-30.46	71.92	51.46
Max	108.15	107.98	260.77	244.59
Mean	33.39	33.13	171.29	153.81
Change at mean($)	0.26	0	10.44	-7.04
% by segment	0.78		2.11	
Feeders pay a higher price				
Min	-30.12	-30.46	70.31	50.50
Max	108.16	107.98	259.16	243.64
Mean	33.4	33.13	169.68	152.86
Change at mean($)	0.27	0	8.83	-7.99
% by segment	0.78		0.52	
Higher feed efficient genomic bulls				
Min	-29.03	-30.46	74.18	51.46
Max	109.25	107.98	262.87	244.59
Mean	34.49	33.13	173.50	153.81
Change at mean($)	1.36	0	12.65	-7.04
% by segment	4.12		3.49	

Note: calf prices [35]($/cwt): minimum $73.30(heifer) and 73.41(steers).

Net returns to feeders increases by 3.38, 3.38 and 5.59/calf under subsidy, differential prices and higher feed efficient calves respectively. This represents 1-4% increase when compared with the baseline scenario.

The sensitivity analysis also allows for the assessment of the role of a feed efficient herd in moderating the effect of price volatility on cattle producer profits[36]. In Figure 3.15, changes in net returns at both minimum and maximum calf price relative to the mean calf price are examined. The net returns at the mean baseline calf price represent the zero axis in Figures 3.15 and 3.16. For

[35] 550 lbs

[36] With the minimum and maximum price being the polar cases.

example, Feeder A's net returns increase by 13% at the minimum 550 lbs calf price as compared to the mean calf price. The base scenarios in Figure 3.15 represent the absence of genomically improved calves. The introduction of genomic calves increases net returns by a further 6-9% depending on the scenario. Inversely, at maximum calf price net returns reduce by 12% at the baseline. Feed efficient calves increase net returns by an additional 6-8%.

Table 3.9: Sensitivity of cattle producer net returns to changes in 550 lbs price (maximum)

	Cow-calf A	Cow-calf B	Feeder A	Feeder B
Base scenario				
Min	-12.1	-12.1	41.20	41.20
Max	11.98	116.98	222.90	222.9
Mean	60.53	60.53	124.00	124.00
Subsidy scheme for genomic bulls				
Min	-11.79	-12.1	51.68	34.02
Max	117.15	116.98	236.77	214.11
Mean	60.76	60.53	134.11	117.27
Change at mean($)	0.23	0	10.11	-6.73
% by segment	0.38		2.73	
Feeders pay a higher price				
Min	11.78	-12.10	50.08	33.07
Max	117.16	116.98	235.16	213.16
Mean	60.77	60.53	132.51	116.32
Change at mean($)	0.24	0	8.51	-7.68
% by segment	0.39		0.67	
Higher feed efficient genomic bulls				
Min	-10.69	-12.1	84.1	34.02
Max	118.25	116.98	238.95	214.11
Mean	61.86	60.53	136.32	117.27
change($)	1.33	0	12.32	-6.73
% by segment	2.20		4.51	

Note: maximum $135.53(heifers) and $142.95(steers).

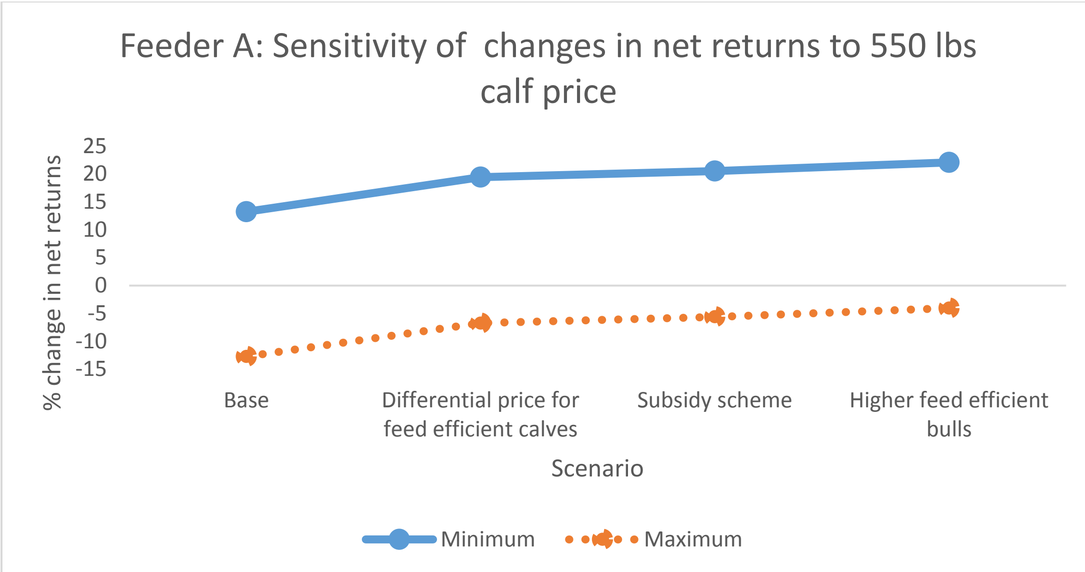

Figure 3.15: Sensitivity of Feeder A's net returns to changes in calf price

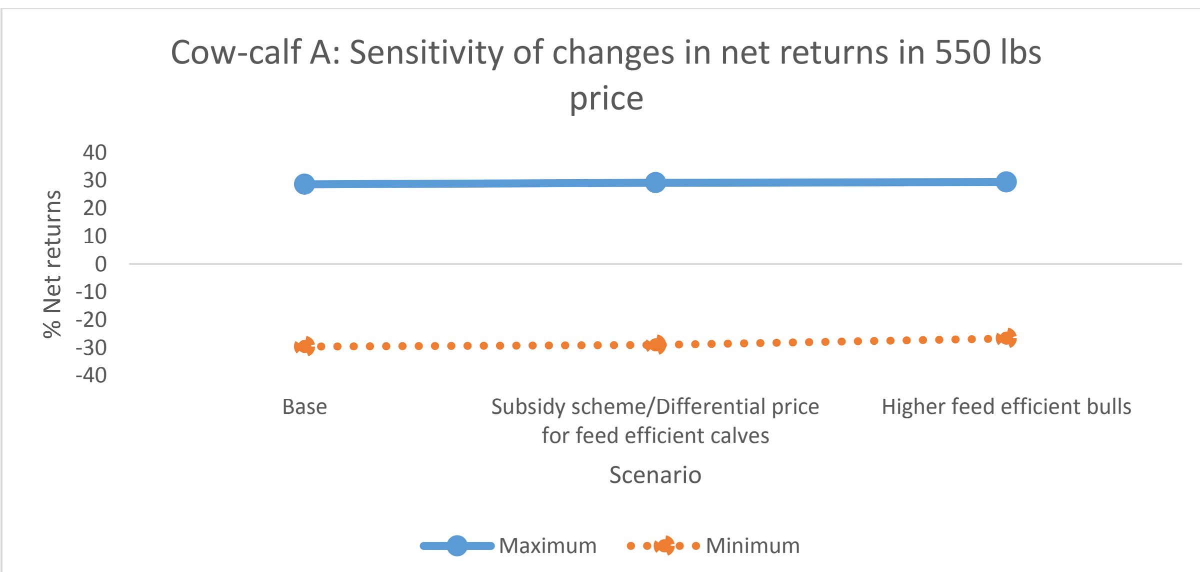

Figure 3.16: Sensitivity of Cow-calf producer A's net returns to changes in calf price

Similar outcomes are obtained for cow-calf producer A (Figure 3.16). In the case of cow-calf producers however, the impact of feed efficient calves is considerably lower. For example, at the maximum calf price, the purchase of genomic bulls increase net returns by 0.52 - 0.75%. At minimum price, net returns are 0.57-2.88% higher as compared to the base scenario.

3.6.5 Effect of Changes in Finisher Cattle Price

Sensitivity of net returns to changes in the price of finished cattle is also analyzed. The impact of changes in finished cattle price in the absence of feed efficient calves is compared with the scenario where the cattle feeder purchases feed efficient calves. This analysis also allows for the comparison of the role of feed efficiency in reducing output price volatilities in cattle feeding.

Table 3.10: Sensitivity of cattle producer net returns to changes in 1225 lbs price

Low 1225 lbs price			High 1225 lbs price		
	Feeder A	Feeder B		Feeder A	Feeder B
Base scenario					
Min	32.93	32.93	Min	61.08	61.08
Max	220.28	220.28	Max	248.65	248.65
Mean	125.66	125.66	Mean	154.36	154.36
Subsidy					
Min	45.77	23.33	Min	69.19	56.31
Max	232.47	211.62	Max	256.72	244.81
Mean	138.23	116.4	Mean	162.25	149.9
Change at mean ($)	12.57	-9.26	Change at mean ($)	7.89	-4.46
% by segment	2.63		% by segment	2.22	
Subsidy scheme for genomic bulls					
Min	44.17	22.38	Min	67.59	55.36
Max	230.87	210.66	Max	255.12	243.86
Mean	136.63	115.45	Mean	160.65	148.86
Change at mean ($)	10.97	-10.21	Change at mean ($)	6.29	-5.5
% by segment	0.60		% by segment	0.51	
Higher feed efficient genomic bulls					
Min	48.18	23.33	Min	71.61	56.31
Max	234.65	211.62	Max	258.9	244.81
Mean	140.44	116.4	Mean	164.46	149.9

Change at mean ($)	14.78	-9.26	Change at mean ($)	10.1	-4.46
% by segment	4.39		% by segment	3.65	

Note: high steer price= $120.68/cwt; low price=$93.69/cwt. High heifer price=$117.46/cwt; low=$93.14/cwt.

Table 3.11: Sensitivity of cattle producer net returns to changes in feed barley price

Low feed barley price			High feed barley price		
	Feeder A	Feeder B		Feeder A	Feeder B
Min	52.38	52.38	Min	48.51	48.51
Max	240.36	240.36	Max	235.31	235.31
Mean	146.06	146.06	Mean	140.96	140.96
Subsidy scheme for genomic bulls					
Min	63.53	44.62	Min	59.01	41.32
Max	249.82	236.38	Max	245.13	229.06
Mean	156.33	139.21	Mean	151.21	134.09
Change at mean ($)	10.27	-6.85	Change at mean ($)	10.25	-6.87
% by segment	2.34		% by segment	2.40	
Feeders pay a higher price					
Min	61.93	43.67	Min	57.41	40.37
Max	248.22	235.43	Max	243.53	228.11
Mean	154.73	138.26	Mean	149.61	133.14
Change at mean ($)	8.67	-7.8	Change at mean ($)	8.65	-7.82
% by segment	0.60		% by segment	0.59	
Higher feed efficient genomic bulls					
Min	65.85	44.62	Min	61.44	41.32
Max	251.86	236.38	Max	247.32	229.06
Mean	158.52	139.21	Mean	153.43	134.06
Change at mean ($)	12.46	-6.85	Change at mean ($)	12.47	-6.9
% by segment	3.84		% by segment	3.95	

Note: High and low feed barley prices ($/tonne) set at $206.84/tonne and $102.46/tonne respectively.

In general, the effect of improvements in feed efficiency is higher at relatively low \$93/cwt finished weight price as compared to high price (\$120/cwt). As showed in Table 3.10, the purchase of feed efficient calves increases net returns by 0.60-4.39% and 0.51-3.65% in the former and latter respectively. Improved feed efficiency also reduces the effect of higher feed costs by ~ 1-4%. Net returns increase by a similar proportion when feed barley is low (Table 3.11).

3.6.6 Effect of Higher Finished Weight

One of the potential consequences of improvements in feed efficiency may be the tendency for producers to feed to cattle to heavier weights[37]. This is primarily because the return on gain (\$/lbs) increases with the reductions in cost of gain through improved feed efficiency. If cattle is purchased at 550 lbs and fed to 1225 lbs, the additional weight gained is 675 lbs. The purchase of genomic calves increases the return per weight gain (\$/lbs) from \$0.21/lbs in the baseline scenario to \$0.23/lbs under the subsidy scheme. To further explore the impact of increases the higher return on gain, the finished weight of cattle is increased from 1225 lbs to 1300 lbs. Feeding cattle to higher weights increases mean returns by about 11% as compared to finishing cattle at 1225 lbs. At 1300 lbs, net returns increase by 0.60-4% under the different scenarios assessed (See Table 3.12).

[37] All else equal.

Table 3.12: Estimated net returns at finished weight of 1300 lbs

	Feeder A	Feeder B
	Base scenario	
Min	63.61	63.61
Max	255.06	255.06
Mean	158.91	158.91
	Subsidy scheme for genomic bulls	
Min	74.85	55.78
Max	265.4	248.34
Mean	169.78	151.54
Change at mean ($)	10.87	-7.37
% by segment	2.20	
	Feeders pay a higher price	
Min	73.25	54.83
Max	263.8	247.39
Mean	168.18	150.59
Change at mean ($)	9.27	-8.32
% by segment	0.60	
	Higher feed efficient genomic bulls	
Min	77.49	55.78
Max	267.75	248.34
Mean	172.2	151.54
Change at mean ($)	13.29	-7.37
% by segment	3.73	

3.7 Discussion

The estimated mean net returns ($/cow wintered) for the cow-calf segment in the base scenario ($47.07) is lower than the $59.26 reported for Alberta[38] in the Agri$profit survey (AARD, 2012) but lies well within the $35.71-$65.36 reported for the different geographical locations within the province. Further, net returns for feeders also lies between the ranges ($191-228) and ($7.87-$292.84) reported by Khakbazan et al. (2014) and Twine (2014) respectively. Khakbazan et al. (2014) compared returns from different feeding systems in Manitoba and Saskatchewan. Twine (2014) tracked monthly cash flow for cattle feeders in Alberta in the assessment of cattle feeder loan guarantee program in Alberta.

As evident from the results of the optimization model, at conservative levels of improvement, it is not optimal for cow-calf producers to purchase genomic bulls without the payment of a higher price for genomic calves by cattle feeders or the implementation of a cost share scheme that partially compensates the producers. The level of price increment in weaned calves that causes cow-calf producers to switch to genomic bulls i.e. $0.90/calf is lower than estimates of payable premiums for feed efficient calves ($2/cow) reported by Exton et al. (2010). The benefit to both feeders and cow-calf producers is higher under a subsidy scheme. This is unsurprising as the subsidy scheme is the zero cost option for producers.

Alternatively, a GHG emission reduction tax payable by feedlot operators can be instituted. From the analysis in Chapter 4 the selection for feed efficient cattle reduces GHG emissions by approximately 13 Tonnes CO_{2eq}/year. This implies, an emission reduction tax of 6.9 cents/CO_2eq can be charged per calf to raise revenue to subsidized cow-calf producers. This will have the same effect as the government support subsidy scheme or the payment of premiums by feedlot producers

[38] Provincial average

but has the relative advantage of capturing the positive environmental externalities of higher feed efficiency.

However, with increasing feed efficiency in bulls (for example, under the higher feed efficiency scenario), there are incentives for cow-calf producers to adopt. These higher levels of improvement can only be attained from increased selection emphasis on the trait and the development of more accurate genomic selection indicators. This indicates the cyclicality of the innovation and the need for producers to adopt. Further, the results from the sensitivity analysis suggest that genomic improvement in feed efficiency can reduce the impact of price volatilities in both cattle and grain markets.

In terms of relative benefits, these results suggest that genetic improvements in feed efficiency offer little economic benefit to the cow-calf producer given that calves generally raised on lower cost pasture. Improvements in the trait however benefits downstream sectors such as feedlots where animals are fed a much more expensive grain-based diet. Since there is currently no market mechanism that rewards cow-calf producers that sell more feed efficient feeder calves, cow-calf producers can reap the benefits of these improvements through retained ownership of calves or some form of strategic alliance. This highlights the apparent lack of incentive for producers to purchase bulls with genomic information on feed efficiency. It also supports the strong linkage between retained ownership and cow-calf producer preference for genomic information on feed efficiency identified in Chapter 2.

The results of this study have a number of important implications. First, while cow-calf producer adoption of genomic selection for feed efficiency has economic outcomes, the misalignment of incentives in the beef supply chain is likely to slow down the decision to adopt. This is evident from the value distribution from improvements in the trait along the supply chain and the current lack of price differentiation for feed efficient calves. Given the structure of the supply chain, and the limited role of the cow-calf sector in influencing prices, the adoption of this innovation remains unlikely under particular assumptions of additional bull cost and conservative feed efficiency gains. Breeder led diffusion models that have been successful in the dairy industry (Strauss, 2010) may have limited success in beef cattle due to differences in production and marketing systems and structure of the genetics industry.

3.8 Conclusions

In this study, an ex-ante approach was used to evaluate the cow-calf producer incentive adoption of bulls with genomic information on feed efficiency. A theoretical model was developed and key outcomes were evaluated with a stochastic integer optimization model. The analysis was situated in an industry context and accounted for heterogeneity in producer type (e.g. potential adopters and non-adopters) within segment and between levels of production (cow-calf and feeders) Heterogeneity in the quality of calves (i.e. regular or genomic) based on the bull choice was also accounted for. The study showed that at present, the existing incentives for cow-calf producer uptake of the technology may not be adequate despite the potential benefits of the technology to the beef industry. This outcome is not surprising as the relative disadvantage of cow-calf operators in extracting value for different traits in beef cattle supply chains is well-known. In fact, on the issue of value signalling related to output traits, Schroeder (2003) noted that:

These meandering value signals are especially problematic for cow-calf and seed stock producers whose genetic selection decisions are long run in nature and appropriate signals need to have long run focus.

The results of the present analysis indicate that value signally with respect to input traits can be even more problematic. From the comparison of the different policy scenarios, it seems that the institution of a subsidy scheme such as the Irish Genomic project would be beneficial to cow-calf producers at least until the level of attainable improvements in the genomic bull is sufficient to stimulate uptake. Such a scheme must however overcome the peculiar complexities associated with the structure of the Alberta beef industry. The Irish beef production system is less disaggregated as the Alberta system. There is also the Irish Cattle Breeding Federation (ICBF) that functions as an intermediary between all relevant stakeholders in the cattle industry. Alternatively, strategic alliances between feedlot operators and cow-calf producers can be developed to overcome the supply chain bottlenecks identified in this study.

Future studies can improve on the present results can improve by accounting for reductions in the cost of the innovation over the time once these estimates become available. Alternative approaches such as a real options approach that accounts for uncertainties in decision making will be a useful extension to the present study. The selection for feed efficiency is linked with the methane emissions and there are emerging institutional mechanisms in Alberta for cow-calf producers to obtain additional streams of net returns. This study did not however, consider these environmental outcomes and the effect of this additional revenue stream on the incentive to adopt. It is also plausible that beef cattle producers can extract additional value from environmentally conscious consumers willing to pay premiums for feed efficiency. Whether or not these additional values are adequate to stimulate uptake is an open empirical question.

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APPENDIX 3A: ADDITIONAL DATA AND TABLES

Table 3A1: Cattle feed intake requirements for the different segments of production

INPUT	VALUES		
	COW-CALF		
WINTER FEEDING***			
Calves (1.65lb/day):	INTAKE	COWS	BULLS
Days on Feed Hay (lb DM/day) Barley silage (lb DM/day)	40.00 7.00 11.50	112.00 24.07 9.10	112.00 26.00 9.10
	GRAZING REQUIREMENTS		
CATTLE	AUMs		
Bulls Cull Cows Unbred/Retained Heifers Weaned Steers Weaned Heifers	1.79 1.31 1.03 0.55 0.55		
	RATIONS		
	FEEDER RATION (ADG*=2.00 lbs/day)	FINISHER RATION (ADG=3.10 lbs/day)	
Barley(DM/lbs/head/day) Silage(DM/lbs/head/day) Supplement(DM/lbs/head/day)	5.425 9.61 0.465	15.84 7.68 0.48	
TOTAL DMI(DM/lbs/head/day)	15.50	24.00	
	WEIGHT ASSUMPTIONS		
	PURCHASE WEIGHT		SALE WEIGHT
Backgrounding	550 lbs		750 lbs; 900 lbs
Finisher	750 lbs; 900 lbs		1225 lbs;1300 lbs

Source: Alberta beef cow-calf manual (AAF 2008) *lower rate of gain (1.75 lbs/day) assumed for heifers; **Livestock ration is assumed to be composed of approximately 60% barley and 40% hay.

Table 3A2: Input cost data: cow-calf and feeding segments of production

	COW-CALF	
GENERAL LIVESTOCK COSTS	per/cow wintered	
Veterinary & Medicine Utilities & Miscellaneous Custom Work & Specialized Labour Paid Labour & Benefits	$14.04 $11.91 $3.26 $17.32	
Pasture costs-owned	($/acre)	
	FEEDING SEGMENT	
INPUT	Finisher (cost/head)	Backgrounding (cost/head)
Bedding	$0.00	$0.05
Veterinary and medicine	$0.06	$0.09
Trucking and Marketing	$0.02	$0.02
Utilities & Miscellaneous	$0.02	$0.02
Custom Work & Specialized Labour	$0.00	$0.00
Operator and Hired Labour	$0.09	$0.09
Operating interest paid	$0.10	$0.10

Source: Alberta beef cow-calf manual (AAF, 2008) *lower rate of gain (1.75 lbs/day) assumed for heifers; **Livestock ration is assumed to be composed of approximately 60% barley and 40%

Table 3A3: Values used to parameterize biological model

parameter	description	value
γ	bull: cow ratio	1:23
cow_{ot}	cow beginning inventory	280
θ^{B}_{cull}	bull culling rate	25.00%
θ^{C}_{cull}	cow culling rate	13.00%
$\theta^{c}_{\exp}$	cow exposure rate	100%
θ^{c}_{con}	cow conception rate	87.93%
θ^{c}_{R}	cow replacement rate	1.00%
$\theta^{H}_{\exp}$	heifer exposure rate	20.00%
θ^{H}_{con}	heifer conception rate	87.54%
θ^{C}_{CR}	cow calving rate	97.22%
θ^{H}_{CR}	heifer calving rate	95.89%
θ^{c}_{W}	cow weaning rate	96.91%
θ^{c}_{W}	heifer weaning rate	95.78%
φ	steer-heifer ratio	51.00%

Note:

Table 3A4:LR, FPE, AIC, HQIC and SBIC values for lagged crop prices

	Crop prices					
	Lag	LR	FPE	AIC	HQIC	SBIC
Wheat	0		2812.83	10.78	10.80	10.82
	1	30.76	1207.44	9.93	9.96	10.02
	2	6.13	1069.83	9.81	9.86	9.95
	3	12.05*	796.65*	9.52*	9.52*	9.70*
Barley	0		1444.73	10.11	10.13	10.16
	1	21.59	812.046	9.54	9.57	9.63
	2	9.08	659.59	9.33	9.37	9.46
	3	16.32*	433.093*	8.91*	8.97*	9.09*
Forages	0		743.84	9.45	9.46	9.49
	1	44.81	211.20	8.19	8.22	8.28
	2	3.02	205.01	8.16	8.21	8.30
	3	4.28*	191.81*	8.09*	8.15*	8.27*
Barley silage	0		98.62	7.43	7.44	7.47
	1	21.68	55.29	6.85	6.88	6.94
	2	9.15	44.82	6.64	6.86	6.77
	3	16.62*	29.17*	6.21*	6.27*	6.39*

Note: * denotes selected lag length

Table 3A5:LR, FPE, AIC, HQIC and SBIC values for lagged livestock prices(cow-calf)

Cattle prices						
	0		523.27	9.10	9.11	9.14
Steer	1	73.83*	68.09*	7.06*	7.09*	7.15*
	2	1.28	69.52	7.08	7.13	7.21
	3	0.25	73.12	7.13	7.19	7.31
	0		417.02	8.87	8.89	8.92
Heifers	1	79.32*	45.80*	6.66*	8.69*	6.75*
	2	1.32	46.72	6.68	6.73	6.81
	3	0.54	48.74	6.73	6.78	6.90
	0		410.77	8.86	8.87	8.90
Cull cows	1	32.64*	171.18*	7.98*	8.01*	8.07*
	2	0.37	179.40	8.03	8.07	8.16
	3	0.86	185.44	8.06	8.12	8.24
	0		232.68	8.29	8.30	8.34
Bred heifers	1	20.22*	118.52*	7.61*	7.64*	7.71*
	2	0.39	125.89	7.67	7.72	7.82
	3	0.94	131.11	7.71	7.77	7.90

Note: * denotes selected lag length

Table 3A6: LR, FPE, AIC, HQIC and SBIC values for lagged livestock prices (feeder segment)

Cattle prices (Feeding phase)						
	Lag	LR	FPE	AIC	HQIC	SBIC
	0		295.59	8.53	8.54	8.58
Heifers	1	8.53*	227.68*	8.27*	8.29*	8.27*
(900lbs)	2	0.63	240.67	8.32	8.36	8.34
	3	0.05	260.65	8.40	8.45	8.44
	0		493.60	9.04	9.05	9.08
Steers	1	36.13*	186.20*	8.06*	8.10*	8.15*
(900lbs)	2	0.76	192.96	8.10	8.15	8.23
	3	0.12	203.70	8.15	8.21	8.33
	0		274.76	8.45	8.47	8.50
Steer	1	9.92*	200.20*	8.14*	8.16*	8.23*
(900+ lbs)	2	0.75	210.60	8.19	8.23	8.33
	3	0.10	227.55	8.26	8.32	8.46

Note: * denotes selected lag length

Table 3A7: KPSS tests for crop and livestock prices

	KPSS Test with trend
Wheat	0.504
Barley	0.463
Forages	0.349
Barley silage	0.466
Steer (550 lbs)	0.327
Heifers (550 lbs)	0.228
Cull cows	0.199
Bred heifers	0.369
Heifers (900 lbs)	0.170
Steers (900 lbs)	0.156
Steers (900+ lbs)	0.198
Critical value*	0.146

*-critical value at 5% level

Table 3A8: Correlation matrix of residuals: Feed crop prices

	Wheat	Barley	Forage	Barley silage
Wheat	1.00			
Barley	0.75	1.00		
Forage	0.20	0.35	1.00	
Barley silage	0.74	0.99	0.33	1.00

Table 3A9: Correlation matrix of residuals: Cow-calf cattle prices

	Steers (550lbs)	Heifers (550 lbs)	Cull cows	Bred heifers
Steers (550lbs)	1.00			
Heifers (550 lbs)	0.94	1.00		
Cull cows	0.56	0.48	1.00	
Bred heifers	0.79	0.68	0.48	1.00

Table 3A10: Correlation matrix of residuals: feeder cattle prices

	Steer (900 lbs)	Heifer (900 lbs)	Barley
Steer (900 lbs)	1		
Heifer (900 lbs)	0.4033	1	
Barley	-0.1261	0.0509	1

Table 3A11: Seemingly unrelated regression estimates feed crop prices

Variables	Wheat	Barley	Forages	Barley silage
Constant	40.64*** (15.35)	50.26*** (15.04)	10.44 (7.39)	13.07*** (3.93)
L1. Wheat	0.97*** (0.12)			
L2. Wheat	-0.58*** (0.17)			
L3. Wheat	0.37*** (0.12)			
L1. Barley		0.83*** (0.10)		
L2. Barley		-0.53*** (0.12)		
L3. Barley		0.36*** (0.10)		
L1. Forages			1.14*** (0.14)	
L2. Forages			-0.66*** (0.20)	
L3. Forages			0.38*** (0.13)	
L1. Barley silage				0.84*** (0.10)
L2. Barley silage				-0.53*** (0.12)
L3. Barley silage				0.36*** (0.10)
R-squared	0.74	0.68	0.80	0.68
P-value	0.00	0.00	0.00	0.00
RMSE	28.21	23.53	12.84	6.14

Note: 1% ****; 5%**; 10%*

Table 3A12: Seemingly Unrelated Regression Estimates: Cow-calf

Variables	Steers (550lbs)	Heifers (550 lbs)	Cull Cows	Bred Heifers
Constant	20.97***	19.16***	19.96***	26.38***
	(6.34)	(7.19)	(7.19)	(6.42)
L1. Steers (550lbs)	0.81***			
	(0.05)			
L1. Heifers (550 lbs)		0.82***		
		(0.06)		
L1. Cull cows			0.70***	
			(0.10)	
L1. Bred heifers				0.62***
				(0.09)
R-squared	0.79	0.77	0.53	0.50
P-value	0.00	0.00	0.00	0.00
RMSE	12.55	12.07	12.90	12.45

Note: 1% ****; 5%**; 10%*

Table 3A13: Seemingly Unrelated Regression Estimates: Feeding Segment

Variables	Steer (900 lbs)	Heifer (900 lbs)	Barley
Constant	2.10	2.54	61.72***
	(2.08)	(2.57)	(22.77)
L1. Steers (900 lbs)	0.49***		
	(0.13)		
L1. Heifers (900 lbs)		0.83***	
		(0.12)	
Barley	-0.01**	-0.03***	
	(0.01)	(0.01)	
Steers (900+ lbs)	1.11***	1.06***	
	(0.17)	(0.02)	
L1. Steers (900+ lbs)	-0.58***	-0.89***	
	(0.14)	(0.13)	
Barley			0.56***
			(0.16)
R-squared	0.99	0.99	0.30
P-value	0.00	0.00	0.00
RMSE	1.09	1.40	24.66

Note: 1% ****; 5%**; 10%*

Chapter 4 : Genomics, Feed Efficiency and Beef Producer Participation in Carbon Offset Markets

4.1 Introduction

Agriculture contributes about 80% of total greenhouse gas emissions (GHG) from food systems globally (Vermeulen et al., 2012). Most of these emissions are livestock based and are expected to increase as a result of increasing population and incomes in many countries (UNDES, 2015; Springmann et al., 2016). The impact of methane emissions from meat production particularly cattle production on the environment is a major concern (Pitesky et al., 2009). It is estimated that methane produced from enteric fermentation in cattle accounts for over 70% of the 80 Teragrams (Tg) of methane produced globally every year (Pitesky et al., 2009; Johnson and Johnson, 1995). Available country-level estimates are consistent with these patterns (see for example, Environmental Protection Agency, 2014). Concerns about the environmental impact of these emissions and the need to meet international obligations on emission levels has instigated the establishment of market and non-market based measures in several countries (Cooper et al., 2012). One of such measure is the Low Residual Feed Intake (RFI) Protocol under the Alberta[39] Offset System (Government of Alberta, 2012). Under this protocol, a cow-calf producer can receive credits for breeding feed efficient cattle to reduce methane emissions. These credits can be purchased by other industries to "offset" their own emission levels. The protocol aims to incentivizing producers to breed for more feed efficient cattle as increased feed efficiency in the cattle can reduce methane emissions. Previous studies (e. g. Alford et al., 2006) have shown that breeding for feed efficient cattle could reduce methane emissions by approximately half a million tonnes over a 25-year period. Alford et al., (2006)'s was based on the total cattle inventory in Australia and assumed a 20% adoption rate.

[39] Alberta has the largest cattle inventory in Canada.

However, it cannot simply be assumed that the additional revenue from an offset scheme is adequate to incentivize cow-calf producers to breed more feed efficient cattle as they face a multiplicity of other costs in their decision making. Indeed, as feed consumed per unit cattle decreases (higher feed efficiency), producers may find it beneficial to increase stocking rates given the lower demand per animal for grass. This suggests that, while emissions per head may decrease, aggregate farm level emissions may increase/decrease/stay the same due to changes in herd size. Stocking rates within a given region also differ widely across different agroecological zones as a result of differences in precipitation and forage yields. Ensuing from this, is the question as to how the economic opportunities provided by offset markets (as an addition to private benefits obtained through lower feed cost for example) can influence cow-calf producer decision making. The objectives of this paper are therefore:

1. To estimate the environmental impact of higher feed efficient cattle. The analysis focusses on methane and nitrous oxide emissions from three cow-calf operations representing different agroecological zones in Alberta.
2. To assess the extent to which the availability of the additional revenue from carbon offsets will change behavior and whether this incentive is homogeneous across agroecological zones.

While different aspects of the management of livestock on rangeland have been examined (e.g. Unterschulz et al., 2004; Huffaker and Cooper, 1995; Ritten et al., 2010a), the combination of changes in the grazing herd linked to environmental outcomes, the opportunity to change feed efficiency through selective breeding and the potential impact of carbon offset markets on cow-calf producer decision making has not been previously addressed. The contribution of this paper is two-fold: first, this paper contributes to existing literature on the environmental impact of cow-calf producer breeding decisions in extensive livestock production systems. More importantly, this paper makes a unique and timely contribution to the on-going discourse on the effectiveness of measures such as offset markets in reducing production based emissions in cattle systems, given an important tool such as genomic selection and its ability to change the feed intake of animals through breeding.

The rest of the chapter is organized as follows: section 4.3 is a discussion of the relevant literature. The conceptual framework is presented in section 4.4. The empirical framework and data sources are described in sections 4.5 and 4.6. The results of the empirical analysis are presented in section 4.7. Section 4.8 is the discussion of results. Conclusions are presented in section 4.9.

4.2 Literature Review

The literature review presented in this section comprises four subsections. In these sections, previous research on greenhouse gas emissions from agriculture and beef cattle in Canada, the quantification of emissions from livestock, carbon offset markets and GHG mitigation in livestock production and producer participation in carbon offset markets are discussed. At the conclusion of the literature review, a brief outline is provided of what previous work has accomplished and the contribution of this paper to the existing body of work.

4.2.1 Overview of Greenhouse Gas Emissions in Canada

The total greenhouse gas (GHG) emissions in Canada for 2014 was 727 Mt CO_2 (Environment Canada, 2016). This represented a 0.3% reduction below the 2013 level (722Mt CO_2) and an 18% increase over the emissions reported in 1990 (Environment Canada, 2016). By sector, these emissions were distributed as: energy sector (81%); industrial processes and product use (7%); agriculture (8%) and waste (4%) (Environment Canada and Climate Change, 2016). The comparatively lower level of emissions from agriculture notwithstanding, the sector's contribution to major GHG gases such as methane (CH_4) and nitrous oxide (N_2O) was sizeable-27% and 70% of overall CH_4 and N_2O emissions respectively (Environment Canada and Climate Change, 2016). Figure 4.1 shows agricultural GHG emissions by source in Canada from 1990-2014.

