Economics of Preconditioning Beef Cattle

by

Michael Sydora

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Department of Resource Economics and Environmental Sociology
University of Alberta

Abstract

Calf morbidity and mortality due to Bovine Respiratory Disease (BRD) is highest in the first two weeks after arrival at the feedlot. Feedlots use antimicrobial drugs (AMDs) to maintain calf health, which contributes to general antimicrobial resistance (AMR). AMR causes externality costs to human health care. Preconditioning is a practice designed to prepare calves for the transition to a feedlot and reduce antimicrobial use (AMU). Despite a large literature on the improved health of preconditioned (PC) calves at the feedlot, preconditioning has not been widely adopted in Canada. I hypothesize that this is mainly due to the presence of uncompensated externalities leading to a market failure for PC calves.

Data from a University of Calgary study was used to examine three economic aspects of preconditioning: (1) the impact of PC calves on AMU and the AMR externality costs to human health, (2) feedlot cost differences for PC and non-PC calves, and (3) an updated profitability analysis of preconditioning for cow-calf operations.

The results showed that the expected number of AMD treatments for BRD was 37-53% lower for PC calves, which would reduce the negative externality of AMR in Alberta and Saskatchewan by up to $450,000 for each annual fall feedlot intake. PC calves showed a reduction in feedlot health costs of $8.57-$13.86 per head compared to non-PC calves, and were not adversely impacted by commingling with non-PC calves. However there was no difference in the net return from PC calves compared to non-PC calves. Cost-return analysis for preconditioning at the cow-calf level showed a small loss of $38.57/head, suggesting that there is no financial incentive for cow-calf producers to precondition calves prior to selling in the absence of additional premiums.

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Abbreviations

AD Auction-derived.

ADG Average Daily Gain.

AMD Antimicrobial Drugs.

AMR Antimicrobial Resistance.

AMU Antimicrobial Use.

BRD Bovine Respiratory Disease.

BSE Bovine spongiform encephalopathy.

BVDV Bovine Viral Diarrhea Virus.

DM Dry Matter.

DMFC Dry Matter Feed Conversion.

FC Feed Conversion.

PC Preconditioned.

RS Ranch-sourced.

WHO World Health Organization.

Chapter 1

Introduction

1.1 Motivation

The beef industry is one of Canada's largest and most important agricultural sectors. In 2019, sales of cattle and calves amounted to \$9.39 billion in cash receipts, accounting for just over 14% of the cash receipts for Canada's entire agriculture sector (Canfax, 2020). The sector is responsible for many major environmental and social impacts due to its scale (Balmford et al., 2018). Of increasing concern is antimicrobial[1] use (AMU) on livestock to treat infections and its relationship with general antimicrobial resistance (AMR), which negatively impacts human health. Pressure has been mounting in recent years for Canada to increase surveillance and stewardship of AMU in its livestock sectors (Hannon et al., 2020; Sargeant et al., 2019). Relatively minor changes in production practices have the potential for large cumulative effects due to the size and increasingly centralized structure of the industry.

Calf morbidity and mortality is highest in the first few weeks after arrival at the feedlot, when calves are approximately 6-7 months old. Prior to arriving at the feedlot, calves will have been weaned off their mother's milk and transported to live auction markets where potentially thousands of calves per week from dozens of operations are sorted into groups of similar sex, weight, and breed. Due to the stress

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[1] Antimicrobial refers to products that act against microorganisms. Antibacterials/antibiotics, antifungals, and antivirals are subsets of antimicrobials that act on bacteria, fungi, and viruses, respectively.

from weaning and transportation, calves are especially susceptible to diseases such as Bovine Respiratory Disease (BRD), which can create substantial costs for feedlot owners (Chirase et al., 2004; Peel, 2020).

One practice aimed at reducing these health issues is preconditioning, a practice designed to reduce health costs through slow weaning and feeding of calves for a minimum of 45 days before sale or shipment to a feedlot (Radostits, 2000). The concept of preconditioning has existed since the 1960s (Bristol, 1967; Herrick, 1968; Sheldon, 1968; Totusek & Stephens, 1969), and gained some traction in the 1980s in Canada (Novak, 1984; Schipper et al., 1989), but was relatively short-lived, and no certification presently exists. In contrast, preconditioning has been growing in popularity in the United States since the 2000s (Lalman & Ward, 2005; Lhermie, Verteramo Chiu, et al., 2019).

Preconditioned (PC) calves have several positive qualities that have been well documented, including potential positives externalities to human health. The main reason for feedlots to purchase PC calves is decreased morbidity and mortality for the PC calves (Lalman & Ward, 2005). PC calves may also spend more time feeding and are less susceptible to shrinkage from transportation, though these benefits are not guaranteed (Barnes et al., 2007; Pritchard & Mendez, 1990; Woods, Mansfield, et al., 1973). Potential benefits can also take on intangible qualities, such as positive feelings for both producers and consumers associated with improving animal welfare (Olynk et al., 2010; Stampa et al., 2020). Parties outside beef producers and consumers benefit from cattle that use fewer antimicrobial drugs (AMDs) because it reduces the probability that new AMR strains will spawn.

Most cow-calf producers use either traditional abrupt weaning or fenceline weaning prior to selling their calves (University of Saskatchewan, 2018). In the case of abrupt weaning, calves are taken from their mothers and sold immediately. Fenceline weaned calves will spend an additional week with limited access to their mothers before being sold (Price et al., 2003). Preconditioning requires that producers hold on to calves for at least 45 days after removing them from their mothers, as well as implementing booster vaccinations, castration, and dehorning using a method that reduces stress (Radostits, 2000). Cow-calf producers bear all the costs of preconditioning which includes extra feed for 30-60 days, labour, and vaccinations. Cost recuperation may come in the form of a preconditioning premium, with feedlots paying specifically for the benefits they anticipate. In practice, preconditioning premiums are not guaranteed and depend heavily on fluctuating calf prices (Brooks & Eirich, 2014).

To some extent, there is an element of information asymmetry that reduces the incentive for feedlots to pay a premium for PC calves. PC calves are difficult to differentiate from other calves visually, and not all producers follow the same protocols for preconditioning (Martin et al., 2019). For example, some cow-calf producers may claim they precondition simply by holding on to calves for an additional 30-60 days without any vaccinations. This also makes it difficult to determine precisely how many cow-calf producers precondition, though survey data suggests it is more common in the United States than in Canada (Martin et al., 2019), and preconditioning certification programs in the United States have contributed to higher premiums for PC calves there (Schulz et al., 2010). Certifications for preconditioning have existed in the United States since the late 1960s (Woods, Pickard, et al., 1973), and were also created in Canada in the 1980s in order to promote preconditioning and ensure complete information for buyers, but certifications were discontinued in Canada after about a decade (Jim & Gulchon, 1990). However, if lack of information about preconditioning practices was the only hurdle limiting its adoption, preconditioning should be more widespread in the United States, and would have likely seen widespread adoption in Canada when certification did exist (Jim & Gulchon, 1990).

Two major obstacles exist in the Canadian beef industry that appear to limit the adoption of preconditioning, and both apply to the American beef industry as well. The first is market failure due to externalities. PC calves provide direct benefits to feedlots, but there is also a societal benefit from programs aimed at reducing

AMU. Overuse of AMDs increases the likelihood of AMR, which presents a cost to society, most prominently in the form of additional costs to human health (Coast et al., 1998). The link between AMU in feedlots and AMR is complex, and it remains difficult to precisely value these externalities as a result of AMU in feedlots (Cameron & McAllister, 2016; Rao et al., 2010). Early certification of preconditioning did not reference any reduction in externalities, as the concern of overusing AMDs in livestock was not as well known. If PC calves reduce these externalities, then there should be more of an incentive to adopt the practice of preconditioning.

