

Profitability of Growth-Enhancing Technologies in Canadian Feeder Cattle Production

by

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Abstract

The Canadian beef industry is experiencing heightened domestic and global demand; however, it is constantly challenged by the extremely narrow profit margins. In an effort to enhance efficiency, the cattle feeding industry has adopted the use of growth-enhancing technologies (GETs), which has resulted in cattle getting to finished weights more quickly. This study focuses on three types of technologies in the feedlot phase of the beef supply chain, including a trenbolone acetate + estradiol (TBA) implant, melengestrol acetate (MGA) feed additive and ractopamine hydrochloride (RAC) feed additive. Previous research has found positive impacts of GETs on animal performance and environmental sustainability; however, economic dimensions have not been as thoroughly explored. Accordingly, this thesis is the first attempt to use recent Canadian feedlot data to determine economic gains from GET adoption by feedlots. The objective of the research conducted for this thesis is to determine the relative profitability of cattle feeding in Canada using GET (conventional) versus non-GET (non-conventional) systems. Supporting objectives are to evaluate and compare measures of animal performance of the treatment groups; and determine the efficiency of conventional and non-conventional systems by estimating the probability distribution of risk. To achieve these objectives, data from a four-year animal trial at the Agriculture and Agri-food Lethbridge Research and Development Center are used, along with supporting price data from CanFax Research Services and Statistics Canada within an enterprise budgeting framework with accompanying risk analysis. Results from the partial enterprise budget indicate that the feeding system which employed TBA has the highest net returns for both heifers and steers; however, results from the risk analysis differ. Using stochastic dominance, feed additives were discovered to be second-degree stochastic dominant for their respective sex class. Further investigation confirms that a production system providing

an RAC feed additive to steers is the least likely to generate a negative net return; and likewise for heifers receiving a TBA implant.

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Chapter 1: Introduction

1.1 Problem Statement

Canadian producers have been raising beef cattle with the use of growth-enhancing technologies (GETs) since the 1960s, facilitating dramatic increases in efficiency and sustainability within production systems (Canadian Animal Health Institute 2022). The use of GETs (i.e. implants, beta-adrenergic-agonists, melengestrol acetate, feed-grade antibiotics, ionophores) has generated benefits throughout the supply chain, including improvements in dry matter intake (DMI), average daily gain (ADG), feed efficiency (FE), and dressing percentages (Ribeiro et al. 2021). Additionally, observed decreases have been realized in greenhouse gas emissions (GHG), water usage, on-farm waste and manure output, and cattle population size required (Wileman et al. 2009; Capper and Hayes 2012; Crawford et al. 2022). These production advancements, such as improved DMI, ADG, FE and cattle population size, in turn generate economic development within the supply chain leading to declines in input materials, labour, fixed and variable costs, that ultimately benefit farm profit margins.

Although all GETs used in Canada to produce beef are approved by Health Canada and regulated by the Food and Drugs Act, some consumers and countries still have a negative perception of these conventional technologies (Canada Beef 2016; Yang et al. 2020; Boonstra et al. 2023). A number of regulatory bodies have banned the use of GETs (e.g. the European Union, China and Russia), leading to an increased consumer demand for GET-free beef and alternative market opportunity for producers raising fed-cattle non-conventionally (Aboagye et al. 2022). As a result, there may be a higher willingness-to-pay (WTP) for beef raised without GETs. This type of beef has become more common and expensive, and consumers' purchasing decisions are recognized to be influenced by an individual's perceptions (Yang et al. 2017).

The beef supply chain incorporates multiple stages and stakeholders, from production to processing and packaging to distribution to retail. The production stage includes the cow-calf, backgrounding, and feedlot operations where feed is costly (accounting for up to 70% of overall livestock production expenses) but fundamental as an input for beef cattle to create profitable margins (Alqaisi et al. 2017; Iowa State University 2017). Among stages in the beef supply chain, the most gain in value is accrued during the cattle feeding stage due to the intensive grain/high energy feed rations being consumed. Accordingly, any enhancement to feed use efficiency and associated reduction of production costs (as may result from the use of GETs) is likely to financially benefit feedlot operations. In turn, these benefits are likely to compound throughout the beef supply chain and be experienced by all stakeholders, hopefully allowing for reduced retail prices to be realized by consumers.

Beef producers' profit margin per dollar of revenue has been continuously decreasing over the past six years (Statistics Canada 2019; 2021b; 2023; 2024b), while retail prices and consumer demand for alternative proteins are climbing, all combining to threaten the longevity and profitability of these production systems. Additionally, feedlot operations are especially sensitive to financial decisions since they are price takers when purchasing feeder cattle and feedstuffs and even when selling fed cattle to packers due to the pressures of supply and demand (Oosthuizen and Maré 2018). For any operation, especially in a feedlot, the level of efficiency is an integral factor for producers to increase or maintain positive profit margins; therefore, feedlots must optimize their inputs to produce highest quality and quantity of outputs in the most efficient manner while financially maintaining operations.

1.2 Objectives

The primary objective of the research reported in this thesis is to determine the relative profitability of conventional cattle feeding systems using GETs (conventional) to systems where GETs are not used (non-conventional). Supporting objectives are to evaluate and compare measures of animal performance of the treatment groups; and determine the risk efficiency of conventional and non-conventional systems by estimating the probability distribution of risk. The productivity and feasibility of both conventional and non-conventional production systems will be examined by evaluating production costs and revenue in the feedlot phase using enterprise budgeting techniques and a stochastic simulation as a risk analysis. It is expected that the conventionally raised beef will experience increased production costs, revenue (return on carcasses) and net returns, when fed for an equal number of days.

1.3 Thesis Outline

Commencing with a review of the current economic and environmental state of the Canadian beef industry, Chapter 2 will proceed to describe consumer attitudes towards beef relating to its effect on human safety, sustainability and affordability. A review of previous literature will follow in Chapter 3 outlining existing publications relating to the research objectives. Chapter 4 will include a description of the Agricultural and Agri-Food Canada Lethbridge Research and Development Center experiment, origins of data used within the research and manipulations required for the models applied. Chapter 5 will explain the theory of expected profit maximization behind partial enterprise budgeting and the elements of risk relating to the specific stochastic simulation methods; and Chapter 6 will provide a description of the methodology of implementing the data into the models. Results of the animal and economic budget and simulation will be presented in Chapter 7 and will include interpretations of the figures and

tables containing inputs and outputs. Conclusions drawn from the economic methods will be discussed in Chapter 8, as well as limitations of the current research and suggestions for future research.

Chapter 2: Background

2.1 Beef Industry in Canada

Canada's beef industry has seen strong growth over the past fifty years. Cash receipts in 1971 were \$4.65 billion, which almost doubled to an average of \$9.1 billion per year over the period of 2016 to 2020 (CanFax 2021). Most recently, cash receipts have reached an average of \$10.4 billion per year from 2020 to 2022 accounting for 12% of all farm cash receipts, which is the second largest sector across all farm receipts (Canadian Cattle Association 2023).

Although the beef industry is significant related to farm receipts, beef cattle farms maintain the lowest profit margin of all farm types. In 2017, average operating profit margin per dollar of revenue for beef cattle ranching and farming was 8.9 cents with a national agriculture sector average of 18.4 cents; in 2018, it fell to 6.2 cents per dollar of revenue, further shrinking to 5.7 cents in 2019, 5.5 cents in 2021, and finally 4.0 cents per dollar of revenue in 2022 (Statistics Canada 2019; 2021b; 2023; 2024b). Conversely, at the retail level, consumers are paying more for beef items in Canada.

The Canadian beef industry produces beef for both domestic and export purposes. Beef exports accounted for 30.35% of production in 2013 (324,420 tonnes) growing to 43.36% of production in 2022 (597,770 tonnes; Statistics Canada 2024e), with 2021 recording the second highest volume exported since 2002 and the highest year ever by dollar value (Canada Beef 2022; Statistics Canada 2024e). The majority of exports out of Canada go to the United States of which accounted for 72.7% in January 2023 and 77.1% in January 2024 (Government of Canada 2024).

Over the years, the Canadian beef production experienced much change at the farm level including a significant decrease in the number of beef cattle operations of which, according to

the most recent quinquennial Canadian Census of Agriculture, has decreased by 35% from 2006 to 2021, (609,500 to 396,300 farms; Statistics Canada 2022). Within the same time period, the number of head per operation in Canada has also significantly decreased, with a decline of 29% from 2006 to 2021 (5.25 to 3.71 million), respectively, and a further decline in 2023 to 3.55 million (Statistics Canada 2021a). Beef output per head in Canada throughout the same time period, however, has not followed this downward trend, with an increase of on average of 354.6 kg in 2006 to 385.7 kg in 2021, and a further increase to 392.1 kg in 2022 (cold dressed weight; Statistics Canada 2024a). For reference, the beef industry in the United States has shown similar changes within this timeframe, with the number of beef cattle decreasing from 2006 to 2021 by 3.6% (97.1 to 93.6 million head), and a further decline of 7.3% from 2021 to 2024 (93.6 to 87.2 million head) (US Department of Agriculture (USDA) Economic Research Service (ERS) 2024). Additionally, commercial beef production in the United States has increased 6.5% between 2006 and 2021 (26.2 to 27.9 billion, respectively) with a further increase to 28.3 billion in 2022 (USDA ERS 2023). The USDA ERS (2019) states in an article that these increases are due to the average weight of beef cattle increasing over the years largely due to the improved production efficiency.

Given beef's decreasing profit margin at farm level and increasing price at retail level in Canada, it becomes increasingly important for the beef industry to continue to adapt to optimize opportunities and face challenges. The world population is predicted to reach 9.7 billion by 2050, and by mid 2080 could further increase to almost 10.4 billion if continuing on the anticipated trajectory (United Nations 2023). Van Dijk et al. (2021), reviewed 57 studies to assess the range in the projections of global food production projections required to meet this growing population. Their literature review noted the most cited projection was an increase of 70% in global food

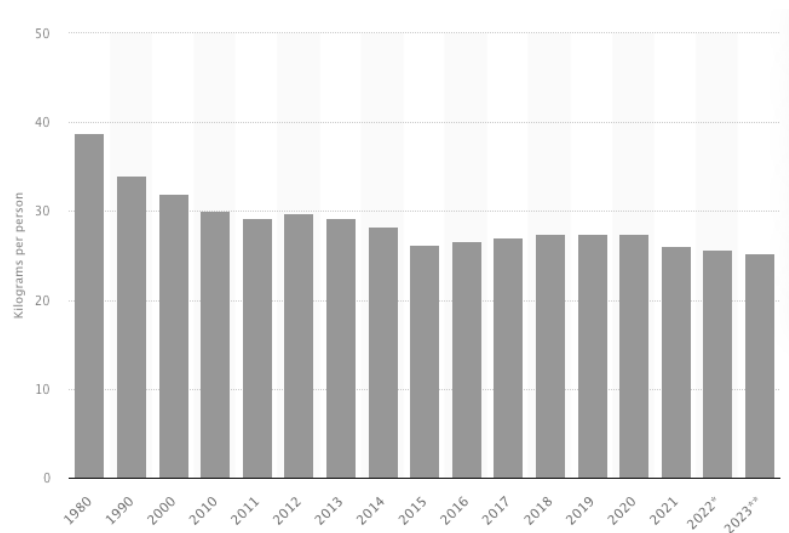
production made by FAO (2023); however, results from their research estimate an increase of 51% in total food consumption by 2050. Regardless of the specific figure, the beef industry will play a critical role in meeting future global food production demand. Research by Adesogan et al. (2020) reviews animal-source foods' contribution to meeting the future global food and nutrition requirements, citing the World Health Organization's claim that "animal-source foods is the best source of high-quality nutrient rich food for children aged 6-23 months."

Environmental sustainability will continue to be an important issue for the beef industry, given ongoing scrutiny it faces over its ecological footprint. Research articles have claimed beef to have the highest environmental impact among all livestock classes, implying a need to limit beef consumption (Eshel et al. 2014). However, Legesse et al. (2015) report that Canadian beef produced in 2011 had 14% less GHG intensity than beef produced in 1981, mainly due technological advancements such as nutrition improvements and GETs. Additional environmental benefits and other opportunities related to GETs within the beef industry will be further reviewed in the remainder of this report, in accordance with its objectives.

2.2 Canadian Beef Consumption and Consumer Perceptions

As shown in Figure 1, per-capita beef consumption (beef disappearance) in Canada has been on a long-term decline, with consumption in 1980 at 38.8 kilograms per capita, falling to 26.1 kilograms in 2021 and further to 25.7 in 2022 (Statista 2022).

Figure 1. Per-capita beef disappearance, Canada, 1980 – 2023



Source: Statista (2022)

A study to determine consumer attitudes towards beef in California showed that beef consumption is largely associated with consumer perception of beef production methods, which include healthfulness of beef, its effects on the environment, and beef quality (Tait et al. 2018). Furthermore, the study showed that 73% of respondents agreed/partially agreed that they were worried about long term effects of conventional modern beef production. Similarly, results from a 2021 survey suggest there is possibility for a steeper decline in the future, given that a large number of Canadians have considered limiting or cutting beef from their diets, with the highest contributing factors being price (49%), health concerns (49%), effects of production on the environment (44%), better plant-based options (40%), and media depictions of animal cruelty (37%) (Agri-Food Analytics Lab 2022).

The importance of consumer perceptions associated with beef production provides motivation for the beef industry to continue to adapt production methods that focus on improving efficiency and the cost of production, such as the use of GETs, in order to be economically

sustainable. In the current era of unprecedented consumer interest in food, public curiosity about GETs is natural. To some, it can seem un-natural or unwholesome to use enhancing technologies; however, most beef sector stakeholders are confident that these proven technologies and the associated positive economic impacts resulting from their use at micro and macro levels are both safe and desirable for the industry. Of increasing importance are consumer perceptions of beef and their effect on beef consumption. The following subsections of the background attributes the decline to consumer perceptions related to the cost of beef, its healthfulness and food safety, and its effect on the environment.

2.2.1 Human Safety

As noted above, the use of GETs in beef production is approved and regulated by Health Canada and Food and Drug Acts; this requiring extensive monitoring, including determination of maximum residue levels (MRLs) and ongoing random sampling by the CFIA (Aboagye et al. 2021). These MRLs are found to be different in certain countries because alternative guidelines have been established instead of following those of the Joint FAO/WHO Expert Committee on Food Additives (Aboagye et al. 2021). Antibiotics are a more specific matter in the group of growth promotants, as antimicrobial resistance is a developing issue leading to their banning in Canada since December 2018. In fact, the Global Roundtable for Sustainable Beef (GRSB) views antibiotics only as a means of health maintenance and explicitly not for production enhancement (Aboagye et al. 2021). Moreover, research exploring the naturally occurring hormones in beef products consumed by humans has been done in attempt to combat one of the most prominent factors of consumers' negative perception of conventional production – the residue levels of GETs. Studies have concluded the levels of hormones and hormone-like

substances found in the typical serving size of commonly consumed foods, including beef, are within a safe range, if not undetectable (Palacios et al. 2020).