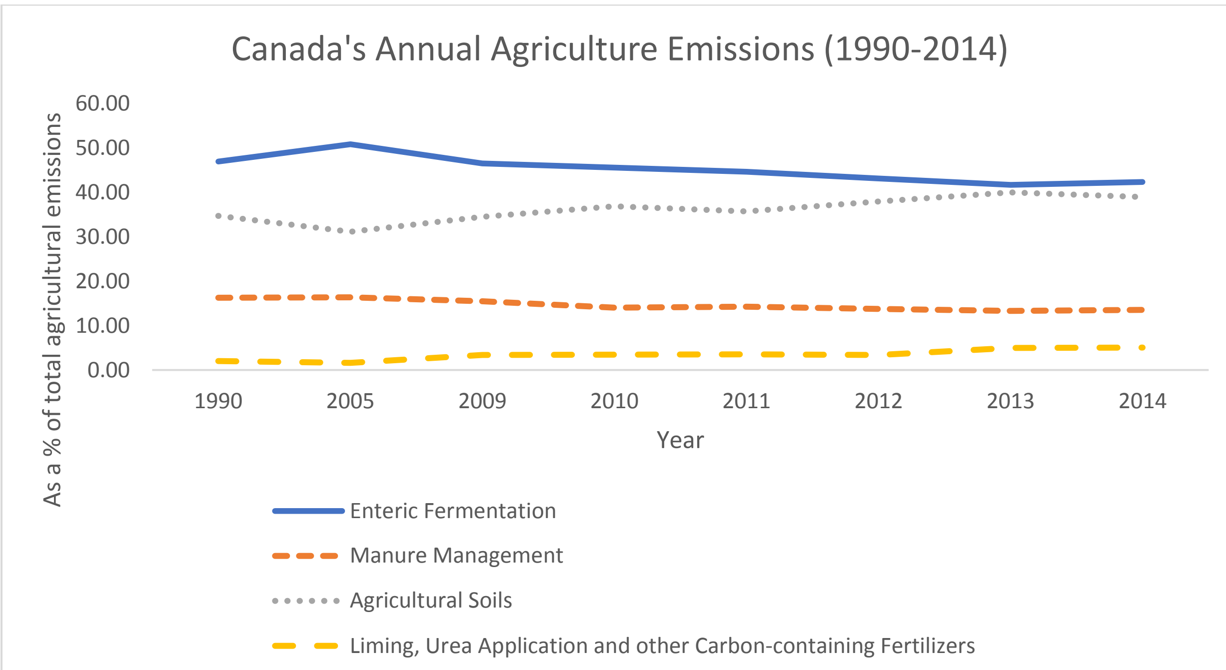

Figure 4.1: Trends in agricultural emissions by source (Data source: Environment and Climate Change Canada, 2016)

As evident from the trends in Figure 4.1, livestock production is a major source of agricultural GHG emissions in Canada. This is because the sector is the main source of emissions from manure and enteric fermentation. Emissions from livestock production as a percentage of total agriculture GHG emissions averaged 60% from 1990 to 2014 (Environment Canada and Climate Change, 2016). From Figure 4.2, changes in agricultural emissions tend to mimic changes in the beef cow inventory. This is not surprising as beef cows are a major source of GHG emissions in cattle production (Beauchemin et al., 2010; Beauchemin et al., 2011).

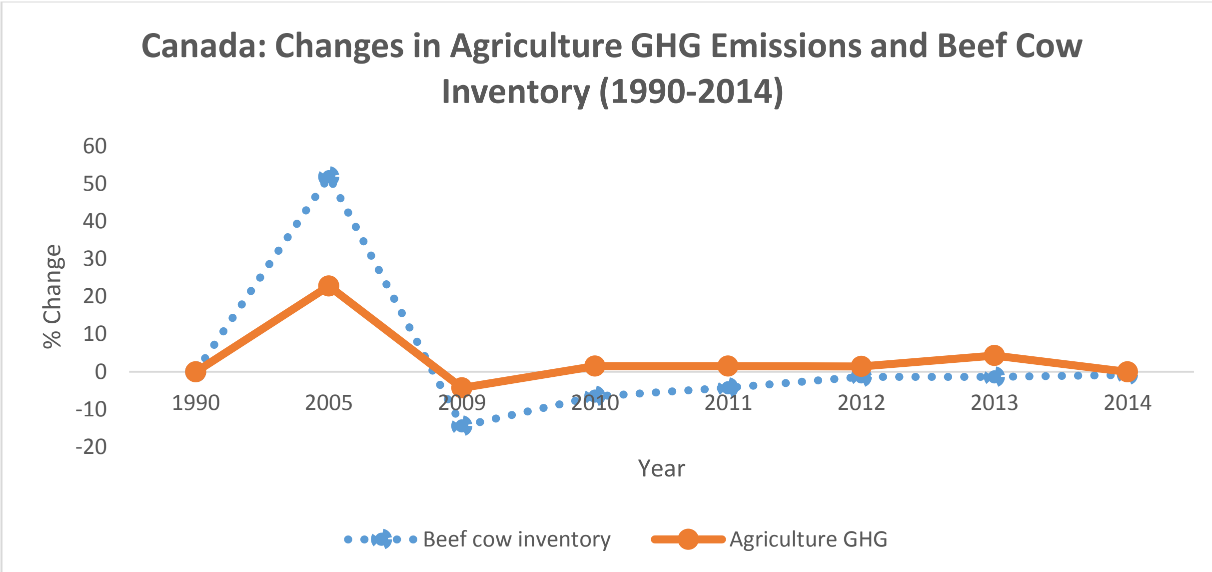

Figure 4.2: Canadian Agriculture GHG Emissions (Data sources: Environment and Climate Change Canada, 2016; Statistics Canada, CANSIM, table 003-0032 and Catalogue no. 23-012-X)

4.2.1.1 Emissions from Beef Cattle Production in Canada

Several studies have reported greenhouse gas emission intensities for beef cattle in Canada (Legesse et al., 2016; Basarab et al., 2012; Beauchemin and McGinn, 2005; Beauchemin et al., 2010; Verge et al., 2008). These estimates vary widely based on factors such as scope (e.g. the inclusion or exclusion of crop complexes), type of production system (e.g. cow-calf versus feedlot), production practices (e.g. cattle feeding practices) etc.

Greenhouse gas emission estimates from beef cattle range from 17.2 $kgCO_2\ kg^{-1}$ carcass weight to 21.7 $kgCO_2\ kg^{-1}$ carcass weight (Verge et al., 2008; Beauchemin et al., 2010). Emissions are highest in the cow-calf sector (~80%) as compared to backgrounding and feedlot segments which account for 8 and 12% respectively (Beauchemin et al., 2010; Beauchemin et al., 2011). Methane from enteric fermentation accounts for the highest proportion (60-50%) of emissions from beef cattle production (Legesse et al., 2016; Beauchemin et al., 2010; Verge et al., 2008).

Emission intensities also differ by the production practices undertaken by cattle producers. Beauchemin and McGinn (2005) reported that finisher cattle fed corn-based diets produced 30% less methane as compared to cattle fed barley-based diets. Basarab et al. (2012) found that emissions were about 3 times higher for cattle raised in yearling-fed as compared to calf-fed systems. Table 4.1 is a summary of selected studies that have evaluated GHG emissions from beef cattle production in Canada.

The emission intensity (per carcass weight) of beef cattle in Canada has declined over time due to increases in productivity resulting in higher meat yields from fewer cows (Legesse et al., 2016; Verge et al., 2008). Legesse et al., (2016) compared GHG emissions from beef cattle production in Canada between 1981 and 2011. The study found that GHG intensity in 2011 was about 14% lower than the 1981 levels. An earlier study by Verge et al., (2008), reported much higher reductions[40] (~36%) in emission intensity between 1981 and 2001.

The reported emission intensities (kg^{-1} carcass weight) for beef cattle in Canada are higher than the 10 $kgCO_2\ kg^{-1}$reported for Australia but lower than 44 $kgCO_2\ kg^{-1}$ for Brazil (Cederberg et al., 2011; Peters et al., 2010). Emissions from beef cattle in Canada are however more comparable to the US. Johnson et al., (2003) estimated emissions for cattle production in the US of approximately 22 $kgCO_2\ kg^{-1}$ of beef. The cow-calf sector accounted for 75% of this total. Johnson et al., (2003)'s estimate was higher than the 14.8 $kgCO_2\ kg^{-1}$(Subak, 1999) and15.5 $kgCO_2\ kg^{-1}$ (Phetteplace, 2001) previously reported.

[40] Underlying assumptions in the two studies differ.

Table 4.1: Summary of studies evaluating Greenhouse gas emissions from beef cattle in Canada

Authors	Objectives	Methodology	Data	Results
Legesse et al., (2016)	Comparison of GHG emissions from beef production in 2011 with that in 1981.	Life-cycle analysis. Emissions estimated with the HOLOS model	Data on cattle inventory, feed intake requirements.	Estimated total emission was 12.0 kg CO_2 kg^{-1} live weight in 2011 and 14.0 kg CO_2 kg^{-1} live weight in 1981. Enteric methane accounted 73% of total GHG emissions in 1981 and 2011.
Basarab et al., (2012)	Compare GHG emissions from different cattle feeding systems in Alberta with and without the use of growth promotants.	Life cycle analysis(LCA)	Data on farm level cattle inventory, feed intake, cropping inputs and output.	12.23 $kgCO_2$ kg^{-1} live weight (calf-fed no implant); 11.63 $kgCO_2$ kg^{-1} live weight (calf-fed implanted); 13.22 $kgCO_2$ kg^{-1} live weight (yearling-fed no implant); 13.22 $kgCO_2$ kg^{-1} live weight (yearling-fed implanted).
Beauchemin and McGinn, (2005)	Assesses methane emissions from feedlot cattle fed barley and corn backgrounding and finisher diets.	Emissions measured in an environmental chamber s	Diet information, farm level cattle inventory, emission data measured using emission chamber.	Estimated methane emissions were 254 g/day (cattle fed corn backgrounding diet); 185 g/day (cattle fed barley backgrounding diet); 79 g/day (cattle fed corn finisher diets); 108 g/day (cattle fed barley finisher diets).
Beauchemin et al., (2010); Beauchemin et al., (2011)	Assessment of whole-farm GHG emissions from cattle production in western Canada	Life-cycle analysis; Emissions estimated with the HOLOS model.	Farm level cattle inventory, feed intake, fertilizer, emission factors based on IPCC (2006).	Overall emission intensity 21.73 $kgCO_2$ kg^{-1} carcass weight;80% of emissions from cow-calf;8% backgrounding; 12% feedlot operator. By gas type CH_4 from enteric fermentation constituted 63% of total emissions.
Verge et al., (2008)	Estimate emissions from beef cattle industry and assess trends in emissions from 1981-2001.	Greenhouse gas (GHG) budgets.	Provincial cattle inventory; feed intake; acreage data; emissions calculated with Tier II methodology.	Estimated emission intensity for the Canadian beef industry of 17.2 $kgCO_2$ kg^{-1} carcass weight in 2001 as compared to 27.1 $kgCO_2$ kg^{-1} carcass weight in 1981. Methane from beef cattle was 76% of total enteric methane in Canada in 2011.

Note: HOLOS is a whole farm GHG estimation model developed by Agriculture and Agri-food Canada (Little et al., 2008)

4.2.2 Livestock Greenhouse Gases: Quantification and Mitigation

The evaluation of the impact of a mitigation measure is often initiated by the quantification of emissions from a given production system. In this regard, two approaches (i.e. "top down" and "bottom up") are commonly reported in the literature. These approaches differ based on the perspective from which environmental impact is addressed. The "top down" approach is food caloric based (Eshel et al., 2014; Hoekstra and Chapagain 2006) while the "bottom up" approach is production oriented (Beauchemin et al., 2010; Beauchemin et al., 2011; Casey and Holden 2005). Using the former approach, Eshel et al., (2014) quantified the impact of production of major animal protein sources i.e. dairy, pork, beef and eggs on land, GHG, reactive nitrogen and irrigation water use in the US. Beef cattle was found to be least resource efficient across the four measures examined- inefficiencies were 5-28 times higher in beef as compared to other livestock sources.

The bottom approach includes system based methods such as life cycle analysis (LCA) and the use of emission budgets (Beauchemin et al., 2010; Beauchemin et al., 2011; Casey and Holden 2005). Casey and Holden (2005) quantified GHG emissions from Irish milk production using life cycle analysis (LCA). The LCA is a holistic method of assessing GHG emissions using a range of impact categories (Udo de Haes, 1996). It provides the framework for the system-wide assessment of GHG emissions as an aggregation of emissions through the lifecycle of a product (Opio et al., 2013). In the Casey and Holden (2005)'s study, three mitigation methods: i.) Improved milk productivity; ii.) Slaughtering of lower productive cows; and iii.) A combination of i.) and ii.), were examined. The results of the analysis showed that that increasing milk productivity represented the most effective mitigation approach. This resulted in increased milk yields whilst herd size declined. Increasing cow efficiency led to GHG reductions of up to 1.23kgCO_{2ECM}. This comprised reductions of 9.5% in direct enteric fermentation and 13% from complementary changes in nutrient management and concentrate feeding. Apart from the elaborate data requirement of the LCA approach, other factors can limit the comparability of different LCA estimates. These include differences in assumptions about system boundaries, functional units and emission factors (Opio et al., 2013).

Emission budgeting methods such as the Intergovernmental Panel on Climate Change (IPCC) tier 1 and 2 based methodologies (e.g. IPCC, 1997; IPCC, 2010) are also used to measure GHG emissions form cattle. In the IPCC tier 1 approach, emissions are estimated as the product of animal population and average emission levels assuming homogeneity in livestock populations. The tier 2 approach incorporates a wider set of factors that contribute to differences in emissions such as age, gender and feed composition. These different assumptions account for the wide differences in. For example, Ominiski et al., (2007) found that methane emissions of beef cows were approximately 20% higher when estimated with the IPCC tier 2 as compared to the tier 1.

4.2.2.1 Approaches to Emission Reduction in Beef Cattle

Greenhouse gas emissions from beef cattle can be reduced through a variety of ways. These include, changes in feed composition, use of dietary additives, grazing and manure management practices, animal breeding and management practices (Smith et al., 2008).

From Table 4.2, estimated reductions in emissions vary widely (4-25%) across the different interventions. The emphasis on single gas emissions often masks the effect of a number of these practices on whole farm emissions. Also, emissions per unit output (emission intensity) may increase, although emissions per se, would decrease. For example, Hunerberg et al., (2014) found that while feeding corn distiller's grain decreased methane emissions, emission intensity increased due to increases in nitrogen (N) excretion. Stewart et al., (2009) found that a switch to lower quality pasture resulted in higher methane emissions but lower N emissions.

The main relative advantage of selective breeding for traits such as feed efficiency (low RFI) is the potential to introduce permanent and cumulative changes into the herd. As compared to, for example, the inclusion of additives in diets which leaves the underlying genetic composition of the herd unchanged.

Table 4.2: Approaches to reducing methane emissions from cattle production

Approach		Estimated reductions in methane emissions	Reference
Feeding practices	Replacement of forages with concentrates in diets	Methane emissions/kg 2.8 (corn) vs. 4.03% (barley) of GE.	Beauchemin and McGinn, (2005)
		Reductions in CH_4 as % of GEI F/C ratio (0.65:0.35)=6.00% F/C ratio (0.10:0.90)=4.44%	Lovett et al., (2003)
	Addition of oil to diet	Increase in diet coconut oil from as a proportion of dietary dry matter reduces CH_4 by up to 250g/day. Sunflower oil (21[1]% reduction in GE loss CH_4).	Jordan et al., (2006) McGinn (2004)
	Addition of distiller's grains	2% reduction in CH_4 emission with the inclusion of corn distiller's grain	Hunerberg et al., (2014)
Use of dietary additives	Growth implants	9% reduction from the methane emissions from higher milk yields in dairy cows.	(Johnson et al., 1991)
	Additives	Ionophores (9% reduction in gross energy loss in CH_4)	McGinn, (2004)
Animal breeding	Selecting for feed efficiency cattle (residual feed intake (RFI))	Reductions of 13.38 for a 1kg/day reduction in RFI_{EBV} 15-25% less methane produced by low RFI cattle vs. high RFI cattle.	Hegarty et al., (2006) Basarab et al., (2013)
Management practices	Grazing practices	Keeping cattle on alfalfa reduces emissions by 0.53-1.08t CO_2e/t	(Stewart et al., 2009)

	Manure management practices	Installation of AD systems on US dairy farms can result in the reduction of 220MT/unit	Gloy, (2011)

4.2.3 Carbon Offset Markets and GHG Mitigation in Livestock

The options for the abatement of greenhouse gas (GHG) emissions from agriculture comprise market based measures (emission taxes and trading schemes), regulations and standards, and voluntary compliance programs (Cooper et al., 2013; Gerber et al., 2010). Historically, mitigation policies related to agriculture have been non-mandatory (Cooper et al., 2013). This is informed by several idiosyncratic characteristics of both crop and animal production systems. Firstly, agriculture makes a relatively small contribution (as compared to other sectors such as the energy sector) to overall GHG emissions in most countries. The aggregate contribution to overall anthropogenic emissions is <10%, although the sector accounts for about 40% of CH_4 and 65% of N_2O emissions (Steinfeld et al., 2006). Secondly, emissions per farm tend to be small, and may be difficult to measure (Evory et al., 2011). This further compounded by the heterogeneity of farms and farming practices and concerns about the impact of mandatory emission caps on food security (Evory et al., 2011; Springmann et al., 2016)[41].

Incentive based instruments such as subsidies and trading enable the creation of markets and quasi-markets for emissions (Perman et al., 2003). The basic premise being that, differences exist in both the intensity of emissions and the costs of reduction thereby providing trading opportunities for different sectors. As illustrated in Figure 4.3, differences in marginal abatement cost (MC) exist between two firms i.e. X (MC_X) and Y (MC_Y). With the creation of the appropriate framework,

[41] A notable exception is the case of California. California recently passed a law that requires the state to reduce methane emissions from cows by 40%.

opportunities for trading between the higher cost (X) and lower cost firms (Y) in the presence of standard that limit emissions (A) can reduce aggregate emission levels.

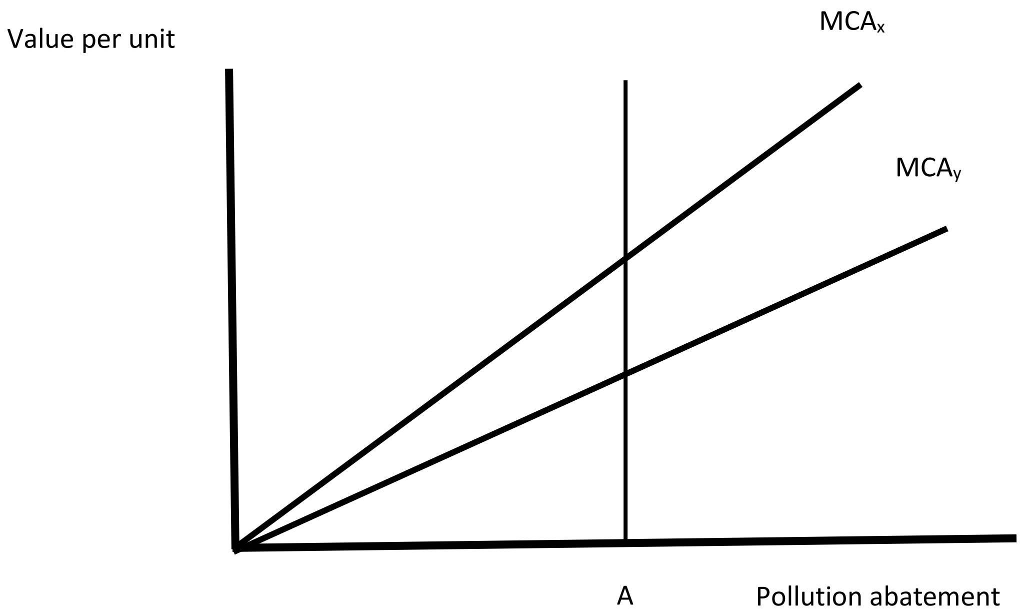

Figure 4.3: Emissions standards and marginal abatement costs (Source: Prato, 1998)

Voluntary compliance programs such as offsets schemes allow farmers to market reductions in carbon emissions to Large Final Emitters (LFEs) as carbon credits. These carbon credits are verifiable reductions[42] in greenhouse gas emissions (GHG) (Bosch et al., 2008). Large Final Emitters may buy these "credits" in order to meet regulatory limits under mandatory compliance schemes. For example, the Regional Greenhouse Gas Initiative (RGGI)[43] has a mandatory cap on

[42] One carbon credit is equivalent to one tonne reduction in carbon.
[43] A nine-state GHG reducing initiative

emissions from the power sector in nine states in the United States. Dairy farmers undertaking methane emission reduction activities through for example, the adoption of anaerobic digesters, can trade credits under the scheme (RGGI, 2016). These trading opportunities can provide incentives for producers in both regulated and unregulated sectors and facilitate the reduction of overall emissions (Johnson et al., 2017)

Practices that yield tradeable credits must meet a number of conditions. Principal amongst these are the additionality and permanence conditions (McFarland, 2012). Additionality requires that the producers must be engaged in emission reducing practices beyond “business as usual” practices (Ruseva et al., 2017). In other words, eligible practices would not occur without the additional income from the offset scheme (McFarland, 2012). The permanence condition requires that carbon reductions persist for a 100-year period (Ruseva et al., 2017).

Most of the existing carbon offset schemes in agriculture are crop-based. A significant proportion of these schemes involve the sequestration of carbon in cropping systems (Capalbo et al., 2004; Antle et al., 2003; Mooney et al., 2004). A fewer number of schemes that allow livestock producers to trade reduced emissions are currently operational.

Table 4.3 is summary of key characteristics of existing livestock offset schemes in major beef cattle producing countries (Australia, the US and Canada).Under the Australia Carbon Farming Initiative (CFI), livestock producers can earn credits from greenhouse gas (GHG) reducing activities such selecting low RFI animals, use of dietary supplements and manure management practices (Government of Australia, 2017). Dairy farmers in the jurisdiction of the RGGI, a nine-state GHG reducing initiative in the US can sell carbon credits from methane emission reductions attained from the use of anaerobic digesters (RGGI, 2016). Similar opportunities exist for hog and dairy cattle producers under the Livestock Projects Compliance Offset Protocol in California (California Environmental Protection Agency, 2017).

In the Canada, Alberta operates a compliance based carbon trading system linked with an offsets scheme. The Alberta Specified Gas Emitters Regulation requires that large scale emitters- facilities emitting 100,000 tonnes or more greenhouse gases (GHG) annually must reduce site-specific emission intensity levels below their typical baseline by 15% in 2016 and 20% in 2017 (Government of Alberta, 2016). Firms can meet these limits by either adopting more environmentally friendly practices that result in lower emissions or by purchasing carbon offset credits. Alternatively, these LFEs can pay into the Climate Change and Emissions Management Fund (CCEMF) for each additional tonne of emissions (in excess of the emission cap). The option to pay into the CCEMF indirectly becomes the ceiling on the price of carbon in the offset market. Firms are currently required to pay a rate of \$20/tonne of carbon for every tonne produced in excess of reduction targets representing an increase of \$5/tonne above the 2015 price level. This is expected to increase to \$30 in 2017 (Government of Alberta, 2016). Revenue accruing into the CCEMF is used to fund projects that lower carbon emissions in Alberta (CCEMC, 2016).

Table 4.3: A Cross-country comparison of livestock related carbon offset schemes in different countries

Scheme[1]	Location	Agriculture based qualifying activities	Farmer participation rates
Alberta Offset System (Canada)	Alberta	Beef cattle: Reducing age at harvest; Reducing days on feed; Selection for low residual feed intake. Dairy Cattle: Increased milk production; Retaining fewer replacement heifers; Increased feed efficiency; Manure management changes.	1 project under the reducing days on feed protocol in beef cattle out of 120 (agricultural related) and 216 (total active projects).
Carbon Farming Initiative (Australia)	Australia (nationwide)	-The capture and combustion of methane from pig manure using bio-digesters. -Beef cattle herd management practices: selecting for low RFI cattle; reducing the average days on feed; culling unproductive animals, etc. -Capture and combustion of methane from dairy cattle manure. -Reduction of GHG emissions from dairy and beef cattle through the addition of dietary supplements.	7 projects related to methane emissions from pigs manure.
The Regional Greenhouse Gas Initiative (RGGI) (United States)	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont	Reduction in methane emissions from dairy cows using anaerobic digesters.	No current farmer-based projects.
Livestock Projects Compliance Offset Protocol (United States)	California	Installation of anaerobic digesters for manure management on dairy cattle and swine farms.	N/A

[1]Country and parenthesis; N/A- Data not available.

For beef cattle producers in Alberta, there are opportunities to claim offsets credits from the adoption of new practices and methods that reduce GHG emissions. One of such, is the selection for feed efficient cattle. The low residual feed intake (RFI) carbon offset protocol is part of a variety of agriculture-based protocols that allow farmers to earn additional revenues from engaging practices that reduce GHG emissions. Summarily, the project based credit offset program comprises: i.) Registration and third party review and; ii.) Allocation of offset credits; and iii.) Credit trading under the domestic trading scheme (Baranzini et al., 2017). As outlined in "The Quantification Protocol for the Selection for Low Residual Feed Intake (RFI) in Beef Cattle" document (Alberta Environment, 2012), there are three main components of the protocol: i.) Establishment of baseline conditions; ii.) Implementation of project; iii.) Carbon credit claim. The baseline condition establishes the GHG emissions of a herd of cattle prior to the implementation of the project. Data requirements includes the maintenance of a 3-year average feed intake and ration data. For cattle outside feedlots, intake estimates must be based on the Intergovernmental Panel on Climate Change (IPCC) equations (IPCC, 2006). The implementation of the low RFI protocol requires producers to introduce new breeding practices for the selection of feed efficient i.e. low RFI cattle. Producers are required to test and determine the feed efficiency potential of the breeding stock (i.e. sires or dams). Based on these estimates, the percentage reduction in feed intake and greenhouse gas emissions attainable by the progeny of low RFI sires and dams is derived. Cattle eligible for carbon credits under this protocol, must be: i.) Registered in the national (Canadian Cattle Identification Program) or provincial registry. ii.) Tested and verified by a third party (typically a certified North America or Alberta testing facilities) as low RFI, iii.) The genetic linkages between progeny and feed efficient parents must be clearly established. Farmers can claim credits for only the first generation of progeny. Once the compliance and verification is completed a claim for the eligible credits is made to the Alberta Emission Offset registry. One carbon offset credit is set equivalent to a one-tonne reduction in greenhouse gas (GHG) emissions. The credits are listed in the registry listings. Transactions between buyers and sellers are conducted privately.

According to data published in the offset registry, there are currently 216 projects operating under the scheme (Climate Change and Emissions Management Corporation, 2016). Cumulatively these projects are expected to produce credits of approximately 124,568,326 t CO_2 eq. over their lifetime. Out of this total, 120 projects are agriculture related. This amounts to 48% (60,055,170 t CO_2 eq.) of the total number of credits. Most of these agriculture-based protocols are zero tillage practices. At present, there are three protocols related to livestock production- one under the reducing days on feeding protocol (feedlot operators) and the remaining two relating to waste treatment by meat processors.

Several aspects of the existing protocol may inhibit participation in the scheme by cow-calf producers. In particular, the current framework does not account for the effects of economic and spatial heterogeneity. Stocking rates differ by pasture availability which in turn differs by agroecological zones due to differences in factors like precipitation, temperature and soil characteristics. The current design of the low offset protocol does not incorporate these sources of heterogeneity. The reminder of this paper focusses on this issue within the context of genomic selection for feed efficient cattle.

4.3.5 Livestock Producer Participation in Carbon Offset Schemes

Most of the studies that examine livestock producer participation in carbon credit market focus on dairy farmer adoption of anaerobic digesters (Goly, 2011; Key and Sneeringer 2011).

Goly (2011) assessed the level of carbon offset price that would be adequate to incentivize producers to adopt anaerobic digesters (AD). These AD systems require substantial capital investment but can reduce methane emissions from manure. The study found that relatively high carbon prices ($20-30/tonne) would be required to modify producer behavior. The results of the study also showed that the allocation of benefits may be biased towards larger scale operators due to economies of scale. Key and Sneeringer (2011) addressed the distributional effects identified in by Goly (2011). Their study found that due to the link between manure production and herd size, revenues from the carbon credit scheme was positively related to farm size. This indicates that smaller scale operations may require additional incentives to adopt AD systems.

Bosch et al., (2008), evaluated the potential for additional revenue from carbon credits to incentivize cow-calf and dairy producers to adopt environmentally friendly grazing practices. Specifically, the change from conventional to rotational grazing was examined. Reductions in emissions of carbon emissions ranged from 17.0tCO_2eq-53.3tCO_2eq depending on boundary assumptions. Results of the study however showed that the additional revenue from the sale of these credits may not be sufficient in incentivizing producers to change production practices.

In this paper, the environmental impact of improved efficiency on pasture based cow-calf production systems is examined. A significant proportion of the literature has examined different aspects of pasture based cattle systems (e.g. Unterschultz et al., 2004; Holechek, 1988; Huffaker and Cooper, 1995, Passmore and Brown, 1991; Ritten et al., 2010a; Ritten et al., 2010b; Torell et al., 1991). Most of these studies focus on the link between stocking rates, plant biomass and economics returns (Torell et al., 1991).

Hildreth and Riewe (1963) found that net returns to land were influenced by: (1) stocking rate; (2) cattle performance; (3) price margin; (4) animal cost. Economically optimal stocking rates were found to be increasing in price margins and cattle performance (rate of gain) and decreasing in maintenance costs.

Torell et al., (1991) developed a dynamic cattle stocking model that incorporated both current and future considerations. Consistent with the previous studies, animal performance was found to be major determinant of producer stocking decisions. Torell et al., (1991) however, failed to incorporate stochasticity due to changes in weather. They argued that these changes were offsetting on average therefore unlikely to affect optimal outcomes. Evidence from other studies (Ritten et al., 2010a; Ritten et al., 2010b) suggests the contrary- climatic factors particularly precipitation has a major impact on stocking rate and rangeland productivity.

Ritten et al. (2010a) compared supplemental feed and partial herd liquidation in grazing cattle management under weather and cattle price variability. Although yearly returns were responsive to cattle price fluctuations, precipitation was found to be the most significant driver of changes in management decisions. This was through the effect of precipitation on forage growth. Other studies (e.g. Ritten et al., 2010b) have examined stocking rates in cattle backgrounding. Unterschultz et al., (2004) examined the impacts of the adoption of different rangeland management practices in the riparian areas in western Canada using a ranch simulation analysis. A production system modelled as a typical Alberta cow-calf operation was developed. The estimated net benefits were found to be particularly sensitive to factors such as high calf price expectations in the short run. Further, the size of riparian zones and adoption costs significantly influenced producer adoption decisions.

This literature review has shown that, beef cattle production particularly cow-calf production makes a significant contribution to overall agricultural GHG emissions. This notwithstanding, the environmental impact of breeding for feed efficiency in cattle using genomic selection has not been previously examined. Further, the role of revenue from carbon offset markets on cow-calf producer incentive to select for more feed efficient cattle has not been studied. This research and the previously stated objectives are an attempt to fill this gap. Specifically, this paper extends the existing literature by linking the opportunity to participate in a carbon offset scheme to the impact of genomically improved feed efficiency in cow-calf operations in different agroecological areas in Alberta. The analysis accounts for both spatial and economic heterogeneity. The latter is achieved through the use of region specific economic variables (input and output prices for example). In the case of the former, region specific precipitation and temperature variables are incorporated into the model. These variables determine pasture yields and land holding capacity. Figure 4.4 highlights the links between the different factors that influence the cow-calf producer's decision.

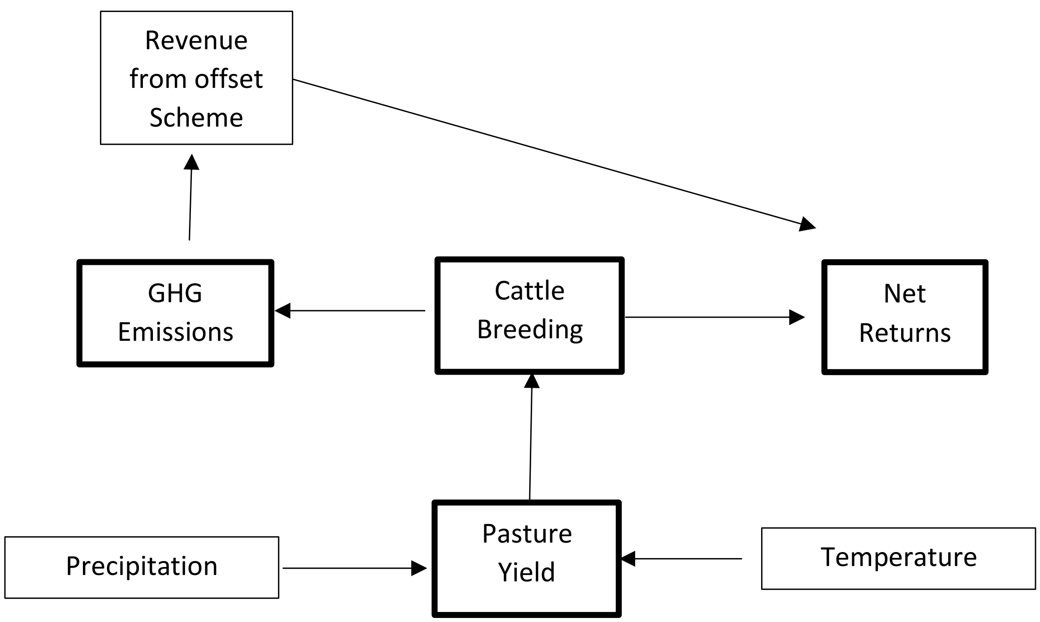

Figure 4.4: Linkages between pasture yield, cattle breeding and revenue from carbon offset scheme

4.3 Conceptual Framework

The potential role of revenue from carbon offset schemes in incentivising cow-calf producers to raise feed efficiency cattle that produce lower GHG emissions is addressed using a framework that accounts for both spatial and economic heterogeneity. It is similar to the model developed by Antle et al., (2003) to evaluate optimal contract design in the sequestration of carbon in cropland soils. The spatial characteristics of the Antle et al., (2003) framework are particularly relevant to cow-calf production as stocking rates are linked to climatic factors that differ across agroecological zones. Let $l = 1, 2, ...L$ represent a given agroecological zone in Alberta, and $e = 1, 2, ...E$ represent the region-specific economic variables such as cattle prices and input costs. Antle et al., (2003) refer to differences in economic factors across locations as economic heterogeneity.