Another explanation for the minimal uptake of preconditioning are the tight profit margins for both cow-calf and feedlots operators. There exists a long entrenched "buy 'em cheap" mentality in many feedlots, and some feedlot operators believe that greater economic returns can be achieved by managing disease rather than purchasing more expensive PC calves (Fulton, 2009; Jim & Gulchon, 1988). In 2020, Canadian beef producers earned an average operating profit of $0.046 for every dollar of revenue (Statistics Canada, 2022a), which marks the lowest profit margin of any agricultural activity in Canada. For reference, hog production is the only other agricultural activity with profit margins less than $0.12 per dollar of revenue (Statistics Canada, 2022a). As small producers, cow-calf operators tend to be risk averse, and may be hesitant to change production practices to avoid losses (Alemu et al., 2016; Pope et al., 2011; Pruitt et al., 2012).

1.2 Thesis Objectives

There are three main objectives for this thesis. The first objective is to calculate the change in societal welfare from the adoption of preconditioning. To the author's knowledge, no previous study has estimated the changes in social welfare from PC calves. Changes in social welfare were measured by applying the externality cost of AMDs found in Innes et al. (2020) to AMD treatments in a feedlot study and extrapolated to all feedlots in Alberta and Saskatchewan. This analysis of the societal benefits of PC calves can provide an estimate for the social market value of PC calves.

This second objective is to examine PC calf feedlot health and profitability metrics in the context of commingling. These results show whether there are any differences in feedlot performance contributing to financial returns associated with feeding PC calves under different commingling proportions with non-PC calves. Several previous analyses of preconditioning have focusing on the direct benefits and costs of preconditioning for beef producers (Avent et al., 2004; Dhuyvetter et al., 2005; Hilton & Olynk, 2011; Novak, 1984), however, none of these studied the effects of commingling PC calves and non-PC calves. Step et al. (2008) examined feedlot performance[2] and calf health for PC calves during and after commingling, but only in a single pen with a 50% PC 50% non-PC mix.

Finally, following Dhuyvetter et al. (2005) and Schunicht (2017), this thesis provides an updated examination of the profitability of preconditioning for cow-calf operations in the contemporary Western Canadian context, with the aim of providing an estimate of the price and/or premium that would be required for preconditioning to be profitable. Various scenarios are accounted for, including high and low price scenarios, high and low cost scenarios, and a difference in calf daily gain as a proxy for different calf breeds. Determining an accurate value for any practice is important for an industry with such thin profit margins.

1.3 Thesis Outline

This thesis is divided into six chapters. Chapter 2 provides background information on the Canadian beef cattle industry, its structure, production practices, and where preconditioning fits into the structure. Chapter 2 will also provide a literature review of economic valuation of beef cattle health practices, consumer preferences, and externalities produced by beef production. Technology adoption and information asymmetry are also briefly discussed in relation to preconditioning and cattle health

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[2] Study used average daily gain (ADG) and dry matter intake (DMI) as performance metrics.

programs to give a well-rounded view of the economics of preconditioning. Chapter 3 describes the conceptual framework of externalities and how they are applied to the beef industry in the context of preconditioning. The data used to analyze preconditioning is discussed in Chapter 4, as well as empirical specifications of the economic models used in analysis. In Chapter 5, results from the empirical analysis will be summarized and discussed. Finally, Chapter 6 will summarize significant results findings, implications of these findings, the limitations of the analyses, and directions for future research.

Chapter 2

Background and Literature Review

This chapter describes the structure of the beef supply chain in Canada, common beef production practices, and how preconditioning fits in to that structure. Section 2.1 is an overview of the industry as a whole. Section 2.2 explains what preconditioning is and why it is becoming more prominent again. Section 2.3 provides a description of each stage of production, how markets operate and how prices are set, followed by the production decisions from individual firms. Cattle health and the use of antimicrobials in beef production are also described. Section 2.4 provides a literature review on economic concepts as they relate to preconditioning: preconditioning as technological change, an information asymmetry problem, consumer preferences for antibiotic-free or organic meats, and finally externalities produced by beef production.

2.1 Beef Production in Canada

As of January 2021, Canada's cattle herd stands at 11.15 million head, down from a high of nearly 15 million in 2015 (Canfax, 2020). Of Canada's 189,874 farms, 72,405 of them (38%) raise cattle, ranging from small hobby farms with only a handful of cattle to large multi-thousand head operations (Statistics Canada, 2021). The current average number of cattle and calves per farm is 159 (Statistics Canada, 2021). According to the 2021 Census of Agriculture, 39,633 farms classified as specializing in beef cattle production (Statistics Canada, 2022b). About 1/3 of Canada's cattle herd is raised on the largest 1,800 farms, another 1/3 is raised on the remaining beef specialized farms, and the final 1/3 are raised as supplemental income for farms that specialize in agricultural activities other than raising beef cattle.

Cattle fall under two categories - fed and non-fed - with the vast majority of slaughtered cattle being fed cattle. Fed cattle describes steers and heifers raised solely for beef production, whereas non-fed include culled bulls and cows that are no longer able to reproduce, and may also include older dairy cows.

The three general stages of fed cattle production before slaughter at a packing plant are calving[1], backgrounding[2], and finishing[3]. There are several paths from calf to slaughter, and not all calves go through every stage. Some cow-calf operators background their calves, some feedlots have backgrounding operations, and a few farms may raise cattle from birth to slaughter. Ownership of each calf can change at any stage, and several options for leasing or loaning cattle are possible.

Following calving, backgrounding, and feeding, fed cattle are slaughtered and processed at packing plants. Beef products are packaged according to retail specifications or for wholesale, sent to distributors, and finally sold to consumers. The entire process from a calf's birth to consumer market generally takes 15-24 months, making beef production one of the longest agricultural production processes.

Canada's cattle slaughter capacity is approximately 65,000 head per week, with 3.057 million head slaughtered in 2020 for a combined carcass weight of nearly 3.3 billion pounds (Canfax, 2020). Canada's herd size fluctuates according to market prices. Fed steer prices peaked in 2015 and have been on a downward trend[4] (Canfax, 2020). Canada is a large beef exporter, with net exports accounting for 1/3 of production, contributing just under 5% of worldwide beef exports (USDA, 2021). The United States is by far Canada's largest beef export market, with nearly 75% of

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[1] Calves are bred and raised on their mother's milk and pasture until weaning.

[2] Also known as stocking. Cattle are fed a forage-based diet while waiting for feedlot placement.

[3] Also known as feeding. Cattle are finished at feedlots on a grain-based diet to ensure consistent meat qualities before slaughter.

[4] Cow prices follow a similar trajectory.

beef exports.