A portion of this consumer skepticism relating to health concerns stems from the ban of GETs by regulatory bodies in a number of jurisdictions. The most influential regulation has been by the EU, where restrictions were implemented on livestock production starting in 1981, and imports were officially banned of all beef raised with the use of specific growth promoting agents – provisionally banning progesterone, testosterone, melengestrol acetate, zeranol, and trenbolone acetate; permanently banning estradio-17 β in 1989 (Johnson 2015). The US and Canada responded to this regulation by implementing a tariff on EU exported products. A significant cause of these ongoing disputes between countries is the same as what fuels consumer uncertainty: the precautionary principle, which drives the EU’s regulation as it believes in being proactive rather than reactive to the possible consequences of GETs. In a Congressional Research Service Report, Johnson (2015) observes this driving factor has been challenged numerous times by other beef producing countries (USA and Canada) at the World Trade Organization (WTO), questioning the validity of scientific evidence which deems GETs as unsafe for human consumption. Science-based reviews from both perspectives (EU and USA) have been funded and presented with findings supporting each body’s respective stances. This long-standing disagreement continued into 2017, where the Comprehensive Economic and Trade Agreement (CETA) was initiated between Canada and the EU which allow both parties to export numerous tariff-free products, including a 50,000-tonne quota of Canadian hormone-free raised beef (Government of Canada 2017; 2021). In order for Canadian beef producers to take advantage of this new market opportunity, they must follow strict guidelines, including being able to qualify for an Annual Certificate of Compliance, possess a valid Canadian Food

Inspection Agency recognition, and use an EU approved Federally Registered Slaughter Establishment (Government of Canada 2022).

2.2.2 Sustainability

The current consumer interest in the sustainability of products and services they consume is resulting in increasing numbers of environmentally friendly agricultural practices being implemented. A significant factor in consumer acceptance for food is the assurance of minimal negative, if not beneficial, impact on the environment by the purchased product. This idea has influenced a series of animal and environmental research studies pertaining to the beef sector and its use of GETs in attempt to build and maintain consumer trust. These studies include work by Capper (2011) which compared the environmental impacts of production in 1977 to those in 2007 and found similar results to Legesse et al. (2015) in the reduction of GHG emissions from beef production between 1981 and 2011. Capper (2011) reports the 2007 system used decreased amounts of animals (69.9%), feedstuffs (81.4%), water (87.9%), land (67.0%); and generated decreased amounts of manure (81.9%), CH₄ (82.3%), and N₂O (88.0%) in comparison to the 1977 system. When producing the equivalent amount of beef (per billion kg), Capper concluded that 2007 had a 16.3% smaller carbon footprint than 1977 thus, suggesting there has been significant improvement within beef production throughout the years. Capper (2012a) expanded her 2011 work by comparing the environmental impacts of three different beef production systems – conventional, natural and grass-fed. The conventional system was favoured in general over the others, as various production factors were improved, including a reduced number of animals (56.3%); and decreased amounts of water (24.8%), land (55.3%), and fossil fuel energy (71.4%) relative to the grass-fed production system to produce the same amount of beef (1.0 x 10⁸ kg). Later, a study by Capper and Hayes (2012) evaluated the environmental and economic

impacts of removing GETs. These results highly favoured the conventional production systems, seeing a decrease in total feedstuffs (10.6%), land required (10.0%; to produce 454 x 10⁶ kg of beef), water used (4.2%), manure produced (10.1%), N and P excreted (9.8% and 10.6%, respectively), carbon emissions (9.8%; to produce 454 x 10⁶ kg of beef), and fossil fuels used (7.6%). In order to produce the same amount of US beef without GETs, a 10% land increase would be required – an area of land larger than the state of Texas (Capper and Hayes 2012). Subsequent research done by Capper et al. (2021) focused on the Brazilian beef production system, highlighting the necessity of using sustainable practices, as the country continues to be one of the top beef producers globally. This study found results corresponded with previous studies, as reduced input levels such as land (13.7%) and feed (13.3%) were calculated for the hormonal implanted-cattle group (administered in cow-calf, backgrounding and finishing) relative to the non-implanted cattle group.

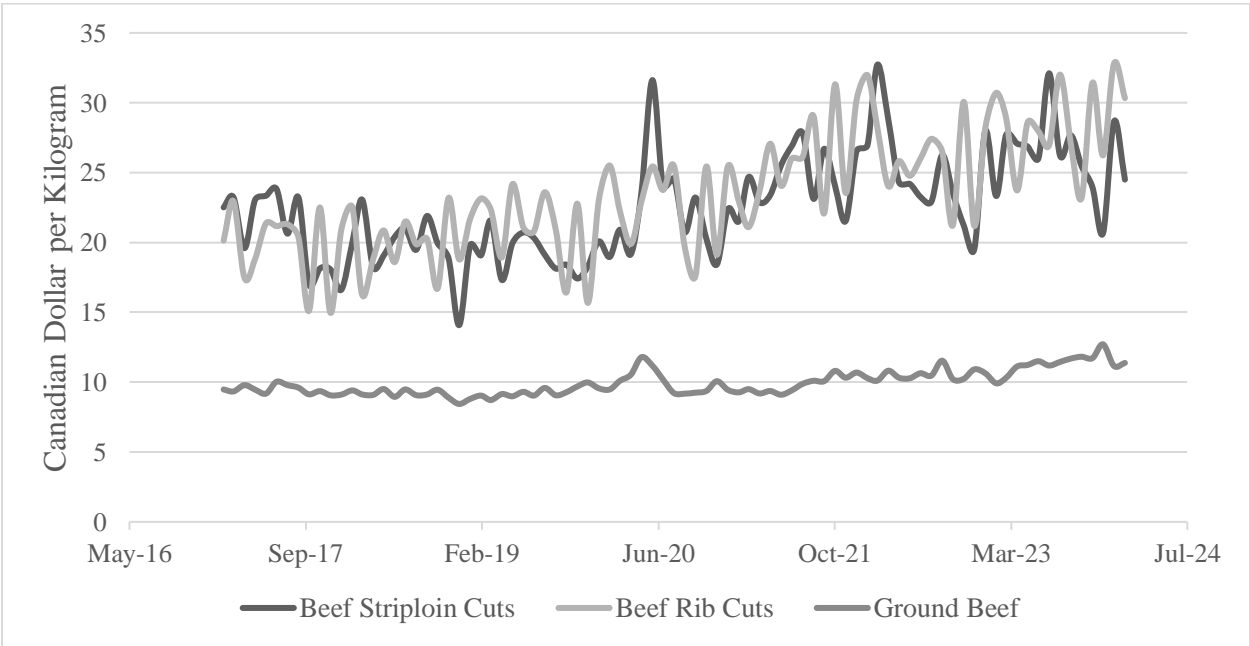
An emerging concern of consumers is related to the crop and livestock industries' contribution to global GHG emissions. The agriculture industry, beef included, contributed roughly 10% of Canada's total GHG emissions in 2023 (Government of Canada 2023). However, the use of GETs in beef production has been shown to promote a positive environmental impact (Aboagye et al. 2022). It is likely that consumers will be more prone to approve these technologies in beef production if these positive environmental outcomes are known.

2.2.3. Affordability

As global food prices continue to surge, many families are forced to prioritize affordability and nutrition over preferences. Beef – specifically, striploin cuts (22.5%), rib cuts (50.7%) and ground beef (20.0%), has experienced large increases in retail prices from February 2017 to

February 2024, as seen in Figure 2 (Statistics Canada 2024d). These increases are the largest in relation to other increases of common meat proteins at retail over the same time span, such as pork loin and rib cuts (22.2% and 7.3%), chicken breasts and thighs (16.5% and 26.9%) and salmon (6.9%) (Statistics Canada 2024d). The constant increase of Canadian beef prices underlines the necessity of efficient production in attempt to stabilize retail prices for consumers.

Figure 2. Canadian retail beef prices of popular cuts over an 8-year span.



Source: Statistics Canada 2024d

Now more than ever, consumers have access to more beef options at restaurants and in retail stores. This is largely attributed to the trends towards various types of non-conventionally produced beef – natural, organic and no added hormones or antibiotics. As such, a contributing factor to the increasingly expensive food prices are premiums placed on these specialty products, which describe the amount a consumer is willing to pay for items over the regular prices, using conventional production in this case, known as willingness to pay (WTP) premiums. Aboagye et al. (2021) reported the WTP premiums to be 47%, 29% and 20% over the conventionally produced beef products in US retail stores when labelled “raised without antibiotics or

hormones”, and in Germany and the UK when labelled as “organic”, respectively (White and Brady 2014; Lewis et al. 2016). The connection between a consumer’s WTP and the profitability of non-conventionally produced beef in Canada is further discussed in the subsequent sections.

The various types of beef products at retail grocery stores and restaurants mentioned above originate from different production systems. The conventional production system is the least restrictive and can include the use of antibiotics for cattle health – prohibited for growth-enhancement in many countries; and can be administered limited types of growth-enhancing technologies – dependent on region regulations. This system also contains less restrictive diets, housing/living, transportation and slaughter conditions. Natural, also known as ‘Never Ever’, beef becomes more restrictive in processing standards; however, the designation varies from brand to brand due to vague and differing definitions and on-farm practice restrictions (Certified Angus Beef 2024). For example, the brand Certified Angus Beef requires cattle in natural production to never be administered any antibiotics or added hormones and consume a strict vegetarian diet with minimal processing; whereas the USDA standards allow beef products to be labelled ‘natural’ at retail if there is minimal processing with no artificial ingredients – no on-farm requirements are mentioned (Certified Angus Beef 2024; USDA Food Safety and Inspection 2024). Organic beef comes from the most restrictive system as it must follow the Canadian Organic Standards of which extensively outline all regulations within an organic livestock production. Production must follow most natural production and processing requirements in addition to many others, including: consumption of only organic feed and its storage standards; on-farm cattle living and health conditions; transportation, slaughter, and processing requirements; and every touch point in between (Organic Federation of Canada 2024).

2.3 GETs in Beef Production

Several studies have investigated the animal science aspect of GETs used at the individual enterprise level. The most common types of GETs used in production are hormonal implants, melengestrol acetate, beta-adrenergic-agonists, ionophores, and in-feed antibiotics. The research reported in this thesis looks specifically at the first three of those.

Duckett and Pratt (2014) described hormone implants as natural or synthetic hormones within capsules that supplement an animal's natural hormones, contributing to their growth. This study provided an overview of several benefits associated with implanting animals within the feedlot phase, including an increase of 18% in the ADG of cattle and 5% in carcass weight; as well as a 6% higher feed intake and an 8% greater FE. More recently, Ribeiro et al. (2021) found implants of trenbolone acetate + estradiol (TBA), a type of hormone, to increase ADG (11%), gain to feed ratio (5%), ribeye area (4%) and carcass weight (6%) in beef cattle. TBA is a familiar and popular hormone used in growth implants for beef production and, when applied properly into the ear, is considered safe due to the release period. The Beef Cattle Research Council (2019) states that for a 200 mg implant of TBA, it takes roughly 200 days to release the full dose into an animal.

Melengestrol acetate (MGA) is an estrus synchronizing or inhibiting feed additive that simultaneously maintains appetite and mitigates restlessness that in turn promotes greater FE (11%) and allows for faster weight gain (20%) in fed-cattle (O'Brien et al. 1968; Sides et al. 2009). Ribeiro et al. (2021) fed this synthetic progesterone feed additive to heifers throughout the backgrounding and finishing stages of production. They found that most of the effect occurred in the finishing stage, seeing an increase in total body weight gain, ADG and FE (also increased in backgrounding). Similarly, Perrett et al. (2008) recorded improved ADG, FE,

carcass quality grade and net economic advantage (\$11.31/hd) in feedlot heifers provided with MGA relative to those without MGA. An earlier study by Cook et al. (2001) compared the use of MGA and TBA in beef heifers and observed that the implant (TBA) was more beneficial than the feed additive (MGA) in terms of improving carcass weight, ribeye area, marbling and yield grade.

Beta-adrenergic-agonists are additives that increase lean muscle mass and decrease fat deposition when fed to feedlot cattle during the final 20 to 40 days of the finishing period (Strydom 2016). A study by Capper (2012b) determined that the removal of beta agonists paired with steroid implants led to a 10 percent decrease in feed costs per 363 kg hot carcass weight (HCW). Additionally, Ribeiro et al. (2021) added the beta-adrenergic-agonist feed-additive, ractopamine hydrochloride (RAC), to the use of TBA implants to promote lean muscle gain and fat mobilization in fed-cattle. This study specifically provided the TBA+RAC treatment strictly to steers, resulting in reduced back fat and improved ribeye area at slaughter when comparing to non-conventionally raised cattle. Favourable results have been experienced by producers using beta-agonists in beef cattle production not only in the animal performance but also as increased net returns (\$128.23/hd; Johnson et al. 2014).

Chapter 3: Literature Review

3.1 Production Costs

Scientists have explored the topic of GETs quite early in the onset of their use, publishing studies which found greater performance indicators, such as ADG, DMI, G:F, HCW and quality grades, in cattle that were administered the specified treatments of interest. Some of these studies include O'Brien et al. (1968), Bartle et al. (1992), Fernandez and Woodward (1999), Berthiaume et al. (2006), Bryant et al. (2010) and Maxwell et al. (2014b) – many estimating the conventional systems' improved performance indicators being linked to decreased production costs relative to non-conventional systems. Continued research on the use of GETs and the associated effects on animal performance indicators has been more recently published by Smith and Johnson (2020), Aroeira et al. (2021) and Ribeiro et al. (2021) finding similar results as to those previously mentioned.

Although the topic of GETs in livestock production is familiar (and sometimes controversial) to many agriculture stakeholders, minimal recent economic analyses have been performed, especially for the Canadian feedlot level, while studies looking at all-natural or organic production systems have become more popular. These studies include Coopridge et al. (2011) which looked at two US feedlot management systems' cost per kilogram of animal weight gain, the Never Ever (\$1.35/kg) in comparison to the conventional (\$1.12/kg). Additionally, Smith et al. (2020) found the factors of cost of production, operating costs, price paid for feeder calves and price received for fed cattle within an American all-natural feedlot production system relative to a conventional system to favour the latter system for the first three factors. Although these studies had similar research objectives, they cannot be fully equated since higher premiums

are reported to be applied on these the organic and natural/never-ever products; and the control group does not meet the Canadian Organic Standard and Never Ever Program requirements.