Consistent with the notation introduced in chapter 3, assume that a cow-calf producer in the *lth* agroecological zone in period *t* with e economic inputs obtains profit from raising cattle given by:

$$\pi_{elt} = \pi(P^{y}_{elt}, u_{lt}, w_{elt}, F_{lt}, m_{elt}, P^{B}_{elt}, \psi, H_{lt}) \qquad (1)$$

where π is profits, P^{y} is the sale price of weaned calves, u is the number of weaned calves, w is non-feed related costs, F is feed intake, m is feed related costs, P^{B} is the bull price, ψ is the measure of the level of feed efficiency in the herd and H is the cow herd[44].Cattle production is associated with the production of greenhouse gases (Beauchemin et al., 2011). This is primarily from methane and nitrous oxide emissions from enteric fermentation and manure related sources. Let these emissions (C) be defined as $C = c(u_{lt}, F_{lt}, \psi, H_{lt})$. Furthermore, assuming that a breeding innovation such as genomic selection for feed efficiency, k is introduced that enables cow-calf producers to breed more feed efficient cattle and produce lower levels of GHG emissions. These

[44] The time, economic and spatial subscripts are suppressed for analytical tractability

reduced emissions can be traded as carbon offsets under a scheme such as the Alberta low RFI protocol. The price of carbon is exogenously (P_t^c) determined by the regulator and is independent of location l. In Alberta, the price of carbon was capped at $20/tonne in 2016. This is expected to increase to $30 in 2017 (Government of Alberta, 2016). Further, there are additional compliance costs (f) incurred from participating in the offset scheme. These include transactions costs related to record keeping, animal testing and verification etc. Given the nature of these costs, it is conceivable that they are not independent of herd size. In the present analysis however, these costs are assumed fixed. The overall profit including revenue from participating in the carbon offset scheme obtained by the cow-calf from using the breeding technology k is given by:

$$\pi_{lt}^{k}(P_{lt}^{y}, u_{lt}, w_{lt}, F_{lt}, m_{lt}, P_{lt}^{B}, \psi, H_{lt}) + P_t^c \Delta C_{lt}^k - f \qquad (2)$$

where ΔC_{lt}^k is the reduction in emissions from improved feed efficiency through the breeding of more feed efficient calves using genomic selection. Profits from conventional breeding practices (r) is given by:

$$\pi_{lt}^{r} = \pi(P_{lt}^{y}, u_{lt}, w_{lt}, F_{lt}, m_{lt}, P_{lt}^{B}, \psi, H_{lt}) \qquad (3)$$

The reduction in emissions in equation 2 can be written more explicitly as:

$$\Delta C_{lt}^k = C_{lt}^r - C_{lt}^k, \text{ where } C_{lt}^r > C_{lt}^k \qquad (4)$$

Equation 4 holds because GHG emissions from more feed efficient cattle is lower than less feed efficient cattle:

$$C_{lt}^r(\psi^r) > C_{lt}^k(\psi^k) \qquad (5)$$

The producer chooses the newer breeding technology (k) over the conventional technology (r) and participates in the carbon offset scheme if:

$$\pi^k_{lt}(P^y_{lt}, u_{lt}, w_{lt}, F_{lt}, m_{lt}, P^B_{lt}, \psi, H_{lt}) + P^c_t \Delta C^k_{lt} - f > \pi^r_{lt}(P^y_{lt}, u_{lt}, w_{lt}, F_{lt}, m_{lt}, P^B_{lt}, \psi, H_{lt}) \qquad (6)$$

Equation 6 implies that for the offset scheme to be effective the revenue from the scheme less compliance cost should exceed the opportunity cost of the switch from r to k:

$$P^c_t \Delta C^k_{lt} - f > \pi^r_{lt} - \pi^k_{lt} \qquad (7)$$

Equation 7, this implies that the effective price of carbon should be such that:

$$P^c_t > \frac{\pi^r_{lt} - \pi^k_{lt} + f}{\Delta C^k_{lt}} \qquad (8)$$

There are a number of unique features that distinguish this framework from other livestock and crop-based systems. Firstly, unlike practices such as carbon sequestration and the adoption of anaerobic digesters, changes in profits resulting from breeding practices such as the selection for feed efficiency are not strictly negative. This is due to potential reductions in feed cost per cow from grazing and overwintering, and additional revenues if processors pay premiums for feed efficient calves. Secondly, π^r_{lt} and π^k_{lt} may differ by l and e for different cow-calf producers. This suggests that the impact of P^c_t may not be uniform across all agroecological regions. For any two producers (A and B) in two different regions, the institution of the carbon credit scheme may further widen difference between overall profits where the differences in profit is partly attributable to both agroecological and economic factors. Thirdly, the link between herd size and the feed efficiency profile of the herd on the one hand, and carbon emissions and revenue from the offset scheme on the other hand, implies that the cow-calf producer's incentive to participate in the offset scheme is not straightforward. In fact, it is plausible that improvements in feed efficiency in the herd can result in higher stocking rates which can lead to higher overall emission levels. To illustrate, consider the Hein and Weikard (2008)'s specification that links forage production ($yield$) with grazing capacity ($S_{\max}$):

$$S_{\max} = \frac{1}{\phi} yield(l) \qquad (9)$$

where $S_{\max}$ is the grazing capacity and $\frac{1}{\phi}$ is the amount of pasture necessary for the subsistence of cattle. Grazing capacity differ across ecological zones (l) because of the differences in factors such as precipitation and temperature. Also, assuming a rate of gain in cattle (Δs) of:

$$\Delta s = \lambda \left(1 - \frac{s}{s_{\max}} \right) s \qquad (10)$$

where s is the number of cattle[45] per unit land (stocking rate) and λ is a growth parameter. Assume the revenue from the carbon credit scheme, $P_t^c \Delta C_{lt}^k$ is g. Further, assuming that revenue from the offset scheme is a function of s, s i.e. $g(s)$. The cow-calf producer chooses s that maximizes expected profits:

$$\underset{s}{Max}\ \pi = p^y \Delta s - c^f(\psi)s - c_0 + g(s) \qquad (11)$$

where c^f is the feed cost and c_0 is the fixed costs related to cattle production. It is further assumed that $\frac{\partial c^f}{\partial \psi} < 0$ and $\psi^k > \psi^r$. The first order condition (FOC) is given as:

$$\frac{\partial \pi}{\partial s} = p^y \lambda \left[1 - \frac{2s}{s_{\max}} \right] - c^f(\psi) + g^1(s) = 0 \qquad (12)$$

$$p^y \lambda - \frac{2p^y \lambda}{s_{\max}} s + g^1(s) = c^f(\psi) \quad = \frac{s_{\max}[p^y \lambda + g^1(s^*) - c^f(\psi)]}{2p^y \lambda} = s^* \qquad (13)$$

[45] A function of number of cows previously described.

From equation 13, it can be shown that improvement in feed efficiency in the herd can result in higher stocking rates. Assuming that $g^1(s^*)$ is equal to zero for simplicity, then:

$$\frac{s_{\max}[p^y\lambda - c^f(\psi)]}{2p^y\lambda} = s^* \qquad (14)$$

All else equal, if $\psi^k > \psi^r$ and $\frac{\partial c^f}{\partial \psi} < 0$ then $s^{k*} > s^{r*}$. This implies that for the carbon credit scheme to be effective: $g^1(s^*) \geq c^f(\psi)$. In other words, the additional revenue from the offset scheme should compensate the producer for the opportunity cost of not taking advantage of the reductions in feed cost. Also, $S_{\max}$ differ by agroecological zones suggesting that stocking rates are likely to differ as well.

Figure 4.5 illustrates the trade-off the cow-calf producer has to make. The upper panel shows the change in feed cost ($c^f(\psi^r)$ to $c^f(\psi^k)$) with the genomic selection for feed efficiency. The opportunity for the producer to increase stocking rates from s^{r*} to s^{k*} is shown on the horizontal axis. The lower panel shows corresponding revenue from the scheme. As showed in equation 14, the cow-calf producer has the incentive to adjust herd size at lower feed cost (area A). However, emissions may increase beyond the pre-innovation levels with the adjustment in herd size. Hence for the scheme to be effective, revenue from the offset scheme (area B in the lower panel) obtainable by the producer from maintaining stocking rate must be at least as large as A, which is the forgone opportunity of increasing stocking rates. Under the current design of the program, farmers can sell credits for a cohort of cattle verified as being more feed efficient. It is possible that farmers can sell credits for this subset of cattle whilst overall farm level emission increase due to higher stocking rate. A number of these outcomes are explored in the empirical analysis.

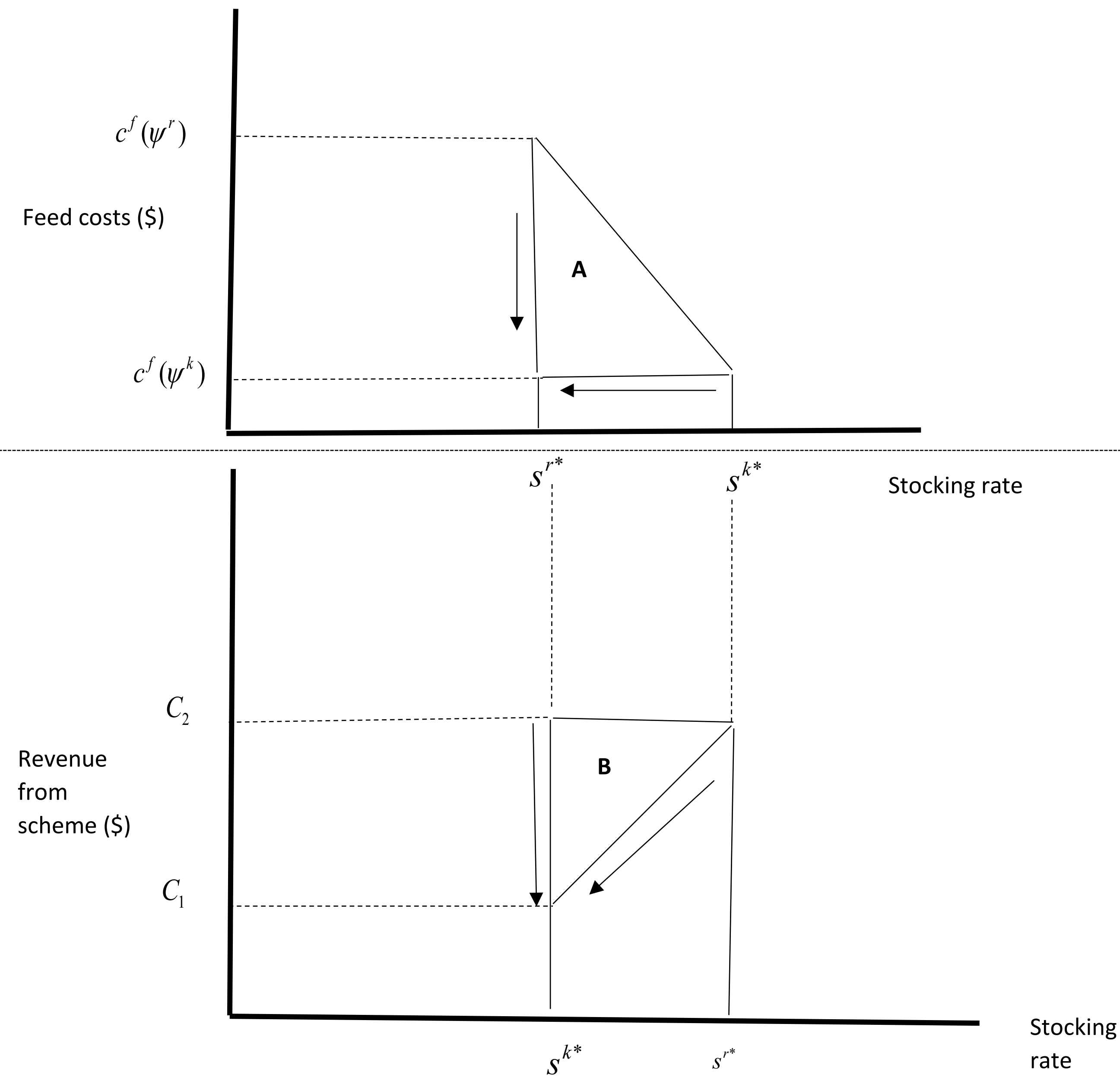

Figure 4.5: Changes in stocking rate, improved feed efficiency and revenue from offset scheme

4.4 Empirical Framework

In this section, the empirical framework used to evaluate key outcomes of the conceptual model is outlined. The emphasis is on cow-calf producers is relevant as these subset of producers make the breeding decision i.e. the purchase of genomic bulls in the present case. As shown in Figure 4.4 and described in section 4.3, it comprises four sub-components: breeding, pasture yield, greenhouse gas (GHG) emissions and economic. The present model differs from the one specified in chapter 3 to analyzed cow-calf producer incentive to purchase genomic bulls and produce feed efficient calves in a number of ways. For example, the breeding component of the model is parameterized with region-specific variables for three regions in Alberta-north, south and central. Further, a pasture yield function which predicts available pasture based on weather temperature and precipitation for each of the three regions is included in the model. Furthermore, region-specific cattle price and cost of production data are used. A brief outline of the different components is provided below.

4.4.1 Cattle Breeding

The breeding section outlines the relationships between the different types of cattle that make up the cow-calf producer's herd in each region. It tracks the production of steers, heifers and cows over time. The overall schematic outline was presented in the previous chapter. Here the focus is on the breeding sub-component particularly the cow herd dynamics. This particularly relevant given the important role of the cowherd in greenhouse gas emissions from beef cattle operations.

In this model, the breeding sub-component is initiated by the beginning cow inventory and the bull-cow ratio. Consistent with production practices in Canada, steers are not retained- all bulls are purchased (Canada Cattlemen's Association, 2017). For each period (t) and region (l) the beginning cow inventory (cow_{0lt}) is used to initiate the model. Cows purchased (cow_{plt}) are determined from beginning cow inventory and the cow replacement rate ($\theta^{c}_{R_l}$):

$$cow_{plt} = cow_{olt} * \theta^{c}_{R_l} \qquad (15)$$

The number of cows (cow_{slt}) sold in each period is given as:

$$cow_{slt} = cow_{olt} + cow_{plt} + heif_{tlt} - cow_{dlt} \qquad (16)$$

where $heif_t$ is heifers retained and cow_d is cow loss through death:

$$cow_{dlt} = \lambda^{c}_{D_l} * (cow_{olt} + cow_{plt} + heif_{tlt}) \qquad (17)$$

where λ^{c}_{D} is the death rate. The number of pregnant cows (cow_{preglt}) is estimated from the available cow herd, exposure ($\theta_{\exp}$) and conception[46] (θ_{con}) rates as:

$$cow_{preg_{lt}} = (cow_{olt} + cow_{plt} - cow_{slt} - cow_{dlt}) * \theta^{c}_{con_l} * \theta^{c}_{\exp_l} \qquad (18)$$

Changes in the heifer herd over time include changes in: beginning inventory ($heif_0$), purchased ($heif_p$), retained ($heif_t$) and culled ($heif_c$). Based on the resulting available number of heifers for each period, the number of pregnant heifers is derived as ($heif_{preg}$):

$$heif_{preglt} = (heif_{plt} + heif_{tlt} + heif_{clt}) * \theta^{h}_{con_l} * \theta^{h}_{\exp_l} \qquad (19)$$

Heifers unable to conceive (open heifers) ($heif_o$) are culled:

$$heif_{oplt} = (heif_{plt} + heif_{tlt} + heif_{clt}) * (1 - \theta^{h}_{con_l}) \qquad (20)$$

Cows wintered (cow_w) for each period are derived as:

[46] C,h and b superscripts denote cow, heifers and bull respectively.

$$cow_{wlt} = cow_{olt} + cow_{plt} + heif_{tlt} - cow_{dlt} - cow_{slt} \qquad (21)$$

Equation 21 also captures the cow-herd for the next period i.e. $t+1$.

The bull inventory ($bull_0$) is derived from the beginning cow inventory (cow_o) and bull-cow ratio (γ):

$$bull_{0lt} = \frac{cow_{0lt}}{\gamma_l} \qquad (22)$$

A proportion of the existing inventory of bulls is purchased in each time period ($bull_p$) to maintain a stable bull herd.

$$bull_{p_{lt}} = bull_{olt} * \theta^{B}_{cull_l} \qquad (23)$$

where $\theta^{B}_{cull_l}$ is the bull culling rate. The number of bulls sold ($bull_{slt}$) is given as:

$$bull_{slt} = bull_{olt} - \frac{cow_{wlt}(1-\theta^{c}_{\exp_l} * \theta^{c}_{con_l}) + heif_{wlt}(1-\theta^{h}_{\exp_l} * \theta^{h}_{con_l})}{\gamma_l} \qquad (24)$$

where $heif_w$ is the number of wintered heifers. Following this, the bull inventory for the next period is the beginning inventory plus the difference between bulls purchased and sold.

From the cow-inventory, the number of calves produced in the subsequent period is estimated from the number of pregnant cows and heifers. For steers $(steer_{mklt})$ this is equivalent to:

$$steer_{mklt} = (cow_{preglt} * \theta^{c}_{CR} * \theta^{c}_{W}) + (heif_{preglt} * \theta^{h}_{CR} * \theta^{h}_{w}) \quad * \varphi \qquad (25)$$

Heifers marketed ($steer_{mklt}$) is the difference between heifers retained and heifers transferred out. The latter is derived as:

$$heif_{tlt} = (cow_{preglt} * \theta^{c}_{CR} * \theta^{c}_{W}) + (heif_{preglt} * \theta^{h}_{CR} * \theta^{h}_{w}) \quad * (1-\varphi) \qquad (26)$$

Heifers transferred out ($heif_o$) is given as:

$$heif_{olt} = heif_{tlt} * \theta^{h}_{\exp} \qquad (27)$$

It follows that the total calf crop ($calfmkt$) marketed each year is the sum of steers ($steer_{mkt}$) and heifers ($heif_{mkt}$).

4.4.2 Pasture Yields

Cattle are assumed to be raised predominately on pasture[47]. In this model, pasture availability is determined by yields from a pasture yield function. Several factors account for the growth of pasture. These include temperature, sunlight, precipitation, wind velocity etc. Following the approach in previous studies (e.g. Unterschultz et al. 2004), precipitation and temperature are used as a proxy for these other determinants of yields. Region specific distributions derived from historical weather data are incorporated into pasture yield function to predict pasture realizations for each period. The yield function is obtained from a 50-year pasture study in Alberta (Smoliak, 1986). Smoliak (1986) estimated pasture yields as a function of June and July precipitation, and May and June temperature. Galindo et al., (2017) evaluated the performance of this prediction function in a study of the effect of the impact of climate change on cattle production. The specific form of the yield function is given as (Smoliak, 1986):

$$yield_{lt} = 1021.8 + 1.40 Juneppt_{lt} + 3.83 Julyppt_{lt} - 22.2 Maytemp_{lt} - 37.7 Junetemp_{lt} \qquad (28)$$

where $Juneppt_{lt}$ is June precipitation in (mm), $Julyppt_{lt}$ is July precipitation (mm), $Maytemp_{lt}$ is May temperature (°C) and $Junetemp_{lt}$ is June temperature.

Pasture yield is converted to animal unit months (AUM). An animal unit is defined as:

[47] Supplemental feed is also accounted for.

One mature cow and her suckling calf weighing a cumulative 1,000 pounds (a 920-pound cow with an 80-pound calf) requiring 26 pounds of dry matter (DM) forage per day. An animal unit may also be only a 1,000-pound cow that requires about 26 pounds of DM forage per day (Alberta Agriculture and Forestry, 2017).

For each realization in each period, the available pasture ($AUMprod$) is estimated as:

$$AUMprod = f(yield, land, \lambda) \qquad (29)$$

where *land* is area under pasture and λ is the available pasture rate assumed to be 50% of total pasture produced. Following Unterschultz et al. (2004), it is assumed that 2185 hectares of land is allocated for pasture in each operation in each region. This is to ensure comparability between the regions. Cattle grazing requirements ($AUMreq$) defined as:

$$AUMreq = f(cattle, days, intake) \qquad (30)$$

where $cattle$ is cattle on pasture, *days* is number of days on pasture and *intake* is daily feed requirement of cattle.

It assumed that cow-calf producers purchase additional feed if:

$$AUMreq > AUMprod \qquad (31)$$

The cost of the supplementary feed is thus equivalent to:

$$(AUMreq - AUMprod) \times Hprice \qquad (32)$$

where $Hprice$ is the price of hay. Alternatively, cow-calf producer can adjust the size of the cattle herd in the subsequent period by purchasing more cows if:

$$AUMreq < AUMprod \qquad (33)$$

The additional cows placed on pasture:

$$\frac{AUMprod - AUMreq}{AUM / cow} \qquad (34)$$

4.4.3 Environmental Component

The greenhouse gas emissions from the cattle herd is determined by the herd size, feed intake and composition, days on feed and the emission factors (See Table 4.5)[48]. This links the herd dynamics (Equations 15-24) to the feed intake requirements of the herd (Equations 29-34).Two types of GHG gases i.e. methane and nitrous oxide, from six sources are tracked in the model. These include methane from enteric fermentation and manure handling and storage, and nitrous oxide from manure decomposition, storage, volarization and soil leaching (Table 4.4). The emissions are linked to the amount and type of feed consumed by cattle (pasture/silage/hay). The emission estimates are based on the Intergovernmental Panel on Climate Change (IPCC, 2006) formulas (see Table 4.5). Emission reductions (ΔGHG) from the breeding for feed efficient cattle are derived as:

$$\Delta GHG = GHG_1 - GHG_o \tag{35}$$

where GHG_o is the baseline GHG emissions with no change in the feed efficiency profile of the herd and GHG_1 is the level of emissions when there is a change in the efficiency of cattle. This is equivalent to:

$$\Delta \quad (FEED_{CH_4} + Manure_{CH_4}) * c_f^m + (Manure_{DNO_2} + Manure_{VNO_2} + Manure_{SNO_2} + Soil_{NO_2}) * c_f^n] * (cattle_1 - cattle_0) \tag{36}$$

where the emission categories are described in Table 6, $cattle_1$ is the number of feed efficient herd and $cattle_0$ is the regular herd and c_f^m and c_f^n is the carbon equivalence factor for methane and nitrous oxide respectively. Carbon equivalence factor are reported in Table 4.4.

[48] To ensure consistency with the nomenclature of the offset protocol, herd and intake are denoted as cattle and dry matter intake respectively.

Table 4.4: Sources of GHG by type tracked in the model

Gas	Source	Carbon equivalence factor
Methane	Enteric Fermentation Manure handling and storage	21
Nitrous Oxide	Manure decomposition Manure storage Manure volarization Soil leaching	310

Note carbon equivalence factors taken from http://www.icbe.com/emissions/calculate.asp

Table 4.5: Sources of greenhouse gases sources and identities

Gas	Source	Equation	Reference
Methane	Enteric fermentation ($FEED_{CH_4}$)	$FEED_{CH_4} = \sum_i^N \left[\frac{cattle_i * DOF_i * DMI_i * GE * (Enteric_{EF_i} / 100\%)}{Methane_{EC}} \right]$	Alberta of Alberta (2012); IPCC(2006)
	Manure handling and storage ($Manure_{CH_4}$)	$VS_i = [(DMI_i * GE * (1 - TDN_i / 100\%)) + (UE * DMI_i * GE)] * (1 - (ASH / 100\%) / GE)$ $Manure_{CH_4} = \sum_i^N [cattle_i * DOF_i * DMI_i * VS_i * \beta_0 * \rho_{CH_4} * (MCF / 100\%)]$	IPCC(2006)
Nitrogen	Manure Decomposition ($Manure_{DNO_2}$)	$Manure_{DNO_2} = \sum_i^N [cattle_i * DOF_i * DMI_i * NE_i * CF_{manure}] * (44/28)$ $NE_i = [(DMI_i * (CP_i / 100\%) / CF_{protein} * (1 - NR)]$	IPCC(2006)
	Manure Volarization ($Manure_{VNO_2}$)	$Manure_{VNO_2} = \sum_i^N [(cattle_i * DOF_i * DMI_i * NE_i * MS_\beta * EF_V)] * (44/28)$	IPCC(2006)
	Manure Storage ($Manure_{SNO_2}$)	$Manure_{SNO_2} = \sum_i^N [cattle_i * DOF_i * DMI_i * NE_i * MS_\alpha * EF_{Storage})] * (44/28)$	IPCC(2006)
	Soil Profile ($Soil_{NO_2}$)	$Soil_{NO_2} = \sum_i^N [cattle_i * DOF_i * DMI_i * NE_i * MS_\gamma * EF_{leaching})] * (44/28)$	IPCC(2006)

Notes: $cattle_i$ is number of the *ith* type of cattle; *DOF* is days on feed; *DMI* is dry matter intake, *GE* is gross energy in diet; $Methane_{EC}$ is; *VS* is volatile solids; $Enteric_{EF}$ is emission factor for enteric emissions; *TDN* is total digestible energy; *UE* is urinary energy; *ASH* is ash content; β_0 is maximum methane producing capacity for manure; ρ_{CH4} is density of methane; *MCF* is methane conversion factor; CF_{manure}; *NE*, *CP* is crude protein from diets; $CF_{protein}$ is conversion factor from dietary protein to mass dietary nitrogen; *NR* is nitrogen retention; MS_β is fraction nitrogen excreted under a manure storage system; EF_V is the emission factor for volarization; MS_α is fraction of nitrogen volatilized; $EF_{storage}$ is emission factor for storage; MS_γ is fraction of nitrogen leached; $EF_{leaching}$ is emission factor for leaching.

Table 4.6: Greenhouse gases and emission factors

Gas	Parameters	Emission factors
Methane	GE	18.45 MJ/$kg_{drymatter}$
	$Enteric_{EF_i}$	6.5 %
	$Methane_{EC}$	55.65 MJ/$kg_{methane}$
	TDN (pasture)	50 %
	TDN (hay)	55 %
	TDN (silage)	59 %
	UE	0.04 %
	ASH	2 %
	β_0	0.19 m^3 $_{CH4}$/$kg_{vs\ excreted}$
	ρ_{CH_4}	0.67 m^3/kg
	MCF	1.6 %
Nitrous Oxide	CF_{manure}	0.02
	CP_i (pasture)	20 %
	CP_i (hay)	25 %
	CP_i (silage)	25 %
	$CF_{protein}$	6.25 $kg_{feed\ protein}$/$kg_{nitrogen}$
	NR	0.07 $kg_{retained}$/kg_{intake}
	MS_β	0.2
	EF_V	0.01 $kg_{N2O\text{-}N}$/$kg_{Nitrogen\ Excreted}$
	MS_α	0.8
	$EF_{Storage}$	0.007 $kg_{N2O\text{-}N}$/$kg_{Nitrogen\ Excreted}$
	MS_γ	0.1
	$EF_{leaching}$	0.0125 $kg_{N2O\text{-}N}$/$kg_{Nitrogen\ Excreted}$

Source: Government of Alberta (2012)

4.4.4 Economic Component

Following Antle and Diagana (2003), the *ith* cow-calf producer in the *lth* region's discounted returns over period *T* (=25) are given as:

$$NPV_{il} = \sum_{t=1}^{T} D_t \left[NR(p_c, w_t, p_b, p_{cw}, AUMreq, AUMprod, cattle, \phi, c_p, GHG_1, GHG_o \right] \qquad (37)$$

where D_t is the discount rate *NR* is net returns p_c is calf price, *w* is input cost, p_b is the price of the bull, p_{cw} is the price of cows, ϕ is a discrete variable defined such that $\phi = 1$ if the producer participates in the offset scheme and 0 otherwise, c_p is the price of carbon and *cattle* is the cattle herd on pasture.

Stochastic cattle price forecasts in each region for each period are estimated using a system (Seemingly Unrelated Regression) approach that allows for correlation between price series.. For each price series, 25 random normal innovations with a mean of 1 and 0 standard deviations are drawn. Following Hall (2003), these error terms are scaled by their respective standard deviations.

$$P_i^{S550} = \alpha_0 + \alpha_{S550} P_{t-1}^{S550} + \varepsilon_t^{S550} \qquad (38)$$

$$P_i^{H550} = \alpha_0 + \alpha_{H550} P_{it-1}^{H550} + \varepsilon_t^{H550} \qquad (39)$$

$$P_i^{cc} = \alpha_0 + \alpha_{cc} P_{it-1}^{cc} + \varepsilon_t^{cc} \qquad (40)$$

$$P_i^{BD} = \alpha_0 + \alpha_{BD} P_{it-1}^{BD} + \varepsilon_t^{BD} \qquad (41)$$

where P_i^{S550} is the 550 lbs steer price, P_i^{H550} is the 550 lbs heifer price, P_i^{cc} is the cull cow price and P_i^{BD} is the bred heifer price. The carbon price is assumed fixed.

4.5 Data and Model Parameterization

Data from multiple sources is used to estimate the simulation model. The farm model for a representative cow-calf producer in each region is calibrated with breeding and production parameters obtained from the Agri$Profit – a survey of cow-calf producers (1998-2010) published by Alberta Agriculture and Rural Development. Data on forage and feed barley yields are obtained from crop yield data published in the Alberta Agriculture Statistics Yearbook 2010.This is in addition to data on herd management cost and grazing requirements. Bull price data on 18,935 transactions from 2006 to 2014 were collated from a regional cattle auction outlet. This data comprises sales in different locations across Western Canada. Based on this data, price of the regular bull is assumed to follow a triangular distribution with the following parameters: a minimum value of $2,000; a maximum of $12,000 and a mode of $4,000[49]. Other regional cattle prices (for Lethbridge, Red Deer and Grand Prairie) are obtained from Alberta Agriculture and Forestry. Weather data (1952-2007) for these selected locations representing South (Lethbridge), North (Grand Prairie) and Central (Red Deer) were obtained from Environment Canada. See Figures 4.6 for a description of the relevant agroecological zones (see Appendix 2 for distributions of weather variables). Table 4.7 is a summary of the dominant soil types, precipitation, temperature and size of the constituent ecological zones in each region.

The multi-year simulation model for each region over 25-year period was done in @Risk Palisade. There are several approaches to mathematical modelling (simulation models, network planning, econometric models, mathematical programming etc.) and each of these approaches has its own requirements, strengths and drawbacks (Williams, 2003). Despite being relatively straightforward to implement, the use of econometric approaches (for example) typically requires a large number

[49] Bull price was assumed to be the same for the three locations.

of observations for each of the variables under consideration (Ekman, 2002). Mathematical programming techniques can be useful for solving problems with a large set of decision variables and constraints, the computational requirements tend to be burdensome in certain instances such as the case of multiple interacting systems (Ekman, 2002). Simulations are particularly adaptable to modelling different interacting systems and are relatively less difficult to implement (Andersen, 1974; Ekman, 2002). However, modelling multi-objective problems using simulations tend to be more challenging as compared to mathematical programming methods. This notwithstanding simulations have been applied in different contexts (Bechini and Stockle, 2007; Donatelli et al., 2002; Poluektov and Yopaj, 2001). A number of studies have examined the looked at different aspects of cow-calf production using simulations (Gradiz et al., 2007; Pang et al., 1999; Unterschultz et al., 2004). Following Goddard et al. (2016) breeding for feed efficiency was introduced into the herd through the purchase of genomic bulls. Based on estimates by Alford et al., (2006), a rate of improvements in bulls of −0.43/kg/dry matter/day is assumed. The transmission of feed efficiency from selected bulls and cows to calves is estimated as the average of the parent bull and cow's feed efficiency.