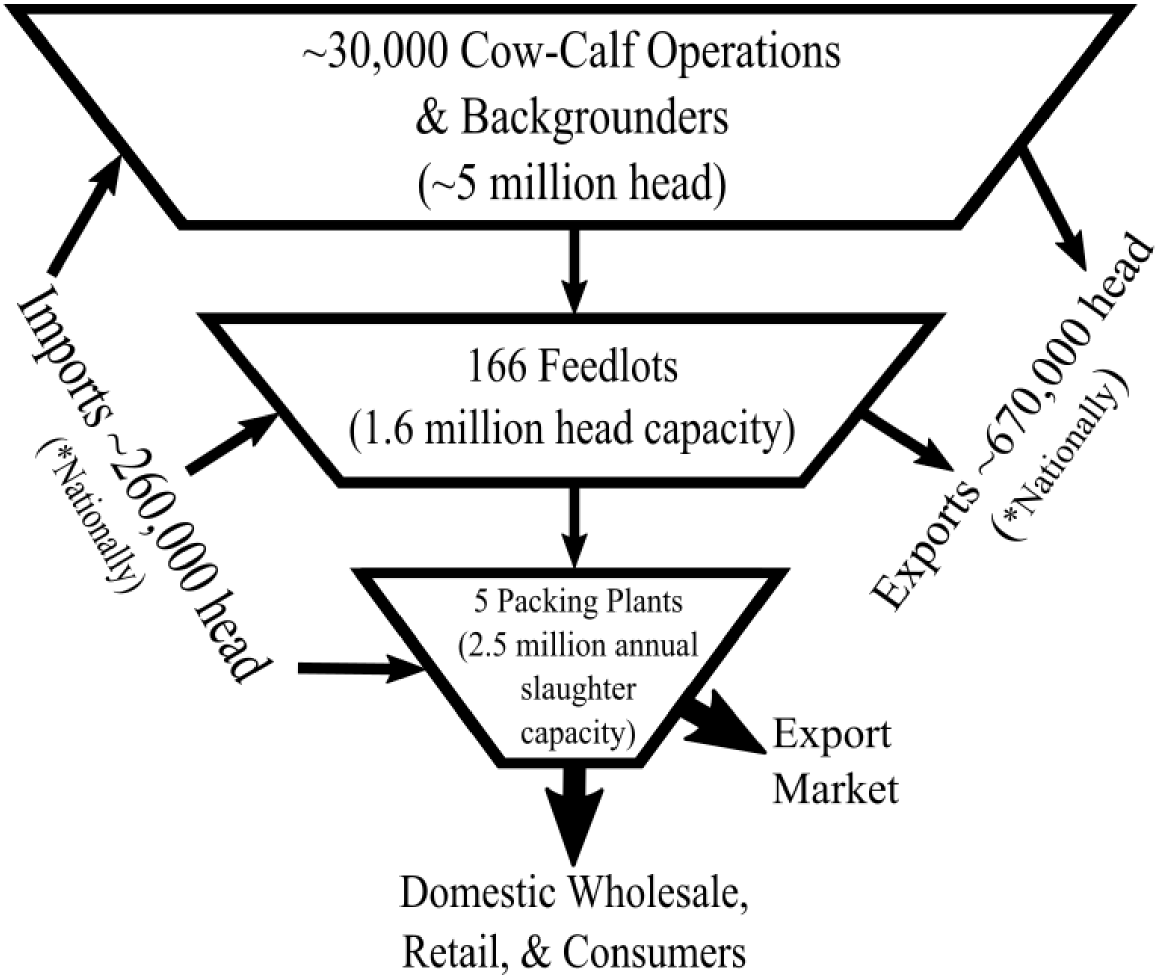
Beef cattle are raised in several distinct stages that have very little vertical integration compared to the production of other meats (Crespi & Saitone, 2018). In general, livestock such as broiler chickens and hogs are raised from birth to slaughter in one place and ownership only changes when the animals are sold for slaughter, whereas very few farms raise cattle from calf to slaughter. Ownership of cattle generally remains separate for each stage.

Economies of scale have a varying presence throughout the production chain, creating a reverse pyramid of supply (see Figure 2.1). A very small number of packing plants purchase fed cattle from a few hundred feedlots, which purchase calves from tens of thousands of individual farms. Feedlots, and especially slaughterhouses benefit from economies of size due to the large infrastructure requirements for production, as well as the repetitive production lines of meat packing (Ji & Chung, 2010). Thousands of cattle are processed per week in these large meat-packing plants, meaning only a few plants are needed to maintain supply. Economies of scale are less prevalent at the cow-calf stage, as the mean number of cattle per farm is 171, and very few cow-calf operations have more than 500 head (Langemeier et al., 2004; Ramsey et al., 2005; Statistics Canada, 2021). Section 2.2.1 will cover the costs of cow-calf operations and some insights into economies of scale.

2.2 Preconditioning

Preconditioning describes calf management practices intended to optimize immune system response to infections and reduce stress in weaned calves (Mathis et al., 2008; Wilson et al., 2017). While the term preconditioning has been used to describe a wide range of practices, the typical definition involves castration and dehorning in a stress minimizing way, and retaining and feeding calves for 30-60 days after an abruptly weaned calf would normally be sold. Calves are also given a series of vaccinations,

Figure 2.1: Beef Cattle Supply Chain in Alberta and Saskatchewan (2020 data)



are weaned in a gradual manner (usually fenceline weaned or nose-paddle weaned[5]) and taught to feed from bunks as they would at the feedlot.

The concept of preconditioning cattle prior to entering the feedlot has existed since the mid-1960s (Bristol, 1967; Herrick, 1968; Meyer et al., 1970). In these early days, preconditioning was advertised to cow-calf operators as a means of gaining a premium on their calves while providing feedlots with healthier calves that would incur fewer health costs (Wirak et al., 1976). In Canada, certified preconditioning programs began in 1980 with the Alberta Certified Preconditioned Feeder Program (Church, 1988). At the peak of the program in 1987, 24,108 certified PC calves from

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[5] A nose paddle is inserted into the calf's nose so they can stay with their mother but cannot suckle from their mother.

257 farms were sold at auction. This represented only 1.9% of all calves sold in the province, and less than 1% of farms (Schipper et al., 1989). The economic benefits for feedlot operators that might justify preconditioning was already beginning to show some weaknesses before the program was discontinued (Novak, 1984; Peterson et al., 1989). Either feedlots were not as willing to pay for premiums as initially anticipated or the cost of a PC calf for feedlots was greater than the benefits of a PC calf (Avent et al., 2004). Jim and Gulchon (1988) estimated a net benefit of only $15 per PC calf for feedlots, while some PC calves were being sold for $60 more than non-PC calves. Feedlots started to become worried that they were overpaying and began to seek new strategies of disease mitigation. Currently, most feedlots vaccinate almost all calves upon arrival at the feedlot, and processing often includes other treatments such as parasite control (USDA APHIS, 2012). As these practices became more common, preconditioning fell out of favour in Canada.

Table 2.1 shows the typical requirements of preconditioning in Canada. All vaccinations, castration, and dehorning should be performed at least 3 weeks before weaning, though castration and dehorning are usually performed much earlier. The time ensures vaccine effectiveness once calves reach the feedlot. A minimum of 45 days of weaning and feeding is also required. In the United States, preconditioning requirements differ between auctions. Superior Auctions, for example, has several certified value-added programs, including seven vaccination programs designed to increase buyer information ("Superior Vaccination Programs", n.d.). Several of these programs are essentially preconditioning with different weaning time periods and vaccination requirements.

Previous studies have found that PC calves have consistently outperformed control groups of traditionally weaned calves at the feedlot (Church, 1988; Hentzen et al., 2020; Lalman & Mourer, 2017; Taylor et al., 2010). PC calves spend more time feeding, have lower rates of morbidity, and are less likely to require antibiotics. However, the optimal time needed to precondition and how late preconditioning should

Table 2.1: Preconditioning activities and minimum time prior to sale/shipment (Radostits, 2000).

Castrated	21 days
Dehorned	21 days
Vaccinated against:	
Infectious Bovine Rhinotracheitis (IBR)	21 days
Parainfluenza3 (PI-3) Virus	21 days
Multi-clostridial	21 days
Haemophilus somnus	21 days
Treated for warbles	21 days
Weaned	45 days

be started is debated (Anderson et al., 2016; Arthington et al., 2008; Mathis et al., 2009). While premiums for PC calves are larger for calves that have been preconditioned longer, there is some evidence to suggest that calves will become somewhat naturally preconditioned as they grow older. Calves that will be retained for backgrounding have no need for preconditioning because they will spend time on a mostly forage feed with some grain feed before being sold to a feedlot.

Though premiums for preconditioning can be inconsistent, improving animal well-being is still a goal for many farmers, who have recently shown a willingness to shift towards newer health practices for their cattle (Bassi et al., 2019). These changes have been occurring quite rapidly in the last 10 years. According to the 2014 Western Canadian Cow-Calf Survey, abrupt weaning (or traditional weaning) was by far the most common form of weaning at 70% of respondents. In the 2017 edition of the survey, 49% of farmers practiced abrupt weaning, while 35% practiced fenceline weaning, 12% practiced nose paddle weaning, and 3% practiced natural weaning (University of Saskatchewan, 2018). The 2017 survey also showed rates of preconditioning rising from 9% of respondents to 22% of respondents – although without 3rd party confirmation it is unknown whether all parts of preconditioning were followed. The

National Farm Animal Care Council (2013) also recommends preconditioning or low stress weaning methods.

The benefits of preconditioning tend to dissipate after four weeks at the feedlot (Pritchard & Mendez, 1990). After several weeks, calves will become accustomed to the bunk feeding, so behavioural differences will decrease by the time calves reach slaughter weight. In taste and carcass studies of PC calves after slaughter, Holland et al. (2010) and Roeber et al. (2001) found that there is no noticeable difference in beef products from PC cattle versus non-PC cattle.