Early and influential environmental research published by Capper and Hayes (2012) investigated the effects of withdrawing GETs from the US beef industry on an economic and environmental scale. This study outlined a previous model system used in the aforementioned literature, Capper (2011; 2012a), which was adopted for the research reported in this thesis. This model included resource inputs and waste outputs spanning the production phase from input production to slaughter; and the feedlot phase that occurs until fed heifers and steers met a certain body weight. The GETs included in the conventional system were steroid implants, in-feed ionophores, in-feed hormones and beta-adrenergic agonists; and it was stated that there were multiple subclasses due to the assumption that producers are more likely to use some technologies when paired with others (i.e. beta-adrenergic agonists administered with ionophores and/or implants). The animal categories that made up the slaughter population of conventional and non-conventional systems were calf-fed feedlot finished animals, yearling-fed feedlot finished animals and dairy feedlot finished animals. The days on feed were equal for each subclass' animal categories, where the average slaughter weight for the conventional system was 574 kg in comparison to the non-conventional slaughter weight of 521 kg. The economic aspect of the report began by stating the impact of removing GETs from the US beef production would be similar to imposing a tax; as well, has the potential to decrease US beef production and increase world beef prices. The study results favoured the conventional production system as it found that removing GETs from production would increase production costs by 8.2%. The research further performed the economic analysis to estimate the impact of an economic policy implementation or adjustment on certain variables. This model estimated the values of US beef

production, trade and exports for the following 10 years using the 8.2% increase in production costs for non-conventional production and found US beef trade to decrease by 17.1% and subsequently, competitive international beef producers to likely increase outputs in attempt to stabilize global supply.

Continued research by Capper et al. (2021) on the economic and environmental impacts of hormonal implants on Brazilian beef production systems determined similar results as previous reports. Rather than studying results for specific hormonal implants (i.e. TBA), this study took a generic approach by including any type of hormonal implant on a scale of low, medium and high dose administration. Data from the study originated from a questionnaire distributed to Brazilian producers in four states which collectively accounted for 39.4% of the total head of cattle in the country and 73% of the nation's feedlot operations. A more in-depth description of the assessed cattle groups' characteristics in each phase can be found in Table 1, 2 and 3 in the *Materials and Methodology* section of Capper et al. (2021). Data collected included animal performance, feed, transportation, crop production and infrastructure, cost of production and revenues. The economic analysis specifically used the production costs based on feed intake results and input costs within the boundaries of crop (feed) production to transportation to slaughterhouse location and only included the principle product of beef (no co- or by-products). The implant cost per animal was simulated using a 5% mark-up on the 2020 price of implant products produced by Zoetis (Parsippany NJ, US), plus 0.017 hours of labour required for administration. The analysis calculated gross and net margins and return on investment (ROI; implant) using the revenues, effective operating costs and total operating costs of the surveyed operations. Results indicated the use of implants required 5.8% less cattle head to produce 10 x 10⁶ kg of HCW as well as decreased age of slaughter and increased slaughter and carcass

weights; and a 6.13% increase in HCW (kg of beef produced). This improvement has the potential to create a higher turnover rate and a greater quantity of cattle to allocate costs over time thus, likely reducing the cost of production per head. In fact, Capper et al. (2021) reported a 3.76% reduction in production costs and a 4.4% increase in the average ROI per kg of HCW beef.

Wileman et al. (2009) utilized a meta-analysis and forest plot to investigate the animal performance data (ADG, DMI, G:F) and animal health using conventional technologies in feeder cattle including steroid implants, monensin (ionophore), tylosin (antibiotic), endectocides (antiparasitic) and metaphylaxis (antimicrobial; plus various antibiotics). This report states it also used a breakeven model to determine certain technologies' relative cost of production. Data collection consisted of three databases where journal articles and data from existing literature were chosen contingent to having at least one specified search term that pertains to the treatments and outcomes for the cattle group and production phase of interest; manuscripts and bulletins were also chosen that used a single steroid implant. Wileman et al. (2009) used forest plots to ensure the select studies had uniform outcomes for technologies so that the treatment groups can be compared using the MIXED procedure in SAS. After the model-adjusted means and standard error for the animal performance data assessed gave a 95% confidence interval, data were included in a breakeven model. The animal performance results showed the metaphylaxis (plus various antibiotics) feeder cattle treatment group experienced an increase of 0.11kg/d in ADG compared to feeder cattle not provided metaphylaxis (plus various antibiotics); implanted heifers increased their ADG by 0.08kg/d relative to non-implanted heifers, but no differences in G:F and DMI were realized; and, implanted steers had a higher ADG (0.25 kg/d) and DMI (0.53 kg/d) relative to nonimplanted steers, but no difference in G:F were noted. A

breakeven model incorporated the differences in ADG and DMI for implanted steers which estimated a decreased cost of production for implanted steers relative to nonimplanted steers on a nonorganic diet (\$77/hd) and nonimplanted steers on an organic diet (\$349/hd). A sensitivity analysis was also done, on the assumption that organic feed costs are more expensive (1.5x) than conventional, which found feed prices to be highly sensitive.

While the above studies provide economic analyses of production costs in cattle raised with GETs relative to those without, there is a gap of knowledge and findings based on Canadian operations; these include market prices of feeder and fed cattle, and feed or data collected from Canadian randomized and replicated feeding trials. Additionally, an initial review of literature surrounding this topic indicates economic analyses are not the primary research objective of animal or environmental studies; instead, economic analyses that compare the economic performance (gross revenue, production costs and net return) of an enterprise, specifically using costs that vary between production systems, are treated as a supplementary subject to the study.

3.2 Agricultural Risk Analyses

Various studies over time have recognized the uncertain nature of the expected returns in the beef cattle industry and have accordingly applied risk analyses to assist producer decisions. Mark et al. (2000) conducted research on the relative effects of production variables on the feedlot profitability according to gender and placement weight; and reported previous findings by Trapp and Cleveland (1989) that fed and feeder price risk and production risk largely explains profit variability in feedlot production. Production variables were included in the regression, and it was concluded the most impactful of these upon revenue per head were fed and feeder cattle prices, corn price, interest rate, ADG and feed conversion according to gender, placement weight and

month. Results suggest that cattle price margins (feeder and fed cattle price difference) and feed prices should be monitored by feedlot producers to ensure proper management of risk.

Lawrence and Ibarburu (2007) used 170 beef production research trials to conduct a meta-analysis of GETs throughout the cow-calf, backgrounding and feedlot phases. This research aimed to estimate economic costs and benefits associated with GETs within production; and determine the effects on the US agriculture market and industry, and retail prices if GETs were removed from production. Specifically reviewing the feedlot research portion, a budget was created to evaluate the costs and benefits using an average of 2005 auction cattle prices from various states. The model combined both sexes to estimate a single output and a Monte Carlo simulation was applied to estimate the effects of GETs on ADG, FE and final weight. Simulation results indicate that implants and beta-agonists produce the largest effect on ADG and FE. The authors also applied simulated animal performance outputs to the budget model, and determined that cost of production would increase by \$68/head if implants were no longer used, and by \$12-13/head if beta agonists/ionophores were removed from the feedlot, respectively.

Maxwell et al. (2014a) examined various performance measures related to technology use in feedlot production, including expected net returns. Two sets of data from multiple feedlot trials were analyzed separately and used to compare treatment groups. The first data set included two treatment groups of steers: CON – administered Component TE-G (TBA) implant; and NAT1 – no implant. Prior to the finishing phase, the conventional group received monensin (ionophore), tylosin (antibiotic), Zilmax (beta-agonist) and was later implanted with Component TE-S with Tylan within the last 20 days on feed. Steers were further separated within the two treatment groups into two diet groups: LOW – consuming 7% DM of roughage; and HIGH - consuming a 12% DM of roughage. The second data set included three treatment groups of

steers: CONZ – administered Zilmax; CONT – administered Component TE-G implant, no Zilmax; and NAT2 – no implant or Zilmax. The first data set included variables of feeder calf value, cost of grain (\$300/907.2 kg), technology (Rumensin, Tylan and Zilmax) and implant cost (\$36.51 and \$3.60, respectively) and base carcass price (\$180/45.4 kg in 2012). The second data set included the variables of feeder calf price, cost of grain (\$300/907.2 kg), technology (CONZ \$36.36; CONT \$6.36; \$0 NAT) and implant (CONT \$8.25) cost, and base carcass price (\$200/45.4 kg). Three separate stochastic sensitivity analyses occurred for individual carcass values and net returns using five different carcass grids, feed costs and base carcass values while holding the other variables constant. It was determined CON and CONZ had the highest cost of production within their respective data sets, due to technology costs and greater DMI. Noteworthy results include the Choice/Select spread sensitivity analyses for data set one and two which calculated a premium range of \$58.69 to \$201.07 and \$116.43 to \$147.68, respectively, per head required for the natural production system to offset the decreased profits compared to profits from the conventional systems. Additionally, the base carcass price sensitivity analyses for data set two calculated an increase in CONT carcass value from \$1,548.88 to \$1,892.52 when base carcass price changed from \$180 to \$220.

Khakbazan et al. (2014) used experimental data from three research centers in Manitoba and Saskatchewan throughout 2007 to 2009 to evaluate four alternative calving and feeding systems biologically and economically. To determine profitability, an enterprise budget was developed for the backgrounding, pasture, swath-grazing and finishing phases which included revenue and cost variables such as feed, technologies, pharmaceuticals, labour, capital, feed and feeder prices, etc. A stochastic budget and simulation were additionally created to obtain estimates through statistical distributions instead of assumed data using the Monte Carlo

simulation method to simulate random values. Next, a sensitivity analysis was used in conjunction with a grid pricing criterion developed by Cargill to assess two scenarios: good situation (25% increase in slaughter price and ADG and decrease in fed and feeder price); and a worse situation (25% decrease in slaughter price and ADG and increase in fed and feeder price). Stochastic efficiency with respect to a function was used and incorporated a utility function depending on preferences of risk. The certainty equivalent which is the amount of return to sway a decision maker to be indifferent of expected returns, was also calculated to determine which alternative calving and feeding systems is preferred.

Silva et al. (2017) studied the risk associated with feeding different levels of concentrate mixed with sugar cane roughage to feedlot cattle in Brazil using 30 crossbred Zebu bulls for 90 days. The risk was measured using various stochastic simulation methods including Monte Carlo, stochastic dominance and sensitivity analyses while also comparing the costs and revenues when correlations were, and were not, applied. There were three treatment groups each receiving different amounts of concentrate depending on a 40-, 60- or 80-DM% as well as differentiated amounts of digestible nutrients and crude protein. Production costs included in the analysis were feeder calf price, roughage and concentrate feed price, manual labour, health and pharmaceuticals, depreciation and other expenses. Income included solely fed cattle prices based on 12 years of historical prices dependent on animal start and finish weights, ADG and daily DMI. The output variable and financial indicator was net present value. Using Microsoft Excel, @RISK and SAS, the cumulative distribution functions (CDFs) were compared and tested using the Kolmogorov-Smirnov test to find first- and second-degree stochastic dominance; and a sensitivity analysis was subsequently performed.

Chapter 4: Data

4.1 Animal Performance

The animal performance data used in this paper originate from a complete randomized design feeding trial conducted over four years (2016 – 2019) at the AAFC Lethbridge Research and Development Centre (hereafter, AAFC Lethbridge). Ribeiro et al. (2021) provide a detailed description of the experimental treatments; Table 1 below summarizes the treatment schedule.

Table 1. Schedule of treatment administration in experiment phases

Treatment Groups	Experiment Phases		
	Arrival	Backgrounding	Finishing ¹
T1 (Control)			
T2 (TBA) ²	Component TE-100 with Tylan	Component TE-100 with Tylan	Component TE-200
T3 (MGA) ³	MGA 100 Premix	MGA 100 Premix	MGA 100 Premix
T4 (RAC + TBA) ⁴	Component TE-100 with Tylan	Component TE-100 with Tylan	Optaflexx 100 Premix Component TE-200

¹ This research focuses on the feedlot phase but includes the TBA dose in backgrounding phase as the effects are realized in the finishing phase.

² Included three doses of implants throughout the duration of the experiment: (1) Component TE-100 with Tylan was administered upon arrival and (2) 84 days later; (3) Component TE-200 was administered 86 days after and 84 days prior to slaughter.

³ Daily dose administered in supplement with a 24-hour withdrawal period.

⁴ Daily dose administered in feed throughout the last 42 days with a 24-hour withdrawal period; given in addition to three doses of TBA implants.

Following their arrival to the research facility, calves were vaccinated and randomly assigned to one of four pens per treatment group. Pens consisted of compacted clay floors, free access to duo-shared water stations, and uncovered feed bunks that housed 10 cattle. All four years consisted of treatments that included 84 days on feed during backgrounding, 28 days during step-up, and varied amounts of days for finishing with a consistent 262 ± 8 days on feed for all treatments. Over the four years, the study used 880 British x Continental crossbred beef calves that began each trial with an initial 279 ± 10.1 -kilogram live body weight. Specifically, year one and two included 120 heifers and 80 steers whereas, year three and four contained 120 heifers and 120 steers. Ribeiro et al. (2021) detail how the trials followed all guidelines from The Canadian Council on Animal Care, and all techniques and procedures within the study were approved by AAFC Lethbridge Animal Care Committee. Additionally, the diets provided (DM basis) in the backgrounding (60% corn silage and 40% concentrate) and finishing (93% concentrate and 7% corn silage) phases were prepared as total mixed rations which met feed requirements in accordance with National Academies of Science, Engineering and Medicine (2016).

The six treatment groups within the study included: (1) a control group of steers; (2) a control group of heifers; (3) TBA-implanted heifers; (4) MGA-fed heifers; (5) TBA-implanted steers; and (6) TBA-implanted and RAC-fed (Optaflexx, Elanco Animal Health) steers. A summary of treatment-specific statistics and experimental variables appears in Table 2, below. Essentially, the experimental treatments in the experiment fell into three categories: control, implant and feed additive. The control category was initially vaccinated and divided into separate pens where no further administrations occurred. The implant category consists solely of TBA implants for both heifers and steers used in production to supplement natural hormones to

promote lean tissue growth (Guiroy et al. 2002; Duckett and Pratt 2014; Ribeiro et al. 2021). Throughout the trial, heifers and steers were given three TBA implants, with the first implant given at the beginning of the study, the second implant given in the backgrounding/step-up phase roughly 86 days before the third implant, and the final implant given at least 84 days before processing. This thesis focuses upon the latter two implants, as the resulting gain is realized in the feedlot phase. The final category encompasses two feed additive technologies: MGA and RAC. Heifers in the trial were given MGA feed additives daily until the 24-hour withdrawal period before harvest, while steers in the trial that were provided RAC in their finishing phase diet (treatment only provided in the third and fourth year of the experiment) were also implanted with TBA and only ingested RAC for the last 42 days of the trial with a 24-hour withdrawal period before harvest (Ribeiro et al. 2021).