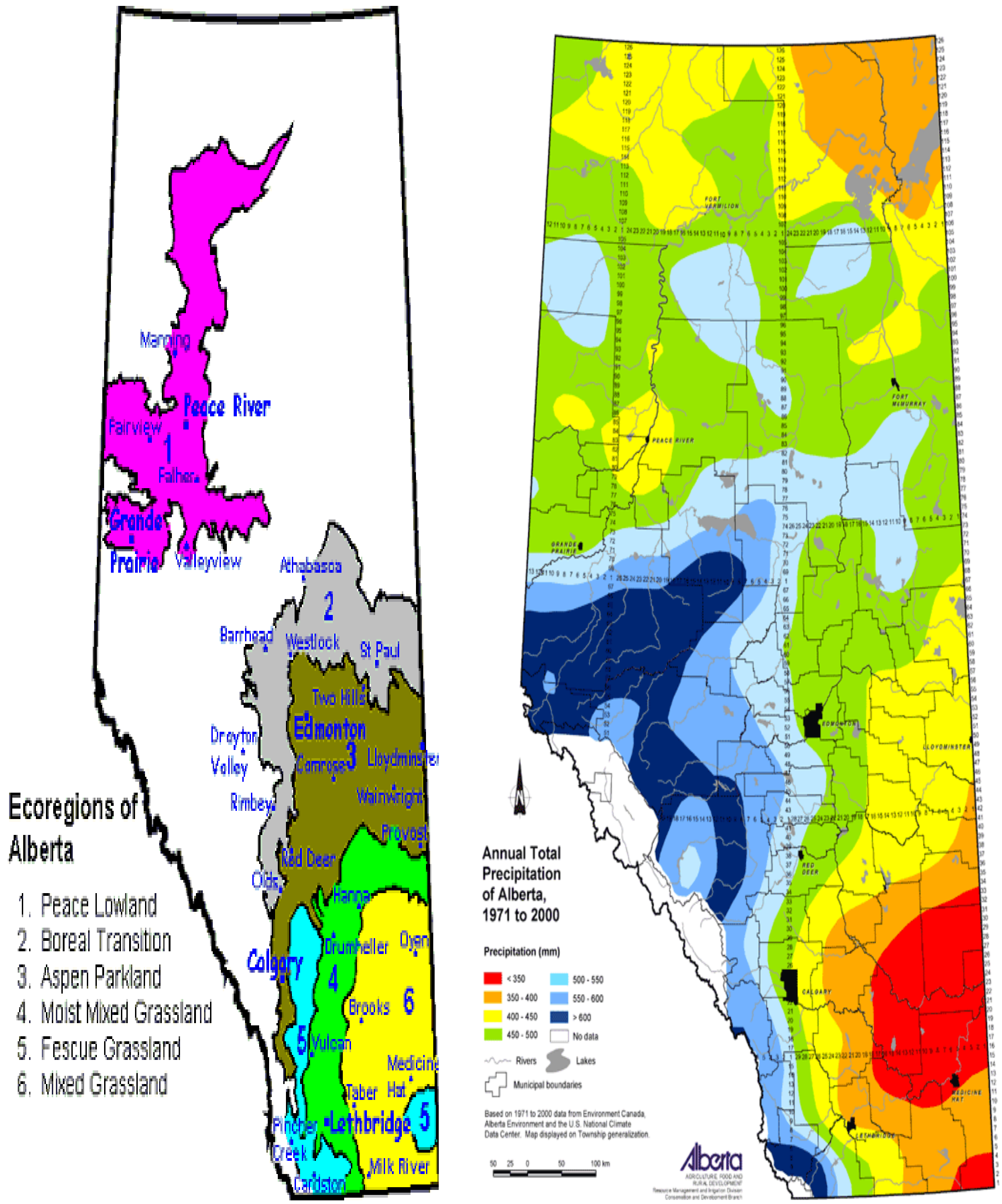

Figure 4.6: Ecoregions of Alberta and annual precipitation (1971-2000) (Source: Environment Alberta)

Table 4.7: Rainfall, temperature and soil characteristics of different regions

Region	Ecological zone	Mean Annual Rainfall	Dominant Soil types.	Mean Summer Temperature	Size (% of total land mass of province)
South	Fescue Grassland	400-450 mm	Black Chernozemic, Gleysolic	14C	2%
	Mixed Grassland	250-350mm	Brown Chernozemic, Solonetzic.		6%
	Moist Mixed Grassland	350-400mm	Dark Brown Chernozemic, Solonetzic	15.5C	5%
Central	Aspen Parkland	400-500mm	Black Chernozemic, Gleysolic	15C	9%
	Boreal Transition	450mm	Gray Luvisols, Dark Gray Chernozemic	14C	6%
North	Peace Lowland	350-600mm	Dark Gray, Luvisols Solods and Chernozemic		8%
	Boreal Transition	450mm	Gray Luvisols, Dark Gray Chernozemic	14C	6%

Source: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag14493

4.6 Results

The analysis presented in this section is preceded by a description of cattle practices, production practices and climatic variables across the three regions examined. As evident from Table 4.8, cattle prices differ across the three geographical locations. In general, cattle prices are highest in the Southern Alberta and lowest in Central Alberta. Mean calf (550 lbs) price ($/cwt) in the South for steers and heifers are $139.18 and $125.14 respectively. In contrast, steers and heifer prices in the Central Alberta are lower $124.06 and $112.6 respectively. Mean calf price in northern Alberta ranged from $70.37-286.15 with a mean price of $137.85 and $122.41 for steers and heifers respectively.

Table 4.8: Descriptive statistics of livestock prices in Alberta by region

Variable	Mean	Std. Dev	Min	Max
South Alberta				
Steer (550 lbs.)	$139.18	$31.99	$78.45	$304.88
Heifer (550 lbs)	$125.14	$36.32	$70.89	$264.83
Cull cows	$54.93	$16.87	$11.59	$100.22
Bred heifers	$829.33	$224.30	$467.29	$1347.84
Central Alberta				
Steer (550 lbs.)	$124.06	$26.44	$80.86	$230.01
Heifer (550 lbs)	$112.66	$25.42	$70.89	$208.85
Cull cows	$49.79	$16.49	$11.59	$100.22
Bred heifers	$829.33	$224.30	$467.29	$1347.84
Northern Alberta				
Steer (550 lbs.)	$137.85	$34.33	$81.27	$286.15
Heifer (550 lbs)	$122.41	$29.70	$70.37	$259.88
Cull cows	$54.08	$17.21	$11.91	$125.48
Bred heifers	$829.33	$224.30	$467.29	$1347.84

Note: all prices reported in ($/cwt) with the exception of the bred heifer price ($/head)

The regional differences in prices may be a result of several factors: costs of production and proximity to markets. Heterogeneity across regions is not limited to economic indicators alone. Costs of production different from those above and the performance characteristics of the herd also differ regionally. This is addition to differences in production practices. Cattle performance characteristics such as conception rate, calving rate and weaning rate are reported in Table 4.9.

The bull cow-ratio is highest in the north and lowest in the south. The conception and calving rates are comparable across regions although the former is marginally lower in Central Alberta whilst the latter is lowest in the South. On average, cattle in the North have the longest duration on feed (i.e. 188 days) as compared to 131 days in the South and 186 days in the Central Alberta. This implies that cattle on cow-calf operations in the North spend the least amount of time on pasture i.e. 172 days whilst grazing periods are longest in the south (229 days).

Table 4.9: Mean performance, cattle and pasture production cost by region

Physical Performance Indicators	North	Central	South
Calf crop (%)	86	85	84
Feeding season (days)	188	186	132
Open cows (%)	9	4	10
Death Loss of calves (%)	3	4	4
Conception rate (%)	90	89	91
Calving rate (%)	99	98	98
Weaning rate (%)	97	97	96
Cows per bull	25	24	22
Variable costs ($/cow wintered)			
Bedding	14.40	18.10	7.20
Veterinary and medicine	19.50	19.60	15.70
Trucking and marketing charges	12.60	11.00	15.00
Fuel	12.90	13.60	12.50
Paid Labour and Benefits	15.20	12.90	14.10
Acres	2185	2185	2185
Pasture rental cost($/AUM)	25	20	30

Note: calf crop is the number of calves weaned as a ratio of the number of cows exposed.

4.7.1 Price Modelling Results

Tables 4A4-4A6 in Appendix 4Aare summary results of the system estimates of cattle prices by region. As discussed previously, the present analysis using region-specific prices as compared to the provincial averages used in chapter 3. For each region, current prices are estimated as a function of previous year's prices. The system approach is used to allow for correlation in errors. The error correlation estimates are reported in the Appendix 4A (Table 4A1-4A3). From Tables 4A4-4A6 all the lagged price coefficients are statistically significant. In general the coefficient on the lagged own prices for each individual price series is positive and significant. The estimated R^2 ranges from 0.78-0.96. Individual price forecast are derived from the coefficient estimates of Tables 4A4-4A6 above and the stochastic error terms that account for the joint distribution of prices. Figures 4A1 and 4A2 in Appendix 4A show stochastic price forecasts for steers and heifers by region.

4.6.2 Weather and Forage Yields

Monthly precipitation data for June and July, in addition to May and June temperature from 1942-2007 are used to predict forage yields. From Table 4.10 the distribution of weather variables differ across regions. Average total precipitation (mm) for June and July is highest in Central Alberta. In contrast, June precipitation is lowest in the North whilst July precipitation is lowest in the South (Table 4.10). Average monthly temperatures for May and June are highest in the south and lowest in the north. The linkages between these climatic variables and pasture yields suggest that pasture availability will also differ across regions.

Table 4.10: Summary statistics of temperature and weather variables

	June Precipitation (mm)			
Region	Mean	Std. Dev	Min	Max
Central	83.35	41.14	18.8	222.8
South	78.27	52.99	3.2	272
North	70.15	41.91	3.6	169.7
	July Precipitation(mm)			
Central	84.65	43.52	15.8	248.4
South	42.71	32.10	1.00	141.10
North	67.93	40.16	6.60	173.10
	May Temperature(C)			
Central	10.24	1.39	7.30	14.10
South	11.05	1.47	8.10	15.00
North	10.11	1.41	6.90	14.30
	June Temperature (C)			
Central	14.27	1.28	11.50	18.60
South	15.35	1.39	13.20	19.80
North	13.99	1.09	11.90	16.30

The distributions of the weather variables are derived from their historical trends. The optimal historical distributions are selected using the Akaike Information Criteria (AIC). Based on the individual realizations of the climatic variables in each region and Smoliak (1986)'s model, individual yield predictions are obtained for each period. Figures 4A3-4A6 in Appendix 4A are predicted weather variables. Figure 4A7 shows yield realizations by region.

Consistent with the trends in the weather variables, mean pasture yield (AUMs) for north, central and south Alberta are 2141.73, 1878.34 and 1532.89 respectively. Total pasture produced for each region is derived from yield estimates for each period and pasture acreage values in Table 4.9. Fifty percent of the pasture produced is made available for grazing in the model[50]. This is to ensure that pasture is not overstocked to unsustainable levels (Tuck, 2006).

4.6.3 Simulation Analysis

The results of the simulation model are presented in this section. First, the baseline results are presented (Table 4.11). This represents the "business as usual" scenario. The cow-calf producer in the representative farm in each region is assumed to purchase regular bulls at fixed stocking rate. Genomic bulls are subsequently introduced into the model under fixed and variable stocking rates scenarios. Under the latter scenario, stocking rates are allowed to vary depending on the availability of pastures as determined by the stochastic weather variables in each region (temperature and precipitation) in each region. For each simulation, three measures are reported: economic, physical performance and environmental measures. Economic outcomes are reported as discounted net returns. The farm physical performance measures are in the form of stocking rates measured in AUM/ha and cow/ha. Methane and Nitrous oxide emissions from six sources are also reported. Specifically, the methane emissions are from enteric fermentation and manure handling and storage. The nitrous oxide emissions comprised emissions from nitrogen excreted, direct and indirect nitrous oxide, nitrous oxide from storage and leaching. These emissions are aggregated and reported as mean methane emissions (tonnes/year), nitrous oxide emissions (tonnes/year), mean total emissions (Tonnes CO_{2eq}/year) and emission intensity (Tonnes CO_{2eq}/kg carcass weight/year) Where farmer participation in the offset scheme is addressed, revenue from the offset scheme is also reported.

Consistent with distribution of pasture yield, and the differences in cattle prices and input costs, net returns, stocking rates and GHG emissions differ across regions. The latter less so than the former. Mean net returns ($/cow wintered) to cow-calf producers from the sale of calves in the baseline scenario range from $110-190. In general, net returns are highest in the north and lowest in Central Alberta – central ($148), south ($109) and north ($187.62). These estimates are lower than the mean gross margins reported in the Agri$profit survey (Alberta Agriculture and Forestry, 2015). The mean gross margins reported in the 2010 survey were $258 (north), $189 (south) and $179 (central). The baseline estimates in this study however lie well within the range reported for the three regions in 2010-$189.80-317.25 (south); $66.97-226.36 (central); and $69.25-360.52 (north) Consistent with the results of the this study mean net incomes tend to be highest in the north and lowest in the south.

Stocking rates are comparable across regions ~1.0, although rates are marginally higher in the south. In general, emissions from methane sources make up the bulk of GHG emissions. Average methane emissions (Tonnes/year) is approximately 18 tonnes as compared to 1.2 tonnes of Nitrous oxide. The high proportion of methane is consistent with previous studies on beef cattle emissions (e.g. Legesse et al., 2016). Greenhouse gas emissions are mainly driven by the cow herd. Mean emission intensity (Tonne CO_2eq/kg carcass weight) is about 0.008 in central south and northern Alberta.

Table 4.11: Base scenario by region: Absence of genomic bulls

Region	Economic Indicators			
	Mean	Min	Max	
South	\$109.35	-\$41.99	\$256.76	
Central	\$148.38	\$4.73	\$283.52	
North	\$187.62	\$19.40	\$348.84	
		Physical Indicators		
		Stocking rate		
	AUM/ha		Cows/ha	
South	1.06		0.13	
Central	0.81		0.13	
North	0.81		0.13	
		Greenhouse Gas Emissions		
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_{2eq}/year)	Emission intensity (Tonnes CO_{2eq}/kg carcass weight/year)
South	17.54	1.23	750.42	$8.12\text{x}10^{-3}$
Central	17.54	1.23	750.31	$8.13\text{x}10^{-3}$
North	17.54	1.23	750.42	$8.13\text{x}10^{-3}$

Given these baseline results, the scenario of improved feed efficiency at fixed stocking rate is examined (Table 4.12). With introduction of genomic selection for feed efficiency through the purchase of genomic bulls, the feed efficiency profile of the herd improves. The stocking rate, mean discounted profits and GHG emissions change[51] in all the three regions. With reduced feed costs net returns increase. In southern Alberta, this increment is approximately \$ 3.69 (4%). The corresponding increases in central and northern Alberta are \$4.65 (3%) and \$3.91 (2%) respectively. Stocking rate measured AUM/ha declines by 2-3% across the three regions. Further, greenhouse gas emissions in southern Alberta decrease by: 1.82% (methane), 1.63% (nitrous oxide) and 1.79% (Tonnes CO_{2eq}/year). In central Alberta, greenhouse gases reduce by: 1.71%

[51] Emission intensity remains unchanged because of rounding up

(methane), 1.63% (nitrous oxide) and 1.66% (Tonnes CO_{2eq}/year). Similar reductions are reported for northern Alberta - 1.82% (methane), 1.63% (nitrous oxide) and 1.79% (Tonnes CO_{2eq}/year).

Table 4.12: Purchase of genomic bulls at fixed stocking rate

Region	Economic Indicators			
	Mean	Min	Max	
South	\$113.38	-\$36.66	\$260.40	
Central	\$153.03	\$10.17	\$287.01	
North	\$191.53	\$24.52	\$352.35	
	Physical Indicators			
	Stocking rate			
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.797		0.13	
North	0.789		0.13	
	Greenhouse Gas Emissions			
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_2/year)	Emission intensity (TonnesCO_{2eq}/kg carcass weight/year)
South	17.22	1.21	736.95	$8.02x10^{-3}$
Central	17.24	1.21	737.83	$8.03x10^{-3}$
North	17.22	1.21	737.01	$8.03x10^{-3}$

Furthermore, the case where cow-calf producers purchase genomic bulls and at variable stocking rate is examined. Under this scenario, herd size is allowed to vary depending on pasture availability and changes in cattle feed intake requirements (feed efficiency). Table 4.13 is a summary of results. As compared to the base scenario, the economic, physical and environmental indicators show marked spatial heterogeneity across the three regions. As evident from Figure 4.7, changes in herd are most pronounced in the north and compared to the south and central Alberts. Stocking rate (AUM/ha) increase by 13% and 8% in Northern and Central Alberta respectively. In contrast, stocking in Southern Alberta remains unchanged as compared to the scenario where stocking herd size is fixed. Relative to Table 4.11, mean returns increase by: 2% (South); 19% (Central) and 11% (North).

Table 4.13: Purchase of genomic bulls at variable stocking rate

Region	Economic Indicators			
	Mean	Min	Max	
South	$113.38	-$36.66	$260.40	
Central	$177.50	$26.49	$307.29	
North	$207.81	$56.47	$364.15	
	Physical Indicators			
	Stocking rate			
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.88		0.15	
North	0.92		0.16	
	Greenhouse Gas Emissions			
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_{2eq}/year)	Emission intensity (TonnesCO_{2eq}/kg carcass weight/year)
South	17.22	1.21	736.95	8.02×10^{-3}
Central	19.18	1.35	820.74	8.02×10^{-3}
North	20.21	1.42	864.90	8.03×10^{-3}

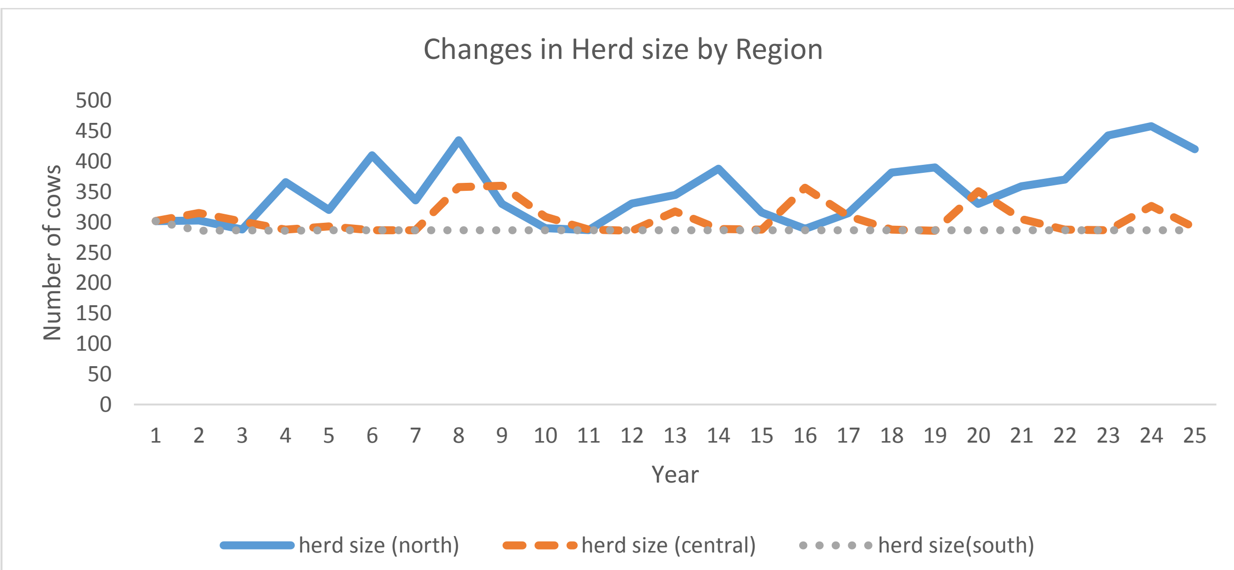

Figure 4.7: Trends in herd size by region across time

As a consequence of the changes in herd size and improvements in feed efficiency in the herd, GHG emissions and emission intensity also changes. In Figures 4.8-4.10, methane emissions in the three regions by source are compared under the three scenarios examined- Methane from enteric fermentation makes up the significant proportion of total emissions across the three regions - 96% of total methane emissions while emissions from manure and storage makes up the remaining 4%. Although the proportion of methane versus manure remains largely unchanged, the overall level of emissions within a region changes depending on the scenario examined. In southern Alberta, methane emissions decrease by about 2% in the genomic selection under fixed and variable stocking scenarios as compared to the base scenario.

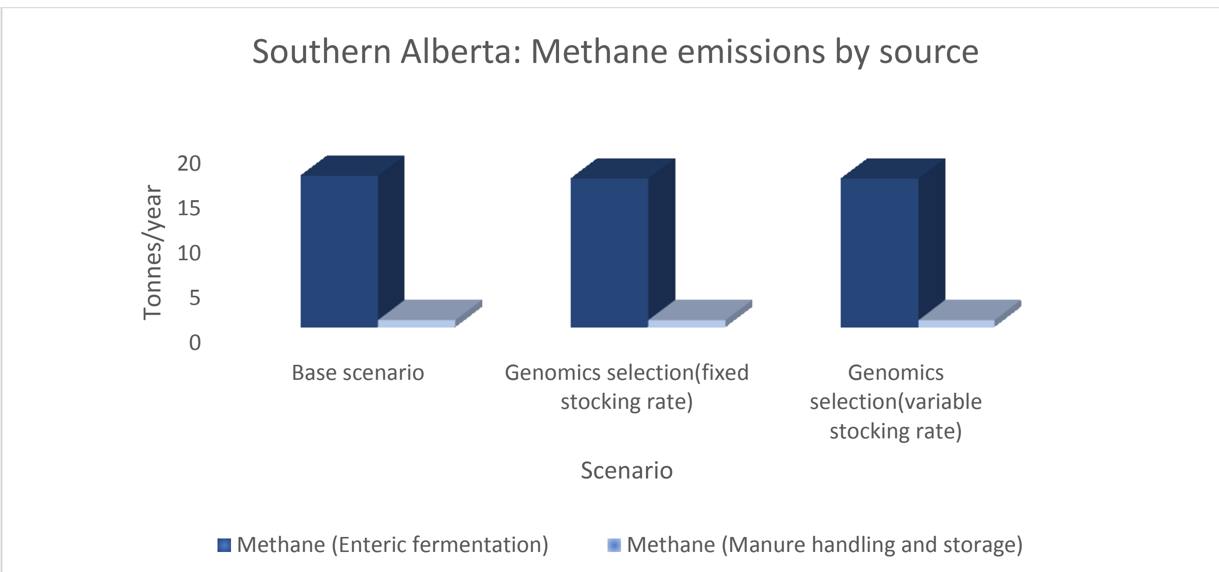

Figure 4.8: Methane emissions by source under different scenarios (Southern Alberta) (Source: Author's own)

In contrast, methane emissions in central Alberta decreases (2%) with the purchase of genomic bulls at fixed stocking rate but increases (7%) when stocking rate is allowed to vary. Similar trends are observable for northern Alberta, the magnitude of the changes in methane emissions are however much higher- 2% (fixed stocking rate) and 15% (variable stocking rate). Regional differences in nitrous oxide emissions under the different scenarios are shown in Figures 4.11-4.13. As compared to methane emissions nitrous oxide emissions represent a smaller proportion (7%) of average total emissions (tonnes/year).

The composition nitrous oxide by source are as follows: nitrogen excreted (30%), direct nitrous oxide (60%), indirect nitrous oxide (1.3%), nitrous oxide from storage (13%) and nitrous oxide from leaching (0.2%). This indicates that excreted nitrogen is the most important source of nitrous oxide emissions across the three regions.

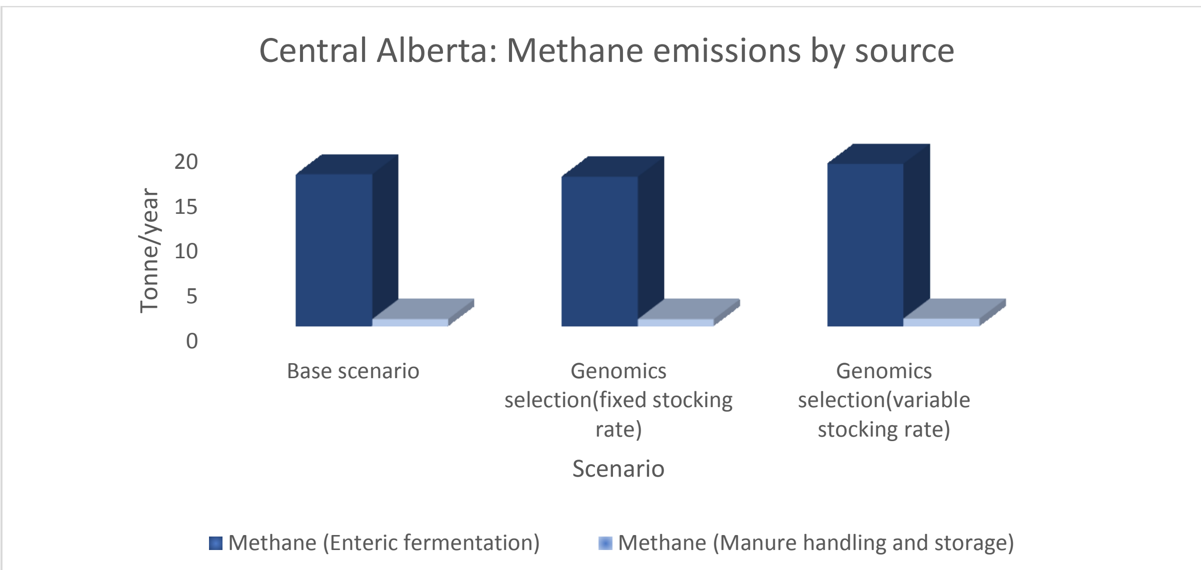

Figure 4.9: Methane emissions by source under different scenarios (Central Alberta) (Source: Author’s own)

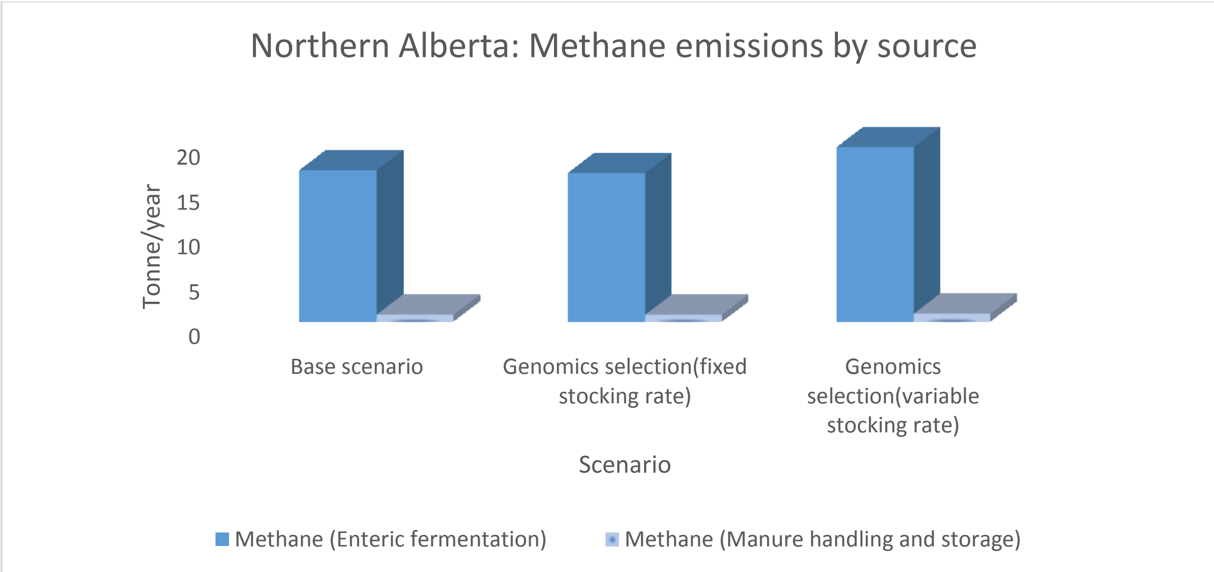

Figure 4.10: Methane emissions by source under different scenarios (Northern Alberta) (Source: Author's own)

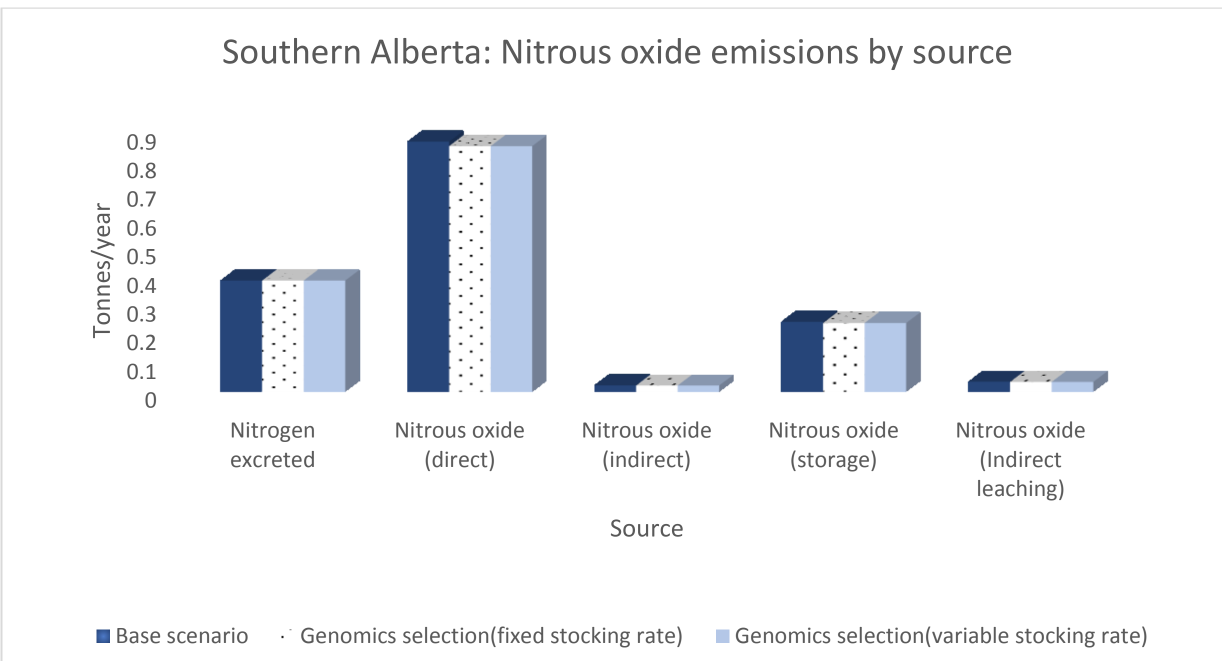

Figure 4.11: Nitrous emissions by source under different scenarios (Southern Alberta) (Source: Author's own)

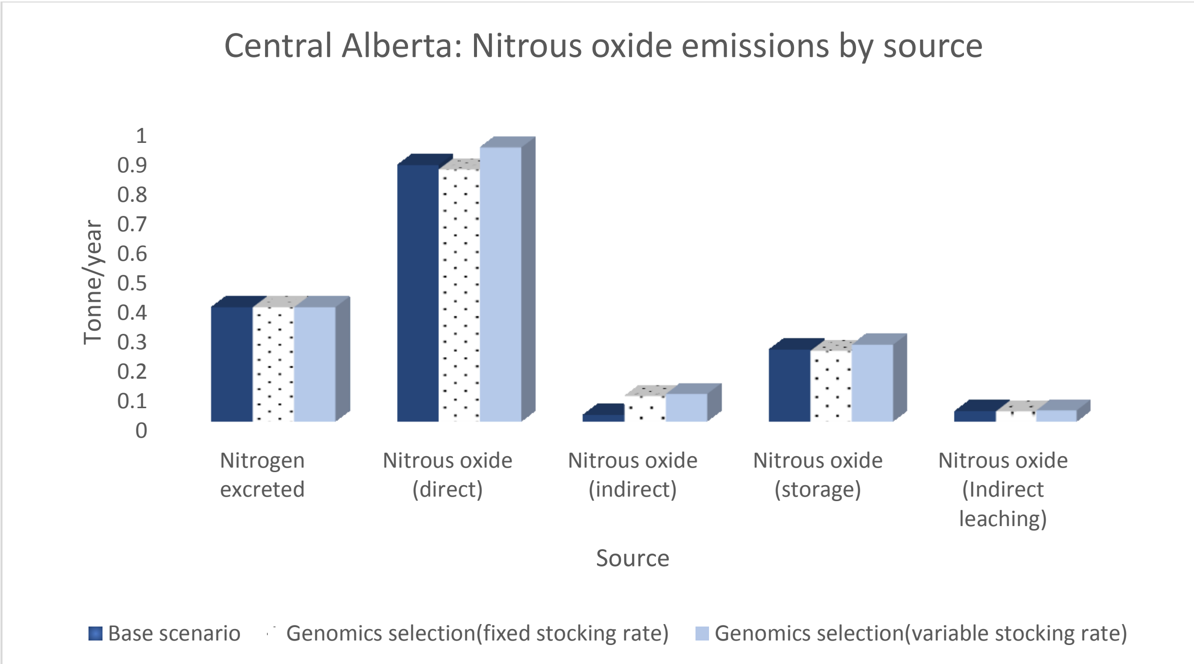

Figure 4.12: Nitrous emissions by source under different scenarios (Central Alberta) (Source: Author's own)

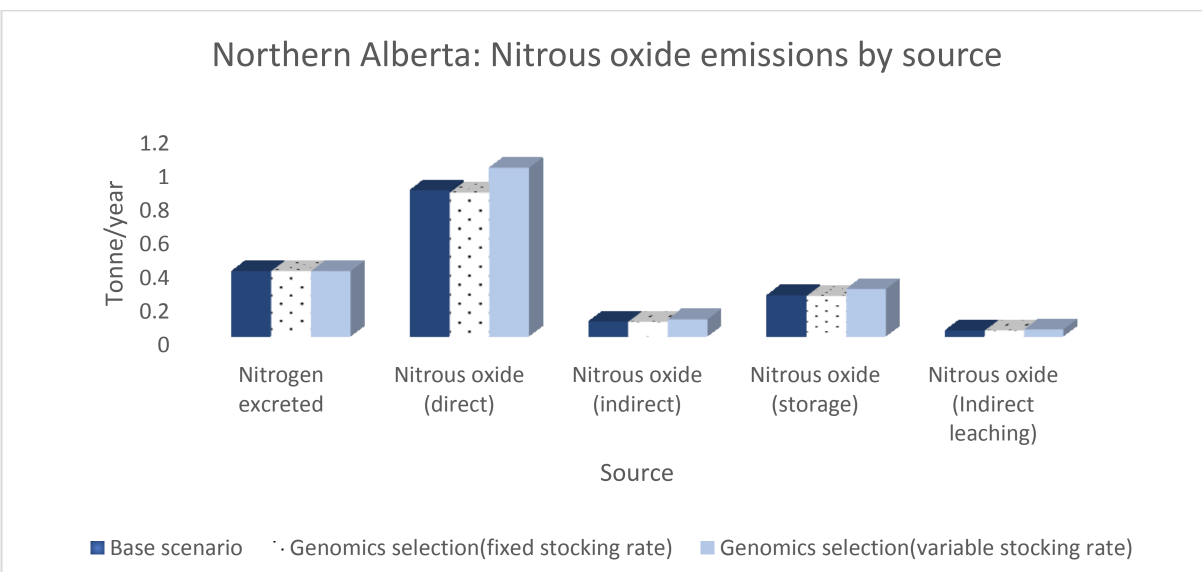

Figure 4.13: Nitrous emissions by source under different scenarios (Northern Alberta) (Source: Author's own)

To a large extent, the changes in nitrogen emissions mimic that of methane although the absolute level of emissions in this case out much lower. Relative to the base scenario, changes in nitrous oxide emissions are consistent with the dynamics in intake requirement and stocking rates. Changes in nitrogen emissions are highest in northern Alberta under the scenario with variable stocking rate. Emissions in Southern Alberta remains relatively unchanged. The magnitude of changes in Central Alberta is intermediate between the two regions.