Value added from preconditioning has been observed in premiums paid at auction (Macartney et al., 2003), or measured through hedonic models (Carlberg & Hogan Jr, 2013; Zimmerman et al., 2012). Premiums paid for PC calves have varied substantially based on calf market prices, but calves that have been preconditioned for longer lengths of time generally earn a larger premium (Dhuyvetter et al., 2005; Hilton et al., 2015).

2.3 Fed Cattle Production

This section provides a basic overview of beef cattle production, cattle health issues, and why these health issues remain a challenge, and is divided into five subsections. Subsection 2.3.1 describes the production of fed calves and the role of each stage of production. Subsection 2.3.2 describes markets for fed calves, how they operate, and where market power lies. Subsection 2.3.3 provides the measures of profitability for fed cattle producers, and the costs associated with raising cattle. Subsection 2.3.4 explains calf health issues during production; when and where calves are most vulnerable, and a description Bovine Respiratory Disease (BRD), which is the most common source of cattle morbidity and mortality. Subsection 2.3.5 describes the role of antimicrobial use (AMU) in feedlots, common reasons for using antimicrobial drugs (AMDs), and how AMU in cattle feedlots contributes to antimicrobial resistance (AMR), a global health threat.

2.3.1 Production Chain

Fed cattle production begins with cow-calf producers. These initial producers either maintain a few bulls, or lease bulls from purebred producers to be turned out with their cows in the summer for breeding. Cow-calf operators increase the production of new calves when calf prices are high, though responses to changes in price can take years (Alberta Agriculture and Food, 2008). Increasing the number of calves is achieved by holding on to a higher proportion of heifers from previous calf crops in order to increase production. This pattern perpetuates a long-term price cycle, as it takes several years from the time heifers are bred to calf weaning. By the time calves are weaned, the supply is high and prices fall, which decreases the number of heifers that will be bred.

Annual calf prices are cyclical. The lowest prices are in the fall when most calves are weaned, and highest in the spring when the fewest number of calves are weaned (Canfax, 2020; Peel & Riley, 2018). These price signals combined with costs of production will inform producers in their decision to hold on to calves and cattle if they are able, or to sell. Approximately 34-38% of cow-calf producers also have backgrounding operations, allowing the option to hold on to calves if returns do not appear favourable (Sheppard et al., 2015; University of Saskatchewan, 2018).

Calves spend the spring and summer raised on their mothers' milk until fall weaning. Newborn calves weigh around 90 lbs depending on breed and other characteristics, and the typical weight for a weaned calf is 400-600 lbs (Lalman et al., 2019). Maximizing weight gain to about 2-3 lbs/day is desirable for cow-calf operators, as a heavier calf will sell for more at auction. The majority of calves are dehorned and castrated shortly after birth (University of Saskatchewan, 2018). Nearly all cow-calf operators vaccinate their calves sometime before weaning, with the most common vaccines administered for clostridial diseases (91-97% of operations) and respiratory diseases (82-85% of operations) (University of Saskatchewan, 2018; Waldner, Parker,

& Campbell, 2019).

Traditionally, calves are abruptly weaned (i.e. taken from their mothers and immediately transported to auction for sale). Suckling calves are raised on pasture, and therefore have limited exposure to feed bunks, which is how they will be fed at the feedlot. The stress from transportation and relocation reduces immune response to illnesses (Chirase et al., 2004). Abruptly weaned calves are significantly more likely to be treated for BRD than calves that are preconditioned and/or administered booster vaccinations (Macartney et al., 2003; Step et al., 2008). Fenceline weaning and nose-paddle weaning are two common alternatives to abrupt weaning intended to reduce stress for calves at weaning, and are recommended by the Beef Code of Practice (Enrıquez et al., 2011; National Farm Animal Care Council, 2013; University of Saskatchewan, 2018). Both of these methods require at least 7 days of additional weaning time, but these methods alone generally have little effect on feedlot performance or health (Campistol et al., 2013; Enrıquez et al., 2010; Step et al., 2008).

Following weaning, calves may be backgrounded before entering a feedlot. Because most calves are born in the spring, and beef production continues year-round, backgrounded calves are essentially set in a holding pattern until feedlot space becomes available. Calves that are backgrounded prior to entering the feedlot are fed a grass or forage-based diet to achieve daily weight gain of 0.5-2 lbs/day until they weigh 750-850 lbs (Harper & Kime, 2005). Most feeder cattle in Canada will eventually be finished at a feedlot on a grain-based diet to ensure consistent meat properties. Therefore, backgrounders aim to slow weight gain before the cattle enter the feedlot.

Weaned and backgrounded calves are sold to feedlots for finishing before slaughter. Unlike cow-calf and backgrounding operations, whose head count varies annually, feedlots maintain a relatively consistent head count throughout the year. Cow-calf operations will have the greatest number of cattle in the summer, and the least over winter, whereas feedlots will try to maintain their head count year-round. In 2020, there were 166 feedlots in Alberta and Saskatchewan with over 1000 head capacity (Canfax, 2020).

At the feedlot, cattle are given a grain-based diet to increase daily weight gain, with a finished weight of around 1,300-1,400 lbs. Calves that have been backgrounded for a long period of time may not need much time at the feedlot, whereas younger calves fresh from being weaned could spend several months finishing. Once cattle are brought up to the finished weight they are shipped to a packing plant for slaughter. Twenty-two federally inspected packing plants operate in Canada, with around 80% of production coming from the three largest plants (Canada Beef, n.d. Canfax, 2020). Beef products are then sold by the packing plants to distributors and retailers before eventually reaching consumers, or exported to foreign consumer markets.

2.3.2 Markets

Most calves are sold from cow-calf and backgrounding operations to feedlots via in-person, video, or internet auctions, which operate as spot markets. Crespi and Saitone (2018) using work from Williamson (1991) show that industries with low transaction costs and less specific assets are more likely to operate on spot markets without contracts and little vertical integration. In the beef industry, spot markets persist because of the relative homogeneity of cattle, once breed and sex are accounted for. Feedlots are able to keep transaction costs low knowing that nearby cattle will match their orders. This comes at the expense of farmers who wish to differentiate their cattle. If the assets do not match the buyers' specifications, either the cattle will not be bought, or additional attributes (such as better immunity to disease) will not be reflected in the final sale price (MacDonald, 2011).

At live auctions, calves from cow-calf farms and backgrounders are transported to the auction site and sorted into groups with cattle of the same breed, sex, age, and weight before being sold to feedlots for finishing. Though online auctions are becoming increasingly more common, especially during the COVID-19 pandemic, online auctions still represent a minority of cattle transactions. In Alberta, 12% of calves were sold via online auctions between 2016 and 2020, with the rest being sold at traditional live auctions (Monvoisin, 2021).

For feedlot owners, live auctions are preferred due to the low number of buyers at these auctions (Trotter, 2020). Cow-calf operators will have few options but to sell to whichever buyers are available, which gives them little incentive to add additional costs for cattle attributes that are not desired by feedlots (Gillespie et al., 2004). In the United States, some auctions such as Superior Auctions, will have more pre-sorting and less mixing, which allows cow-calf producers better options to market their calves ("Superior Vaccination Programs", n.d.). In Canada, groups auctions with calves mixed from many producers are more common, providing fewer opportunities for cow-calf producers to market their calves.

The size of cow-calf operations corresponds with auction preference as well. For a large cow-calf operation that is able to fill a feedlot's entire order, video or internet auctions may land them the best price while also reducing transportation time and costs, which can reduce stress and the resulting negative health effects (Gillespie et al., 2004; Mackenzie et al., 1997). For smaller operations, live auctions may be the only realistic option if feedlots are less willing to purchase small orders from several sources via online auctions.

Sales from feedlots to packing plants on the other hand often behave like informal contract-based markets, even if they are spot markets on paper (Hunnicutt et al., 2004; Xia et al., 2019). Feedlots provide packing plants with the desired number of cattle of a certain breed, age, sex, or other attributes. Keeping inputs consistent and dependable works in favour of both packing plants and feedlots, and may also prevent the market power of the packing plants from affecting prices (Xia et al., 2019). Cow-calf to feedlot contracts are less practical, as fulfilling contractual obligations for a certain number of calves could encourage cow-calf operators to over-produce to ensure they can meet the terms of the contract (Trotter, 2020). For larger operations, this may only represent a relatively small marginal increase in costs, but for small operations, this could drastically change their business.