Table 2. Summary statistics of experimental variables

Year	Variable	Heifer			Steer		
		Control	TBA	MGA	Control	TBA	RAC+TBA
1	Feedlot on-date	Mar 10	Mar 10	Mar 10	Mar 11	Mar 11	
	Feedlot off-date	Aug 8	Aug 8	Aug 8	Aug 9	Aug 9	
	DOF	151	151	151	151	151	-
	SFBW	1287.32	1337.20	1325.86	1370.63	1493.92	-
	(std dev)	(94.21)	(121.22)	(106.81)	(112.75)	(135.96)	
	HCW	772.68	818.14	816.48	872.48	894.86	-
	(std dev)	(56.17)	(69.74)	(68.25)	(77.17)	(106.62)	
	OBS	40	40	40	40	40	-
CWT	245	245	245	245	245	-	
2	Feedlot on-date	Feb 16	Feb 16	Feb 16	Feb 17	Feb 17	
	Feedlot off-date	July 04	July 04	July 04	July 05	July 05	
	DOF	139	139	139	139	139	-
	SFBW	1291.49	1411.88	1356.10	1358.96	1556.64	-
	(std dev)	(95.58)	(97.49)	(99.43)	(117.88)	(118.85)	
	HCW	779.79	857.49	823.49	831.39	960.66	-
	(std dev)	(57.50)	(62.23)	(61.68)	(76.53)	(76.54)	
	OBS	40	40	40	40	40	-
CWT	280	280	280	280	280	-	
3	Feedlot on-date	Feb 22	Feb 22	Feb 22	Feb 21	Feb 21	Feb 21
	Feedlot off-date	July 18	July 18	July 18	July 17	July 17	July 17
	DOF	147	147	147	147	147	147
	SFBW	1363.36	1459.06	1374.80	1400.21	1572.84	1586.96
	(std dev)	(87.05)	(83.29)	(105.95)	(80.36)	(97.51)	(72.04)
HCW	804.71	880.29	820.62	834.66	950.43	973.26	

	(std dev)	(53.28)	(52.12)	(74.39)	(46.60)	(67.89)	(43.03)
	OBS	40	40	40	40	40	40
	CWT	247	247	247	247	247	247
	Feedlot on-date	Apr 2, 3	Apr 2, 3	Apr 2, 3	Apr 2, 4	Apr 2, 4	Apr 2, 4
	Feedlot off-date	Sept 9, 10	Sept 9, 10	Sept 9, 10	Sept 9, 11	Sept 9, 11	Sept 9, 11
	DOF	160	160	160	160	160	160
	SFBW	1390.79	1483.00	1434.03	1417.89	1554.09	1583.91
4	(std dev)	(79.33)	(96.92)	(93.40)	(90.64)	(100.23)	(84.74)
	HCW	830.71	903.96	870.75	840.57	949.01	969.36
	(std dev)	(50.54)	(58.68)	(59.90)	(61.50)	(66.86)	(52.99)
	OBS	40	40	40	40	40	40
	CWT	239	239	239	239	239	239

Note: Feedlot on/off-date; std dev = standard deviation; DOF = days on feed (units in days); SFBW = shrunk final body weight (units in pounds per head); HCW = hot carcass weight (units in pounds per head); OBS = observations (units in head of cattle); CWT = per hundredweight valuation (units in Canadian dollars); Year 1-4 = 2016-2019.

Measurements obtained over this four-year study, outlined above, generated cross-sectional data which contain correlations among observations for each gender and particular treatment. The daily amount of offered feed and weekly leftovers were weighed, sampled and recorded, and the DMI was calculated accordingly. The shrunk weight and ADG were calculated using the weights recorded at the beginning and end of backgrounding and finishing, and throughout each phase (every 21 and 28 days, respectively) (Ribeiro et al. 2021). The HCW, dressing percentage, rib eye area and quality grade were determined and documented at slaughter. Carcasses were subsequently cooled for 24 hours to be assessed for yield grade and quality grade according to the Canadian Beef Grading Agency (CBGA) standards. The marbling score (quality grade) and rib-eye area were measured using a Computer Vision Grading System; and the liver abscess scores were measured according to the Elanco System (Ribeiro et al. 2021).

4.2 Economic Performance

Data for economic performance includes various inputs for the total cost, gross revenue, and net return outputs. Total cost is calculated as the sum of the feed, supplement and treatment prices from the AAFC Lethbridge's local input supply dealers; feeder calf prices obtained from CanFax Research Services; and two types of interest. Five-year averaged feed prices (\$Can/metric tonne) for rolled barley, distiller's dried grains with solubles (DDGS), corn silage and control supplement are \$227.07, \$266.52, \$70.96, and \$298.00, respectively; and five-year averaged treatment prices (CAD/unit) for TE-200 (assuming same unit price for TE-100), MGA supplement, and Optaflexx premix are \$277.92/100 doses, \$392.50/MT and \$58.97/lb, respectively. A 10-year market average of Alberta backgrounded calves weighing 900-999+ pounds at purchase, with the average finishing on-date of March 6, is used as the cost of the feeder calves for steers (\$1.82) and heifers (\$1.67). The finishing on-date average is created

using an average of the calculated yearly on-dates then subtracted from the respective annual DOF from the market date (assumed off-date). An interest rate of 8.5% is used to calculate both interest types including the interest on housing feeder cattle and interest of operating capital during the feeding period.

The cost of grain (\$/lb) was the sum of the three weighted products for each of the feed ingredients multiplied by the finishing DOF. This is calculated as the sum of three products: [1] DMI, dry matter percentage (DM%) of rolled barley (0.80) and the price (\$0.13/lb); [2] DMI, DM% of corn silage (0.09) and the price (\$0.04/lb); and [3] DMI, DM% of DDGS (0.06) and the price (\$0.15/lb); all multiplied by the average 149.5 DOF. Similarly, the cost of supplement is calculated by multiplying the DMI by the DM% of supplement (0.05) by the price for the control (\$0.16/lb) and MGA (\$0.22/lb). The Optaflexx cost per head is calculated by multiplying the DMI by the RAC concentration (0.0057) within the DM% of the Optaflexx supplement (0.05) by 42 days and price (\$58.97/lb). Feeder prices are calculated by multiplying the 10-year average price (CAD/lb) by the beginning weight (lb/hd) for both heifers (1.67; 906.26) and steers (1.82; 932.72). The feeder prices hold the assumption that all cattle are the same price and weight even though upon arrival and before backgrounding, an implant was administered to the TBA and TBA+RAC group and the MGA supplement was provided, as outlaid in Table 1. The interest on housing cattle through the feeding period is calculated as the feeder calf price multiplied by the interest rate divided by 365, multiplied by the feedlot DOF.

Table 3. Percent dry matter and price (\$/lb) for feed ingredients and supplements in finishing phase

Variable	DM %	\$/lb
Rolled Barley	80	0.13
Corn Silage	9	0.04
DDGS	6	0.15
Supplement (no hormone)	5	0.16
Supplement (MGA) ¹	5	0.22
Supplement (RAC) ²	5	58.97

¹ Identical supplement was provided to all treatment groups except for the melengestrol acetate (MGA) treatment group as the chemical composition is slightly different which is thoroughly displayed in Table 1 of Ribeiro et al. (2021).

² Ractopamine hydrochloride and trenbolone acetate (RAC+TBA) treatment group received the Optaflexx feed additive premix combined into the no hormone supplement.

Table 4. Cost of grain, supplement and treatments over finishing phase

Variable (\$/hd)	Heifer			Steer		
	Control	TBA	MGA	Control	TBA	RAC+TBA
Grain						
Barley	322.85	348.52	327.16	325.51	367.64	391.02
Corn Silage	11.35	12.25	11.50	11.44	12.93	13.75
DDGS	28.48	30.68	28.80	28.65	32.36	34.42
Supplement	26.48	28.59	26.83	26.70	30.16	32.07
Treatment						
Implant	0	5.56	0	0	5.56	5.56
MGA	0	0	8.51	0	0	0
Optaflexx	0	0	0	0	0	17.96

Note. TBA = trenbolone acetate + estradiol; MGA = melengestrol acetate; RAC = ractopamine hydrochloride.

Gross revenue per head is solely comprised of the carcass price that was designated by the packer at purchase which is calculated as the HCW (lb/hd) multiplied by the price (CAD/lb) – converted from the per hundredweight valuation (CWT). To eliminate any bias in the steer class revenues, since RAC+TBA was only present for years 3 and 4, the carcass price is manually calculated using an average price per pound (CAD/lb) of \$2.52 for heifers and \$2.50

for steers, which are multiplied by the average HCW of each treatment group. The averages for CWT and HCW are calculated for treatment groups in all four years, seen in Table 2. Finally, net return is calculated as the difference between gross revenue and total cost.

4.3 Stochastic Simulation

The stochastic simulation uses similar data to measure the economic performance with an addition of distributions for the key variables of grain, supplement, feeder and fed cattle prices. All base case values are manually exported from SAS output using the MIXED procedure. Data from Statistics Canada (2024c) are incorporated into the distribution and values for barley, using a 10-year average (2014-2023) of Alberta barley prices to create the minimum, most likely and maximum values. The 10-year Alberta barley values are calculated by multiplying the converted prices (CAD/tonne to CAD/lb) of the minimum, most likely and maximum values by DM% (0.8) of the DMI for the respective treatment group and gender. Minimum, most likely and maximum values for corn silage, DDGS, supplements and feeder price are manually exported from SAS using the proc mixed procedure. The DDGS distribution fit is confirmed by a 10-year average (2014-2023) of Ontario corn for grain prices as Statistics Canada (2024c) did not provide Alberta prices for the required range of years. The DDGS is confirmed by the corn for grain prices since Langemeier et al. (2022) states corn and DDGS prices are highly correlated; however, the prices were not used in the analysis to maintain consistency with corn silage as both historical prices were unable to be found on Statistics Canada (2024c). The minimum, most likely and maximum values for fed cattle price (CAD/carcass) are calculated using converted heifer and steer 10-year average rail prices from CanFax (CAD/lb), and treatment and gender specific HCW (lb/carcass) data from AAFC Lethbridge.

Chapter 5: Theory

5.1 Partial Budgeting

Following the replications of animal performance and using the calculated economic performance data, a partial enterprise budget is developed. The purpose of this type of budget is to assist producers in making operational decisions by calculating the net effects under varying assumptions about input use and their associated costs and benefits. As such, the fed cattle market has a fairly elastic demand and are price takers, as previously mentioned. Similar to fed cattle prices, beef prices are related to utility which relies on the characteristics of a good and how a consumer values those characteristics (Lancaster 1966). However, the primary objective will exclusively look at the aforementioned theory which is associated with the prices, profit and costs of production within the fed cattle market instead of the physical attributes of the animal or retail products.

5.1.1 Profit Maximization

Profit maximization theory has experienced various modifications and critiques over centuries, with contributions from a number of economists. Hawkins (1973) highlights the work of economist Adam Smith who, in 1776, attempted to find the “natural price” of commodities with the idea of a product’s production cost as the basis. Eventually, Smith believed labour, profit (capital) and rent (land) to be the driving factors of cost and therefore, value of a product; and shortly after, in 1806, Jean-Baptiste added entrepreneurship to the list of factors (Hawkins 1973). Subsequently, incorporating many discoveries of new theories by economists, Schumpeter evolved the idea into the Theory of Profits Through Innovation in 1934, and noted the assumption that an increase in profits can occur from an increase of market power (Cantwell 2000). Schumpeter later assumed in 1943, that an increase in profits is associated with constant

implementation of value-adding activities. This type of profit increase is noted in previously mentioned literature which evaluates higher returns in operations that use GETs in the finishing phase. In a review of innovation and profits, Cantwell (2000) notes that it is not only the most technologically advanced firms who use cutting-edge ideas that earn the highest profits, but more so, firms that use technologies which are best suited for their context and who apply them correctly (Nelson 1993). In the case of Schumpeter's theory, innovation specifically assists the aspect of labour to be more efficient, thereby increasing profits. For this research, this theory is applied to inputs which have the potential to be used efficiently as a consequence of implementing innovative activities (i.e. GETs). According to the Schumpeter (1934; 1943), improved efficiency of inputs can lead to reduced expenditures for an operation while the revenue remains constant. This theory is applicable as current literature calculated reduced expenditures from using technologies in cattle production and therefore, supports the position that profit can be estimated using a partial enterprise budget.

5.1.2 First- and Second-Order Conditions

The neo-classical assumption that firms look to maximize profits relies on the satisfaction of the first- (FOC) and second-order conditions (SOC) (Carbaugh and Prante 2011). These conditions are defined below by following an overview of profit maximization by Carbaugh and Prante (2011). The traditional profit function of total revenue minus total cost describes when a firm will breakeven such that,

$$\pi = p(q) - c(q); \quad (1)$$

where π is profit (or net returns), q represents the quantity of a product, p is the price of a product and c is the cost of a product's inputs. Imbedded in equation 1 is the cost function,

$$c(q) = \sum_{i=1}^n (r_i \times u_i) + F \quad (1.1)$$

which is the sum of the product of the input price (r_i) and input (u_i) plus the fixed costs (F) associated with production for product i . Proceeding with the assumption of perfect competition within the finished beef market, the first derivative of equation 1 is taken to fulfill the FOC which is mathematically written as,

$$\frac{\partial \pi}{\partial q} = 0; \text{ or} \quad (2)$$

$$\frac{\partial \pi}{\partial q} = p - c'(q) = 0. \quad (2.2)$$

In rearranging equation 2.2, equation 2.3 and 3 are produced and resemble the traditional form of the profit maximization function since the first derivative of revenue ($\frac{\partial p(q)}{\partial q}$) is marginal revenue (MR), and cost ($\frac{\partial c(q)}{\partial q}$) is marginal cost (MC) (Carbaugh and Prante 2011), so ultimately,

$$p = c'(q) \quad (2.3)$$

$$MR(q) = MC(q). \quad (3)$$

Although equation 3 satisfies the FOC, the result is binomial as it vaguely confirms that profits are either maximized or minimized. In further specification of determining which extreme is present, the second derivative is taken in equation 4 and rearranged in 4.1,

$$\frac{\partial MR}{\partial q} - \frac{\partial MC}{\partial q} \leq 0 \quad (4)$$

$$\frac{\partial MR}{\partial q} \leq \frac{\partial MC}{\partial q} \quad (4.1)$$

where the SOC states that the slope of the tangent of the marginal revenue curve must be negative for a firm to maximize their profits (Carbaugh and Prante 2011). This theory is pertinent

for a profit maximizing firm as a set of inputs is selected in attempt to minimize costs. For this research, the cost function in equation 1.1 holds a variety of inputs where the conventional and non-conventional production systems will employ inputs (u_i) in varying amounts at the same prices (r_i) to display relative profitability.

5.2 Risk Analysis

Stochastic dominance is a type of risk analysis that works to assist decision makers by estimating distributions of input and output values. Through the combination of this analysis, a stochastic budget is built to understand the risk associated with alternative management systems (Richardson 2008).

Risk exists in nearly every choice an individual makes and plays a pivotal role in financial decisions. Gupta (2014) defines risk as the variability of outcomes that can be measured by objective probabilities; meaning observational data are foundation to risk estimates. Risk is found in most agricultural variables including yields, input and output prices, interest rates and others, all of which have the ability to result in uncontrollable outcomes (Richardson 2008). Uncertainty is sometimes misconstrued as risk, but Hardaker et al. (2015) observes that the defining distinction between the two is that uncertainty involves imperfect knowledge – largely as unknown probabilities of alternatives – whereas risk has uncertain outcomes of alternatives with the possibility of being favourable or unfavourable.