In Figures 4.14-4.16, changes in emission intensity is reported and compared across the three regions. For each region, carbon emission intensities are estimated and reported based on three scenarios- i.e. base scenario, introduction of genomic selection at fixed and variable rate stocking rate.

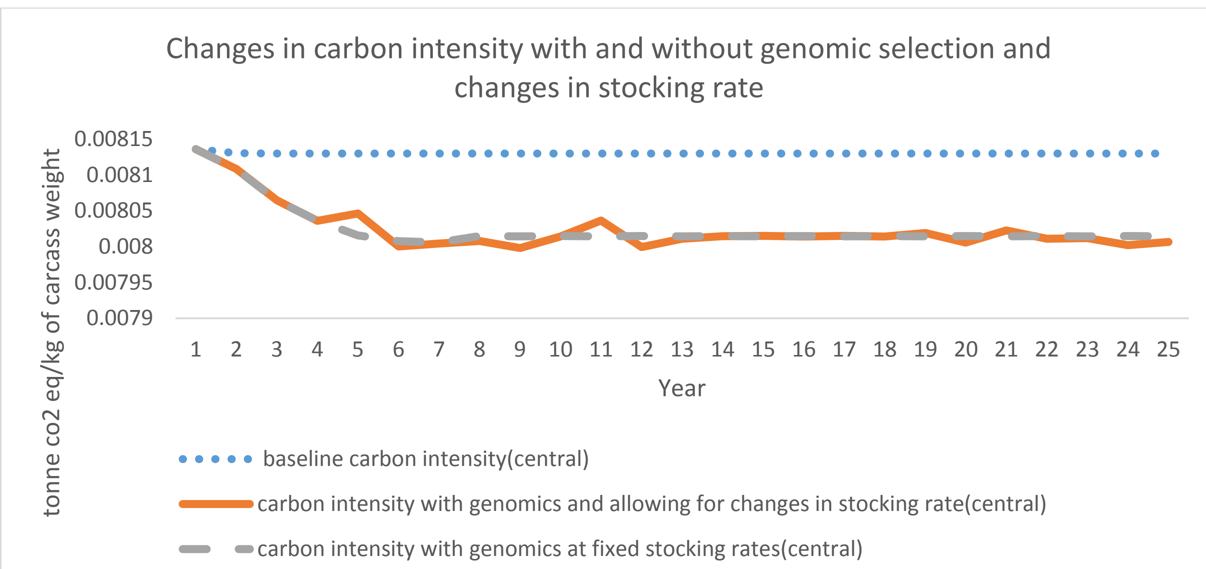

Figure 4.14: Trends in carbon intensity across time (Central Alberta) (Source: Author’s own)

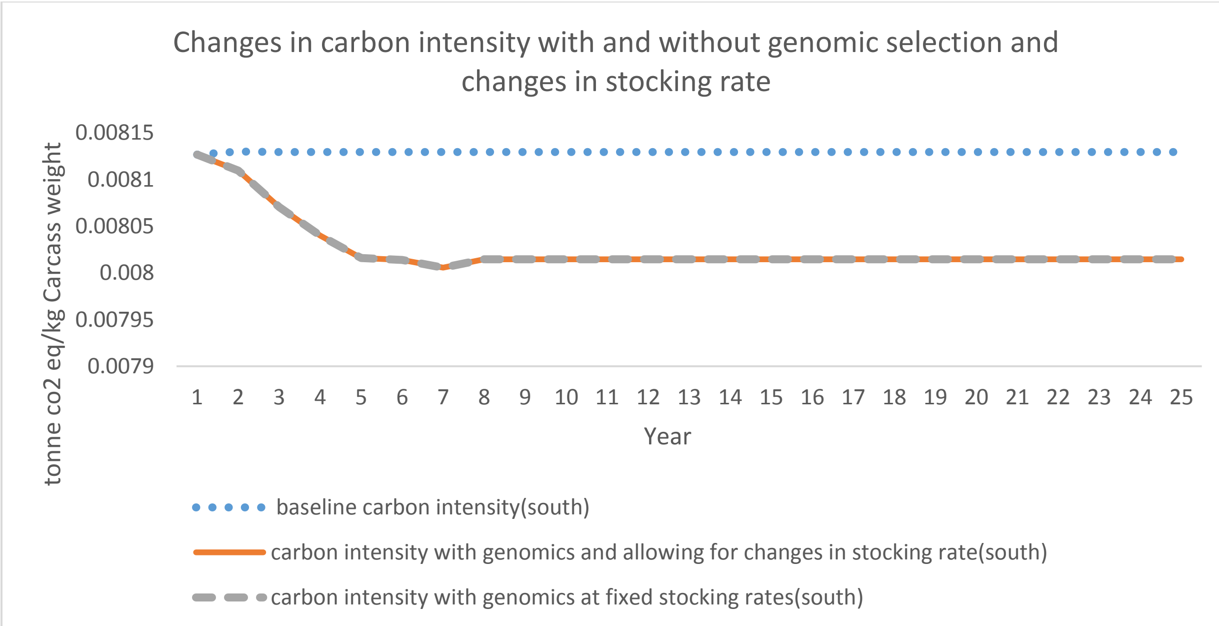

Figure 4.15: Trends in carbon intensity across time (Southern Alberta) (Source: Author's own)

In general, the highest reduction in carbon intensity is attained under the scenario with genomics bulls at fixed stocking rates. This outcome is consistent across regions. The purchase of genomic bulls under a variable stocking rate regime results in marginal increases in emissions intensities in Central Alberta.

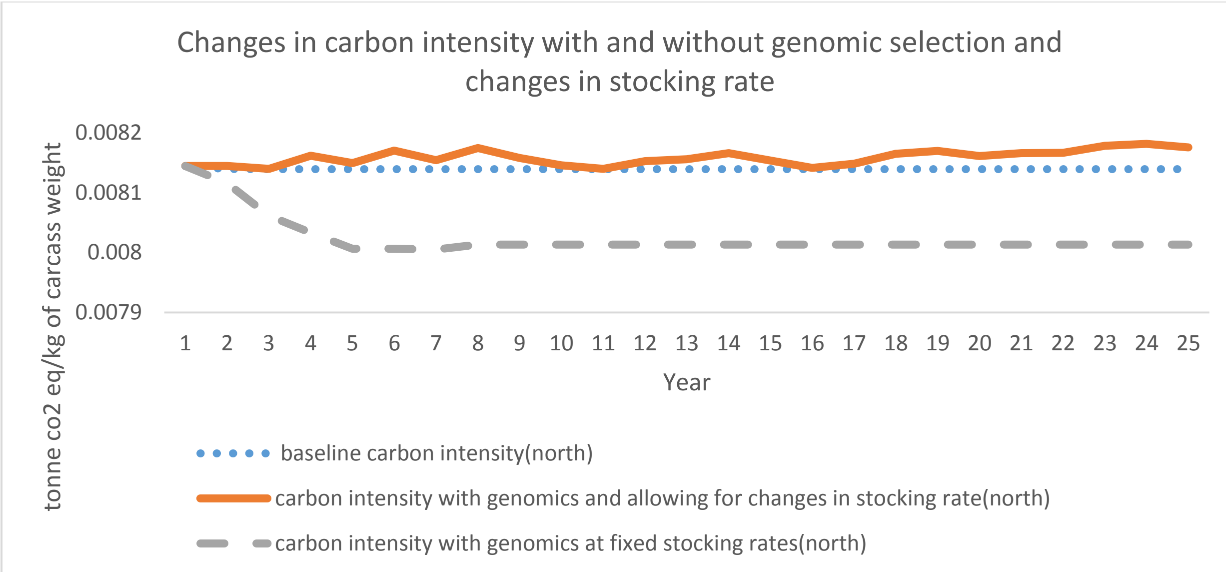

Figure 4.16: Trends in carbon intensity across time (Northern Alberta) (Source: Author's own)

The emission intensity general remains unchanged in the south. In contrast, emission intensity in the north actually increases. This suggests that the reductions in emissions from improved efficiency is not enough to offset the increased emissions from a larger herd.

4.6.4 Role of the Carbon Offsets Market

The current design of the Alberta RFI protocol allows carbon credits to be allocated for a subset of cattle within herd that are verified as being feed efficient. Within this framework however, there are no restrictions on stocking rates. This implies that depending on weather conditions, stocking rates can increase as farmers can adjust herd size with regular cattle. Two scenarios are therefore evaluated. Firstly, cow-calf producer participation in the carbon offsets scheme under fixed stocking rate (Table 4.14). Secondly, the scenario under which stocking rate is variable is examined (Table 4.14). Comparing the former and latter scenarios allows for the assessment of whether revenue from the scheme can influence producer behavior. As compared to base scenario, average net returns marginally increase due to income from participation in the carbon offset scheme which is about $250-270/year depending on the region. Relative to participating in the scheme under fixed stocking rate, net returns changed by: \$4.51(4.12%) (baseline scenario), \$0.48 (0.42%) (Genomics at fixed stocking rate) and \$0.48(0.42%) (Genomics at variable stocking rate). The corresponding changes in the central Alberta are: \$5.20 (3.44%) (baseline scenario), \$0.45 (0.29%) (Genomics at fixed stocking rate) and -\$24.03 (-13%) (Genomics at variable stocking rate). In the north, net returns change by the following magnitudes: \$4.38 (2.33%) (baseline scenario), \$0.46 (0.25%) (Genomics at fixed stocking rate) and -\$15.81 (-7.60%) (Genomics at variable stocking rate). In summary, these results show that participation in the offset market has a minimal impact on farm profitability as net returns (\$/cow wintered) increase by only \$0.45-0.48.

Table 4.14: Purchase of genomic bulls at fixed stocking rate and participation in offset scheme

Economic Indicators				
Region	Mean	Min	Max	
South	\$113.86	-\$36.17	\$260.89	
Central	\$153.48	\$10.62	\$287.69	
North	\$192.00	\$25.00	\$352.83	
Physical Indicators				
Stocking rate				
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.797		0.13	
North	0.789		0.132	
Greenhouse gas emissions				
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_{2eq}/year)	Emission intensity (Tonnes CO_{2eq}/kg carcass weight/year)
South	17.22	1.21	736.95	8.02×10^{-3}
Central	17.24	1.21	737.83	8.03×10^{-3}
North	17.22	1.21	737.01	8.03×10^{-3}
Mean revenue from offset schemes per year				
South		\$269.39		
Central		\$249.65		
North		\$262.28		

Carbon price at \$20/Tonnes CO_2

Although currently, it is possible to participate in the scheme at variable stocking rates. As showed in Table 4.15, this results in increases in overall emissions in certain regions (Northern and Central Alberta).

Table 4.15: Purchase of genomic bulls at variable stocking rate and participation in offset scheme

Economic Indicators				
Region	Mean	Min	Max	
South	$113.86	-$36.17	$260.89	
Central	$153.48	$10.62	$287.69	
North	$192.00	$25.00	$352.83	
Physical Indicators				
Stocking rate				
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.88		0.15	
North	0.92		0.16	
Greenhouse gas emissions				
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Tonnes total emissions (Tonnes CO_2/year)	Emission intensity (Tonnes CO_{2eq}/kg carcass weight/year)
South	17.22	1.21	736.95	$8.02x10^{-3}$
Central	19.18	1.35	820.74	$8.02x10^{-3}$
North	20.21	1.42	864.90	$8.03x10^{-3}$
Mean revenue from offset schemes per year				
South		$269.39		
Central		$249.65		
North		$262.28		

Emissions increase under the variable stocking rate scenario although the cow-calf producers receive the additional income from the subset of feed efficient calves. The changes in economic and environmental outcomes for each farm under the different scenarios are summarized in Figure 4.17. With the exception of Southern Alberta, participation in the offset scheme is only effective in reducing GHG emissions when stocking rates are fixed.

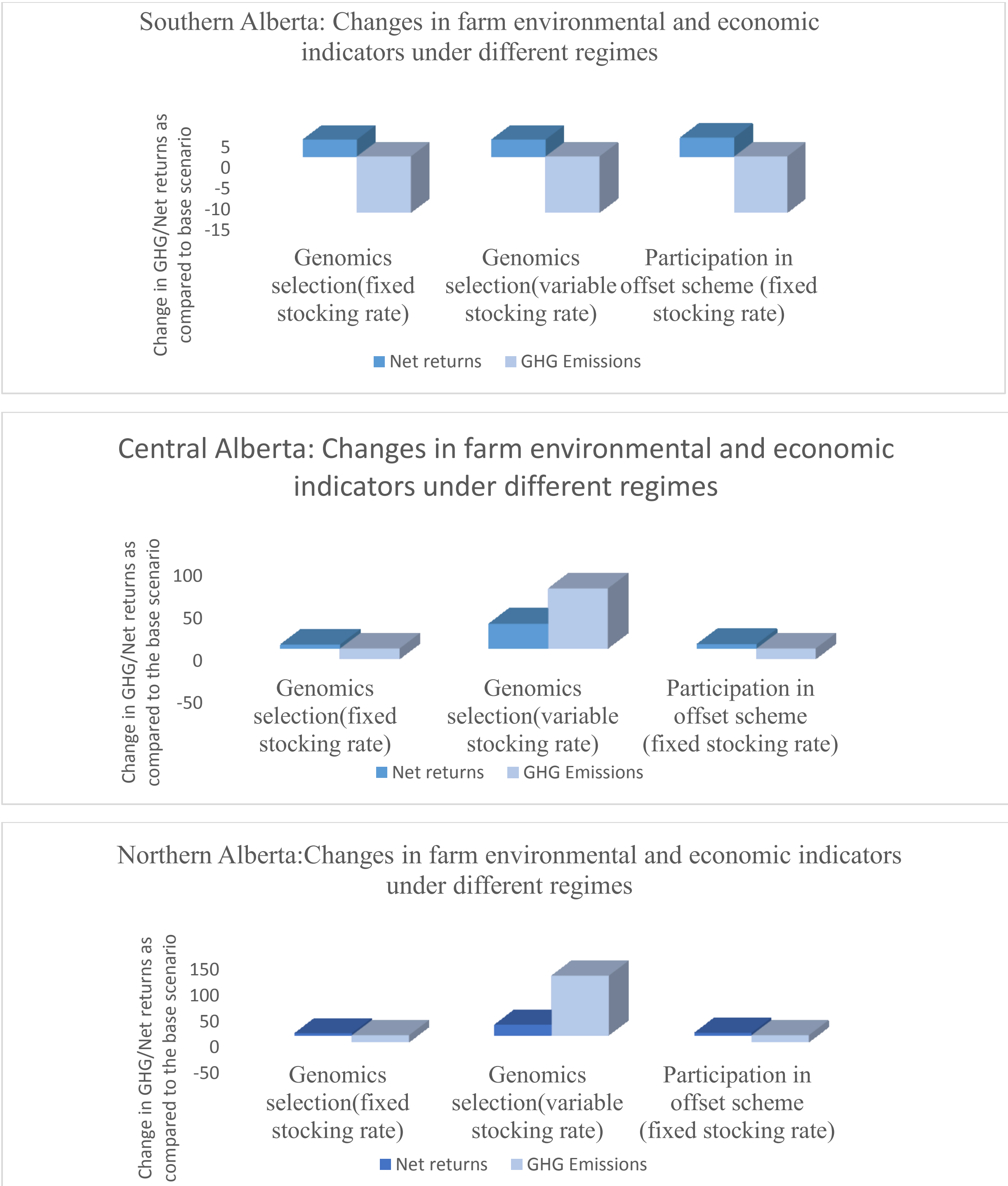

Figure 4.17: Regional differences in changes in total greenhouse gas emissions and net returns under different schemes (Source: Author's own)

Given these changes, it is possible to estimate the economic cost of maintaining a fixed stocking rate. In the conceptual model presented in section 4.4, this is identical to area A in Figure 4.5. The environmental benefit in terms of GHG emissions (Area B in Figure 4.5) can also be estimated.

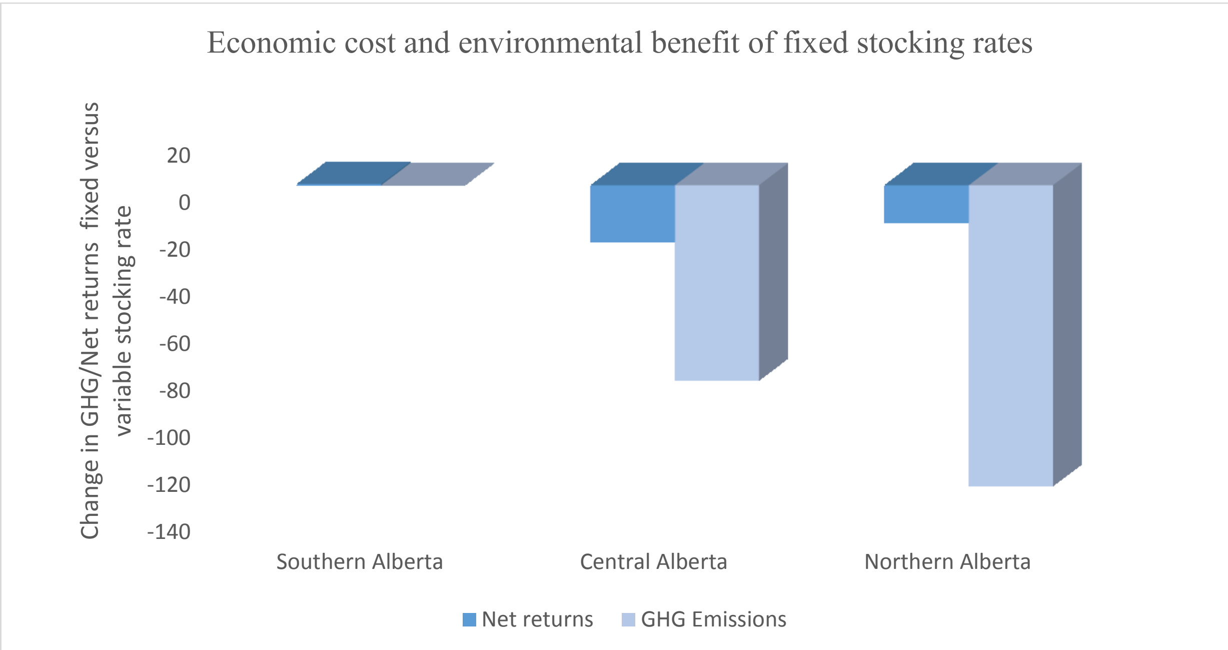

Figure 4.18: The environmental benefit and economic cost of maintaining fixed stocking rate under improved feed efficiency (Source: Author's own)

As evident from Figure 4.18, keeping stocking rate fixed when calves are more feed efficient yields positive environmental benefits (reduced GHG emissions) in all regions. However, this comes at a loss of net income ($/cow) of -$24.47 to producers in Northern Alberta and -$16.28 to producers in Central Alberta relative to the variable stocking rate regime. Net returns in Southern Alberta remain unchanged. This shows that revenue from the scheme is not adequate to compensate producers in specific regions (Central and northern) from the loss in income of maintaining stocking rate fixed.

4.6.5 Sensitivity to Precipitation, Calf and Carbon Price

The effect of changes in June and July precipitation, and calf prices and carbon price are addressed in this section. Precipitation is the main determinate of forage yields and accounts of a significant proportion of the variation in yields in the different regions. Further, income from the sale of calves is the most important source of revenue for cow-calf producers and a significant determinant of profitability. The consideration of the effect of higher carbon prices allows for the assessment of the role of future increases in carbon prices on producer incentive to participate on offset schemes. Relative to changes in precipitation, the effect of four alternative scenarios resulting from different minimum and maximum June and July precipitation are examined. The minimum and maximum precipitation values are obtained from historical trends reported in Table 4.10. Table 4.16 shows discounted net returns from different combinations of minimum and maximum different combination of June and July precipitation under the different scenarios. Compared to the base scenario in Table 4.11 net returns decrease by up to 62% (southern Alberta) at minimum precipitation June and July precipitation. Comparatively, at maximum precipitation levels the highest increases in net returns occurs in Northern Alberta (~ 98%).

At identical precipitation levels, the introduction of genomic selection at fixed stocking rates at minimum and maximum levels are 58% (southern Alberta) and 101% (northern Alberta) respectively. When stocking rates are allowed to change, mean net returns in the south decrease by 58% at minimum precipitation levels. The largest effect of maximum June and July precipitation on net returns at variable stocking rate is reported in Northern Alberta (~113%). The changes in net returns in Central Alberta in response to variability in precipitation is intermediate between the North and South. Table 4.17 is a comparison of changes in stocking rate under the different precipitation scenarios.

These results reaffirms the important role of favorable climatic conditions on cow-calf profitability of cow-calf operations. The present analysis also show that a feed efficient herd can ameliorate the effect of negative climatic events such as droughts on profitability.

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Table 4.16: Sensitivity of net returns to changes in precipitation under different scenarios

Region	June (min); July(min)	June(max); July(min)	June (min); July (max)	June (max); July (max)
		Baseline scenario		
South	$40.89	$125.42	$149.59	$152.34
Central	$106.71	$141.11	$127.22	$126.53
North	$153.56	$180.64	$189.47	$185.72
		Genomic bulls at fixed stocking rate		
South	$45.24	$127.97	$140.86	$153.61
Central	$112.88	$145.58	$131.25	$130.36
North	$159.80	$185.67	$192.75	$189.01
		Genomic bulls at variable stocking rate		
South	$45.24	$127.97	$150.86	$153.61
Central	$113.33	$167.65	$132.26	$127.52
North	$167.58	$195.26	$215.71	$212.94

Table 4.17: Sensitivity of physical performance indicators (AUM/ha) to changes in precipitation under different scenarios

Region	June (min); July(min)	June(max); July(min)	June (min); July (max)	June (max); July (max)
		Baseline scenario		
South	1.06	1.06	1.06	1.06
Central	0.81	0.81	0.81	0.81
North	0.81	0.81	0.81	0.85
		Genomic bulls at fixed stocking rate		
South	1.04	1.03	1.04	1.04
Central	0.79	0.79	0.79	0.79
North	0.79	0.79	0.79	0.79
		Genomic bulls at variable stocking rate		
South	1.04	1.04	1.04	1.04
Central	0.79	1.08	1.53	2.03
North	0.92	0.93	0.93	0.93

Table 4.18: Sensitivity of net returns to changes in calf price

Minimum calf price			
Region	Baseline	Genomic bulls at fixed stocking rate	Genomic bulls at variable stocking rate
South	$9.13	$13.58	$13.58
Central	$62.73	$67.26	$93.45
North	$70.05	$73.79	$97.23
Maximum calf price			
Region	Baseline	Genomic bulls at fixed stocking rate	Genomic bulls at variable stocking rate
South	$391.74	$394.62	$394.62
Central	$345.05	$349.96	$370.47
North	$491.70	$496.07	$494.24

Differences in the sensitivity of net returns in response to changes in calf prices are reported in Table 4.18. At minimum calf price, net returns decrease by 90-47 % depending on agroecological zones and the feed efficiency profile of the herd. Increases in net returns in response to maximum calf price range from 108-258%. The impact of feed efficiency under calf price volatility is most significant when stocking rate are fixed. Changes in calf prices also seem to have a higher pass through as compared to precipitation. This is perhaps a result of the ability of cow-calf producers to make up for partial shortfalls in forage yields through purchases.

The current carbon price in Alberta is $20/tonne and it is expected this would increase to $30/tonne in 2018 and possibly $50 /tonne subsequently (Government of Alberta, 2017; Edmonton Journal, 2017). Table 4.19 is a summary of results from the analysis of changes in cow-calf producer returns in revenue from the scheme by region. As expected revenue from is positively related to the price of carbon although the actual levels differ by region. Revenue from the scheme increases by 50-

100% in north and south Alberta when carbon price increases to $30-$50/tonne. In central Alberta, the corresponding increase in revenue from the scheme is 39-111%.

Table 4.19: Sensitivity of net returns to changes in carbon price by region

	Carbon price $20/tonne		
Region	Mean	Min	Max
South	$113.86	-$36.17	$260.89
Central	$153.48	$10.62	$287.69
North	$192.00	$25.00	$352.83
	Carbon price $30/tonne		
	Mean	Min	Max
South	$114.11	-$35.93	$261.13
Central	$153.71	$10.84	$287.69
North	$192.23	$25.23	$353.06
	Carbon price $50/tonne		
	Mean	Min	Max
South	$114.59	-$35.93	$261.62
Central	$154.16	$11.29	$288.14
North	$192.71	$25.70	$353.53
	Mean revenue from offset schemes per year		
	$20/tonne	$30/tonne	$50/tonne
South	$269.39	$404.08	$673.46
Central	$249.65	$347.48	$624.13
North	$262.28	$393.42	$655.70

The sensitivity of the current estimates to assumption about the pasture yield predict model is also analyzed. Smoliak (1986)[52] model that predicts pasture based on July precipitation is specified. Following Sneva and Hyder (1962) and Unterschultz et al., (2004), precipitation indexes are created by dividing monthly observations by their median and multiplying the result by 100. The results of the analysis are reported in Table 4A4-4A6 in Appendix 4A. Qualitatively, the results are similar to the results reported although the magnitudes differ.

[52] $Yield = 286 + 3.85 * July\ \Pr ecipitation,$

4.7 Discussion

The results of this study indicate that the breeding for feed efficiency cattle can lead to reduced greenhouse gas emissions. This was consistent across all the three agroecological zones examined. Average annual emissions reduced by approximately 12.5-13.5 (Tonnes CO_{2eq}/year). Methane emission reduction was higher (0.3 Tonnes/year) as compared to nitrous oxide (0.02 Tonnes/year). The relatively high proportion of overall methane emissions is driven by emissions from enteric fermentation (methane) which accounts for approximately 53% of total GHG emissions and 90% of overall methane emissions. The contribution of emission from enteric fermentation sources identified in this study is in line with previous estimates (Legesse et al., 2016; Beauchemin et al., 2010; Verge et al., 2008; Basarab et al., 2013).

The estimate of carbon intensity on equivalent unit basis (kgCO2 kg^{-1} carcass weight) is approximately 8. This is lower that estimates reported in previous studies (Beaucheman et al., 2010: Legesse et al., 2016). These differences are unsurprising as emission assessment is sensitive to methodology. For example, Beaucheman (2010) used a more comprehensive life-cycle approach which accounted a wider set of emissions sources such as emissions from crop complexes. The life-cycle approach also measures emissions over the entire lifespan of cattle. This is in contrast to the present estimates that look at the only the cow-calf segment of production.

Furthermore, the observed improvements in environmental outcomes depends on changes in stocking rates which is influenced by the feed efficiency profile of the herd, and pasture availability. The latter is in turn affected by region-specific precipitation and temperature. Under the scenario with the variable stocking rate and genomic selection, GHG emissions in northern and central Alberta increase while the emissions in the south remain largely unchanged. Relative to the scenario with genomic selection and fixed stocking rate, emissions increase by 10% in central Alberta and 15% in northern Alberta. From the present analysis, it seems that intersection between agroecological specific influences, stocking rates and greenhouse gas emissions cannot be disregarded in addressing greenhouse gas emissions from cattle production. Previous studies have identified the important role of precipitation in cattle grazing management (Ritten 2010a, 2010b) in the context of economic outcomes. From this study, it seems that the role of weather variables such as precipitation and temperature are important in environmental management as well.

Given the low level of emissions per farm, revenue from the offset scheme varies spatially depending on the differences in stocking rates and the level of emissions. These results are consistent with previous studies (Glory, 2011; Bosch et al., 2008) that found that the additional revenue from offset schemes is inadequate to change production practices. Glory, (2011) and Key and Sneeringer (2011) found that effect of the additional revenue from the offset schemes differs by farm size. The results of this study show that spatial heterogeneity also matter.

4.8 Conclusion

Greenhouse gas emissions from beef cattle production are an important source of agriculture GHG emissions in many countries. Selective breeding for feed efficiency in cattle through genomic selection can reduce GHG emissions in cattle. The objective of this study was to assess the environmental impact of genomic selection for feed efficiency in beef cattle. The extent to which additional revenues from the trading of emission reductions as carbon offsets can influence cow-calf producer decision making was addressed. Three regional multi-year simulation models that account for stochastic cattle prices, location specific input costs and farm performance characteristics, pasture yield and production practices were estimated. Further, the model tracked the emission of two major greenhouse gases i.e. methane and nitrous oxide emissions from six sources.

The results show that improved feed efficiency can lead to reductions in GHG emissions. The reductions are highest when stocking rates are fixed. Allowing the stocking rate to change with improved feed efficiency and higher pasture yields actually led to increased GHG emissions in certain regions. This highlights the tendency for stocking rate to increase with the breeding of more feed efficient cattle in other to take advantage of reduced feed costs and favorable climate conditions. At present, revenues from the scheme seem inadequate given the price of carbon and the level of emissions per farm, to compensate cow-calf producers for the forgone revenue attainable from increasing stocking rate. This suggests that producers are less likely to participate in voluntary carbon credit schemes such as the Alberta low RFI protocol.

A number of potential weaknesses of the current design of the Alberta low RFI protocol must be addressed to ensure increased participation. First, the credits must be allocable to cow-calf producers who make the breeding decision. The current design where data over the lifetime of cattle is required is problematic as beef cattle production in Alberta is segmented. Also, as evident from the survey results in Chapter 2, cow-calf producers do not typically retain calves till finishing. Secondly, the heterogeneity in production across geography which is driven by differences in agroecological and economic factors must be accounted for. Perhaps a differential carbon credit price can be applied to compensate producers in the low pasture yielding ecological zones to incentivize participation. As showed in this study, emissions per farm are low and the price of carbon seem to have a minimal effect. The former may be an opportunity for an integrator to garner the necessary scale economies and reduce transaction cost per farm. Integrators are common in crop based offset programs such as the "zero tillage" protocol in Alberta. Lastly, to control for the possibility for emission intensities to increase as a result of increases in stocking rate, cow-calf producers must be required to submit data on whole emission intensity in order to ensure that total on-farm emissions do not increase beyond the average of the agroecological zone in which they operate. This is to ensure that changes in carbon intensity do not exceed the levels allowed by regional climatic conditions. A similar approach is used in the Carbon Farming Initiative (CFI) in Australia.

A simulation approach was used in the model estimation and future studies can consider alternative approaches such as a dynamic optimization approach (see for example, Ritten et al., 2010b; Kobayashi et al., 2007). This study could have also benefitted from the availability of region specific pasture prediction functions that account for a broader range of factors such as soil characteristics. Further, zero compliance costs were assumed in order to capture the full range of benefits from cow-calf producer participation in the scheme. Considering the important role of compliance costs, a more rigorous assessment can factor in these costs. Based on the results of this study however, it can be deduced that direct pecuniary benefits from the scheme would further reduce when these costs are accounted for. Thus, further dampening producer incentive to participate. To an extent, this paper highlights the role of spatial heterogeneity and the trade-off between environmental and economic outcomes that cow-calf producers have to make. It further shows the complexity embedded in the design of effective environmental policy related to livestock production systems given the multiplicity of factors that impact production decisions. More importantly, the results suggest that an “all size-fits all” approach that fails to incorporate the peculiar agroecological influences in cattle production systems is unlikely to be effective in reducing GHG emissions from cattle production.