Each level of the production chain is assumed to be profit-maximizing, but each measures their output in slightly different ways. Cow-calf operations measure either in pounds of calf weaned or pounds of calf weaned per female exposed to a bull. This is a simple metric of the total weight of calves or the average weight based on the number of females used for breeding. Feedlots measure output in finishing weight, which again is also a summation of the weight of cattle. Packing plants measure the carcass weight (or dressed weight), which is the weight of the animal after inedible portions have been removed.

Hedonic pricing models are often used to estimate the implicit prices of cattle attributes. These attributes for cattle prices are generally divided into cattle characteristics and market characteristics (Burdine et al., 2014; King et al., 2006; Schroeder et al., 1988; Tate et al., 2016; Williams et al., 2012; Zimmerman et al., 2012). Common characteristics of cattle are age, breed, weight, and subjective "quality" indicators (usually refers to physical defects or health factors), while sale location, sale time, market prices of feed such as corn and barley, and cattle futures are often used for market characteristics (Mitchell et al., 2018). All of these attributes function as search attributes, which can be assessed by a potential buyer before purchase. Breed, weight, and visible quality indicators can be either observed or quickly measured at auction, while market characteristics are widely published.

Experience and credence attributes - attributes that cannot be visually confirmed or measured at auction - are also present in cattle markets. These can create asymmetrical information between buyers and sellers. Additional attributes that may not always be considered or captured in prices include vaccinations, detailed genetics, and traceability (Mitchell et al., 2018).

2.3.3 Producer Profitability

The cattle producers' decision whether to sell or attempt to add value (via additional weight) to a calf can be understood using the formula from Peel and Riley (2018):

$$V = \frac{P_f W_f - P_b W_b}{W_f - W_b} \tag{2.1}$$

alternatively written as:

$$V = P_f + \frac{W_b(P_f - P_b)}{W_f - W_b} \tag{2.2}$$

where V is the value of additional weight (either per pound or per cwt), W_f is the final weight, W_b is the starting weight, P_f is the final price, and P_b is the starting price. Equation 2.2 shows that value is adjusted by the change in weight and prices, as heavier animals generally sell for less per pound or cwt at auction. This is also known as the price slide.

This formula can apply to cattle producers at each stage of production. If V is greater than the cost of production, the cattle producer has an incentive to continue to add weight to the animal, and when V is less than the cost of production, the producer has an incentive to sell. Initial weight has a higher value per pound allowing early cow-calf operators to produce with higher costs, while later weight decreases in value per pound, so the producers must be able to limit their costs as cattle approach finishing weight.

As depicted in Figure 2.1, the beef cattle industry forms a pyramidal buying structure, with most cow-calf producers and backgrounders operating as price-takers. Cattle are treated as a relatively homogeneous commodity, especially those of the same sex, weight, and breed (Schulz et al., 2012). Therefore, the main way for cow-calf producers to increase profits is to optimize productivity and control costs (Alberta Agriculture and Food, 2008). Millang (2003) compared a number of indicators to profitability, such as labour hours, days on pasture, cows wintered, and return on investment. In general, reduction of costs and reduction of labour requirements is correlated with the highest increases in profitability, however, each farmer must tailor their operation according to the resources at their disposal, as inputs rely heavily on local environmental and market conditions.

Output optimization is difficult to generalize for cattle producers due to the heterogeneity of operations, especially at the cow-calf level. As captured by MacLachlan (2001), “calf production is inherently creative”, and producer costs can vary tremendously based on resources available to each farm. Alemu et al. (2016) describe eight general types of cattle farms using cluster analysis from a survey (n=1005), showing large variations in the size and organization of these operations, as well as their aversion or preference for risk-taking behaviour. Adding to the complexity is the fact that around half of farms that produce cattle do not receive all their income from cattle, making it difficult to generalize capital costs associated with cattle production. Structures, vehicles, water infrastructure, taxes, and loan interest for example may be shared amongst various agricultural activities (Alemu et al., 2016).

Economies of scale also vary in cow-calf operations. There are some key differences in the cost structures and risk-taking behaviour between larger operations and smaller operations (Alemu et al., 2016; Martin et al., 2019; Samarajeewa et al., 2012). Larger farms generally receive all their income from cattle operations, with a head count of at least 500. Smaller operations are not solely reliant on income from cattle and usually have fewer than 500 head. The proportion of off-farm income to total income is a strong determinant for risk-taking behaviour, as operators whose primary income is derived from cattle are more likely to take risks by adopting new technologies or practices (Pruitt et al., 2012; Ramsey et al., 2005; Ward, Vestal, et al., 2008). These might include a new breeding technology, feed or feed additives, or health programs.

By far the largest cost to Canadian cow-calf producers is the cost of feed and pasture, estimated at just under 75% of variable costs, or an average of approximately \$660 per weaned calf for cow-calf operations (Alberta Agriculture and Forestry, 2020).

Feed costs for feedlots are similarly around 75-80% of total costs(Canfax, 2022a). The difference in diets between backgrounding and feedlots affects the producers' production choices. Backgrounding requires a forage-based diet, where costs are determined by the prices of stored forage such as hay and alfalfa (Aasen & Bjorge, 2009). Finishing diets are grain-based diets where costs depend on grain prices; mostly barley in western Canada, and corn in eastern Canada and the United States (Zhen et al., 2018). When feed prices are high, feedlots prefer to buy heavy cattle to reduce their feed expenditures, and when prices are low, feedlots will buy lighter cattle as the cost of production decreases. Volatility in feed prices only moves downstream, meaning cattle farmers are always responding to changes in feed prices, and cattle production is unlikely to have an effect on grain prices (Zhen et al., 2018).

Farmers that are able to optimize feeding are generally the most profitable, though the most profitable operations excel at reducing several costs (Pendell et al., 2015). Optimal feeding is also a delicate balance, as farmers will seek to maximize weight gain while avoiding waste. Many smaller cattle operations earn income from crops, so feeding decisions may dictate how much land is designated for pasture and/or feed.

Because the cost of feed is the highest cost for cattle producers, calves that can efficiently gain weight are valuable to beef producers. Individual cattle productivity related to feed is measured using two main metrics: Average Daily Gain (ADG), and Feed Conversion (FC)[6] (Dennis et al., 2020; Irsik et al., 2006). ADG, as the name suggests, measures the weight gain of a feeder calf averaged over the number of days on feed, while FC measures the amount of feed consumed to add one pound of weight to the calf. Calves with high ADG and low FC are the most productive, and volatility in these two metrics will ultimately affect a producer's feed costs. Feed conversion of around 6lbs of feed per lb of weight gain is common in Angus steers (Bishop et al., 1989; Smith et al., 2010).

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[6] Also known as feed conversion ratio. This is often specified as Dry Matter Feed Conversion (DMFC), which counts only the dry matter - or the feed after water weight is accounted for.

The second largest cost to cow-calf producers is labour, both paid and unpaid. Unpaid labour is estimated to be just under $57 per weaned calf, while paid labour is estimated to be just under $19 per weaned calf (Alberta Agriculture and Forestry, 2020). Smaller operations - generally cow-calf - do not often have a need for paid labour, and most work is handled by the operators themselves. In contrast, feedlots tend to rely more on paid labour. Reducing labour is beneficial for operations of all sizes, however, the intuition is slightly different for larger versus smaller operations. Larger operations may seek to reduce the overhead cost of labour, while smaller operations may see increased farm labour as a lost opportunity cost, and will look to reduce their unpaid labour either to increase off-farm income, or to dedicate more time to other farm activities.