Hardaker et al. (2015) outline various types of risk typically seen in the agricultural sector, two of which most closely relate the research reported in this thesis: production risk and price risk. Production risk results from unprecedented weather, pest or disease effects on crops and livestock. Because prices of inputs and outputs can be affected by the success of production

as well as market, interest or exchange rate fluctuations, and vice-versa, price risk is also commonly encountered in agriculture.

5.2.1 Expected Utility Theory

The feasibility of expected net returns for agricultural producers relies heavily on many outside factors, including unprecedented environmental and market occurrences; however, is also a result of producers' preferences and attitudes, as explained by the expected utility (EU) theory or Bernoulli's Principle founded in 1738. In 1944, Von Neumann and Morgenstern expanded Daniel Bernoulli's theory by stating that an individual will maximize their utility; and that this is to be assumed in all analyses applying this theory (Richardson 2008). In order to calculate the EU of an alternative, Richardson (2008) explains the utility function is used and written as

$$U(w); \text{ or} \tag{4}$$

$$U(w) = U(w(\tilde{X}, \alpha)) \tag{4.1}$$

since w is wealth or the economic decision at hand which is dependent on the random variable(s) \tilde{X} and control variable(s) α . Specifically in a stochastic simulation, the utility function is written as

$$U(w_i) = U(w_i(\tilde{X}, \alpha_i)) \tag{5}$$

where α_i and w_i are the scenarios and CDFs of the net return for alternatives, i , respectively; and \tilde{X} is the parameter (Richardson 2008). This research looks at the relativity between alternatives, i , and the corresponding EU of feedlot producers thus, the scenario variable (α_i) is removed.

The EU theory can be used to explain an individual's preference to risk. Pindyck and Rubinfeld (2018) describe three preferences to risk: risk averse, risk loving and risk neutral. A risk averse individual's preference would display a diminishing marginal utility while income increases, meaning they would rather certainty of a lower return rather than a possibility of a

higher return. Risk averse individuals are more likely to pay an amount of money to ensure any avoidance of taking on more risk, also known as a risk premium. In contrast, a risk loving individual would prefer taking on more risk if a higher return is expected. Between risk averse and risk preferred individuals, are those that are risk neutral, who are indifferent to uncertain and certain events with equal expected returns. While agricultural producers are usually depicted as risk averse, research has found an exception for beef feedlot producers, who have been seen to have both risk averse and risk neutral preferences, depending on their production and selling styles. This research will continue in assumption that feedlot producers are risk averse, following the assumption of Fausti and Lange (2011) and the survey results found in McKendree et al. (2021).

5.2.2 Stochastic Simulation

A simulation is a technique that can be used on a model containing equations and parameters that is used to represent an existing system's inputs and outputs (Hardaker et al. 2015). The model possesses flexibility which explores changing variables and quantities to simulate real performance. Within stochastic simulation is a sub-category known as stochastic dominance, or dominance analysis, which measures the efficiency of alternatives by incorporating risk preferences within various efficiency criterion, which become more restrictive as they proceed. The first two criteria, first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD), are applied to the stochastic budgets outlined in Chapter 6.

5.2.3 First-Degree Stochastic Dominance

For a decision maker to compare alternative options, efficiency must be evaluated. Efficiency of alternative choices can be compared using probability density functions (PDF) or CDFs, two types of graphical representations for continuous random variables. A PDF is used to display the

probability $f(x)$, of outcome X , within x ; and satisfies two conditions outlined by Pennsylvania State University (PSU) (2023a): [1] $f(x)$ is positive or $f(x) > 0$ for all $-\infty \leq x \leq \infty$; and [2] the area under the curve $f(x)$ is equal to 1 such that, $\int_{-\infty}^{\infty} f(x)dx = 1$. If the anti-derivative is taken of $f(x)$ to get $F(x)$, then it is possible to find the area under the curve up to X on a CDF. Anderson et al. (1977) mathematically defined a CDF as

$$F(x) = P(x \leq X); \text{ or} \tag{6}$$

$$F(x) = \int_{-\infty}^{x^*} f(x)dx, \text{ for all } -\infty < x^* < \infty \tag{7}$$

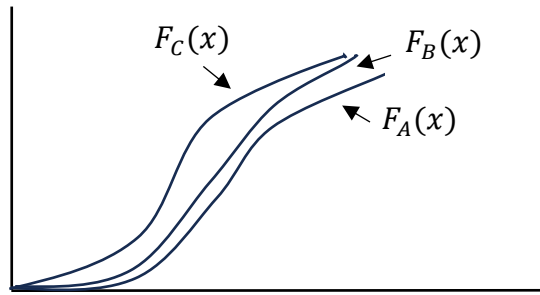
where $F(x)$ is the probability of the value, X is greater than or equal to an uncertain number, x . A CDF must satisfy three conditions outlined by PSU (2023b): [1] $F(x)$ is a non-decreasing function for $-\infty \leq x \leq \infty$; [2] the values of the probability function $F(x)$ range from 0 to 1; and [3] if the minimum value of X is a and the maximum is b , then the probability of anything less than a is 0 and b is equal to 1. The construction of a CDF is essentially joining points that represent the probability ratios of output values for a continuous random variable.

Hadar and Russell (1969) published the idea of FSD which uses the only restriction of assuming positive marginal utility function, where one additional dollar increases a decision maker's utility. This restriction can be applied to a decision maker with any of the three risk preferences, but must believe that greater returns are preferred to less returns. When applying this assumption, the FSD theory states that alternative A dominates B in the first-degree if the CDF of $F_A(x)$ is below, or to the right of $F_B(x)$, both with the probability distribution of outcomes, x , which is described mathematically as,

$$F_A(x) \leq F_B(x) \text{ for all } x, \tag{8}$$

with at least one strong inequality (Hardaker et al. 2015). Richardson (2008) also describes the concept as A dominates B if $[F_B(x) - F_A(x)] \geq 0$ for all x in R . Due to the pairwise comparison of the alternatives, once an alternative is determined to be dominated by the other, it can be fully dismissed from the decision maker's choices, meaning B is no longer an option. Additionally, all stochastic efficiency criterion, including FSD, follows the rule of transitivity which means if A dominates B and B dominates C then A dominates C in the first-degree (Hardaker et al. 2015). Figure 3 graphically illustrates alternative A dominating B and C in the first-degree.

Figure 3. First-degree stochastic dominance



Should the CDF of $F_A(x)$ and $F_B(x)$ cross, further decision analysis is required to evaluate the most efficient decision.

5.2.4 Second-Degree Stochastic Dominance

To further analyze alternatives that are deemed inefficient in the first-degree, SSD applies the more restrictive assumption that the decision maker must be risk averse. The first and second derivative of the risk averse utility function is developed by Hardaker et al. (2015) in equation 8 and 9 and building off equation 5,

$$U^{(1)}(w) > 0; \tag{9}$$

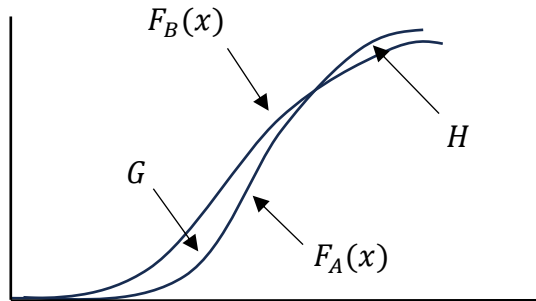
$$U^{(2)}(w) < 0, \tag{10}$$

representing $U^{(t)}(w)$ as the t -th derivative of the utility function for wealth, w . If the first or second derivative of the decision maker's utility function was negative or positive, respectively, then their preference would be deemed risk loving and the SSD concept would not be applicable. Similar to FSD, A is preferred over B in the second-degree if,

$$\int_{-\infty}^{x^*} F_A(x)dx \leq \int_{-\infty}^{x^*} F_B(x)dx, \text{ for all values of } x^* \quad (11)$$

with at least one strong inequality (Hardaker et al. 2015). The addition of an integral focuses on the calculation of efficiency specifically with the area under the CDFs of alternative A and B on a graph. In a graphical sense, this means that if area G is larger than area H in Figure 4, then A is preferred over B in the second-degree.

Figure 4. Second-degree stochastic dominance



In accordance with the restrictions and criteria outlined specific to FDS and SDS, efficiency of technologies within cattle production is estimated and discussed in the subsequent chapters. Results indicated from these analyses are intended to assist the decision maker, or feedlot producer, to appreciate the relativity of the net returns and risk associated with each alternative and understand which best fits their management system.

Chapter 6: Methodology

6.1 Introduction

This section will explain the methodology used to achieve the objectives of this research. First, to evaluate the animal performance, a replication of measures is used. Next, the measures of animal performance will be used to determine the economic performance of conventional and non-conventional feedlot production systems using a partial enterprise budget. Supplementary discriminatory analyses will also be applied using stochastic dominance in the first and second-degree as explained in this section.

6.2 Animal Performance

Replication of the main animal performance measures reported in Ribeiro et al. (2021) provides the data used in this thesis. Data were manually exported from Excel and into SAS, and the MEANS procedure was used to provide the data summary shown in Table 5. That table outlines two sets of measures specific to sex and production system: (1) data imported directly from Ribeiro et al. (2021); and (2) data calculated in SAS using input data from Ribeiro et al. (2021). The first set includes the beginning date and weight, ending date and shrunk live body weight, DMI and HCW; the latter includes these replications being calculated in SAS, finding the ADG from total gain of treatment groups.

Table 5. Measures of average animal performance data over the four-year experiment

Animal Variable	Heifers			Steers		
	Control	TBA	MGA	Control	TBA	RAC+TBA
Beginning date ¹	March 6	March 6	March 6	March 6	March 6	March 6
Beginning weight (lb/hd) ¹	906.26	906.26	906.26	932.72	932.72	932.72
Ending date ¹	August 2	August 2	August 2	August 2	August 2	August 2
Ending shrunk live body weight (lb/hd) ¹	1332.20	1,423.87	1,372.66	1,387.35	1,544.12	1,585.50
Dry matter intake (lb/hd) ¹	21.61	23.33	21.90	21.79	24.61	25.45
Hot carcass weight (lb/hd) ¹	796.45	865.26	833.08	844.79	938.66	971.38
Average daily gain (lb/hd) ²	2.85	3.47	3.12	3.05	4.11	4.27

¹ Directly from Ribeiro et al. (2021)

² Calculated in SAS using input data from Ribeiro et al. (2021)

6.3 Budgeting

Most agricultural businesses use budgets to make decisions; the main three types of budgets used to make farm-level decisions are whole-farm, enterprise and partial – each contributing different information and benefits to the designated outcome (Doye 2008). Partial enterprise budgets are specifically used to account for the benefits and costs that vary between certain decisions – for the purposes of this research, the three conventionally fed cattle production systems being compared to the non-GET system in order to find the most profitable option. This type of budget is effective when altering one component of production to evaluate how the whole system adjusts.

The differing variables included in this partial budget are: revenue of beef carcasses; cost of feed, supplement and treatments; interest on operating capital; and price of backgrounded feeder cattle plus the interest costs associated with housing, as outlined by Table 7 in Chapter 7.

The partial enterprise budget includes variable and fixed costs from calculations performed in SAS using manually written equations and data; with the intended outcome to identify the differences in the net returns of the conventional production systems relative to base case results. The fixed costs within the budget are costs that do not change as the output changes and include feeder calf (according to sex class), TBA implant, MGA feed additive and Optaflexx feed additive prices. The variable costs in the budget are the remaining costs that do change as the output changes which include feed and supplement costs and both types of interest. This budget is displayed through equation 11 which incorporates the profit function and theory from equation 1 and follows Reichhardt et al. (2023) who calculated the expected net return for different cattle breeds and treatments in the feedlot:

$$NR_{ih} = [R_{ih}(HCW_{ih})] - [FP_{ih}(FW_{ih}) + GC_{ih}(GW_{ih}) + TC_{ih}(TW_{ih}) + SC_{ih}(SW_{ih}) + CI + FI], \quad (12)$$

where the expected net return NR is the revenue minus costs for treatment groups $i = C$ (Control), I (Implant), O (Optaflexx), M (MGA) and gender $h = S$ (steer) and H (heifer). The first parenthesis includes the product of R which is the revenue (\$/lb) received from the packer and the hot carcass weight after slaughter is HCW (lb/hd) for treatment i and gender h . The second parenthesis includes the product of feeder price (FP) and weight (FW) of purchased cattle going into the feedlot, followed by the costs and quantity/weight of feed (GC , GW), treatment (TC , TW) and supplement (SC , SW) consumed for treatment group i and gender h and ends with the incurred interest on capital (CI) and of finishing the cattle (FI). The variables chosen for the partial budget in equation (12) show the most variation between each treatment allowing the differences in net return to be representative of each production system

6.4 Stochastic Simulation

The objective of this analysis was to determine the production system most likely to give the highest net return, taking into account variation in key variables over time. This method adds an additional stochastic aspect to the partial enterprise budget to further, find the most risk efficient option. Simulations allow “what-if” questions to be answered or proposed projects to be explored by developing a complex, flexible model in place of an expensive, long-term experiment (Richardson 2008).

A stochastic budget that is being used to make investment decisions must use all the revenue and cost variables that contribute to the key output variable (KOV) (Richardson 2008). The KOV is defined as the variable which provides information to the decision maker, and in this case is the net return of the alternative treatment groups. Variables within a simulation are

one of two types: stochastic or deterministic. Stochastic variables are those that hold risk, and are uncontrollable and unpredictable; whereas deterministic variables are those that are fixed and predictable (Richardson 2008). The stochastic variables defined in the model are all feed ingredients because production is extremely unpredictable from unprecedented weather and therefore the price is uncontrollable. Similarly, feeder calf and fed cattle prices are stochastic as there are unpredictable market shifts and cycles that can affect the prices of backgrounded calves and finished cattle or carcasses. The remaining treatment prices are deterministic variables as they are fixed and constant through each iteration within the simulation.

A probability distribution is incorporated into the stochastic variables and KOV during the large number of simulations to create risk and is present in the error term (e) of the equation $Y = a + bX + e$. It is necessary to define the correct distribution fit for the data that each variable represents to produce the most accurate probabilistic values. The PERT (Program Evaluation and Review Technique) distribution is used for all variables in this risk analysis; and was originally constructed by Clark (1962) for the United States Navy in attempt to estimate milestones in the development of the weapon, Polaris, to assist in determining expected values and variances for scheduled activities. It is now used in most modern risk analyses and was selected for this research due to the consideration of the minimum, most likely and maximum parameters in the development of the expected values. These three parameters play a large role in the model's expected value since Clark (1962) determined an individual's innate estimation of a value is commonly associated to the mode – the most likely value to occur in a distribution; and decided further reliability would come from specified minimum and maximum extremes to create a designated range. The PERT distribution uses the assumptions of the standard deviation equal to one-sixth of the range of values; and the most likely value holds two-thirds of the

model's weight while the extremes share the remaining one-third (Clark 1962). Similar to a normal distribution, PERT fits a smooth bell-shape and is recommended for a large number of observations. Appendix A provides a sample iteration of the stochastic budget according to gender and treatment groups.