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APPENDIX 4A: ADDITIONAL DATA AND TABLES

Table 4A1: Correlation matrix of residuals: Cow-calf cattle prices Northern Alberta

	Steers (550lbs)	Heifers (550 lbs)	Cull cows	Bred heifers
Steers (550lbs)	1			
Heifers (550 lbs)	0.95	1		
Cull cows	0.49	0.47	1	
Bred heifers	0.24	0.23	0.12	1

Breusch-Pagan test for independence: Chi sq. (6): 103.63***

Table 4A2: Correlation matrix of residuals: Cow-calf cattle prices Central Alberta

	Steers (550lbs)	Heifers (550 lbs)	Cull cows	Bred heifers
Steers (550lbs)	1			
Heifers (550 lbs)	0.8401	1		
Cull cows	0.446	0.4459	1	
Bred heifers	0.312	0.2482	0.1471	1

Breusch-Pagan test of independence: Chi sq. (6) = 89.88***

Table 4A3: Correlation matrix of residuals: Cow-calf cattle prices Southern Alberta

	Steers (550lbs)	Heifers (550 lbs)	Cull cows	Bred heifers
Steers (550lbs)	1			
Heifers (550 lbs)	0.86	1		
Cull cows	0.34	0.45	1	
Bred heifers	0.25	0.25	0.15	1

Breusch-Pagan test of independence: Chi sq. (6) = 83.58***

Table 4A4: Seemingly unrelated regression estimate- cow-calf Northern Alberta

Variables	Steers (550 lbs)	Heifers (550 lbs)	Cull Cows	Bred Heifers
Constant	0.80	0.73	0.80	80.35*
	(2.91)	(2.53)	(1.14)	(47.21)
L1. Steers (550 lbs)	1.00***			
	(0.03)			
L1. Heifer (550 lbs)		1.00***		
		(0.02)		
L1. Bred Heifers				0.90***
				(0.06)
L1. Cull cows			1.02***	

			(0.02)	
R-Squared	0.94	0.95	0.96	0.78
RMSE	4.56	4.20	3.79	101.27

Note: Standard error in parenthesis

Table 4A5: Seemingly unrelated regression estimate- cow-calf central Alberta

Variables	Steers (550 lbs)	Heifers (550 lbs)	Cull Cows	Bred Heifers
Constant	1.90	1.24	1.02	82.72*
	(2.94)	(3.06)	(1.14)	(46.73)
L1. Steers (550 lbs)	0.99*** (0.03)			
L1. Heifer (550 lbs)		0.99*** (0.03)		
L1. Bred Heifers				0.90*** (0.06)
L1. Cull cows			1.01*** (0.03)	
R-Squared	0.95	0.93	0.95	0.78
RMSE	4.63	4.92	3.32	101.28

Note: Standard error in parenthesis

Table 4A6: Seemingly unrelated regression estimate- cow-calf southern Alberta

Variables	Steers (550 lbs)	Heifers (550 lbs)	Cull Cows	Bred Heifers
Constant	4.20	2.35	1.07	84.34*
	(3.89)	(3.06)	(1.14)	(47.03)
L1. Steers (550 lbs)	0.97*** (0.03)			
L1. Heifer (550 lbs)		0.99*** (0.03)		
L1. Bred Heifers				0.89*** (0.06)
L1. Cull cows			1.01 (0.03)	
R-Squared	0.92	0.93	0.95	0.78
RMSE	5.91	4.94	3.32	101.32

Note: Standard error in parentheses

Table 4A4: Sensitivity of results to changes in prediction equation (absence of genomic bulls)

Economic Indicators				
Region	Mean	Min	Max	
South	$71.51	-$124.37	$278.85	
Central	$104.18	-$83.83	$289.44	
North	$123.38	-$113.92	$337.37	
Physical Indicators				
Stocking rate				
	AUM/ha		Cows/ha	
South	1.06		0.13	
Central	0.81		0.13	
North	0.805		0.131	
Greenhouse gas emission				
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (TonnesCO_2/year)	Emission intensity (TonnesCO_{2eq}/kg carcass weight/year)
South	17.54	2.37	1101.66	0.011
Central	17.54	2.43	1121.68	0.012
North	17.54	2.43	1121.85	0.012

Table 4A5: Purchase of genomic bulls at fixed stocking rate

Economic Indicators				
Region	Mean	Min	Max	
South	$75.71	-$119.13	$119.13	
Central	$110.19	-$76.05	$292.03	
North	$130.03	-$130.03	$343.65	
Physical Indicators				
Stocking rate				
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.79		0.13	
North	0.805		0.131	
Greenhouse gas emissions				
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_2/year)	Emission intensity (TonnesCO_{2eq}/kg carcass weight/year)
South	17.22	2.32	1081.91	0.012
Central	17.24	2.39	1103.04	0.012
North	17.22	2.38	1101.81	0.0119

Table 4A6: Purchase of genomic bulls at variable stocking rate

		Economic Indicators		
Region	Mean	Min	Max	
South	$75.71	-$119.13	$119.13	
Central	$110.19	-$76.05	$292.03	
North	$140.74	-$65.53	$140.74	
		Physical Indicators		
		Stocking rate		
	AUM/ha		Cows/ha	
South	1.04		0.13	
Central	0.79		0.13	
North	0.92		0.155	
		Greenhouse gas emission		
	Methane (Tonnes/year)	Nitrous oxide (Tonnes/year)	Total emissions (Tonnes CO_2/year)	Emission intensity (TonnesCO_{2eq}/kg carcass weight/year)
South	17.22	2.32	1081.91	0.012
Central	17.24	2.39	1103.04	0.012
North	20.21	2.80	1293.02	0.012

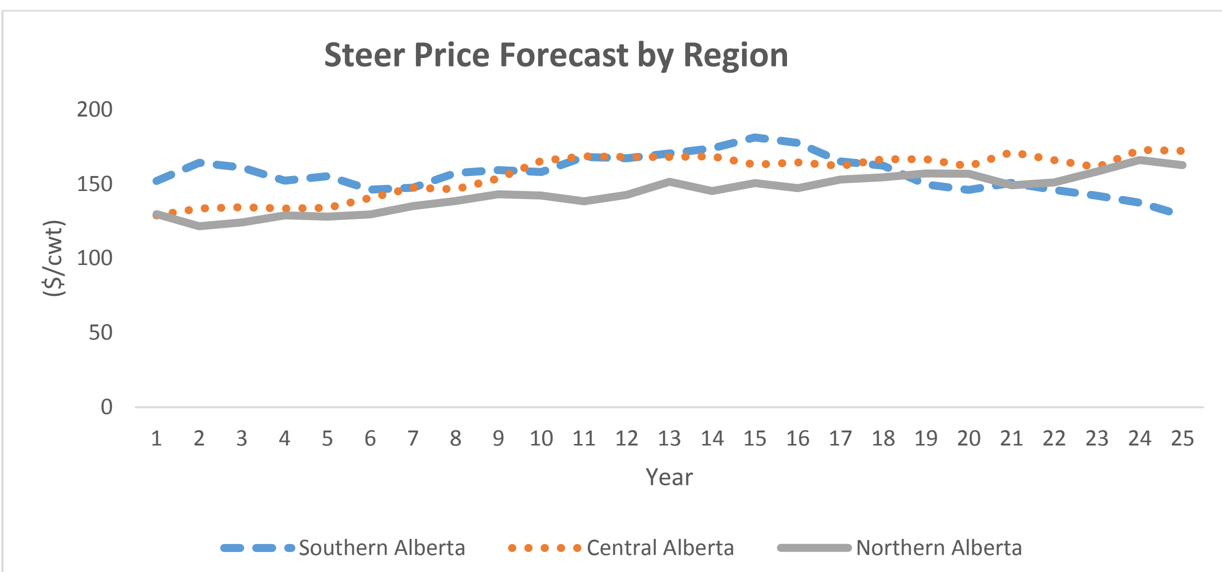

Figure 4A1: An example of steer price forecast by region (Source: Author's own)

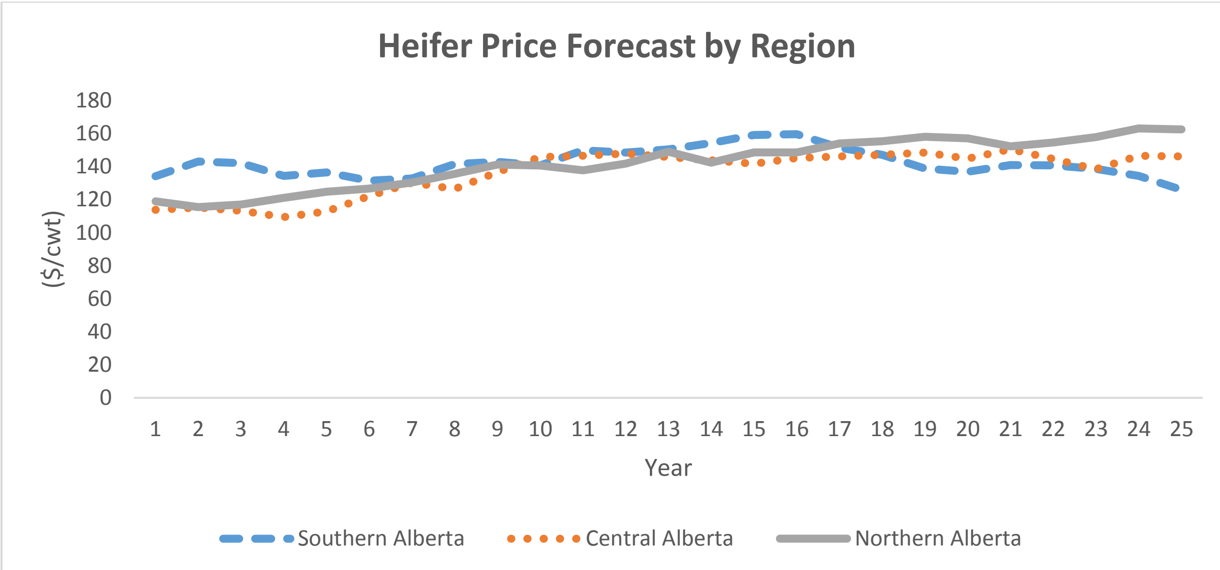

Figure 4A2: An example of heifer price forecast by region (Source: Author's own)

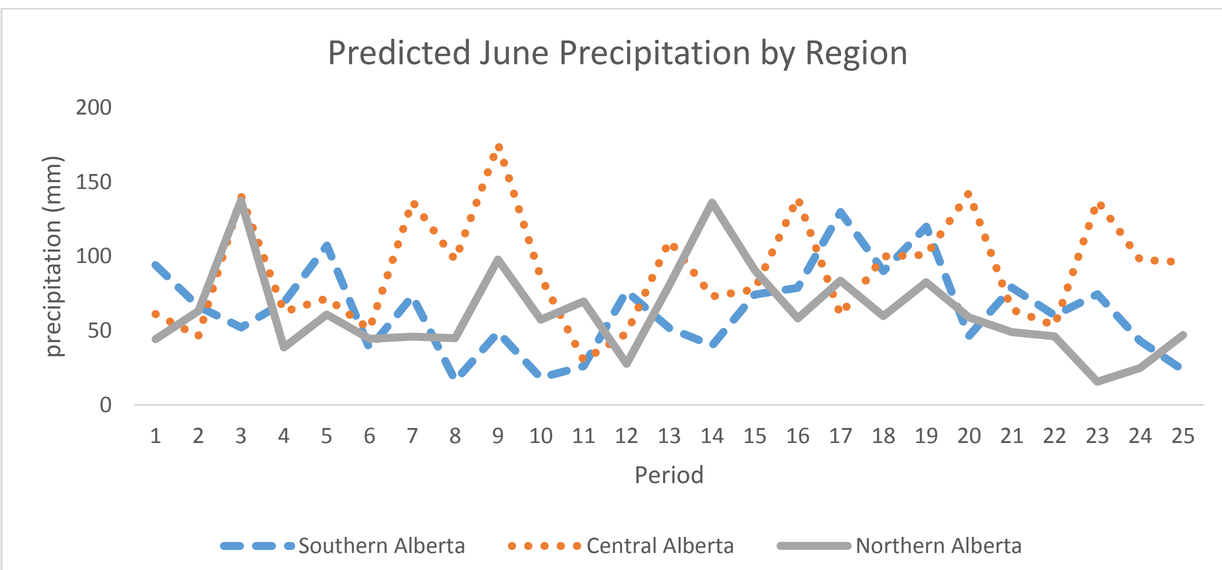

Figure 4A3: Forecasted stochastic June precipitation by region (Source: Author's own)

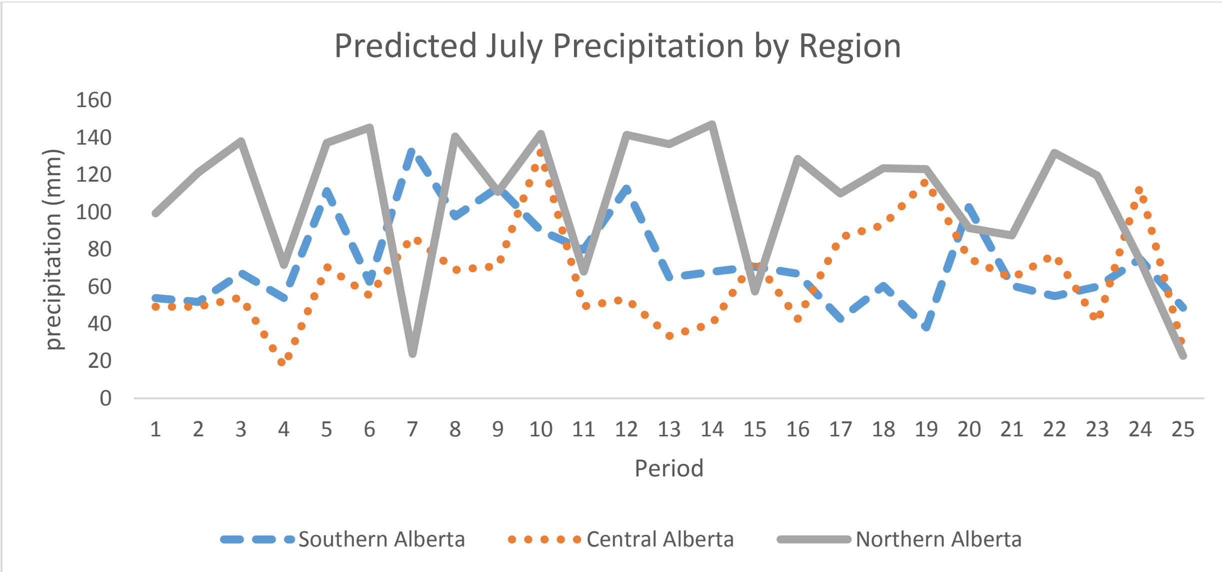

Figure 4A4: Forecasted stochastic July precipitation by region (Source: Author's own)

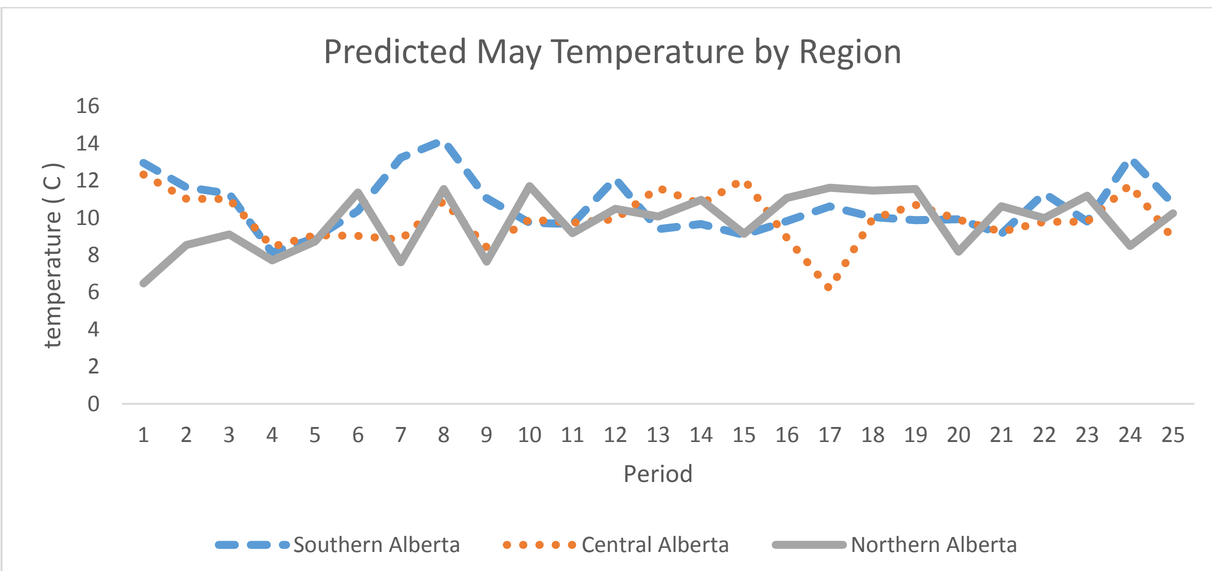

Figure 4A5: Forecasted stochastic May temperature by region (Source: Author's own)

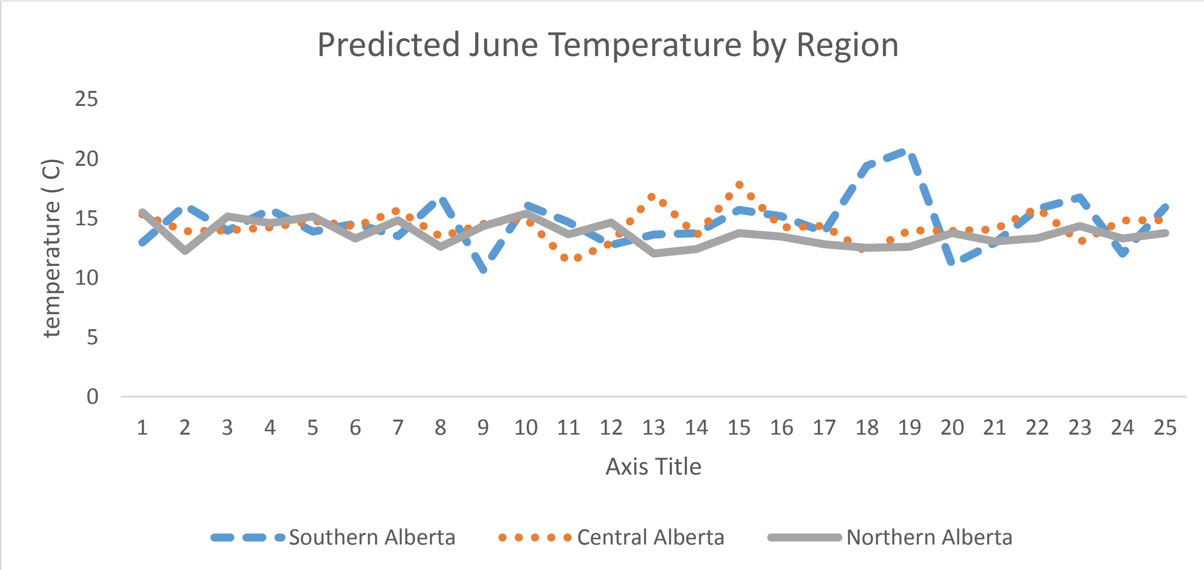

Figure 4A6: Forecasted stochastic June temperature by region (Source: Author’s own)

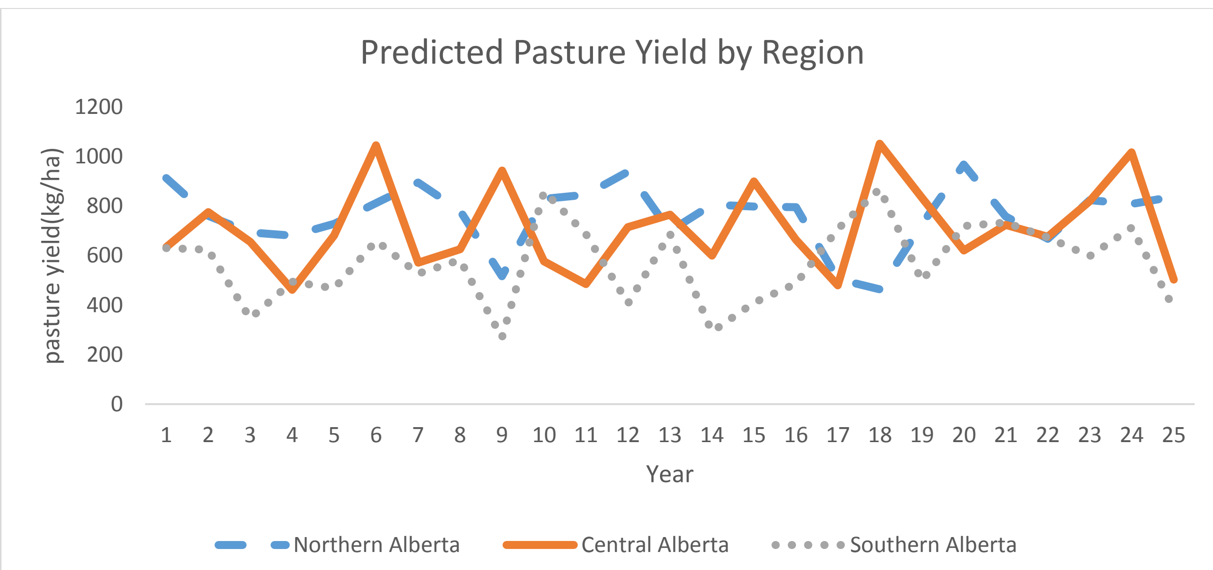

Figure 4A7: Predicted Pasture Yields (25-year period) for Southern, Central and Northern Alberta (Source: Author’s own)

Chapter 5 : Conclusions

5.1 Introduction

This dissertation presents the findings of three studies that looked at three possible outcomes of cow-calf producers' decision to purchase bulls with genomic information on feed efficiency and to breed feed efficient calves. As shown in the conceptual framework in chapter 1, these three aspects are key determinants of the decision by cow-calf producers to purchase bulls with genomic information in their bull replacement decision. Specifically, the following are addressed: (i) factors affecting producer willingness to pay (WTP) for genomically improved feed efficient bulls (ii) the assessment of how supply chain linkages can influence producer decision making (iii) the assessment of environmental outcomes from different decisions made by producers and the extent to which the opportunity to obtain additional revenue from the reduced emissions can influence these decisions. In the first paper, cow-calf producer stated preferences for genomic information on feed efficiency and the heterogeneity in producer preferences resulting from different producer attributes were examined. In the second paper, the incentive for producers to adopt genomic selection (on feed efficiency) as a technology was examined using a stylized industry model that included different segments of producers in the beef cattle supply chain. Results from this study provides insights into the potential supply chain bottlenecks that can influence cow-calf producer decision-making. The third study, addressed the environmental impact of selecting animals for improved feed efficiency in the beef industry. Specifically, reductions in GHG emissions from two important sources i.e. methane and nitrous oxide were examined. The analysis was situated within context of the producer participation in a carbon offset scheme in Alberta (the Low Residual Feed Intake (RFI) Protocol) (Government of Alberta, 2012). This allowed for the assessment of the extent to which the opportunity to obtain additional revenue from the offset scheme may influence cow-calf producer decision making. This is also a measure of the environmental externalities which might or might not be sufficient for some producers to adopt without even receiving higher prices for calves. In this chapter, summaries of the three studies are presented. The policy implications, limitations and directions for future research are also discussed.

5.2 Summary and conclusions

The objective of chapter 2 was to investigate cow-calf producer stated preferences for genomic information on feed efficiency in their bull purchase decision and account for different sources of heterogeneity that can explain the variation in preferences amongst a sample of cow-calf producers. A theoretical framework that situates the producer decision making in a multi-trait context, and incorporates technology, producer, and trait-specific characteristics was developed. This model included aspects of previous work on the derivation of implicit values for genetic inputs, accounting for uncertainty and heterogeneity in adoption decisions (Babcock, 1990; Kerr, 1984; Koundouri et al., 2006). Data for this study was obtained from a survey of cow-calf producers in Canada conducted in 2013. Random parameters and multinomial logit models were estimated and reported. The distributions of willingness to pay by production practices, environmental attitudes and farmer characteristics were also reported.

In general, the results showed that while cow-calf producers willingness to pay (WTP) for genomic information on feed efficiency and the feed efficiency EPD were positive, WTP for the two traits was lower than that for output traits such as the birthweight EPD. In cattle breeding output traits of interest include fertility, growth and carcass traits. Given that feed efficiency is the core trait, the positive valuation for genomic information on feed efficiency suggests that cow-calf producers are willing to pay a premium for genomic information on the trait. Factors such as familiarity with genomics, risk perceptions and retained ownership of calves were positively related to WTP for Genomic information on feed efficiency. The role of environmental attitudes on WTP for genomic information on feed efficiency and the feed efficiency EPD were less clear. This is because most of the cow-calf producers surveyed had a moderate view of environmental risk perceptions (nature tolerant view) as compared to high (nature ephemeral view) and to low (nature benign view) environmental risk perceptions. Further, producers with this moderate view of environmental risk expressed the highest WTP. The absence of a systematic linkage between environmental attitudes and WTP for the feed efficiency related traits may be a result of the low environmental risk perceptions amongst producers, particularly as it relates to their own production practices.

In Chapter 3, an ex-ante approach was used to evaluate cow-calf producers' private incentives to purchase bulls with genomic information on feed efficiency in the context of the overall beef cattle supply chain. It was an expectation that the inclusion of genomic information in the attributes of a particular bull might raise the cost of the bull to the purchaser. The study used an industry framework that allowed for the assessment of the value distribution of the innovation amongst different producer segments. A conceptual framework that accounted for differences in adoption behavior (e.g. potential adopters and non-adopters) and production segments (cow-calf and feedlots[53] was developed. The resulting heterogeneity in the quality of calves (i.e. regular or more feed efficient calves) based on the bull choice was also accounted for. An integer optimization model parameterized with provincial (Alberta) production and price data was estimated. Simulations of uptake under different scenarios were also reported.

The study showed that improvement in feed efficiency is beneficial to both feedlot operators and cow-calf producers. This notwithstanding, a majority of the benefits in terms of reductions in feed costs goes to feedlot operators. This outcome was robust under both conservative and high rates

[53] Also combined backgrounding and cattle finishing.

of improvements in feed efficiency. In contrast, the benefits to the cow-calf producers were relatively small. Paying an additional cost of the bull (assuming genomic bulls are sold at a higher price relative to regular bulls) was only economically feasible under high rates of improvement in feed efficiency. The role of a subsidy and a market based scheme that allowed for the payment of a differential price for more feed efficient calves versus regular calves was also analyzed. The results show that in the absence of a mechanism that rewards cow-calf producers for the investment in the genomic bull, the diffusion of the innovation is likely to be slow. At the very least, these interventions are required until the rate of improvement in feed efficiency is reasonably high to justify the purchase of (higher) cost genomic bulls. Integrated systems which combine both breeding and cattle feeding are more likely to adopt genomic selection for feed efficiency in their bull purchase decisions as the effect of the incentive incompatibility issues highlighted in the analysis are weak or non-existent in these systems.

Chapter 4 addressed the environmental impact of the breeding for feed efficient calves and the extent to which the opportunity to participate in carbon offset schemes (such as the Low Residual Feed Intake (RFI) Protocol) can incentivize cow-calf producers to purchase genomic feed efficient bulls given the environmental benefits of improved feed efficiency. Three farm level models representing three regions in Alberta were specified. This was to account for the effect of region specific climatic factors such as precipitation and temperature that can result in variations in pasture production and stocking rates. Each of these models comprised four sub-components: breeding, estimates of net returns to the cow-calf producer from the sale of feed efficient calves, pasture yield and greenhouse gas emissions. The pasture yield function for each region was fitted with region-specific precipitation and temperature data. Regional cattle price and cost of production data were also used. Two types of greenhouse gases (GHGs) i.e. methane and nitrous oxide, from six sources were tracked in the model. These include methane from enteric fermentation and manure handling and storage, nitrous oxide from manure decomposition, storage, volarization and soil leaching.

The results indicated that the breeding for feed efficiency cattle can lead to reduced greenhouse gas emissions in all the three agroecological zones examined. Annual emissions reduced by approximately 12.5-13.5 (Tonnes CO_2/year). Most of these reductions were related to methane emissions from enteric fermentation. The results also showed spatial differences in total emissions, carbon emission intensities and net returns to cow-calf producers under different assumptions of stocking rate and breeding decisions. Environmental benefits (reduced GHG emissions) are highest when producers purchase bulls selected for feed efficiency using genomic selection while simultaneously keeping stocking rates fixed. Emissions in specific regions did in fact increase in the presence of the feed efficient herd; combined with higher stocking rates. This resulted from adjustment in herd size due to the effect of improved feed efficiency and in the regions with higher pasture availability. The economic cost of maintaining a fixed stocking rate under improved feed efficiency in some regions was higher than the revenue from the offset scheme given the level of GHG reduction per farm and the price of carbon. This suggests that at present the additional revenue from the scheme may be insufficient to change the cow-calf producer incentive to adopt in particular regions. Irrespective of the direct economic benefits, it is possible that some producers who are very concerned about GHG emissions from their operations may be incentivized by the opportunity for additional revenue to change their breeding practices.

5.3 Implications of Study

In general, understanding the processes that underline the uptake of new biotechnologies by farmers is relevant for a number of reasons. As aptly noted by Caswell et al. (1994, p.28):

From a biotechnology investor's perspective, if only a small percentage of potential users will ever adopt a new technology, the high cost of R&D may never be recouped. Also, if the rate of adoption is expected to be very slow, there may not be sufficient incentive to do research. From the public policy maker's point of view, forecasts of technology diffusion could be informative since the effect of biotechnology adoption may have significant impact on farm structure, environmental quality, human nutrition, or animal health.

The results of this study have a number of important implications. Firstly, the results of the stated preference analysis show that cow-calf producer do attach positive values to bulls with genomic information on feed efficiency. Cow-calf producers also value more conventional measures of the trait (Feed efficiency EPDs). The consistency in the valuation of different measures of the feed efficiency traits suggests that co-existence of "low" and high tech" breeding applications i.e. EPDs and genomics, is feasible. This is important as genomics is considered a disruptive technology that could replace traditional selection tools in the long term[54]. In short to medium term however, both conventional and new genomic breeding tools are likely to coexist and the seeming complementarity in preferences for both conventional and new genomic information can facilitate cow-calf producer uptake. Further, the development of genomics and other breeding technologies has exposed livestock producers to a deluge of information. As showed in this study, knowledge about the use of genomics in selective breeding although low, is systematically related to cow-calf producers' stated preferences for genomic information on feed efficiency. This outcome has a number of implications, chiefly: the value of genomics to the cow-calf producers may be linked to a better understanding of its use in breeding. It highlights the critical role of producer education about the use of genomic information in beef cattle breeding.

Secondly, value distribution along the beef supply chain and the alignment of incentives would be important in the diffusion of the innovation. This outcome is evident from: the linkage between

[54] It is important to note that genomic selection requires phenotypic information in order to establish the linkage between genotypes and phenotypes.

retained calf ownership practices and cow-calf producer valuation of feed efficiency chapter 2; the relative value allocation between feedlot operators and cow-calf producers reported in chapter 3; and; the seeming inadequacy of the additional revenue from the current voluntary environmental compliance programs highlighted in chapter 4. As compared to other livestock sectors, the structure of the beef cattle value chain in Canada is unique in several respects and this has been one of the main impediments to the diffusion of innovation (Schroeder, 2003). Indeed, the rapid diffusion of genomics in dairy cattle has been attributed to more efficient institutional and market mechanisms (Strauss 2010). In beef cattle, the development of strategic alliances between for example, cow-calf producers and feedlots can reduce the effect of these market inefficiencies. In the presence of inadequate private benefits, public benefits such as environmental improvements might provide a justification for government intervention. A typical example of a similar scheme is the Irish Beef Data Genomics Programme (ICBF, 2016). However, for this scheme to be effective in reducing greenhouse gas emissions, the spatial heterogeneity in cow-calf production must be accounted for. As shown in this study, a "one-size-fits-all" approach is less likely to be effective. To this end, region specific schemes or a provincial scheme that accounts for climatic factors such as precipitation and temperature may be more effective. To a certain degree, these conclusions are consistent with other studies that have examined cow-calf producer uptake of beneficial products and practices with nebulous value allocation.

5.4 Limitations and Future Research Recommendations

The current research on cow-calf producer decision making with respect to genomic information on feed efficiency can be improved in several ways. As a stated preference study, the results of Chapter 2 must be interpreted with the usual caveats in mind- hypothetical bias, strategic behavior etc. Also, future studies can target a larger sample of cow-calf producers or include other producer segments such as feedlot operators. This can improve the external validity of the results and facilitate the comparison of the valuation of the same innovation by different producer segments. Research on the identification of genes linked to feed efficiency is currently on-going in many countries. Selection trials for improved feed efficiency are also on-going. Once these estimates become available, actual transactional data on bulls sold with genomic information on the trait can be used to estimate hedonic values. This can be compared with the values reported in this study to assess whether the stated preference for genomic information on feed efficiency matches revealed preferences. The rates of improvement in feed efficiency assumed in this study can also be refined once more information on current genotyping and breeding trials become available. In Chapter 2, this could mean the inclusion of genomic breeding values in the experimental design. This would ensure that the valuation of cow-calf producer preferences is not only limited to the presence or absence of genomic information (the "yes" or "no" dichotomous case presented in this study) but actual breeding values with associated accuracies. Genomic breeding values for feeding efficiency were unavailable at the time of this study and once these values become available future studies can include them. The economic models at the farm level (Chapter 3 and 4) can also be linked with a gene flow model, for example. Additionally, the premiums for genomic bulls by environmental attitudes as measured with a New Ecological Paradigm (NEP) or the New Human Interdependence Paradigm (NHIP) scale can be linked with the farm model in Chapter 3. This way, the environmental premiums elicited with the stated preference approach can be combined with the farm-level decision models in Chapter 3 to account for the effect of higher environmental awareness/concerns for the environment on cow-calf producer decision making.

Further, while Chapter 3 segregates cow-calf producers by potential adoption behavior i.e. potential adopters and non-adopters, uncertainty in producer decision making is not accounted for.

Approaches to accounting for uncertainty in decision making such a real-options approach would represent a useful extension to the current work. Additionally, a game theory approach that accounts for strategic behavior between cow-calf producers with different calf retention options on the one hand, and feedlot operators with the option to buy from different cow-calf producers on the other hand, would be useful.

Alternative methods such as dynamic programming approaches can be used for the empirical analysis in Chapter 4. The results of the analysis presented in Chapter 4 can also be improved by the incorporation of region specific pasture yield functions that account for additional factors such as evapotranspiration, soil characteristics etc. Also, a comparison of, for example, increases in the productivity of an output/growth trait and feed efficiency would put the present estimates in context.

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5.6 Glossary of Terms[55]

Average daily gain (ADG): refers to the rate of weight per day over a given period of time.

Backgrounders: Segment of cattle producers who grow weaned calves on pasture until they enter feedlots. These producers add an additional 100-400 lbs. Also known as stockers.

Conjoint analysis: Stated preference methodology in which respondents rank different combinations of different attribute levels.

Birth weight: refers to the weight of an animal at birth. It is measured in lbs.

Expected progeny differences (EPDs): It is an estimate of the genetic value of an animal (usually breeding stock) as a parent. Within the same breed, differences in EPDs for specific traits between two bulls (for example), capture variations in the expected performance of the offspring of the bulls with respect to the traits.

Expected breeding values (EBVs): Expresses the difference in the performance of an animal relative to the breed or herd benchmark (average). The EBVs for specific traits are reported in the same units as the estimated traits (lbs., days etc.) as higher (+) or lower (-) the herd or group average.

Feed conversion ratio (FCR): Feed conversion ratio is a measure of feed efficiency defined as pounds of feed per unit live weight gain.

Feed efficiency: is measure of the efficiency with which an animal utilizes feed for producing a given level of output. Higher feed efficient animals utilize lower amounts of feed to produce a given level of output as compared less efficient animals.

Genetic selection: Selection based on differences in DNA sequence information (gene) related to a trait.

Genome: An animal or organism's complete set of genes (DNA).

Genomic selection: refers to the selection for a trait by accounting for the effect of each single nucleotide polymorphisms (difference in DNA sequences) spread throughout the entire genome.

Genotyping: refers to testing to determine the variation in the DNA sequence of an animal related to specific traits.

Input traits: refers to traits related to inputs of production. For example, traits such as feed efficiency which refers to the efficiency with which an animal utilizes feed (an input).

Output traits: refers to traits such as fertility, carcass attributes, weaning weight etc. that are related to the output of production. In cattle, output can be the final product i.e. beef or the live animal.

[55] Some of the terms are defined specific to farm animals but can apply to other species as well.

Marker-assisted selection (MAS): In marker-assisted selection, molecular markers are used to find genes that control the function of traits of interest in order to select for these traits. These markers typically consist of thousands of single nucleotide polymorphisms (SNPs).