Direct health and veterinary costs are generally around 4% of variable costs at the cow-calf stage, or approximately $33 per weaned calf (Alberta Agriculture and Forestry, 2020). The costs for feedlots are approximately $20-$50 per head (Canfax, 2022a). These direct costs are a combination of both preventative measures and reactionary costs (Campbell & Jelinski, 2006; Fike et al., 2017). Inputs considered preventative will lower the probability of injury, illness, or mortality, and include vaccinations, metaphylactic and prophylactic treatment, nutrition and feed additives, and other basic veterinary services. Reactionary costs are costs associated with medications needed to treat sick animals. Despite consisting of a very small proportion of variable costs for beef cattle operations, preventative costs can potentially avoid large costs associated with morbidity and mortality. For example, Riley et al. (2019) found that enhanced health programs to combat bovine viral diarrhea virus (BVDV) cost around USD$6.46 to USD$7.64 per bred cow, but an infected cow can cost the producer USD$27.96 to USD$96.21.

2.3.4 Cattle Health

Treatment strategies differ from farm to farm. Nearly every cow-calf operation surveyed by Waldner, Parker, and Campbell (2019) and Waldner, Parker, Gow, et al. (2019) had administered vaccinations of some kind, usually before weaning. Vaccinations are highly recommended as a means of reducing the risk of BRD (National Farm Animal Care Council, 2013). One factor that is a strong determinant of health program adoption is the size of the operation, and the farmers' experience (Martin et al., 2019). Experienced cattle ranchers are more likely to have either directly encountered some health issues with their own cattle or learned about outbreaks from other ranchers and are subsequently more likely to take measures to avoid such outbreaks. Larger operations are more likely to have stronger health programs, as health issues will be encountered more frequently, and have the potential to affect more animals than at smaller farms (USDA, 2017). Riley et al. (2019) found the occurrence of BVDV only affects 4% of cow-calf operations, so for smaller operators, they may view an outbreak as an extremely unlikely occurrence, whereas a larger operation may view this as part of the business.

Live auctions present a major health risk to calves, as disease may spread during a weekly pre-sort sale where thousands of calves are housed together from dozens of cow-calf producers. Reducing stress for calves, and reducing the potential for infection prior to entering the auction and subsequent feedlot, will help an animal remain healthy and gain weight efficiently at the feedlot.

Health management practices at the cow-calf level affects the health management decisions of feedlots. Delabouglise et al. (2017) and Johnson and Pendell (2017) showed that maintaining healthy calves substantially increased producer and consumer welfare, except at the cow-calf level, where benefits are very small or non-existent. This means that cow-calf operations do not benefit from healthier cattle at a later stage because they are generally not compensated when calf health improves.

Therefore, cow-calf operations do not vaccinate weaned calves as often as unweaned calves. The number of cow-calf operations that administer booster vaccinations is approximately 57% (Waldner, Parker, & Campbell, 2019). Cow-calf producers operate under very small or even negative returns on labour and capital (Canfax, 2022b; Miller et al., 2002; Ramsey et al., 2005), and have limited negotiating power when selling to feedlots, which is why they may not have a strong incentive to provide boosters (Delabouglise et al., 2017; Ives & Richeson, 2015; Peel, 2020; Riley et al., 2019). If a certified record of vaccination is not available, feedlots will also not pay extra for booster vaccinations.

Feedlots will vaccinate all calves against respiratory diseases upon arrival, though vaccines alone may not be an effective strategy in reducing disease outbreaks, as vaccines take some time before they become effective, and illness is most likely within the first four weeks of arrival at the feedlot (Capik et al., 2021; Taylor et al., 2010). Metaphylactic treatment of high-risk calves (generally lower weight calves) upon arrival at feedlots is a popular health management strategy, as it requires less additional labour versus individual treatment of animals while also showing proven results in decreasing cattle morbidity and mortality, and increasing consumer and producer welfare (Dennis et al., 2020; Dennis et al., 2018; Ives & Richeson, 2015). Metaphylactic treatment usually consists of adding antimicrobial drugs (AMDs) to feed, which kills the microorganisms that are likely to cause illness.

BRD is the most common illnesses affecting cattle in feedlots, and is responsible for 65-80% of morbidity and 45-75% of mortality in North American feedlots (Ball et al., 2019; McGill & Sacco, 2020). Risk factors of developing BRD include the size of the animal cohort, exposure to other animals, length of weaning time, whether the calf was fed grain prior to feedlot entry, and feedlot induction weight (Hay et al., 2016). Newly weaned calves, and calves that have been transported long distances are more susceptible to respiratory diseases (Brault et al., 2019; Sanderson et al., 2008; Tucker et al., 2015).

Treatment of BRD in the United States is estimated to cost a collective USD$800 - USD$900 million annually (Chirase & Greene, 2001). Treatment costs have been increasing, growing from USD$13.90[7] per infected head in 1999 (Snowder et al., 2006) to USD$23.60[7] in 2011 (Peel, 2020). Calves that become chronically ill - defined as being treated 3 or more times - are sometimes culled before they reach finishing weight and become a loss for the feedlot (Johnson & Pendell, 2017). BRD has also been shown to negatively affect marbling scores and carcass weights (Schneider et al., 2009). In general, untreated BRD has been estimated to reduce returns on individual cattle by USD$50 to USD$250 (Krehbiel et al., 2016).

One of the reasons BRD continues to be such a problem in feedlots is its diagnostic difficulty (Buczinski & Pardon, 2020; Wisnieski et al., 2021). There is no gold standard for diagnosing BRD, which is why large-scale administration of AMDs upon feedlot arrival (prophylaxis and metaphylaxis) remains the best option for feedlots to reduce the instance of BRD (Ives & Richeson, 2015). From 2008 to 2012 metaphylaxis was provided to over 70% of calves placed in 36 western Canadian feedlots (Brault et al., 2019). This large-scale use of AMDs presents new problems.

2.3.5 Cattle Production & Antimicrobial Resistance (AMR)

Overuse of AMDs increases the likelihood of antimicrobial resistance (AMR) by increasing the probability of bacterial mutation (Centers for Disease Control and Prevention, 2019). AMR is a global threat to human and animal health, as increased AMR reduces the effectiveness of current AMDs and requires costly investments in research to develop more drugs (Dadgostar, 2019). AMR infections also require longer and more costly hospitalizations, and increase the chance of mortality from an infection.

For human health in the United States, hospitalizations for AMR-related illnesses cost approximately USD$1,383 per case, totaling USD$2.2 billion in additional annual

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[7] Nominal USD.

health care costs (Thorpe et al., 2018). In Canada, the number of resistant infections is increasing, while antimicrobial use (AMU) in humans is also increasing, including "reserve" AMDs designed for multi-drug resistant bacteria (Public Health Agency of Canada, 2020). The AMR rate in Canada was 26% in 2018, and this rate could rise to 40% by 2050 without intervention (Finlay et al., 2019).

Increased AMR also ultimately results in lower animal productivity because of untreatable infections (World Bank, 2017). Feedlot death loss in heifers has increased from under 1% in 1996 to over 2% in 2020 (Babcock et al., 2006; Peel, 2020). BRD infections is believed to be part of this trend, despite the extensive research on controlling BRD.

There are four main uses for antimicrobial drugs (AMDs) in feedlots, ordered from most amount used to least: (1) growth promotion, (2) prophylaxis, (3) metaphylaxis, (4) therapeutic use (Innes et al., 2020; WHO, 2017). Growth promoting AMDs are given to all calves upon arrival at the feedlot to - as the name suggests - increase growth and feed efficiency. Prophylaxis describes the preventative treatment of disease by giving AMDs to calves that are at risk of becoming ill. Metaphylaxis is the treatment of all calves that have come in contact with sick calves. Therapeutic use (or individual treatment) only treats calves that show signs of illness. Good AMU stewardship includes vaccinations when appropriate, using the right treatment for the condition, using AMDs for the full number of days, and not using AMDs to treat viral infections (Beef Cattle Research Council, 2020).

AMU in food producing animals contributes to AMR in both animals and humans (Tang et al., 2017), yet it remains difficult to quantify the impact on human health from AMU in livestock (Singer & Williams-Nguyen, 2014). The Center for Disease Control (CDC) estimates that 20% of AMR bacterial infections are caused by food or interaction with food producing animals (Centers for Disease Control and Prevention, 2019). In Denmark, 19% of *Campylobacter jejuni* infections (the most common source of food poisoning) were attributed to beef cattle products.