The probabilistic values were used as inputs for the respective gender and treatment group net return or KOV (Richardson 2008). The KOV possess a probability distribution that estimates the risk within a variable by performing the simulation multiple times, following the law of large numbers – in this case 10,000 – using the Latin Hypercube method and Mersenne Twister sampling generator. This method is preferred and known for its consistency when sampling random values, taking at least one value from a specified number of intervals; whereas the Monte Carlo method, another well-known procedure, randomly selected values from the input variables' probability distributions, choosing values from around the mean and under both tails, possibly leading to a biased distribution (Richardson 2008).

The risk simulation was performed using an Excel add-in software @RISK (Palisade 2024). Following a similar stochastic simulation in Pacheco et al. (2014), the first-and-second-degree stochastic dominance were analyzed. The outcomes for each production system and ranking for most preferred by a producer are presented in a table format.

Each alternative net return output was used to create a CDF that overlaid the other treatment group according to gender to determine if FSD was present. Chapter 7 includes the overlaid output report showing the CDFs crossing and it was, therefore, determined that the SSD must be tested between the heifer TBA and MGA groups and steer TBA and TBA+RAC groups.

Chapter 7: Results and Discussion

7.1 Introduction

This chapter will include results pertaining to the three objectives outlined in Chapter 1 using the methods described in Chapter 6. The first section will present the animal performance measurements according to treatment group and gender of which results are implemented into subsequent economic and stochastic analyses. The following section will include the partial enterprise budget which will indicate the most economical alternatives through an analysis of the relative net return results. Finally, the third section will discuss results obtained from the risk analysis and determine the efficiency of treatments according to the rankings of first- and second-degree stochastic dominance for both heifers and steers.

7.2 Animal Performance

To begin the analysis of GETs used at the feedlot level, is it necessary to determine the effects on animal performance. Table 6 shows end results that were first presented by Ribeiro et al. (2021) and then replicated in this study. The purpose of this table is to show the differences in total gain and percent increases of total gain relative to base-case results; comparing the total gain to the net return of treatments provides producers with more details to make informed decisions.

Table 6. Animal total gain throughout the finishing phase according to sex and treatment group

Animal Performance	Heifer			Steer		
	Control	TBA	MGA	Control	TBA	RAC+TBA
Total gain (lb/hd)	425.94	517.61	466.40	454.63	611.40	652.78
Difference in total gain relative to control treatment (lb/hd)	Base	91.67	40.46	Base	156.76	198.14
Increase of total gain relative to control treatment (%)	Base	21.52	9.50	Base	34.48	43.58

To allow for a more thorough interpretation of results, the treatments administered to heifers were compared first. The total gain of the TBA group was calculated to be 517.61 pounds per head which was the heaviest within the heifer class and 91.67 pounds more than the control group per head. The MGA group was also heavier than the control group, however, heavier by only 40.46 pounds per head. The steer class experienced larger gains overall in comparison to the respective treatments in the heifer class. Relative to the control group, the RAC+TBA treatment group was the heaviest seeing 652.78 pounds per head in total gain which was 198.14 pounds more than the control group. From these results, it is apparent that the use of GETs at the feedlot level assisted in the overall weight gain for both heifers and steers, specifically from the administration of TBA implants and the combination of TBA implants and Optaflexx feed additive, respectively.

7.3 Economic Performance

The measurements of economic performance for the GET alternatives were analyzed using a two-step process. The partial enterprise budget is first necessary to determine the base case values for deterministic and random variables used within the subsequent stochastic simulation.

Considering these base case values are estimated using assumed data from the AAFC Lethbridge experiment, the values obtained in the partial enterprise budget are applied to the probability distribution parameters of the random variables within the following risk analysis. The simulation used first- and second-degree stochastic dominance analyses to determine the most economical treatments.

7.3.1 Budgeting

A four-year averaged partial enterprise budget was created using SAS outputs through the MEANS procedure and class variables of sex and treatments, as shown in Table 7. The purpose of the budget was to find the profitability of each GET alternative used as well to highlight the relative profitability to the non-conventional production system.

Table 7. Measures of economic performance in feedlot partial enterprise budget

Economic Variable	Heifers			Steers		
	Control	TBA	MGA	Control	TBA	RAC+TBA
Feeder calf purchase (\$/lb)	1.67	1.67	1.67	1.82	1.82	1.82
Feeder calf price (\$/hd) ¹	1,566.06	1,566.06	1,566.06	1,756.55	1,756.55	1,756.55
Interest on owning feeder calf during feeding period (\$/hd)	52.60	52.60	52.60	59.00	59.00	59.00
Grain ration (\$/hd)	362.62	391.45	367.46	365.61	412.93	439.18
Supplement (\$/hd)	26.48	28.59	26.83	26.70	30.16	32.07
MGA (\$/hd)	0	0	8.51	0	0	0
Optaflexx (\$/hd)	0	0	0	0	0	17.96
Implant (\$/hd)	0	5.56	0	0	5.56	5.56
Interest on operating capital (\$/hd)	6.78	7.41	7.02	6.84	7.82	8.86
Total cost (\$/hd)	1,961.94	1,999.07	1,975.88	2,155.70	2,213.01	2,260.18
Gross revenue (\$/hd) ²	2,008.66	2,182.19	2,101.03	2,116.77	2,349.75	2,431.66
Net return (\$/hd)	46.72	183.09	125.15	-38.93	136.74	171.48
Difference in net return relative to control treatment (\$/hd)	Base	136.37	78.43	Base	175.67	210.41

¹ Feeder calf price value includes the interest on owning feeder calf during feeding period.

² Gross revenue is the price received from packer on a per hundredweight valuation of the HCW.

Similar to the animal performance measures, the economic performance results were separated according to sex. Beginning with the heifer class, it is evident the TBA treatment group is the most economic, experiencing a net return of \$183.09 per head. The gap between the control and TBA net returns largely stems from the higher revenue of \$173.53 per head on average, due to the significant additional weight gain of animals in this group which more than offsets the minimal increase in feed costs relative to control at \$28.83 per head on average. These variables together show the highest profitability within the heifer class is realized through the use of TBA implants within the finishing phase. The MGA group is also shown to be relatively more profitable than control from the increase in revenue (\$92.37) and feed costs (\$4.84) per head.

Results for steers follow a different pattern as the combination of the RAC feed additive and TBA implant is calculated to be the most economic option, resulting in net return of \$171.48 per head on average. The TBA and RAC+TBA groups realized significantly higher net returns per animal than the control group largely due to higher sale weight and thus revenues, which were \$232.98 and \$313.89 higher per head, respectively. It is important to note that Table 6 shows TBA for heifers and RAC+TBA for steers as groups with the highest DMI and total weight gain, resulting in the highest feed costs in Table 7. These two groups also received the highest revenues, which means that, in order for these GETs to be an economic option, the increased production costs must be offset by increased revenues. In summary, results from partial enterprise budgeting demonstrate that the TBA implant and RAC+TBA combination are the more efficient options, seeing as they provide a higher net return for the heifer and steer classes, respectively.

7.3.2 Summary Statistics

Four years of data, including 880 cattle, were used to create parameters within the partial enterprise budget taken from SAS output. Table 8 includes summary statistics of the mean, standard deviation, minimum, and maximum of independent variables according to treatment group and gender.

Table 8. Summary statistics for variables in partial enterprise budget

Treatment Group	Variable (\$/hd)	Mean	Std. Dev.	Minimum	Maximum
Heifer Control	Barley	322.85	16.36	300.66	346.08
	Corn Silage	11.35	0.58	10.57	12.17
	DDGS	28.42	1.44	26.47	30.46
	Supplement	26.48	1.34	24.66	28.39
	Feeder price	1,566.06	2.67	1,562.44	1,569.85
	Interest on operating capital	6.78	0.69	5.86	7.77
	Fed cattle price	2,008.66	147.97	1,591.60	2,436.89
Heifer TBA	Barley	348.52	17.71	324.58	373.62
	Corn Silage	12.25	0.62	11.41	13.14
	DDGS	30.68	1.56	28.57	32.89
	Supplement	28.59	1.45	26.62	30.65
	Implant	5.56	0	5.56	5.56
	Feeder price	1,566.06	2.67	1,562.44	1,569.85
	Interest on operating capital	7.41	0.75	6.42	8.49
Heifer MGA	Fed cattle price	2,182.19	171.90	1,678.45	2,594.43
	Barley	327.16	16.63	304.69	350.72
	Corn Silage	11.50	0.58	10.71	12.33
	DDGS	28.80	1.46	26.82	30.87
	Supplement	26.83	1.36	24.99	28.77
	MGA	8.51	0.43	7.93	9.12
	Feeder price	1,566.06	2.67	1,562.44	1,569.85
Steer Control	Interest on operating capital	7.02	0.71	6.07	8.04
	Fed cattle price	2,101.03	174.34	1,647.65	2,773.69
	Barley	325.51	16.55	303.16	348.96
	Corn Silage	11.44	0.58	10.66	12.27
	DDGS	28.65	1.46	26.69	30.72
	Supplement	26.70	1.36	24.87	28.62
	Feeder price	1,756.55	3.00	1,752.50	1,760.80
Steer TBA	Interest on operating capital	6.84	0.69	5.91	7.84
	Fed cattle price	2,114.77	169.01	1,491.09	2,595.74
	Barley	367.64	18.69	342.40	394.12
	Corn Silage	12.93	0.66	12.04	13.86
	DDGS	32.36	1.64	30.14	34.69
	Supplement	30.16	2.53	28.08	32.32
Steer TBA	Implant	5.56	0	5.56	5.56
	Feeder price	1,756.55	3.00	1,752.50	1,760.80

	Interest on operating capital	7.81	0.79	6.77	8.95
	Fed cattle price	2,349.75	211.39	1,766.75	2,877.42
	Barley	391.02	16.66	374.46	407.57
	Corn Silage	13.75	0.59	13.17	14.33
	DDGS	34.42	1.47	32.96	35.88
	Supplement	32.07	1.37	30.71	33.43
Steer	Implant	5.56	0	5.56	5.56
RAC+TBA	Optaflexx	17.96	0	17.96	17.96
	Feeder price	1,756.55	3.00	1,752.50	1,760.80
	Interest on operating capital	8.86	0.74	8.13	9.59
	Fed cattle price	2,431.66	119.63	2,152.18	2,754.63

7.4 Risk Analysis

This analysis elaborates on the findings of the partial enterprise budget by adding distributions to the stochastic variables. Using the historical data outlined in Chapter 4, this analysis suggests the treatment group is more likely to receive the highest net return with the least amount of risk which can be deemed as the most economical alternative.

7.4.1 Summary Statistics

Similar to the partial enterprise budget results, Table 9 displays summary statistics for the stochastic random variables from 10,000 iterations including the mean, standard deviation, minimum, maximum and skewness.

Table 9. Summary statistics for stochastic variables

Treatment Group	Variable (\$/hd)	Mean	Std. Dev.	Minimum	Maximum	Skewness
Heifer Control	Barley	364.73	68.09	222.20	567.78	0.2679
	Corn Silage	11.36	0.30	10.64	12.10	0.0223
	DDGS	28.43	0.75	26.54	30.26	0.0175
	Supplement	26.50	0.71	24.77	28.25	0.0220
	Feeder calf price	1,538.82	129.14	1,257.15	1,888.81	0.1966
	Fed cattle price	2,187.82	173.92	1,759.36	2,619.98	0.0121
Heifer TBA	Barley	393.75	73.47	238.17	603.09	0.2642
	Corn Silage	12.26	0.33	11.48	13.07	0.0254
	DDGS	30.70	0.82	28.67	32.69	0.0193
	Supplement	28.60	0.76	26.67	30.49	0.0173
	Feeder calf price	1,538.84	129.19	1,257.27	1,907.74	0.1994
	Fed cattle price	2,360.02	188.04	1,859.03	2,796.43	-0.0958
Heifer MGA	Barley	369.62	68.98	224.04	569.24	0.2655
	Corn Silage	11.51	0.31	10.77	12.25	0.0208
	DDGS	28.82	0.77	26.93	30.71	0.0188
	Supplement	35.36	0.94	33.13	37.69	0.0224
	Feeder calf price	1,538.82	129.15	1,254.98	1,893.48	0.1965
	Fed cattle price	2,325.85	229.79	1,817.35	2,967.14	0.1764
Steer Control	Barley	367.76	68.60	220.12	538.83	0.2655
	Corn Silage	11.45	0.30	10.67	12.26	0.0274
	DDGS	28.67	0.76	26.72	30.68	0.0241
	Supplement	26.72	0.71	24.90	28.59	0.0212
	Feeder calf price	1,742.97	17.43	1,460.49	2,192.24	0.3305
	Fed cattle price	2,306.77	228.74	1,657.39	2,850.94	-0.1260
Steer TBA	Barley	415.35	77.49	253.46	632.54	0.2636
	Corn Silage	12.94	0.34	12.08	12.84	0.0206
	DDGS	32.38	0.86	30.30	34.55	0.0213
	Supplement	30.18	0.80	28.18	32.20	0.0190
	Feeder calf price	1,742.95	137.34	1,470.65	2,136.42	0.3286
	Fed cattle price	2,573.99	230.96	2,006.14	3,122.67	-0.0397
Steer RAC+TBA	Barley	429.54	80.16	262.86	654.82	0.2657
	Corn Silage	13.75	0.22	13.21	14.31	0.0007
	DDGS	34.42	0.55	33.06	35.82	0.0017
	Supplement	32.07	0.51	30.80	33.37	0.0008
	Feeder calf price	1,742.98	137.53	1,465.75	2,165.11	0.3329
	Fed cattle price	2,684.44	125.24	2,392.78	3,006.71	0.0650

7.4.2 Stochastic Simulation

In addition to the above summary statistics outlining stochastic inputs, Figures 6 and 7 include the overlaid CDF curves of the key output variables for each gender and treatment group. It is noteworthy to mention the lines at -\$157 and \$578 in Figure 6 and -\$324 and \$565 in Figure 7 show the 90% confidence intervals for the heifer and steer control groups, respectively, in comparison to the other treatment groups. This marker is important as it means that there is a 5% chance the heifer control group will receive a net return over \$578 as opposed to a 17.8 or 20.8% chance for the TBA or MGA groups. Likewise, for steers, the control group is estimated to yield net returns over \$565 only 5% of the time; whereas the TBA or RAC+TBA groups are estimated to be 20.5 or 23.1% of the time.