Mid-metabolic body weight: This the mid-point body weight (over a specified period) of an animal raised to the power 0.75.

Phenotype: Observable/expressed traits of an animal. Such as its weight, feed intake etc.

Genotype: underlying genetic code that combine with environmental factors to determine the extent to which phenotypes are expressed.

Residual feed intake: It is a measure of feed efficiency defined as the difference between animal's actual feed intake and its expected feed intake require for maintenance and growth. It is estimated as the errors from regression of actual feed intake on average daily gain and mid-metabolic body weight.

Residual average daily gain: It is a measure of feed efficiency defined as the difference between actual average daily gain and predicted average daily gain. The predicted average daily gain is derived from the regression of average daily gain on feed intake and mid-metabolic body weight.

Single nucleotide polymorphisms (SNPs): A single nucleotide polymorphism occurs when there is a variation in a single nucleotide in a DNA sequence of an animal. For example, when a thymine (T) nucleotide is replace by a cytosine (C) nucleotide.

Weaning weight: refers to the weight of a young animal (e.g. calves in cattle) at a standardized age. It is measured in lbs.

APPENDIX 5A: Beef Producer Survey

Research Investigators:

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Information Sheet for Study Participants

This study is being conducted by researchers in the Department of Resource Economics and Environmental Sociology, University of Alberta. The purpose is to identify cattle producer's interests in science, technology and use of genomics in selective breeding. The analysis will help us better understand the driving factors in producer preferences. Production concerns influence cattle producers to behave in many different ways particularly with respect to breeding animals. The purpose of this research is to understand producer attitudes and how those attitudes influence different decisions made on the farm. You are being asked, as a cattle producer, to participate in a research project through the completion of an online survey. We expect that it might take as long as 45 minutes to complete the survey.

You can be assured that your answers are confidential and will only be released as summaries. Your name will not be collected as part of your survey and thus can never be associated with the data. Your responses will not be individually identified or publicized. Your answers are strictly voluntary. You can feel free to withdraw from the survey at any time, during the survey. You can withdraw by returning an unfinished questionnaire. Submission of the completed online survey will imply consent to the use of the data you have entered. The data will be used for statistical purposes only and statistical results will be reported in research papers, technical reports and academic journals. In the future, the statistical data may be used for subsequent research in the area of farm decision making, as a basis for comparison to future results, and as an example in teaching.

Data collected in this research will only be accessible by members of the research team at the University of Alberta (see above). Data will be stored on secure servers for up to seven years. It will be deleted after all publications using the data are finalized.

There are no anticipated risks to participating in this study. Benefits to participation include a broader understanding of the environment producers operate in and what triggers different types of breeding decisions. This information can contribute to the formation of public policy, particularly around agricultural research. If you have any questions, comments, or suggestions about the survey or the study, please feel free to contact the investigators above. You may also contact the researchers if you would like a copy of the final report.

If you have any further questions or concerns about this research you may contact the Research Ethics Office at 780-492-2615. This office has no direct involvement with this project.

Section A. Farm and Farm operator characteristics

1. Which of the following best describes your cattle operation in 2013?
☐ Owner operator
☐ Partnership
☐ Corporation
☐ Other (please specify:____)

2. In 2013, which of the following strategies did you use to market your cattle/calves? Please check all that apply.
☐ Formula pricing
☐ Auctions
☐ Sealed bid auctions
☐ Direct buy orders/contracts
☐ Other (please describe:____)

3. Including 2013, for how many years have you been raising cattle? _____________ years

4. How many cows did you have on your operation at the beginning of January, 2013?
☐ Zero
☐ 1-99
☐ 100-249
☐ 250-499
☐ 500-999
☐ More than 1000

5. How many cows did you have on your operation at the beginning of January, 2014?
☐ Zero
☐ 1-99
☐ 100-249
☐ 250-499
☐ 500-999
☐ 1000-2999
☐ More than 3000

6. On average, in 2013 what percentage of your total farm sales was from your cattle operation?
- ☐ Less than 20%
- ☐ 20-39%
- ☐ 40-59%
- ☐ 60-79%
- ☐ 80-99%
- ☐ 100%
- ☐ I don't know.

7. What was the total annual revenue from cattle sales in 2013? (Please estimate if you do not know the exact figure.) $ ______________________________

8. Please provide the approximate percentage of your total operating costs for each category in the year 2013. Write "zero" for no purchase or expense.

	Expenditure	Cost (%) in 2013
1	Purchase or prepared feed	
2	Veterinary service: animal disease treatment	
3	Veterinary service: animal disease prevention (e.g, vaccination)	
4	Artificial insemination service	
5	Building maintenance and repairs	
6	Heating, electricity, and other fuel costs	
7	Insurance	
8	New animals bull and/or cows	
10	Building, equipment, and property taxes	
11	Lease and rental payments	
12	Labour	
13	Others	
14	Total cost	100

9. Indicate your labour usage for 2013 cattle operation in number of employees and total person hours per season for each of the following types of employment?

	Type of Labour	Number of employees	Total person hours per year
		1	2
1	Full-time paid labour		
2	Part-time paid labour		
3	Seasonal paid labour		
4	Unpaid family labour		

5	Management		

10. Are you a member of any of the following organizations? Please check all that apply.
- ☐ 1. Co-operative
- ☐ 2. Provincial producers' association (eg. Alberta Beef Producers, Western Stock Feeders)
- ☐ 3. National producer's organization (Canadian Cattleman's Association)
- ☐ 4. National farmer's association (eg. Canadian Federation of Agriculture)
- ☐ 5. Other (please explain)

11. Are you enrolled in any provincial or federal business risk management program that provides benefits to cattle producers (e.g., Agristability)?
- ☐ 1. Yes
- ☐ 2. No

12. Did you purchase any form of private insurance for your operation in 2013?
- ☐ 1. Yes
- ☐ 2. No

13. In which of the following age groups do you fall?
- ☐ 1. 20-29
- ☐ 2. 30-39
- ☐ 3. 40-49
- ☐ 4. 50-60
- ☐ 5. 60-69
- ☐ 6. over 70

14. Please indicate if you are :
- ☐ 1. male or
- ☐ 2. female

15. What is the highest level of education that you have obtained?
- ☐ 1. Less than high school
- ☐ 2. High school diploma
- ☐ 3. College/trade school diploma
- ☐ 4. Undergraduate degree
- ☐ 5. Post graduate degree

16. Your farm is situated in which of the following regions?

- ☐ 1. Quebec
- ☐ 2. Maritimes
- ☐ 3. Ontario
- ☐ 4. Manitoba
- ☐ 5. Saskatchewan
- ☐ 6. Alberta
- ☐ 7. British Columbia

BREEDING DECISIONS

17. Have you ever purchased bulls/semen specifically bred for certain productivity traits?
    - ☐ Yes
    - ☐ No

18. Please indicate the percentage of your cows that come from each of the following sources:

1	Breeder located in your province	%
2	Other Canadian breeder	%
3	Imported from the United States	%
4	Self-produced with semen produced from bulls with known productivity traits	%
5	Another source (please specify)	%
		100%

19. To what extent do you think each of the following make an important contribution to the positive welfare of cattle that are reared for food production?

	Item	Not Important At All		Important		Extremel y Important	Don't Know
		1	2	3	4	5	6
1	Healthy living conditions						
2	Skilled attention						
3	Clean environment						
4	Environment free from disease						
5	Medical treatment						

	when the hog is sick						
6	Comfortable living conditions						
7	Nutrition to strengthen the animal's immune system						
8	Adaptation of the housing system to the needs of the animal						
9	Food to satisfy the animal and to optimize its growth and health						
10	Space to allow the animal to be on its own						
11	Distraction/ variation in the living environment						
12	Prevention of stressful situations						
13	Providing an environment that allows the cattle to experience little or no fear						

20. Each year after weaning, please tell us what you do with your male calves?
    a. How often do you sell the male calves at weaning?
        (1) Never
        (2) Seldom
        (3) Sometimes
        (4) Often

(5) Always

b. How often do you background steers and then sell them?
(1) Never
(2) Seldom
(3) Sometimes
(4) Often
(5) Always

c. How often do you retain steers through to finishingand then sell them?
(1) Never
(2) Seldom
(3) Sometimes
(4) Often
(5) Always

21. To what extent do you agree with the following statements:
a. The breeding decisions I make in my cattle operation have impacts throughout the beef supply
chain?
(1) Strongly agree
(2) Agree
(3) Somewhat agree
(4) Disagree

b. Overall, the decisions I make in my cattle operation have impacts throughout the beef supply
chain.
(1) Strongly agree
(2) Agree
(3) Somewhat agree
(4) Disagree

22. Assuming the costs are the same, would you be interested in purchasing semen for artificial insemination or a bull that demonstrated enhanced feed efficiency with the attendant reduced greenhouse gas emissions?
□ Yes
□ No

General Attitudes
23. In general, to what extent do you feel informed about scientific and technological developments?

Not at all informed 1	Not very informed 2	Somewhat informed 3	Very informed 4

☐	☐	☐	☐

24. All things considered, how do you think science and technology has affected the world? Science and technology have made the world:

A lot worse off	Somewhat worse off	Somewhat better off	A lot better off
1	2	3	4
☐	☐	☐	☐

25. In general, to what extent to you support the use of products and process that involve biotechnology?

Strongly oppose	Somewhat oppose	Somewhat support	Strongly support
1	2	3	4
☐	☐	☐	☐

26. Please identify whether you agree or disagree with the following statements:

	Statement	Strongly Disagree	Mildly Disagree	Neutral	Mildly agree	Strongly Agree	Don't Know
		1	2	3	4	5	6
1	Biodiversity is a measure of the number of different species of plants and animals in a particular area (birds or trees in Ontario, for example)						
2	Biodiversity is a measure of the extent of genetic variation within a species, for example the number of different						

	types of apple trees, different breeds of cattle.						
2	Biodiversity means the number of different types of ecosystems within a particular region – such as wetlands, coastal areas, forest, prairies.						

(Spash and Hanley)

26. Please identify whether you agree or disagree with the following statements:

	Statement	Strongly Disagree	Mildly Disagree	Neutral	Mildly Agree	Strongly Agree
		1	2	3	4	5
1	I worry about changes to the countryside, such as the loss of native plants and animals					
2	There is nothing I can personally do to help stop the losses in the world's biodiversity					
3	We can afford to lose some of the world's biodiversity					
4	Biodiversity losses in animals domesticated for food production are less serious than					

	similar losses in wildlife					

(UK survey with some attitudes towards biodiversity)

27. Please rate the following values according to their importance as guiding principles in your life on a scale from "opposed to my principles" (-1) through "not important" (0) to "of extremely important" (7).

	Opposed to my values	Not important			Important			Very important	extremely important
	-1	0	1	2	3	4	5	6	7
1	RESPECT FOR TRADITION (preservation of time-honoured customs)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	DETACHMENT (from worldly concerns)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	MODERATE (avoiding extremes of feeling and action)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
4	HUMBLE (modest, self-effacing)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	ACCEPTING MY PORTION IN LIFE (submitting to life's circumstances)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
6	DEVOUT (holding to religious faith and belief)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
7	EQUALITY (equal opportunity for all)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
8	INNER HARMONY (at peace with myself)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
9	A WORLD AT PEACE (free of war and conflict)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
10	UNITY WITH NATURE (fitting into nature)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
11	WISDOM (a mature understanding of life)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
12	A WORLD OF BEAUTY (beauty of nature and the arts)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
13	SOCIAL JUSTICE (correcting injustice, care for the weak)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
14	BROAD-MINDED (tolerant of different ideas and beliefs)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
15	PROTECTING THE ENVIRONMENT (preserving nature)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
16	FREEDOM (freedom of action and thought)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
17	SELF-RESPECT (belief in one's own worth)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐

18	CREATIVITY (uniqueness, imagination)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
19	INDEPENDENT (self-reliant, self-sufficient)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
20	CHOOSING OWN GOALS (selecting own purposes)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐
21	CURIOUSITY (interested in everything, exploring)								
	☐	☐	☐	☐	☐	☐	☐	☐	☐

Networking Frequency

28. How often do you have contact with each (category of) organization(s) for *external knowledge and information* (could be technical, financial or market information)? Please choose the option that best approaches the actual situation.

			Never	Once every couple of years	Annually	Semi-annually	Bi-monthly	Monthly	Weekly
			1	2	3	4	5	6	7
		Company and organizations							
1	Feed companies								
2	Feed systems companies								
3	Veterinarians								
4	Other cattle farmers								
5	Abattoirs / slaughterhouses								
6	Meat processors								
7	Transport companies								
8	Supermarkets								
9	Butchers								
10	Banks								
11	Consultancies								
12	Provincial Ministries of Agriculture								

13	Agriculture and Agri-food Canada								
		Branch organizations							
14	Provincial cattle organization (eg. Alberta Beef Producers, Ontario Cattlemen's Association)								
15	Canadian Cattleman's Association								
		Knowledge institutions (only ask relevant provincial organization)							
18	University of Guelph								
19	Laval University								
20	University of Saskatchewan								
21	University of Alberta								
22	University of Manitoba								
23	University of Calgary								
24	University of British Columbia								
25	Nova Scotia Agricultural College								
26	University of Prince Edward Island								
		Animal welfare and environment							
27	Canadian Animal Health Coalition								
28	National Farmed								

	Animal Health and Welfare Council								

29. Indicate to what extent you make use of external sources, knowledge and information for the following issues: *1 = infrequently and 7 = very frequently*

		1 Infrequently	2	3	4	5	6	7 Very frequently
1	Animal welfare							
2	Veterinary issues							
3	Marketing							
4	Regulation							
5	Environmental issues							
6	Subsidies							
7	Animal nutrition/feed efficiency							
8	Collaboration							

30. Indicate to what extent you agree with the following statements: 1 = completely disagree and 7 = completely agree

		1 Completely disagree	2	3	4	5	6	7 Completely agree
	Acquisition capacity							
1	We collect information about developments in the cattle sector through discussions with business partners in the sector.							
2	Our farm participates at least twice a year in seminars and sector-organized conferences to upgrade our expertise and knowledge.							
3	We allocate a lot of time to the establishment of contact with parties who can provide us with knowledge and information about innovations in the sector.							
4	We have sufficient skills to establish contact with parties who can provide us with knowledge and information about innovations in the sector.							
	Assimilation capacity							

5	Our farm is always among the first to recognize shifts in technical possibilities.							
6	Our farm is always among the first to recognize shifts in regulation.							
7	Our farm is always among the first to recognize shifts in market competition.							
8	Our farm is very skilful in detecting new possibilities to serve new customers.							
9	Our farm allocates a lot of time to deliberating with advisors in order to recognize changes in the market early.							
10	Our farm has sufficient skills to deliberate with advisors about how changes in the market can be used to make changes to the business on our farm.							
	Transformation capacity							
11	We record and store newly acquired knowledge for future reference.							
12	Our farm quickly recognizes the usefulness of new external knowledge to our existing knowledge.							
13	We discuss monthly with external advisors how trends in the market could be used to improve our business.							
14	We allocate a lot of time to translation of external information into adaptations to our business.							
15	We have sufficient skills to translate external information into adaptations to our business.							
	Exploitation capacity							
16	We translate external information directly into new business applications.							
17	Application of external information to our business contributes to our profitability.							

18	We have sufficient skills to convert external information into profitability.							

31. Indicate how your operation compares:

	Profitability	1 Much lower	2	3	4	5	6	7 Much higher
1	Compared to our competitors our profitability is:							
2	Compared to our most important competitors our turnover is:							
3	Compared to our most important competitors our growth percentage year over year is:							

32. I have (less success, average success, more success) in managing cattle efficiently on my farm than other comparable cattle farms. Check appropriate box.

1 Less Success	2 Average success (comparable)	3 More success

33. Please respond to the following statement:

	1 Very little time	2	3	4	5 A lot of time
How much time do you spend learning about ways to improve the efficiency of your operations?					

34. In your farm/ranch management, how would your neighbours describe your risk taking behavior?Please select one
    (1) A risk avoider
    (2) Cautious
    (3) Willing to take risks after adequate research
    (4) A real gambler

35. You can sell your calves at different production stages. If given the following options, which would you choose? Please select one
    (1) Sell at weaning
    (2) Retain for two months post weaning with a:30% chance of netting an additional $5/head,10% chance of losing $10/head, or 60% chance of netting no additional $/head.
    (3) Retain through finishing with a: 30% chance of netting an additional $40/head, 15% chance of losing $50/head, or 55% chance of netting no additional $/head

36. Given the best and worst case potential outcomes from marketing your weaned calves, which net return/loss prospect would you most prefer from the four listed below?
    (1) a. $20/calf return best case; $0/calf loss worst case
    (2) b. $35/calf return best case; $20/calf loss worst case
    (3) c. $65/calf return best case;$35/calf loss worst case
    (4) d. $100/calf return best case;$75/calf loss worst case

37. Your trusted friend is putting together investors to fund a new innovative business venture. The venture would pay back more than 50 times the investment if successful. If the venture is a bust, the entire investment is worthless. Your friend estimates the chance of success as 20%. How much would you invest?
    (1) a. Nothing
    (2) b.$1000
    (3) c. $10000
    (4) d.$50000
    (5) e.$100,000
    (6) f.$ More than $100,000

38. If your trusted friend and banker each conclude that the success of the venture in the above question is 60% instead of 20%, how much you invest?
    (1) A. Nothing
    (2) b. $1000
    (3) c.$10,000
    (4) d.$50,000
    (5) e.$100000
    (6) f. More than $100,000

The following are intended to measure risk perceptions:

39. Indicate the level of **concern** you have for the impact on each of the following that may occur as a result of using genomics in selective breeding for increased feed efficiency:

	No Concern (1)	Slight Concern (2)	Moderate Concern (3)	Great Concern (4)
The wellbeing of your herd overall				
The wellbeing of individual animals				
The profitability of your cattle operation				
The beef industry overall				
The cow/calf operations within the beef industry				
The genetic diversity of beef cattle				
The local natural environment				
The global natural environment				

The public consuming beef products produced with this technology				

40. Indicate how **beneficial** selectively breeding for increased feed efficiency could be for each of the follow:

	No Benefits (1)	Slight Benefits (2)	Moderate Benefits (3)	Great Benefits (4)
The wellbeing of your herd overall				
The wellbeing of individual animals				
The profitability of your cattle operation				
The beef industry overall				
The cow/calf operations within the beef industry				
The genetic diversity of beef cattle				
The local natural environment				
The global natural environment				
The public consuming beef products produced with this technology				

41. There a number of management practices producers available to producer to reduce greenhouse emission, increase profitability and increase efficiency. A number of these Best Management Practices (BMPs) are listed below. Do you undertake any of the following BMPs on your farm?

	Best Management Practice		If yes then how many years ago did you start?	
1	Vaccinate cows or calves for diseases such as: Scours, Clostridia(black leg) etc.	Yes □		No □
2	Fall pregnancy check	Yes □		No □
3	Bull evaluation	Yes □		No □
4	Rotational grazing	Yes □		No □
5	Weed control	Yes □		No □
6	Undertake feed management practices such as: feeding high quality feeds and balanced rations, adding grains or lipids to diet, pelleting etc.	Yes □		No □
7	Extend grazing season through swath grazing, stockpiling of perennial forage etc.	Yes □		No □
8	Fertilize tame pasture using manure	Yes □		No □
9	Use off-stream watering systems	Yes □		No □

10	Fence wetlands/riparian areas	Yes □		No □
11	Careful selection of wintering sites as a manure management strategy	Yes □		No □
12	Other(please specify):	Yes □		No □

Section B. Genomic technology in the cattle industry

Scientists at various Canadian universities are developing genomic technologies to enable the breeding of cattle with improved feed efficiency. Genomics is the study of the genes and genetic characteristics of organisms like plants, animals, and humans. The study of genomics in cattle can allow for the identification of specific genes that are linked to enhanced feed efficiency. With knowledge of the presence (absence) of these genes, selective breeding can produce cattle that are more efficient converters of feed into meat, reducing greenhouse gases and improving farm profitability.

42. How would you describe your current level of knowledge about the use of genomic information in selection/breeding?

Not at all familiar	Not Very familiar	Somewhat familiar	Very familiar
1	2	3	4
□	□	□	□

43. Imagine bulls (sires) that differ in genomic information, weaning weight, birth weight, and feed efficiency. These traits are represented as Expected Progeny Differences (EPD). These EPDs provide an estimate of the performance of the bull as a parent. Differences in EPD between two bulls predict differences in the performance of their **offspring** when each bull is mated to animals of the same average genetic merit. The traits included are defined as follows:

Weaning weight EPD: Measured in pounds (lbs) the higher EPDs are desirable. Assuming two bulls: bull A has a weaning EPD of +30 lb. and bull B has a weaning EPD of +20 lb. If you randomly mate these bulls in your herd, you could expect bull A's calves to weigh, on average, 10 lb. more at weaning than bull B's progeny (30 - 20 = 10).

Birth weight EPD: Measured in pounds (Ibs.). Lower estimates are desirable.

Feed efficiency EPD: denotes the efficiency of feed utilization in progeny. Positive values are more favorable.

Accuracy of feed efficiency EPD: Denotes the reliability of the feed efficiency EPD. Estimates close to 100% indicate higher accuracy.

Apart from the traits listed, the bulls are assumed to have the same genetic merit for conformation, temperament, birth weight, calving ease, yearling weight, mature daughter weight, and all other traits. In each of the following scenario, you should choose ONE of the alternatives you would like to purchase or you can choose not to purchase any of the products by checking "None" in each scenario. For each scenario, assume that you have the opportunity to purchase ONE and ONLY ONE of the items at the listed cost.

Q43.1: Scenario 1: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	Yes	Yes	I wouldn't buy either of these types of Bulls
Birth weight EPD(Ibs)	+10	+20	
Weaning weight EPD(Ibs)	-5	-5	
Feed efficiency EPD(Ibs)	+0.10	+0.22	
Accuracy of Feed efficiency EPD (%)	40%	40%	
Price of Bull(CAN$)	$9000	$5500	
I would buy	☐	☐	☐

Q43.2: Scenario 2: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	No	Yes	I wouldn't buy either of these types of Bulls
Birth weight EPD(Ibs)	+20	+10	
Weaning weight EPD(Ibs)	0	0	
Feed efficiency EPD(Ibs)	-0.09	+0.22	
Accuracy of Feed efficiency EPD (%)	50%	60%	
Price of Bull(CAN$)	$5500	$5500	
I would buy	☐	☐	☐

Q43.3: Scenario 3: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	Yes	No	I wouldn't buy either of of these types of Bulls
Birth weight EPD(Ibs)	+30	+30	
Weaning weight EPD(Ibs)	-5	-5	
Feed efficiency EPD(Ibs)	-0.09	+0.22	
Accuracy of Feed efficiency EPD (%)	40%	30%	
Price of Bull(CAN$)	$1500	$9000	
I would buy	☐	☐	☐

Q43.4: Scenario 4: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	No	Yes	
Birth weight EPD(Ibs)	+10	+20	

Weaning weight EPD(Ibs)	0	0	I wouldn't buy either of these Bulls
Feed efficiency EPD(Ibs)	+0.10	+0.10	
Accuracy of Feed efficiency EPD (%)	50%	60%	
Price of Bull(CAN$)	$1500	$9000	
I would buy	☐	☐	☐

Q43.5: Scenario 5: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	No	No	I wouldn't buy either of these Bulls
Birth weight EPD(Ibs)	+20	+30	
Weaning weight EPD(Ibs)	-5	0	
Feed efficiency EPD(Ibs)	+.10	+0.22	
Accuracy of Feed efficiency EPD (%)	30%	50%	
Price of Bull(CAN$)	$1500	$1500	
I would buy	☐	☐	☐

Q43.6: Scenario 6: Please check the ONE item you prefer or none			
Traits	Bull 1	Bull 2	None
Has Genomic information on feed efficiency	Yes	No	I wouldn't buy either of these Bulls
Birth weight EPD(Ibs)	+30	+20	
Weaning weight EPD(Ibs)	0	+5	
Feed efficiency EPD(Ibs)	+0.10	+0.20	
Accuracy of Feed efficiency EPD (%)	60%	75%	
Price of Bull(CAN$)	$5500	$9000	
I would buy	☐	☐	☐

Q.44 Suppose for a moment that you have access to the latest genomic (DNA-mark-assisted) testing (genotyping) that may help you identify heifers with superior genetic merit for calving ease. This could result in lower veterinary fees, and reduced cow and calf mortality at birth. If the price of DNA testing for ease of calving were **$105** per test, would you genotype your heifers before deciding which animals to keep as replacements?

Yes □ ***[If Yes, go to Q44.1]*** No □ ***[If No, Go to Q44.2]***

Q44.1. **If your answer to Q44 is YES**, if the cost were **$125** per test, would you still genotype your heifers?

Yes □ No □

Q44.2. **If your answer to Q44 is NO**, if the cost were **$85** per test, would you genotype your heifers?

Yes □ No □

Q.45. Now suppose using genomic testing that you could identify feed efficient heifers to retain in your breeding herd as replacement heifers. Research has shown that feed efficient cows can consume about 20% less forage as compared to feed inefficient cows. If the price of DNA testing for feed efficiency were **$45** per test, would you genotype your heifers for feed efficiency?

Yes □ ***[If Yes, go to Q45.1]*** No □ ***[If No, Go to Q45.2]***

Q45.1. **If your answer to Q45 is YES**, if the cost were **$65** per test, would you still genotype your heifers?

Yes □ No □

Q45.2. **If your answer to Q45 is NO**, if the cost were **$25** per test, would you genotype your heifers?

Yes □ No □

46. If your production costs were to remain the same, what is the minimum increase in feed efficiency that you would need before you would consider adopting/using semen produced from bulls with higher levels of feed efficiency?
    - □ Between 0 and 19% increase
    - □ Between 20 and 39% increase
    - □ Between 40 and 59% increase
    - □ Between 60 and 79% increase
    - □ Greater than 80% increase

47. Research has shown that a feed efficient bull consumes up to 16% less feed per day as compared to an inefficient bull. This translates to a difference in feed intake of approximately 3kg daily. Assuming feed costs to be similar to the average 2013 costs, how much more will you be willing to pay for a bull that is more feed efficient?
    - □ $0
    - □ Between $0 and $500
    - □ Between $500 and $1000
    - □ Between $1000 and $1500
    - □ Between $1500 and $2000
    - □ Between $2000 and $2500
    - □ Between $2500 and $3000
    - □ More than $3000

48. **1**. In general, would you say that your behaviour and the decisions you take are:

1	2	3	4	5	6	7	8	9
Not at all risky	Not risky	Very few risky	Slightly risky	Moderately Risky	Risky	Very risky	Extremely risky	More than extremely risky
□	□	□	□	□	□	□	□	□

2. For your **farming decisions**, would you say that your behavior and the decisions you take are:

1	2	3	4	5	6	7	8	9
Not at all risky	Not risky	Very few risky	Slightly risky	Moderately Risky	Risky	Very risky	Extremely risky	More than extremely risky
◻	◻	◻	◻	◻	◻	◻	◻	◻

3. With regards to your **finances**, would you say that your behavior and the decisions you take are:

1	2	3	4	5	6	7	8	9
Not at all risky	Not risky	Very few risky	Slightly risky	Moderately Risky	Risky	Very risky	Extremely risky	More than extremely risky
◻	◻	◻	◻	◻	◻	◻	◻	◻

4. With regards to your **health**, would you say that your behavior and the decisions you take are:

1	2	3	4	5	6	7	8	9
Not at all risky	Not risky	Very few risky	Slightly risky	Moderately Risky	Risky	Very risky	Extremely risky	More than extremely risky
◻	◻	◻	◻	◻	◻	◻	◻	◻

49. Please indicate how important the following aspects are to you in adopting the use of genomic information in selection decisions related to your breeding herd.

			1 Very Unimportant	2	3	4	5 Very Important
Observability	1	Contributes to the protection of resources for future generations (such as genetic diversity)					
	2	Improves image and reputation of farmers in society					

	3	Ensures the production of safe products					
	4	Ensures the production of animal welfare friendly products					
	5	Ensures the competitiveness of the cattle industry					
	6	Ensures competitiveness of your farm					
	7	Ensure equal share of profits within the supply chain/Ensure equal power of actors in supply chain					
Complexity	8	Is technically not complicated					
	9	Does not require additional training of employees					
	10	Is challenging and requires all your knowledge					
	11	Does not require additional training for yourself					
Trialability	12	Trials can be made without disturbing farm organization					
	13	The technology can be tested with small batches of animals on farm first					
Compatibility	14	Is compatible with farm philosophy/my own values					
	15	Can easily be integrated into the farm procedures					
	16	Is compatible with the values of the farming community					
	17	Is compatible with the values of society and consumers					
	18	Does not increase problems such as					

Relative advantage in terms of risk		inbreeding, increased susceptibility to other diseases and increased virulence of pathogens					
	19	Is not linked to a high risk of malfunctioning (reliability)					
	20	Causes no decrease in production					
	21	Causes no decrease in product quality					
Relative advantage in terms of time needed	22	Does not imply time shortage for family/hobbies					
	23	Does not increase work load (in general)					
	24	Enables less complex grazing strategies that take the same or even less time than current grazing strategies					
Relative advantage in terms of costs	25	Enables cost neutrality or even cost reduction					
	26	Requires no additional investment					
	27	Entitles to subsidy payments or additional income					
Relative advantage in terms of benefits	28	Decreases monetary and effort costs associated with feeding					
	29	Is more/comparably effective than other control strategies					
	30	Increased genetic gain					
	31	High accuracy on breeding values					

50. Please indicate to what extent you believe the use of genomic information for the selection of feed efficient cattle will result in the following.

			1 Not at all	2	3	4	5	6	7 Very much
Observability	1	Contribute to the protection of resources							

		for future generations (such as genetic iodiversity)							
	2	Improve the image and reputation of farmers in society							
	3	Ensure the production of safe products							
	4	Ensure the production of animal welfare friendly products							
	5	Ensure the competitiveness of the cattle industry							
	6	Ensure competitiveness of my farm							
	7	Ensure equal share of profits within the supply chain/Ensure equal power of actors in supply chain							
Complexity	8	technically not be complicated							
	9	Not require additional training of employees							
	10	Be challenging and will require all my knowledge							
	11	not require additional training for myself							
Trialability	12	Enable trials that can be made without disturbing farm organization							
	13	Be a technology that can be tested with small batches of animals on my farm first							
Compatibility	14	be compatible with the farm philosophy/my own values							
	15	easily be integrated into the farm procedures							
Relative advantage in terms of risk	16	not increase problems such as inbreeding, increased susceptibility							

		to other diseases and increased virulence of pathogens							
	17	not be linked to a high risk of malfunctioning (reliability)							
	18	Not cause a decrease in production							
	19	Not cause a decrease in product quality							
Relative advantage in terms of time needed	20	not imply time shortage for family/hobbies							
	21	not increase work load (in general)							
	22	Enable less complex grazing strategies that take the same or even less time than current grazing strategies							
Relative advantage in terms of costs	23	Enable cost neutrality or even cost reduction							
	24	Require no additional investment							
	25	Entitle to subsidy payments or additional income							
Relative advantage in terms of benefits	26	Decreases monetary and effort costs associated with feeding							
	27	Be more/comparably effective than other control strategies							
	28	Increase genetic gain							
	29	Ensure high accuracy on breeding values							

51. Using genomic information for selective breeding for increased feed efficiency is

		1	2	3	4	5	6	7	
1	Useless								Useful
2	Worthless								Valuable
3	Harmful								Beneficial
4	Foolish								Wise
5	Awful								Nice
6	Disagreeable								Agreeable
7	Unpleasant								Pleasant

52. If I consider all pros and cons of using genomic information to selectively breed for increased feed efficiency and the currently available alternatives to enhance feed efficiency, I believe using genomic information is

		1	2	3	4	5	6	7	
1	Unappealing								Appealing
2	Bad								Good
3	Negative								Positive

53. When genomic information to be used in selective breeding for enhanced feed efficiency is available, I will have full control over the decision to use it (1=strongly disagree, 7=strongly agree)

	1	2	3	4	5	6	7	
Strongly disagree								Strongly agree

54. Please indicate to what degree you agree with the following statements:

		Strongly disagree						Strongly agree
		1	2	3	4	5	6	7
1	I believe the general public would be positive about genomic selection for improved feed efficiency							
2	I believe fellow farmers would be positive about genomic selection for improved feed efficiency							
3	Most people who are important to me would be positive about genomic selection for improved feed efficiency							

55. How much trust do you have in the following institutions or persons that they act responsibly in applying and handling risks associated with using genomic information in selective breeding?

		Very little trust			Trust			Very high trust
		1	2	3	4	5	6	7
1	Veterinarians	□	□	□	□	□	□	□
2	Breed societies	□	□	□	□	□	□	□
3	Agricultural input/sales reps	□	□	□	□	□	□	□
4	Breeding companies	□	□	□	□	□	□	□
5	Research organizations/universities	□	□	□	□	□	□	□
6	Government agencies/public authorities/Teagasc	□	□	□	□	□	□	□

56. To what extent do you trust the information provided by the following organizations/individuals on the use of genomic information in selective breeding? (1=very little trust, 7 =very high trust)

		Very little trust			Trust			Very high trust
		1	2	3	4	5	6	7
1	Veterinarians	□	□	□	□	□	□	□
2	Breed societies	□	□	□	□	□	□	□
3	Agricultural input/sales reps	□	□	□	□	□	□	□
4	Breeding companies	□	□	□	□	□	□	□
5	Research organizations/universities	□	□	□	□	□	□	□
6	Government agencies/public authorities	□	□	□	□	□	□	□

57. To what extent do you believe that the following organizations have the competence to control the use of genomic information in selective breeding for increased feed efficiency.