Reducing AMU in livestock leads to an overall decrease in AMR (Scott et al., 2018). In Japan, following a voluntary withdrawal of cephalosporins in 2012, the prevalence of cephalosporin-resistant *Escherichia coli* isolates from healthy broilers decreased from 16.4% in 2010 to 4.6% in 2013. The discontinuation of ceftiofur use in chicken hatcheries in Canada in 2005, and partial reintroduction in 2007, was associated with respective decreases and increases in ceftiofur-resistant *Salmonella Heidelberg* in samples from both chicken meat and humans. In western Canadian feedlots, targeted treatment using AMDs does not increase AMR compared to large scale AMU (Checkley et al., 2010).

Canadian Animal Health Institute (2018) classifies AMDs into four groups, ranging from category I drugs – those drugs considered very important to human health – to category IV – those considered the least important to human health. The World Health Organization (WHO) recommends the complete restriction of medically important AMDs for growth promotion (WHO, 2017). As of 2018 in Canada, Class I, II, and III drugs are no longer used for growth promotion (Government of Canada, 2017).

In Canada, approximately 349,000kg of AMDs were sold for use in cattle production in 2021 (CIPARS, 2022). Approximately 1,700kg of these AMDs were Class I drugs, which was an increase from 1,500kg in 2020 (CIPARS, 2022). Feedlots use more AMDs than backgrounding or cow-calf operations, with tetracyclines (Class III) being the most commonly used AMD in feedlots (Brault et al., 2019). These are most often used to combat respiratory disease, diarrhea, navel illness, and arthritis. Feedlots rarely use Class I drugs, and only with proper prescriptions (Brault et al., 2019). There are some indications that the use of AMDs in feedlots has been decreasing over the last decade, due to the increased awareness and surveillance of the issue of AMU (Hannon et al., 2020; Public Health Agency of Canada, 2020), however, macrolide use (Class II) was steady over a 4 year study period, and remain the second most common administered AMD in feedlots (Brault et al., 2019).

Despite the cost of treating BRD, feedlots often still prefer to purchase low-weight calves, often marked as high risk for developing BRD (Brault et al., 2019; Ives & Richeson, 2015). As discussed in section 2.2.2, cattle are still treated mostly as a commodity with little differentiation, and equations 2.1 and 2.2 show that the only meaningful way cattle producers can add value is through weight gain. Therefore, prophylactic and metaphylactic treatment of calves arriving at the feedlot is an economic decision based on the concept that purchasing low-weight, high risk calves is more profitable than purchasing higher weight, low-risk calves (Hao et al., 2014).

2.4 Preconditioning Economics

In economic terms, preconditioning can be viewed through several lenses. First, preconditioning as a technology designed to increase beef cattle productivity (section 2.4.1). Second, widespread education and adoption of preconditioning can be seen as a way of reducing information asymmetry in beef cattle markets (section 2.4.2). Third, preconditioning can serve as a method of satisfying consumer demand for antibiotic-free beef or beef products raised with an emphasis on livestock welfare (section 2.4.3). Finally, preconditioning can reduce the externalities caused by large-scale antimicrobial use (section 2.4.4). Each of these roles is covered in detail in the following subsections.

2.4.1 Technological Change

A firm's production technology is the "given state of knowledge about the various methods that might be used to transform inputs into outputs" (Pindyck & Rubinfeld, 2014). The production technology forms a firm's production function, which describes the upper limit of production given its inputs (or production possibilities frontier). Technological change describes an increase or decrease in the productivity of one or several inputs, thereby adjusting a firm's production possibility, or, changing output with the same inputs.

The decision for a firm to adopt a technology is based on several factors as described by Rogers et al. (2014), with profitability being the most important (Griliches, 1957). Farm size has also shown a positive relationship with value-added technologies (Gillespie et al., 2004; Johnson et al., 2010; Ward, Vestal, et al., 2008). Producers whose income relies more on farm income than off-farm income are also more likely to adopt technologies (Gillespie et al., 2007; Martin et al., 2008).

Popp et al. (1999) found that cow-calf producers were more likely to background if they perceived backgrounding to be profitable and within the capacity of their facilities, as well as limit their exposure to price risk. However, several additional inputs are required for preconditioning (as noted in table 2.1[8]), which may increase the value added to each calf, but could reduce the net return for these calves due to added costs.

From a feedlot's perspective, preconditioning would improve the input productivity of feed if average daily gain (ADG) and feed conversion (FC) of PC calves are high enough to increase cattle value more than the additional cost to purchase PC calves. In previous studies, the findings were mixed as to whether or not PC calves perform better in relation to feeding (Avent et al., 2004; Irsik et al., 2006). As discussed in section 2.2.4, increasing beef cattle health decreases losses from morbidity and mortality. Therefore, reducing feedlot losses from morbidity and mortality with the same inputs for health care could be a positive technology change.

2.4.2 Information Asymmetry

The end of section 2.2.2 describes how live calf auctions are not well suited for including credence attributes (i.e. attributes that cannot be discovered after purchase). The lack of verification for credence attributes may have created what could be considered a "market for lemons" in the beef industry (Allen, 1993; Chymis et al., 2007; Schumacher et al., 2012). Information asymmetry leads to reduced prices because buyers

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[8] Castration and dehorning usually take place well before weaning, and is practiced by most cow-calf ranchers (University of Saskatchewan, 2018).

are not always sure whether all medications, for example, are properly administered. This gives cow-calf operators little incentive to add costs. Information asymmetry plays a role in vaccinations as well. Vaccinations would likely be more effective as a health practice at the cow-calf stage as there is a time difference between when the vaccination is administered and when the vaccine is effective, and pathogens may be encountered before the vaccine is effective. Feedlots often vaccinate all calves on arrival regardless in the hope that the vaccine will be effective before pathogens are encountered (Capik et al., 2021; USDA APHIS, 2012). The vaccinations at the feedlot are redundant if the cow-calf operator has already vaccinated (Capik et al., 2021; Taylor et al., 2010).

There is some interest for more vertical integration in beef production in the form of certifications, traceability, and contracts (Chiu et al., 2022; Chymis et al., 2007). Stated preference data have also shown that feedlots are willing to pay for these additional attributes with official certification or age and source verification in the United States (Schumacher et al., 2012). Currently, Superior Auctions in the United States has several certified value-added programs, including seven vaccination programs designed to increase buyer information ("Superior Vaccination Programs", n.d.). These all serve the function of reducing information asymmetry and allowing cattle markets to be better able to capture value-added practices.

Avoiding live auctions may also support information sharing while avoiding the need for commingling at auction houses (Wilson et al., 2017). Because feedlots and packing plants prefer to purchase cattle in bulk sales at auctions or online, smaller calf producers can group their cattle as one sale. Hopkins et al. (2015) found such group sales lead to increases in sales prices for PC calves, with a mean increase of USD$5.08/cwt. Such group sales may become more common as internet sales increase in Canada (Monvoisin, 2021).

Despite the efforts to reduce information asymmetry, it is unlikely that this is the main hurdle for the widespread adoption of preconditioning (Chiu et al., 2022).

Several reputable certification programs have existed or do exist, yet preconditioning remains relatively uncommon. Metaphylactic treatment continues to be a more cost effective solution for disease treatment, even with full information (Chiu et al., 2022; Ives & Richeson, 2015). In Canada, a lack of confidence in the financial viability of preconditioning seems to explain the lack of certifications compared to the United States (Derkson, 2018; Simes, 2017).

2.4.3 Consumer Preferences

There is a large literature on consumer preferences for beef products. Hedonic pricing models are often used to estimate the implicit price for beef product attributes, which may include taste, cut, breed, country of origin, organic labelling, branding, and religious preparation (Carlberg et al., 2007; Martinez, 2011; Schulz et al., 2012; Taylor & Tonsor, 2013; Ward, Lusk, et al., 2008b; Wilfong et al., 2016). These models can provide insight into how consumers value the traits of beef products, and their willingness to pay for additional traits.

Red meat consumption is generally higher in the United States than in Canada (Frank et al., 2021). Canadian survey-based studies have shown a slightly lower willingness to pay for branding or additional health labelling than American surveys, reaching at most a 22% increase in price from individuals with “high purchase intention” (Cranfield, 2018; Froehlich et al., 2009). However, Canadian consumers have a higher willingness to pay for food safety attributes such as traceability, likely stemming from the 2003 Bovine spongiform encephalopathy (BSE) outbreak (Dickinson et al., 2003).