Figure 5. Cumulative distribution functions of treatment alternative net returns in the heifer class

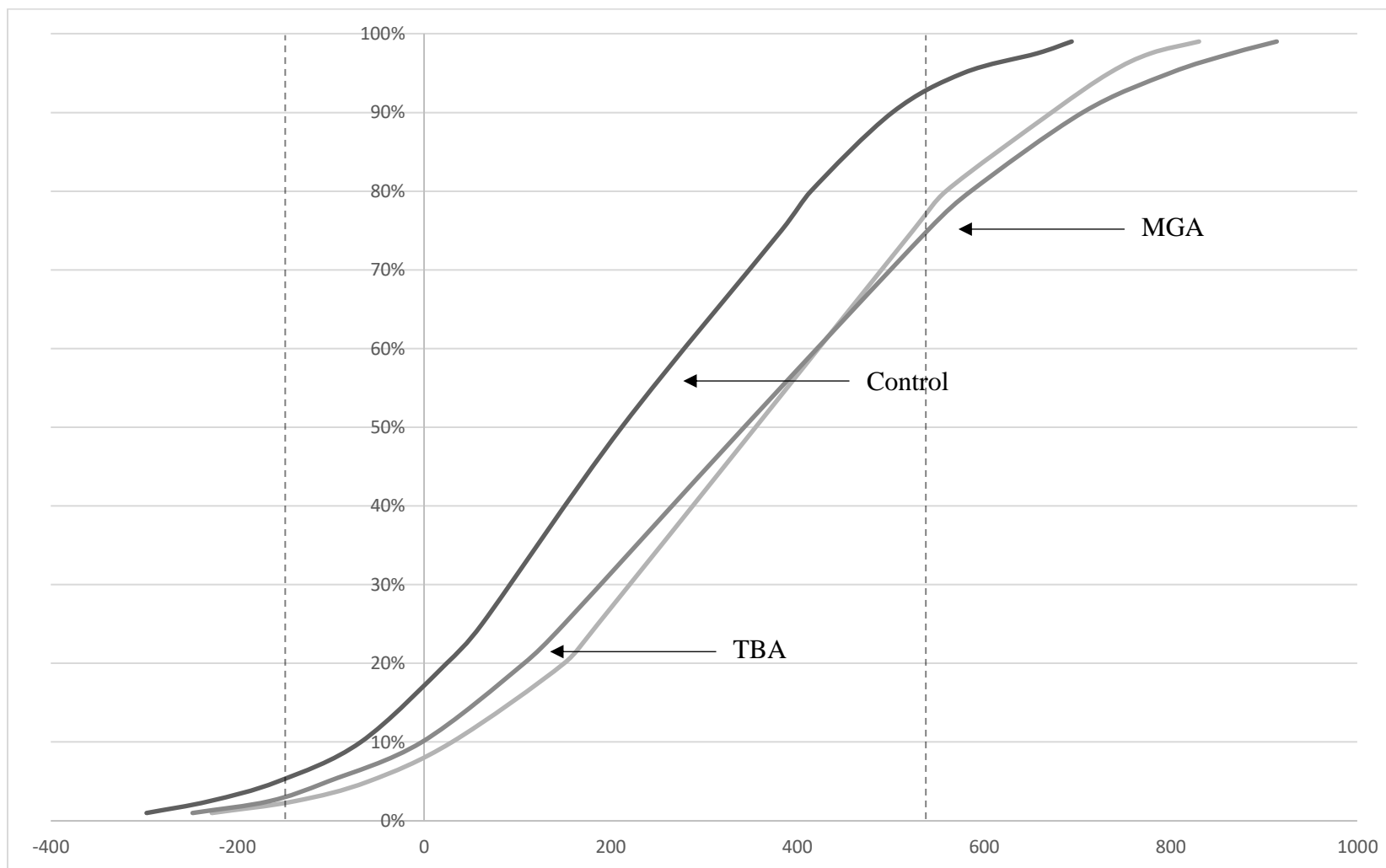
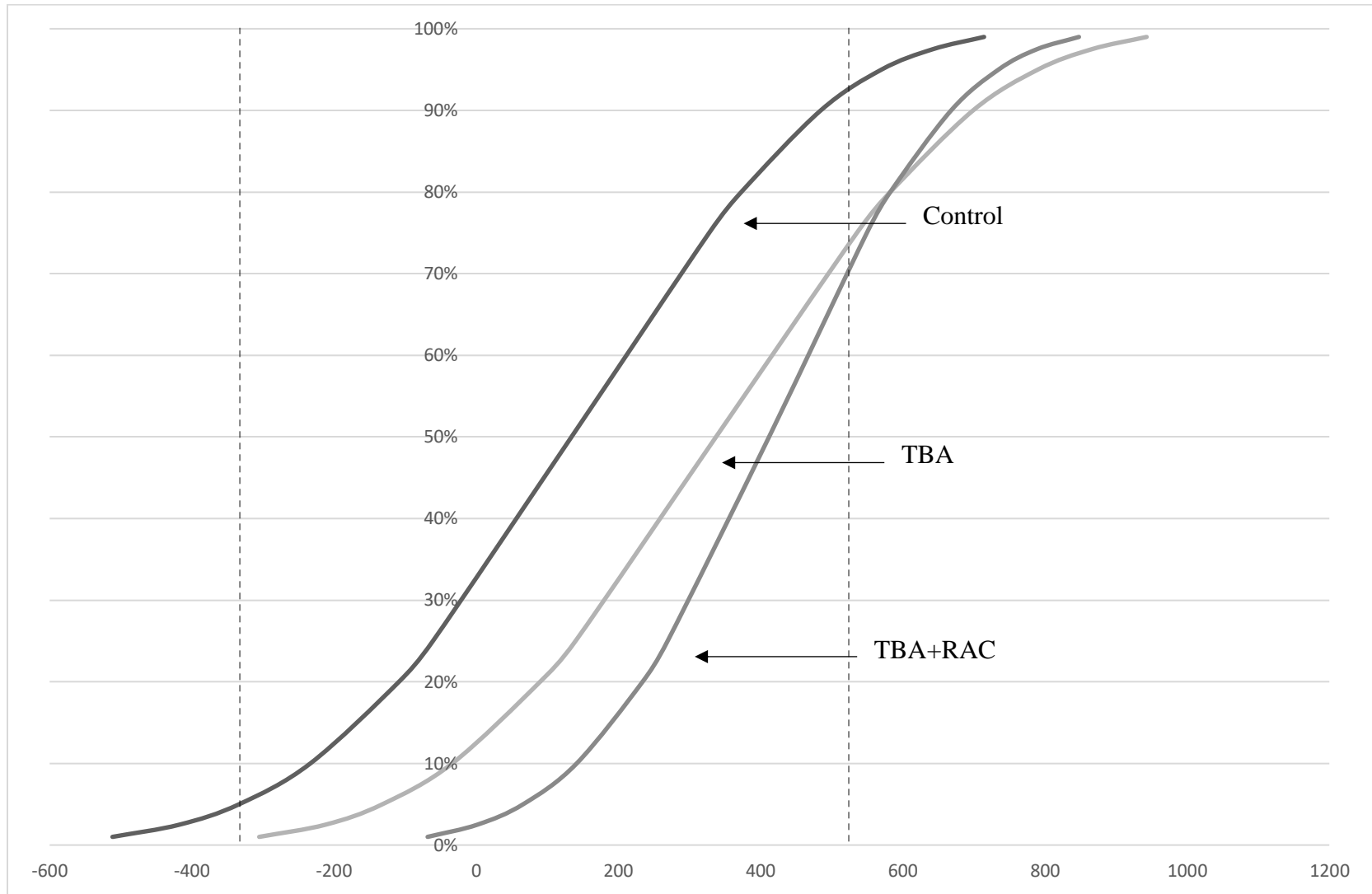


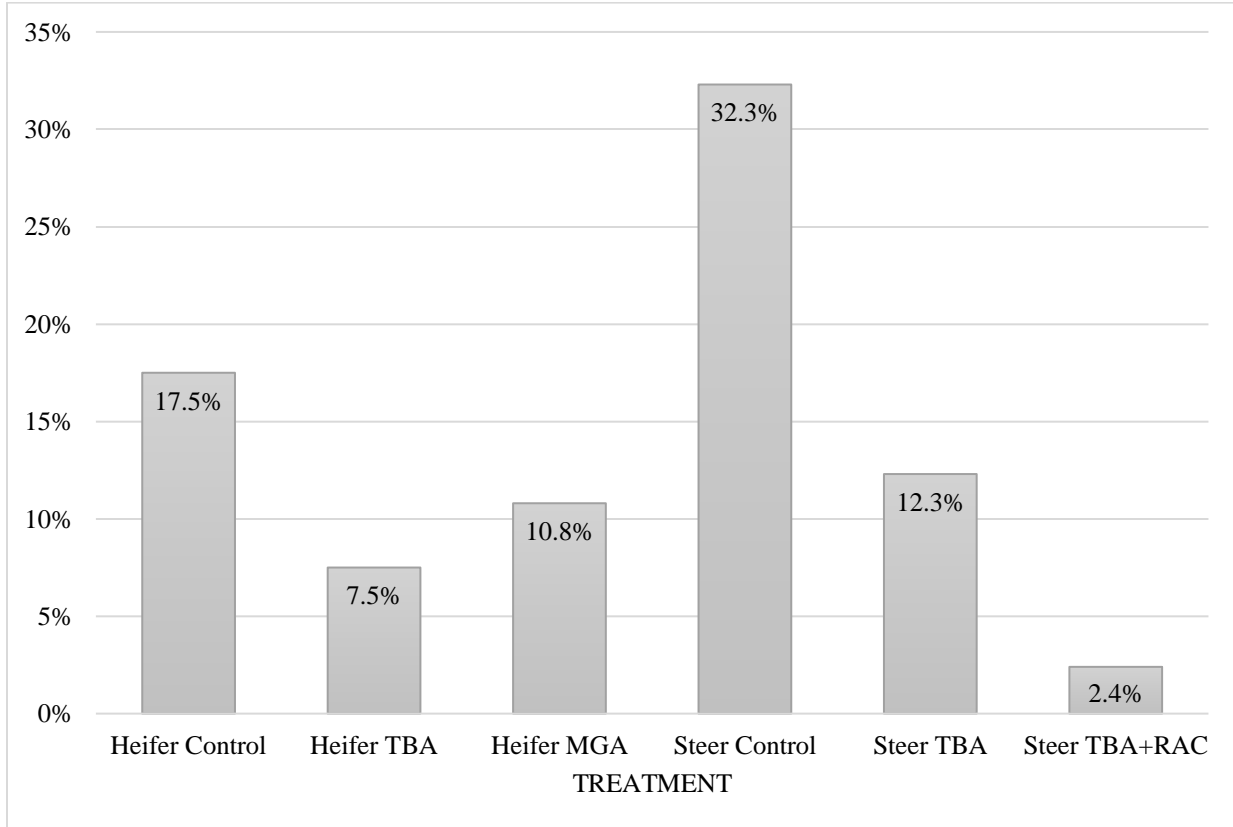
Figure 6. Cumulative distribution functions of treatment alternative net returns in the steer class



When overlaying the CDF curves for each class and treatment group, is it possible to assess stochastic dominance. Beginning with FSD, it is evident through a visual inspection of both the heifer and steer CDFs that the control group is the least efficient in the first-degree. This follows the FSD theory outlined in section 5.2.3 since it is the leftmost curve, meaning the right tail end of the CDF, or the location of higher probabilities, is reaching lower net returns. Through pairwise comparison, the control groups for heifers and steers are eliminated as an alternative option because of its placement. It is clear that for both heifer and steer classes, further analysis using SSD is required to determine which of the remaining alternatives would be preferred for a risk averse producer. Following the theory introduced in section 5.2.4 – which states SSD is determined by comparing the area under each alternative's curves; however, the @RISK student version does not include a function for this test. Although SSD cannot be definitively determined in this research, a visual inspection can estimate that the TBA treatment group is second-degree stochastically dominant to MGA for heifers; and RAC+TBA is second-degree stochastically dominant to TBA for steers. Results from the overlaid CDFs can indicate, according to where the GET curves cross, that MGA will dominate 29% of the time and TBA for other 61% of the time; and TBA will dominate 20% of the time and RAC+TBA for the other 80% for steers.

Since the current SSD cannot definitively indicate which treatment is most risk efficient, the CDF curves can measure and compare the probability percentages at specified values of interest. Figure 5 illustrates the percentages or likelihood of each treatment group, according to sex class, yielding zero or negative net returns.

Figure 7. Probability of treatment groups having a negative net return



Each alternative's CDF curve can estimate the probability of the treatment groups experiencing a net return equal to or less than zero. The above graphical representation of these probabilities makes it visually easy for the decision maker to understand the variation between alternatives. Both control groups for heifers and steers have the highest probability, 17.5 and 32.3% respectively, of realizing a net return equal to or below zero. However, the conventional treatment groups' probabilities are much closer, especially for heifers, where TBA is 3.3% less likely to yield negative net returns than MGA. The best probability, for the steer and heifer class, is seen with the RAC+TBA treatment group which is estimated to experience negative returns only 2.5% of the time when used in the feedlot.

Results estimating the stochastic dominance between alternatives are important supplementary information to those from the partial enterprise budget. This is demonstrated when the latter suggested the RAC+TBA treatment group being the more economical alternative based on four-year AAFC experimental data; and results were strengthened by adding distributions onto the variables based on historical market data in the stochastic budget, producing complimentary results. The key takeaways for the decision maker from the stochastic budgets are within the revenue minimum and maximum differences between alternatives. For example, the revenue range (Appendix A) is much smaller than for RAC+TBA than TBA, specifically due to the higher minimum of RAC+TBA. This alone is evidence that it is less likely for producers using RAC+TBA treatments to experience a negative net return. Moreover, the heifer class is a similar case as estimates for SSD and ranking of probabilities for negative net returns are also complimentary. These results are likely to stem from the revenue ranges in the stochastic budget. The stochastic analysis takes all values on the curve into account when estimating, whereas the probabilities for negative net returns focus on the lower portion of the CDF – both using areas of the overlaid curves where TBA dominates. It is important for a decision maker to understand the analyses’ benefits and suggestions, and implement them in a way that will complement their risk preference and financial situation.

To summarize the economic findings, Table 10 lays out the average total costs, gross revenue and expected net returns from the stochastic simulations.

Table 10. Simulation results of total cost, gross revenue and expected net return

Variables (\$/hd)	Heifer			Steer		
	Control	TBA	MGA	Control	TBA	TBA+RAC
Total cost	1,969.85	2,009.70	1,984.13	2,177.57	2,239.39	2,276.95
Gross revenue	2,187.82	2,360.05	2,325.82	2,306.77	2,574.01	2,684.43
Net return	217.98	350.35	341.69	129.20	334.62	407.48

Note. Results in table show the output from one simulation

In reference to the expectation in Chapter 1, stating that conventional production systems are more likely to experience higher net returns than non-conventional. Early in this thesis, it was hypothesized that conventional (GET) production systems would be more profitable than their non-GET counterparts. The results displayed in Table 10, showing the net returns simulated by the risk analysis, confirm this hypothesis. These economic results are intended to supplement to the previous research provided in Chapter 3, with an attempt to close the gap by contributing more recent beef research on GETs at the feedlot level by using current Canadian data from reputable sources and real-world experiments.