		Strongly Disagree			Neutral			Strongly Agree
		1	2	3	4	5	6	7
1	Veterinarians	□	□	□	□	□	□	□
2	Breed societies	□	□	□	□	□	□	□
3	Agricultural input/sales reps	□	□	□	□	□	□	□
4	Breeding companies	□	□	□	□	□	□	□
5	Research organizations/universities	□	□	□	□	□	□	□

6	Government agencies/public authorities	◻	◻	◻	◻	◻	◻	◻

58. The following organizations are honest about the use of genomic information and other technologies

		Strongly Disagree			Neutral			Strongly Agree
		1	2	3	4	5	6	7
1	Veterinarians	◻	◻	◻	◻	◻	◻	◻
2	Breed societies	◻	◻	◻	◻	◻	◻	◻
3	Agricultural input/sales reps	◻	◻	◻	◻	◻	◻	◻
4	Breeding companies	◻	◻	◻	◻	◻	◻	◻
5	Research organizations/universities	◻	◻	◻	◻	◻	◻	◻
6	Government agencies/public authorities	◻	◻	◻	◻	◻	◻	◻

59. Please identify whether you agree or disagree with the following statements:

	Strongly Disagree	Mildly Disagree	Neither agree nor disagree	Mildly Agree	Strongly Agree
Human beings can progress only by conserving nature's resources					
Human beings can enjoy nature only if they make wise use of its resources.					
Human progress can be achieved only by maintaining ecological balance.					
Preserving nature at the present time means ensuring the future of human beings					
We must reduce our consumption levels to ensure well-being of the present and future generations					

60. Please indicate which one of the following statements corresponds most with your view on nature: **<u>only one answer is possible</u>**

______ Environmental problems can only be controlled by enforcing radical changes in human behavior in society as a whole.

______ Environmental problems are not entirely out of control, but the government

should dictate clear rules about what is and what is not allowed.
______ We do not need to worry about environmental problems because in the end, these problems will always be resolved by technological solutions.
______ We do not know whether environmental problems will magnify or not.

(the above two are from scales in papers by Corral-Verdago et al and by Steg and Sievers)

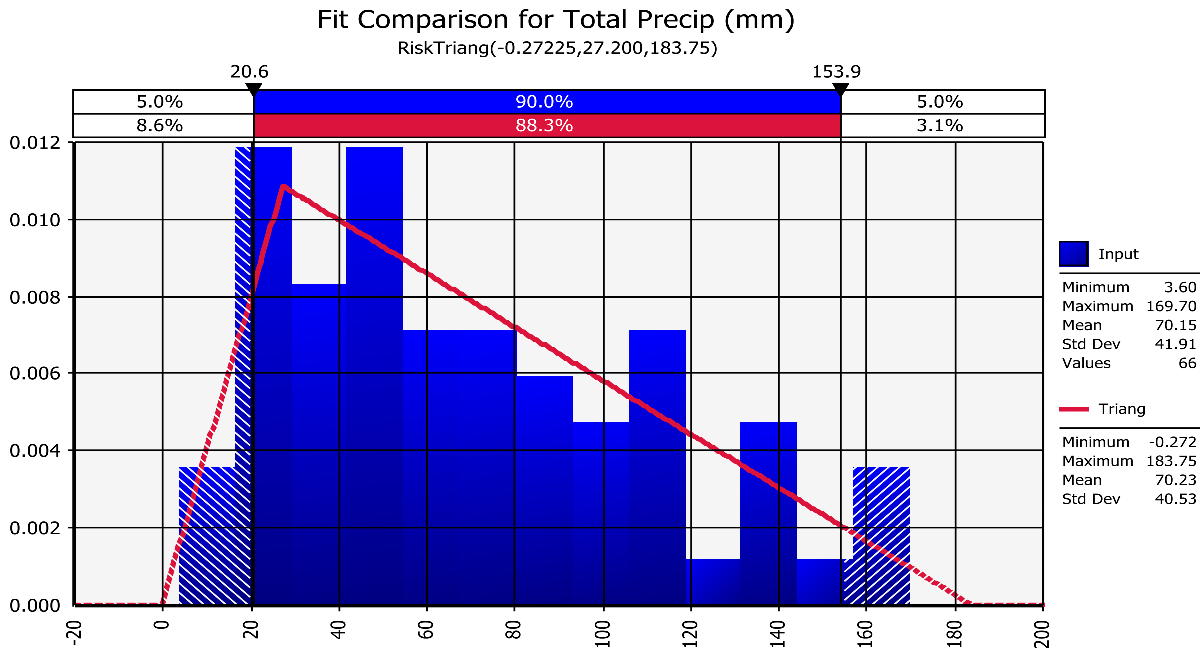
61. Please identify whether you agree or disagree with the following statements:

Statement	Strongly Disagree	Mildly Disagree	Unsure	Mildly Agree	Strongly Agree
	1	2	3	4	5
We are approaching the limit of the number of people the earth can support					
Humans have the right to modify the natural environment to suit their needs					
When humans interfere with nature it often produces disastrous consequences					
Human ingenuity will insure that we do NOT make the earth unlivable					
Humans are severely abusing the environment					
The earth has plenty of natural resources if we just learn how to develop them					
Plants and animals have as much right as humans to exist					
The balance of nature is strong enough to cope with the impacts of modern industrial nations					
Despite our special abilities humans are still subject to the laws of nature					
The so-called "ecological crisis" facing humankind has been greatly exaggerated					
The earth is like a spaceship with very limited room and resources					
Humans were meant to rule over the rest of nature					
The balance of nature is very delicate and easily upset					

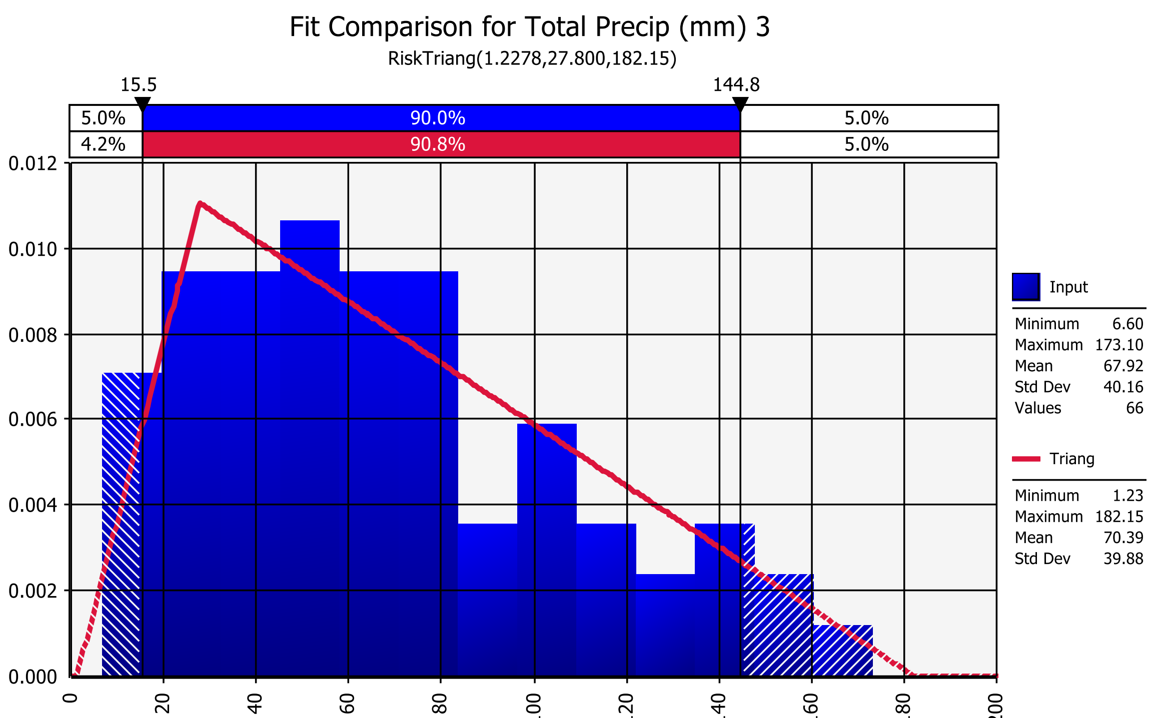
Humans will eventually learn enough about how nature works to be able to control it					
If things continue on their present course, we will soon experience a major ecological catastrophe					

(Dunlap et al, 2000)

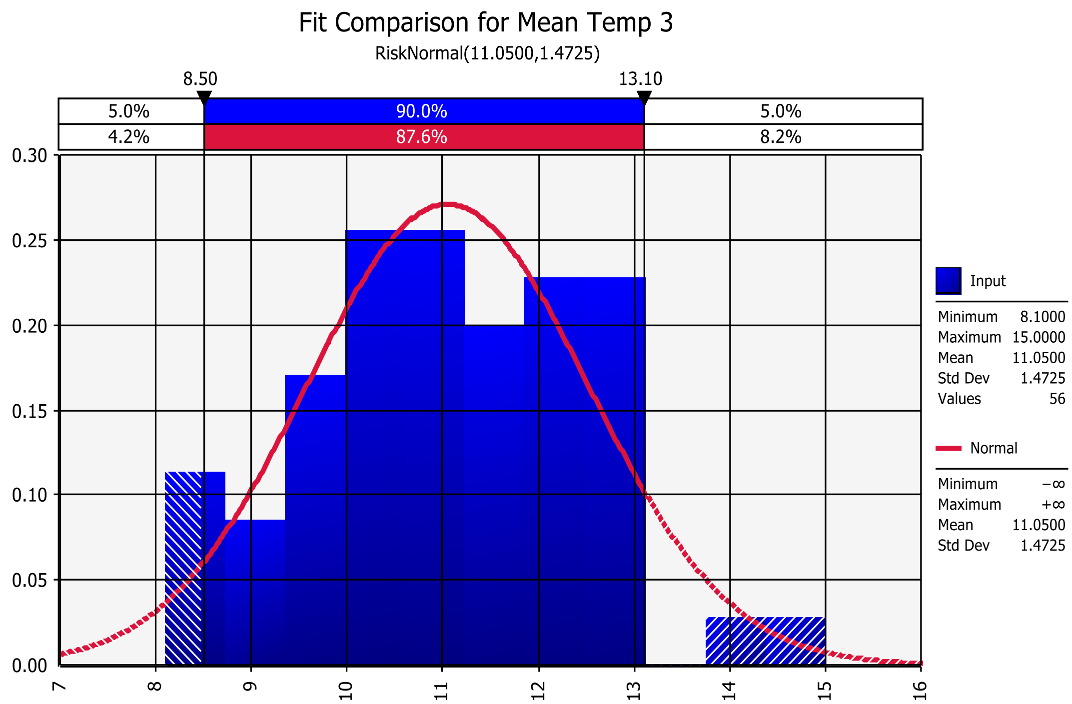
APPENDIX 5B: Distribution of Weather Variables



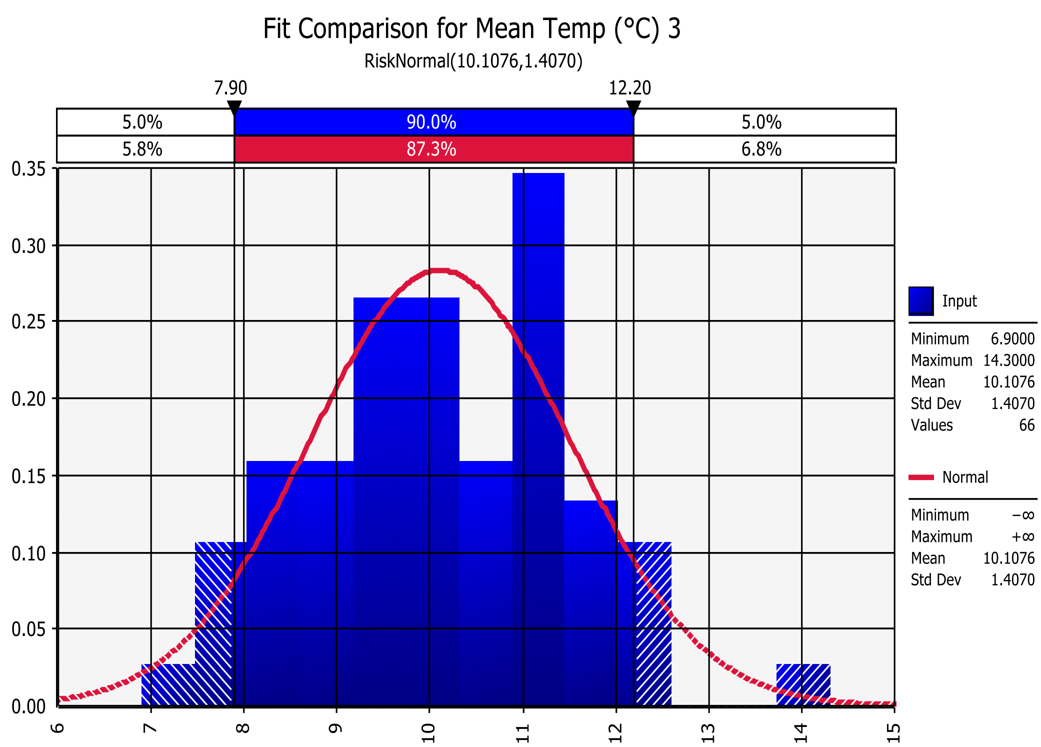
Northern Alberta June Precipitation (AIC=669.20)



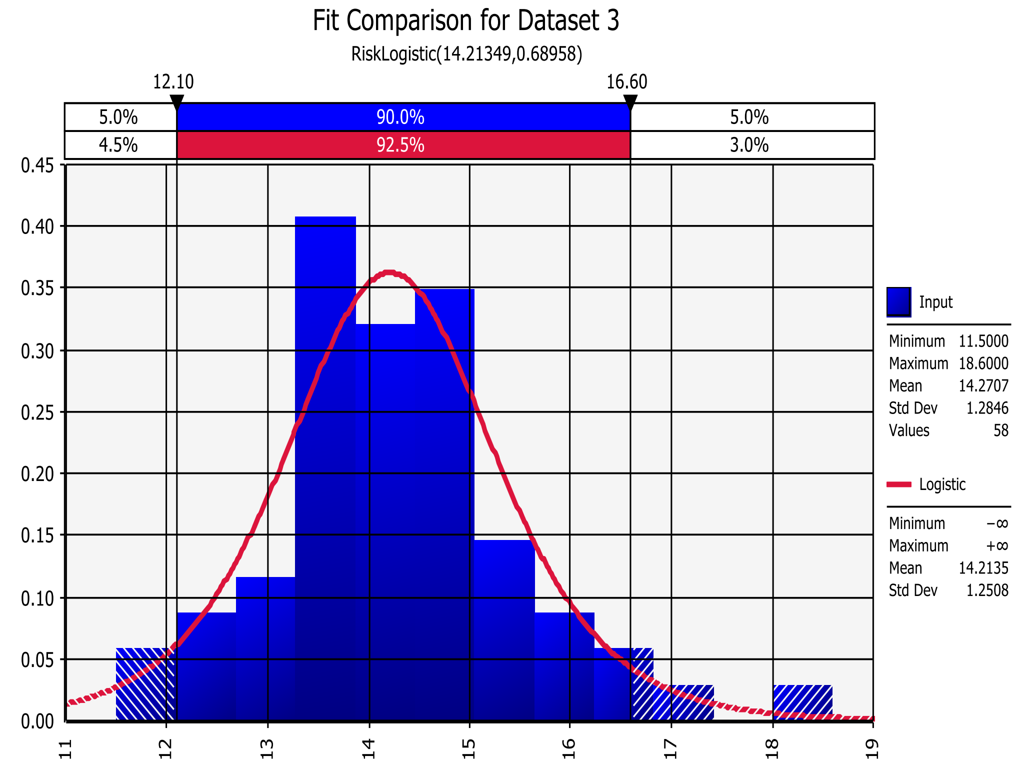
Northern Alberta July Precipitation (AIC=665.63)



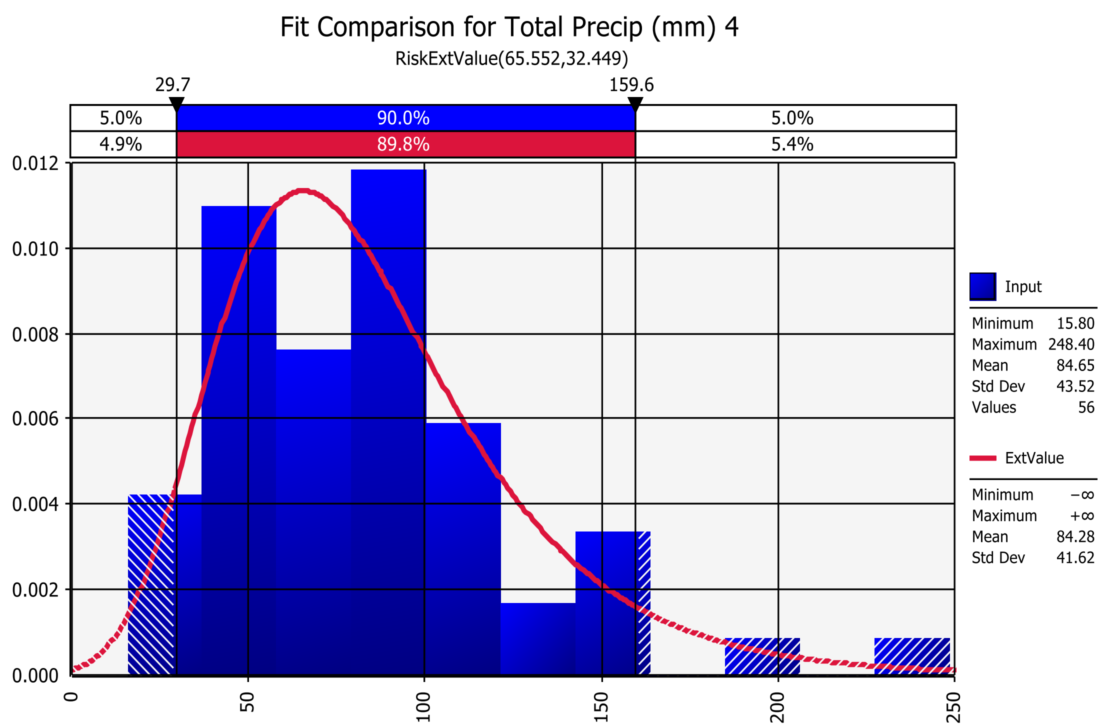
Northern Alberta May Temperature (AIC=235.57)



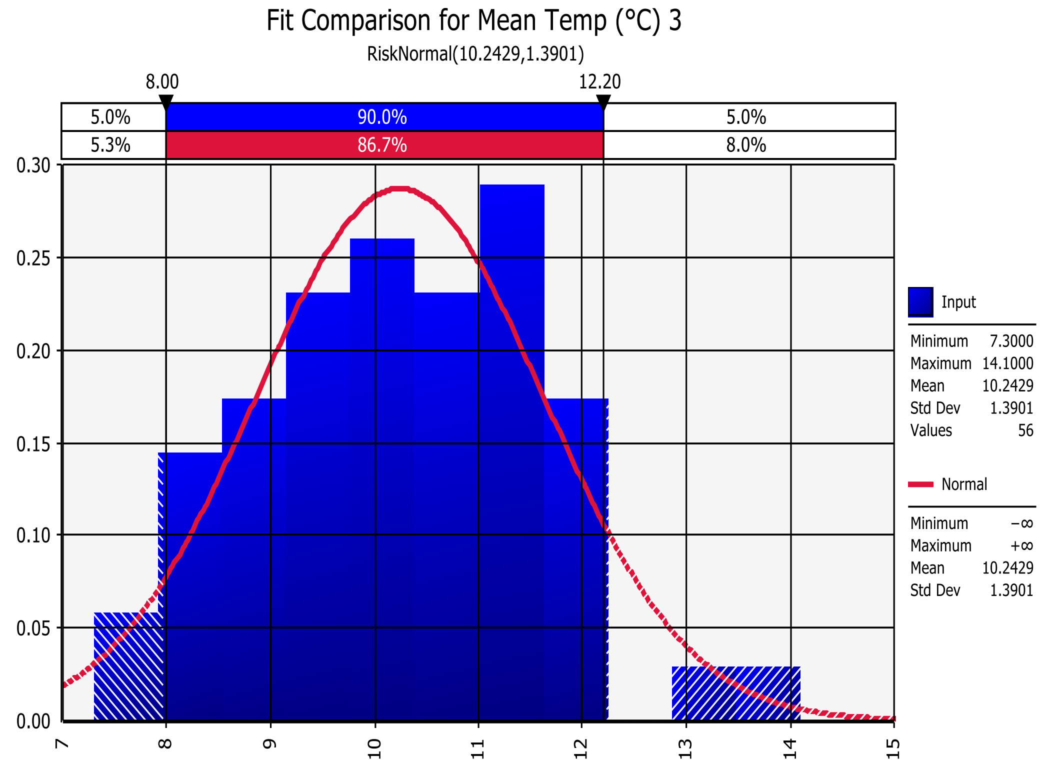
Northern Alberta June Temperature (AIC=205.49)



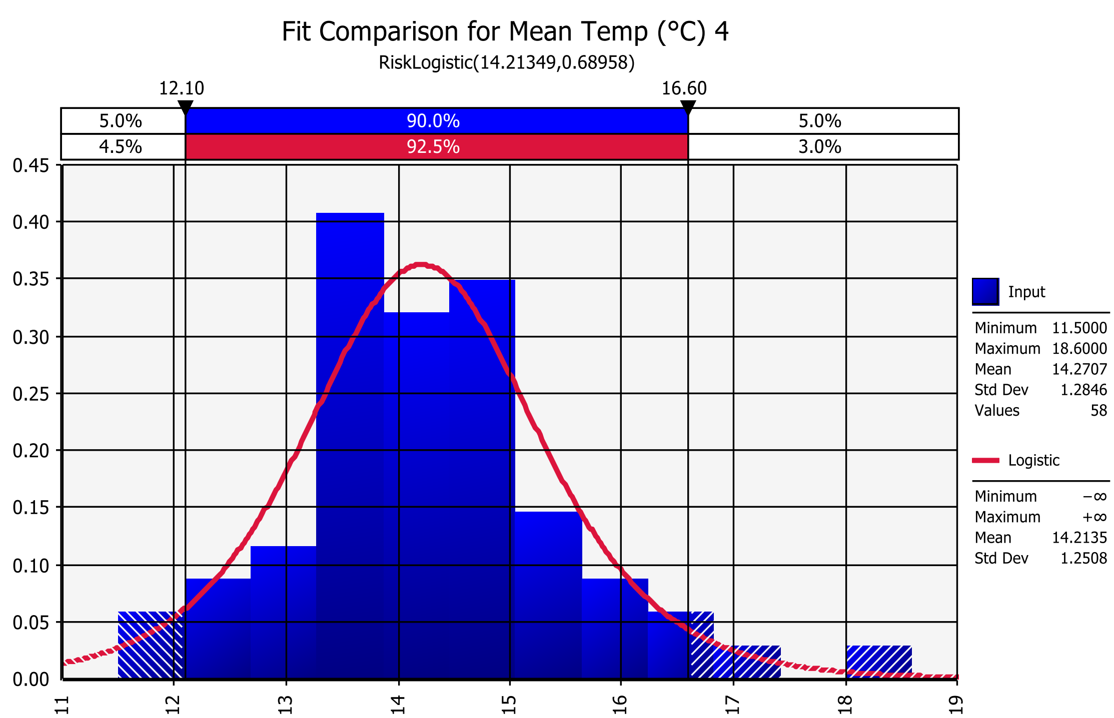
Central Alberta June Precipitation (AIC=193.98)



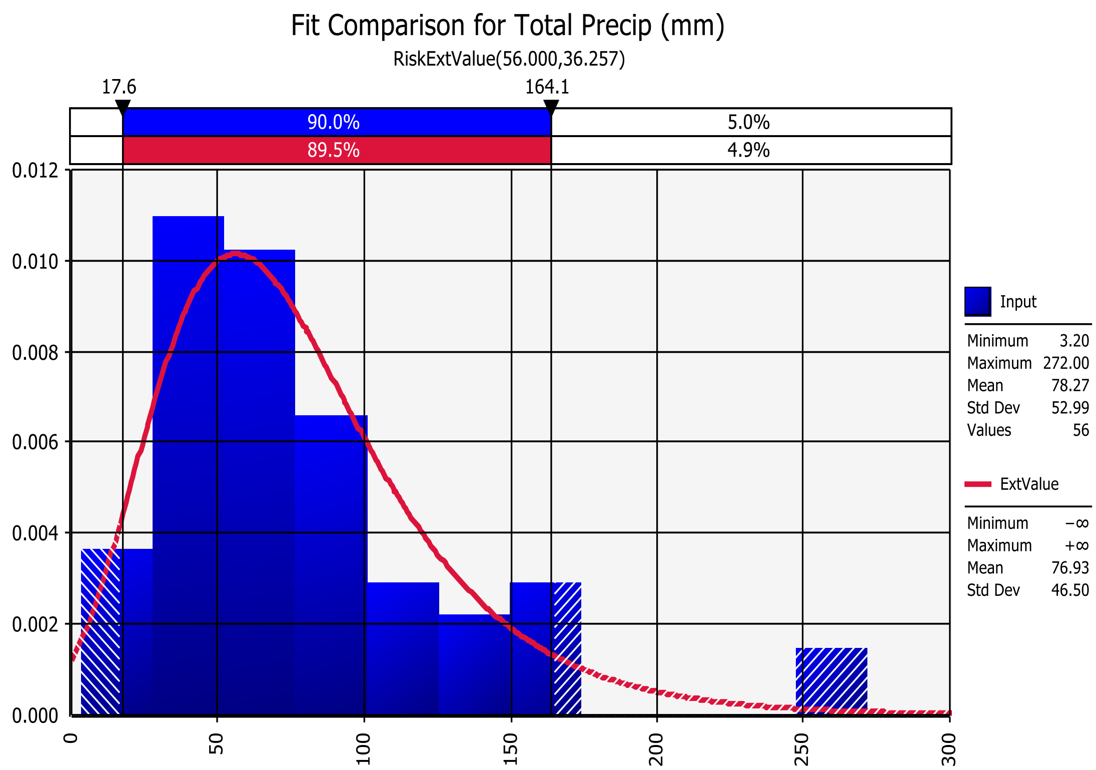
Central Alberta July Precipitation (AIC=571.87)



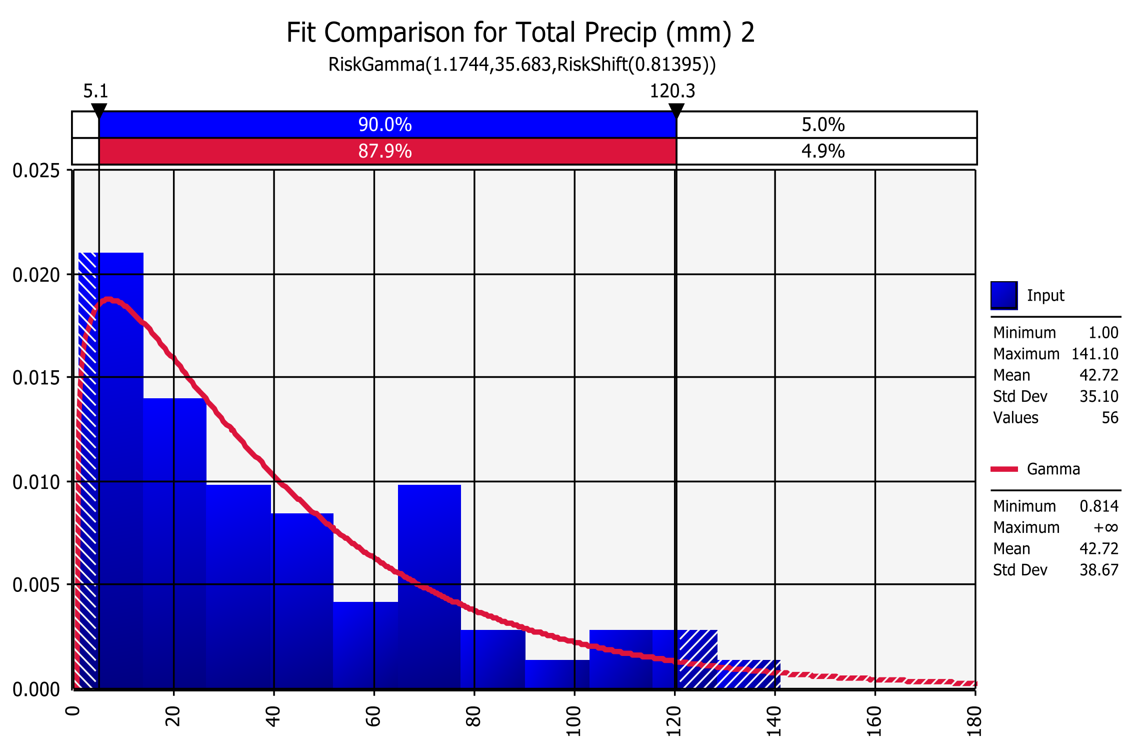
Central Alberta May Temperature (AIC=199.04)



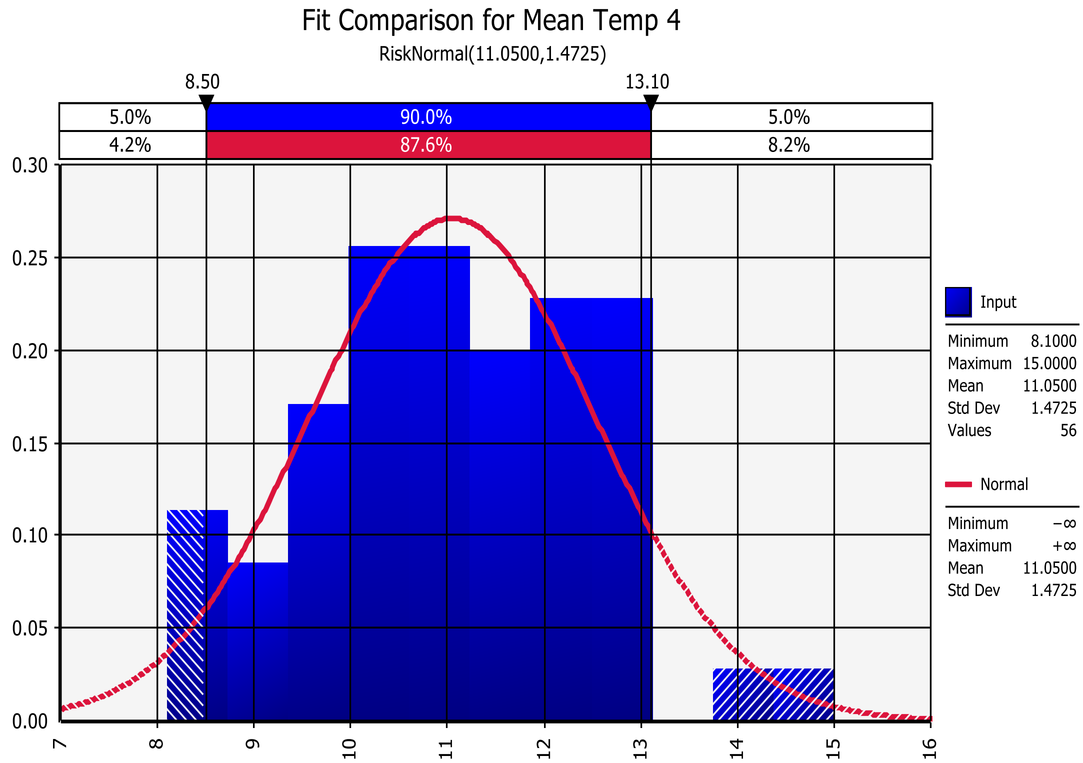
Central Alberta June Temperature(AIC=193.99)



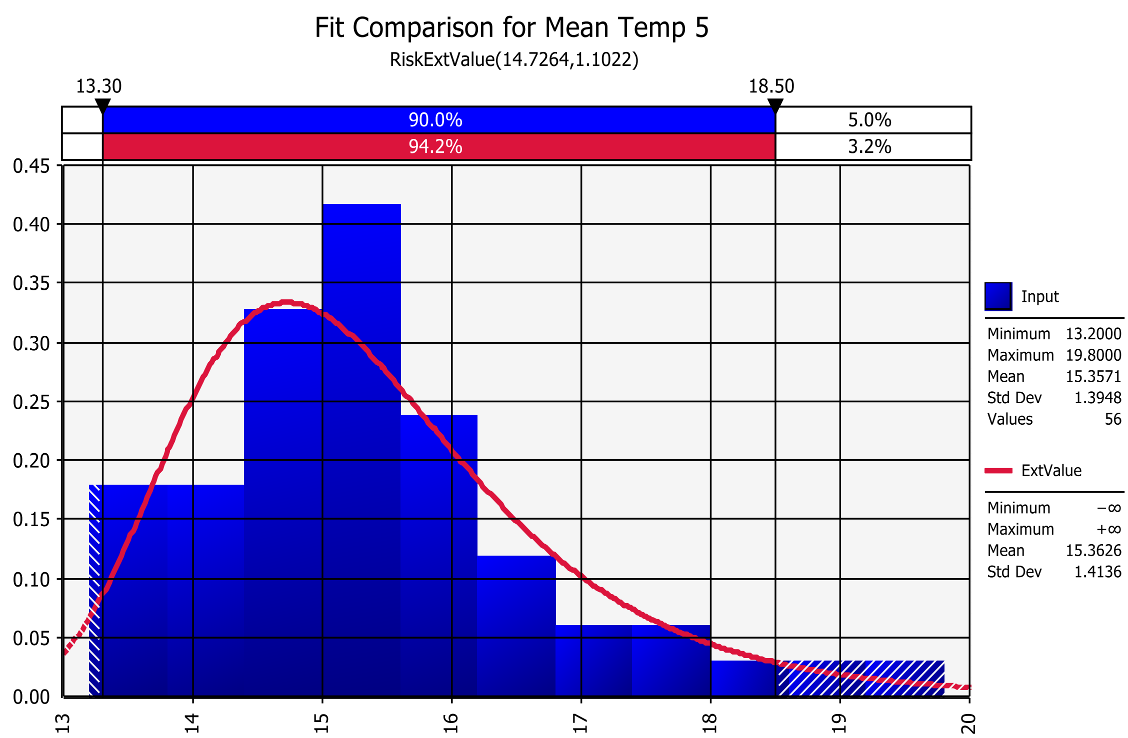
Southern Alberta June Precipitation(AIC=587.17)



Southern Alberta July Precipitation (AIC 535.96)



Southern Alberta May Temperature (AIC=205.49)



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