Chapter 8: Conclusions, Limitations and Suggestions for Future Research

8.1 Conclusions

The primary objective of the research reported in this thesis is to determine the relative profitability of conventional cattle feeding systems using growth-enhancing technologies (GETs) to systems where GETs are not used. Earlier work by Ribeiro et al. (2021) and Boonstra et al. (2023) provide thorough information on the animal and environmental impacts of GETs, respectively, and this new research supplements these studies by adding an important economic dimension. Data from a four-year study on 880 British x Continental beef calves from Agriculture and AgriFood Canada Lethbridge were used to develop a partial enterprise budget in Excel that was imported into SAS which, by manually writing-in code and applying the MEANS procedure, produced results indicating the use of conventional GETs, specifically trenbolone acetate + estradiol (TBA), melengestrol acetate (MGA) and ractopamine hydrochloride (RAC)+TBA experienced higher relative net returns compared to the control. These results included differing gender specific findings such that heifers raised with the TBA implant and steers raised with the TBA implant and RAC feed additive (Optaflexx) generated the greatest net return. Therefore, the partial enterprise budget confirms that the use of GETs can assist in maximizing expected profits at the feedlot stage.

Stochastic simulation using @RISK added a dimension of decision making under uncertainty to the analysis; and additional data were obtained and utilized in the distributions of stochastic variables. To determine risk efficiency of the treatment group net returns, dominance analyses were employed, including first-degree and second-degree stochastic dominance. These simulations produced similar results favouring conventional production systems over non-conventional with respect to net returns. Like the partial enterprise budget findings, additional

gender-specific findings included differences with the heifers favouring the TBA implant and the steers favouring the RAC feed-additive in addition to the TBA implant. Heifers that received the TBA implant and steers that were administered the RAC feed-additive plus TBA implant were estimated to be second-degree stochastically dominant to heifers with MGA feed additives and steers with TBA implants. It is important to additionally note that when estimating the probabilities of each treatment group experiencing a negative net return, results continued to favour the steers receiving RAC+TBA and heifers with TBA implants to be more likely to generate positive net returns.

The results not only identify the most risk-efficient treatment groups according to sex, but also show trends within measurements and prices included in the budget and simulation. Accordingly, it seems clear that from an economic standpoint, the increase in revenue from the use of GETs is driving cattle-feeding profitability, as opposed to any decrease in production costs. The replicated animal performance measures indicate that DMI values for all GETs used in production are higher than the respective control group. Intuitively, the increased DMI indicates cattle consuming more feed throughout the whole finishing phase and therefore, explains the biggest variation to be within feed costs, alongside fed prices. In summary, the results from this thesis contribute to existing research on conventional practices used in beef production and confirm these practices are beneficial to a producer through improved animal performance, sustainability and economic performance.

8.2 Limitations

Field experiments using live cattle within Canada are very expensive and time consuming and as a result are not widely used, leaving a void of information for producers. A considerable portion of the data used in this research were adapted from a four-year trial where substantial and

extensive animal and environmental measures were recorded. Carcass weights and characteristics such as dressing percentages, ribeye area, backfat and quality grades were obtained; however, the hot carcass weights were not valued depending on these traits. Instead, carcasses were priced according to an annual per hundredweight valuation, so premiums or discounts were unaccounted for by the packer. As such, it is recommended that a grid pricing scheme be incorporated within the partial enterprise and stochastic budgets, to further interpretate the monetary benefits that can be derived from these technologies to support producer decision making.

This research used a partial enterprise budget which, by definition, is only a portion of a full enterprise budget. This was chosen as this type of budget's characteristics complement the objective of determining relative profitability, so the focus is on differentiating the outputs of treatment groups; however, the partiality does not give producers a full picture. If additional fixed and variable costs such as labour, pharmaceuticals, machinery investments and depreciation, fuel, land investments and taxes, feed and utility storage or insurance were incorporated into the budget, a more thorough net return could be estimated, as opposed to a narrower scope showing relativity. Further economic benefits can be found in dollar value per head saved by adjusting the DOF of conventional cattle to produce the target weight of non-conventional cattle and calculating the lesser number of days in the feedlot. According to the ADG and total weight gain results it is highly likely producers will benefit. These benefits are predicted to generate a higher animal turnover which in turn can reduce total costs per animal by spreading the annual overhead costs onto more cattle; or minimize the number of DOF for cattle, thereby also contributing a lower environmental footprint throughout production.

The stochastic simulation included the first two, and least restrictive, dominance analyses – first-degree (FSD) and second-degree stochastic dominance (SSD). These restrictions consisted of requiring a positive marginal utility for FSD and possessing a risk-averse risk preference for SSD. This research followed preferences that were applied in previously published literature and considered the more commonly occurring unprecedented market and weather events; therefore, assumed a risk-averse preference. The latter restriction of SSD is not always the case for feedlot producers, however, as market prices and weight requirements can alter producer's preference to be more risk-neutral.

Lastly, the feedlot on-weight, and consequently the feeder price for heifers and steers were assumed to be equal according to sex and treatment group for the sake of calculating relativity of the non-conventional to the conventional feedlot production systems. This assumption, however, excludes the possible cost and weight gain already possessed when entering the feedlot and, therefore, theoretically has potential to marginally reduce the net return of conventional systems.

8.3 Suggestions for Future Research

These research methods and findings aim to create a foundation for future exploration of GETs in various sectors of the cattle industry which currently remain unexplored at a national and international level, as well as within potential producer financial viability and sustainability initiatives.

Although there has been much research demonstrating the benefit of GETs in beef production as previously described, there still continues to be controversy within the beef industry on the environmental and economic impacts of removing GETs from production; and whether is it beneficial for producers to enter into either domestic or international GET-free

markets. As stated in Chapter 1, part of the reason CETA was created is to allow for GET-free beef to be traded by Canada to the European Union (EU), which as reported by Boonstra et al. (2023), could result in \$600 million of revenue through international trade, according to the Canadian Agri-food Trade Alliance. However, as Boonstra also noted, the EU has been slow to show actions of commitment related to CETA; and accordingly, Canada is on a trajectory to experience a \$150 million deficit in traded red meat with the EU (Arnason 2020). This discrepancy between the projected deficit in Canadian revenue and potential opportunity presented through CETA suggests that further research is needed to ensure producers receive an adequate portion of the premiums associated with GET-free beef to compensate for the anticipated decreased net returns demonstrated through the results of this and other existing literature.

A recent article from The Western Producer predicts the demand of various animal proteins including beef (10%) will increase internationally within the next decade; however, notes that Canada has been at stagnant production output values due to the policies established in attempt to decrease Canada's animal production environmental footprint (Arnason 2024). As a result, other beef producing countries are predicted to increase their output to satisfy the increased international demand. This increased supply from other countries can impose a threat internationally because Canada is known to be one of the lowest emitters of greenhouse gasses on a global scale (Arnason 2024). Additional research is encouraged to investigate complementary trade opportunities between beef producing countries and consequential policies to ensure environmental footprints are fairly monitored and controlled.

Finally, replicating the methods used in this research on further economic and animal performance data within the cow-calf and backgrounding supply chain phases and an additional

risk neutral preference can create a more holistic review of GETs' contribution to the Canadian and international cattle industry. Similar budgeting and stochastic simulation methods can also be applied to additional or new technologies to determine profitability and efficiency for producers. Additionally, research incorporating possible environmental trade-offs and rebates throughout the feedlot and other production phases into the budgets and stochastic models for technologies is encouraged.

8.3.1 Willingness-to-pay Premiums

The addition of price grids, noted as a limitation, can be an extension of this research as WTP premiums on non-conventionally raised beef are common in the EU. There are many variables that need to be incorporated into determining whether these WTP premiums are profitable for a non-conventional beef producer.

Based on a preliminary literature review, there is a limited amount of recent extensive research on the additional costs associated with producing non-conventional beef in order to comply with CETA. Although these additional costs are not specifically comparable to those that would be realized by producing GET-free beef to market in Canada, the current research provides direction for further examination required for Canada's beef supply chain. Beckman et al. (2021) indicate that compliance requirements and general additional costs for [US] GET-free beef to enter the EU include certification costs, increased production costs resulting from lower feed efficiency for producers, testing and tracking costs for packers and increased marketing and distribution costs for various stakeholders.

A recent study by Norris et al. (2020) reviewed consumers' WTP for ground beef and steaks that were produced with (conventional) and without (non-conventional) the use of antibiotics and added hormones. Findings of this research indicate that consumers were willing

to pay 225% and 150% more on average for non-conventionally produced ground beef and steak, respectively; however, also indicated that WTP was based on many variables such as purchase location (retail or food service), product type (ground beef or steak) and consumer attributes (preferences and values).

The current research identifies there is profitability in using GETs for beef production; however, it does not dismiss the potential that there could be profitability for feedlots to produce GET-free beef if the premiums negate the increased and additional costs mentioned by Beckman et al. (2021) and Norris et al. (2020). The opportunity for future research is to fill the gap between this research that demonstrates cost savings/increased revenues for conventional beef production and the research conducted by Norris et al. (2020) that demonstrates the WTP for non-conventionally produced beef. Ultimately, additional research is suggested to determine if the premium retained at retail is received throughout the whole supply chain and is substantial enough to relieve additional costs to confirm if non-conventional beef production is a profitable market.

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Appendix A

Table 11.1. Stochastic budget for heifer control treatment group

Cost variable (\$/hd)	Heifer – Control				Probabilistic value ¹	Variable type
	Base Case	Minimum	Most likely	Maximum		
Grain						
Barley	332.85	217.26	346.67	584.44	364.73	Random
Corn silage	11.35	10.57	11.35	12.17	11.36	Random
DDGS	28.42	26.47	28.42	30.46	28.44	Random
Supplement	26.48	24.66	26.48	28.39	26.50	Random
Treatment(s)	0.00	0.00	0.00	0.00	0.00	Deterministic
Feeder price	1513.45	12.44.28	1513.45	1934.84	1538.82	Random
Revenue variable (\$/hd)						
Fed cattle price	2005.98	1731.95	2185.79	2651.78	2187.82	Random
Net return (\$/hd)	103.43	208.71	259.42	61.48	217.98	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation

Table 11.2. Stochastic budget for heifer TBA treatment group

Heifer – TBA						
Cost variable (\$/hd)	Base Case	Minimum	Most likely	Maximum	Probabilistic value ¹	Variable type
Grain						
Barley	348.52	234.55	374.26	630.95	393.76	Random
Corn silage	12.25	11.41	12.25	13.14	12.26	Random
DDGS	30.68	28.57	30.68	32.89	30.70	Random
Supplement	28.59	26.62	28.59	30.65	28.61	Random
Treatment(s)	5.56	5.56	5.56	5.56	5.56	Deterministic
Feeder price	1513.45	12.44.28	1513.45	1934.84	1538.82	Random
Revenue variable (\$/hd)						
Fed cattle price	2183.01	1826.46	2377.65	2823.22	2360.05	Random
Net return (\$/hd)	243.96	275.47	412.86	175.19	350.35	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation

Table 11.3. Stochastic budget for heifer MGA treatment group

Heifer – MGA						
Cost variable (\$/hd)	Base Case	Minimum	Most likely	Maximum	Probabilistic value ¹	Variable type
Grain						
Barley	327.16	220.17	315.32	92.28	369.62	Random
Corn silage	11.50	10.71	11.50	12.33	11.51	Random
DDGS	28.80	26.82	28.80	30.87	28.82	Random
Supplement	35.34	32.92	35.34	37.89	35.36	Random
Treatment(s)	0.00	0.00	0.00	0.00	0.00	Deterministic
Feeder price	1513.45	12.44.28	1513.45	1934.84	1538.82	Random
Revenue variable (\$/hd)						
Fed cattle price	2098.20	1792.95	2285.92	3018.28	2325.82	Random
Net return (\$/hd)	181.95	258.05	345.51	410.07	341.69	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation

Appendix B

Table 12.1. Stochastic budget for steer control treatment group

Cost variable (\$/hd)	Steer – Control				Probabilistic value ¹	Variable type
	Base Case	Minimum	Most likely	Maximum		
Grain						
Barley	325.51	219.07	349.55	589.30	367.76	Random
Corn silage	11.44	10.66	11.44	12.27	11.45	Random
DDGS	28.65	26.69	28.65	30.72	28.67	Random
Supplement	26.70	24.87	26.70	28.62	26.72	Random
Treatment(s)	0.00	0.00	0.00	0.00	0.00	Deterministic
Feeder price	1697.55	1459.05	1697.55	2208.59	1742.97	Random
Revenue variable (\$/hd)						
Fed cattle price	2126.27	16.41.19	2335.59	2857.05	2306.77	Random
Net return (\$/hd)	36.42	-99.15	221.70	-12.45	129.20	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation

Table 12.2. Stochastic budget for steer TBA treatment group

Steer – TBA						
Cost variable (\$/hd)	Base Case	Minimum	Most likely	Maximum	Probabilistic value ¹	Variable type
Grain						
Barley	367.64	246.42	394.79	665.57	415.36	Random
Corn silage	12.93	12.04	12.93	13.86	12.94	Random
DDGS	32.36	30.14	32.36	34.69	32.38	Random
Supplement	30.16	28.08	30.16	32.33	30.18	Random
Treatment(s)	5.56	5.56	5.56	5.56	5.56	Deterministic
Feeder price	1697.55	1459.05	1697.55	2208.59	1742.97	Random
Revenue variable (\$/hd)						
Fed cattle price	2371.45	1944.60	2583.09	3167.08	2574.01	Random
Net return (\$/hd)	225.25	162.31	409.74	206.48	334.62	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation

Table 12.3. Stochastic budget for steer RAC+TBA treatment group

Steer – RAC+TBA						
Cost variable (\$/hd)	Base Case	Minimum	Most likely	Maximum	Probabilistic value ¹	Variable type
Grain						
Barley	391.02	255.86	408.27	688.29	429.54	Random
Corn silage	13.75	13.17	13.75	14.33	13.75	Random
DDGS	34.42	32.96	34.42	35.88	34.42	Random
Supplement	32.07	30.71	32.07	33.43	32.07	Random
Treatment(s)	24.20	24.20	24.20	24.20	24.20	Deterministic
Feeder price	1697.55	1459.05	1697.55	2208.59	1742.97	Random
Revenue variable (\$/hd)						
Fed cattle price	2359.49	2368.83	2676.45	3031.93	2684.43	Random
Net return (\$/hd)	166.48	552.88	466.19	27.21	407.48	Key output

¹ Probabilistic value of random variables is a value from one of 100,000 iterations produced by the Latin Hypercube simulation