The relatively high centralization of the Canadian meat packing and consumer retail sectors compared to the United States may hinder the proliferation of branded meats (Froehlich et al., 2009). Few options for consumers may mean that additional branding is unnecessary. In the United States, beef producers increased the proportion of products that are branded from 42% to 63% between 2004 and 2010, with the

Certified Angus Beef brand being among the most notable (Zimmerman & Schroeder, 2013). In 2008 in Canada, 40.6% of beef products had some form of branding (Ward, Lusk, et al., 2008a). These branded beef products have a large variation in implicit price, ranging from -USD$1.24 to USD$6.20 per kg depending on what attribute or company is being advertised (Ward, Lusk, et al., 2008a).

Consumer preference for organic beef versus conventional beef suggests that consumers are willing to pay for beef produced in an environmentally conscious manner (Napolitano et al., 2010). Beef products labeled as organic or locally sourced, and those with “trusted” branding often sell for higher prices (Adams & Salois, 2010; Martinez, 2011). “Trusted” brands are those that have either one or a combination of three traits: (1) some certification from a recognizable institution, such as the USDA; (2) have existed for several years; (3) have some strong marketing arrangements (Martinez, 2011). Organically raised beef cattle have a lower carcass weight after slaughter and a higher cost of production compared to conventionally raised cattle (Fernandez & Woodward, 1999; Woodward & Fernandez, 1999), so the higher prices are necessary in order for organic ranchers to remain profitable. A similar cost increase was found in poultry, where banning battery cages in egg-laying hen farms increased the price of eggs between $0.48 and $1.08 (Malone & Lusk, 2016).

Consumers have exhibited concern for AMR in the food production system, and have a higher willingness to pay for antimicrobial-free or hormone-free meat products (Calvo & Meltzer-Warren, 2020; Lewis et al., 2017; Newman et al., 2020; Rummo & MSMBA, 2016). However, many consumers are not aware of the actual risks associated with AMU (Barrett et al., 2021), and some terms such as “no antibiotics” may be used inconsistently, further adding to consumer confusion (Parker et al., 2020). Paudel et al. (2022) suggests labeling differences, as there is a large jump in willingness to pay between “some AMD used” and “no AMD used”. In the case of Paudel et al. (2022), consumers were willing to pay $2.88 to $3.46 per pound more for pork products labelled “no AMDs used”, compared to $0.51 per pound for pork products labelled "conventional AMDs used". Several major food retailers, such as McDonald's and Costco, and major packing plant operator Cargill have expressed desires to source beef with reduced AMU (Costco, n.d.; Eistein-Curtis, n.d.; McDonald's, 2022).

2.4.4 Externalities

Beef cattle production practices create a large number of externalities including: land degradation and deforestation, water pollution, greenhouse gas emissions, and destruction of biodiversity (Steinfeld et al., 2006). Each of these externalities has a large literature involving measuring the scope of the externality (Crosson et al., 2011; Lynch, 2019), potential solutions (Herrero et al., 2010), and challenges in policy implementation (Dumortier et al., 2012; Revoredo-Giha et al., 2018).

An example of an externality caused by extensive beef cattle production is greenhouse gas emissions contributing to climate change. In Canada, greenhouse gas emissions reduced from 16.4 to 10.4 kg of CO_2 equivalent per kg of beef product between 1981 and 2001 (Vergé et al., 2008), largely due to changes in feed technology (Beauchemin et al., 2008). However, total emissions increased from 25 to 32 Tg of CO_2 equivalent in that same time period due to increased consumer demand (Vergé et al., 2008). Carbon taxes, a popular means of internalizing externalities caused by greenhouse gas emissions (Pearce, 1991), are difficult to implement in beef cattle production either due to a potential loss in nutritional intake for a population (Revoredo-Giha et al., 2018), or an increase in beef production in areas with higher per unit emissions to cover the supply shortage (Dumortier et al., 2012). Solutions for reducing emissions from beef production and therefore reducing the externality associated with greenhouse gas emissions are driven by better feed efficiency (Eckard et al., 2010; Quinton et al., 2018), and land use practices at the individual farm level (Beauchemin et al., 2011; Herrero et al., 2010).

Increased AMR from overuse or misuse of AMDs is another externality stemming from beef cattle production (Lhermie, Verteramo Chiu, et al., 2019). In 2018 in the

United States, an estimated 35,000 people died from antibiotic resistant infections, an increase from 23,000 estimated deaths in 2013 (Centers for Disease Control and Prevention, 2019). The worldwide annual death toll from AMR infections could reach 10 million by 2050 if AMU is not carefully controlled (O'Neill, 2016). Over 80% of AMDs in Canada were distributed to livestock, mostly for disease management, totalling 1.4 million kgs (Ebrahim et al., 2016). Banning the use of growth-promoting AMDs and spreading awareness of AMR concerns to producers has lead to a decrease in the overall use of AMDs in livestock in the last few years, though AMR still does remain a concern (Ebrahim et al., 2016; Waldner, Parker, Gow, et al., 2019).

In a general sense for both humans and animals AMU represents both a positive and a negative externality (Delmond & Ahmed, 2020; Horowitz & Moehring, 2004; Lhermie, Wernli, et al., 2019). Along with vaccinations, AMU is a positive externality, because the humans or animals treated with vaccinations or AMDs will be less likely to transmit diseases. In feedlots, AMDs remain a critical method of disease control, which ultimately reduces the threat of illness from meat consumption and diseases spread via water infiltration or manure. AMU is often used as an easy method of managing disease in place of other disease management practices such as cleanliness or stress reduction (Ryan, 2019). The fact that there is little to no AMD residue in food produced from AMU in food-producing animals supports the use of AMDs as a safe means of controlling disease (Tang et al., 2019; Treiber & Beranek-Knauer, 2021). However, AMU is also a negative externality in relation to AMR (Giubilini et al., 2017). Increased AMU contributes to increased AMR, which reduces the effectiveness of existing AMDs for both humans and animals.

The difficulty in determining optimal AMU is balancing these two externalities (Laxminarayan & Brown, 2001). Too little AMU allows diseases to easily spread, increasing health care costs and decreasing social welfare. Too much AMU creates a resistance feedback loop as resistant strains are more likely to develop, reducing the effectiveness of those drugs in the future. In the long run, AMR also reduces social welfare as people can no longer be effectively treated for infections. Tang et al. (2017) found that “reducing antibiotic use decreased prevalence of antibiotic-resistant bacteria in animals by about 15% and multidrug-resistant bacteria by 24–32%”, and increasing AMU also increases resistance at an increased rate. Similar to the above example of greenhouse gas emissions created by beef production, supply is ideally maintained while the negative externalities are reduced.

Several theoretical economic models have been created to determine optimal AMU. One approach is a susceptible-infected-susceptible (SIS) epidemiological model to estimate infections in a population, with AMDs as either a renewable or non-renewable resource for treating infections (Laxminarayan & Brown, 2001). As a renewable resource, a use cost is attached to AMDs to accounts for the negative externality of of AMU (i.e. lack of effectiveness from its use). The non-renewable resource version of determining optimal AMU assumes that an AMD’s use is finite before it is no longer effective.

Horowitz and Moehring (2004) use a market equilibrium model to estimate optimal AMU from the social planner’s perspective under different market structures: open access (i.e. free market) or monopoly via property rights on patents. In their model, social welfare is maximized from AMD sales and a benefit is attached to reducing infections, all subject to an increasing cost of AMR. Elbasha (2003) uses a market-based approach but using private household decisions to estimate the deadweight lose from AMD overuse, estimated to be USD$225 million from amoxicillin use. Herrmann and Gaudet (2009) use the SIS model as a constraint for a dynamic market equilibrium model under open access. This model is designed to address a free-rider problem arising from open-access to AMDs as it applies to small farmers in developing countries. While none of these studies are specific to AMU in livestock, they can be used in the context of animals raised for food.

Calculating optimal AMU requires an understanding of the externality costs. Studies that examine the externality costs of AMR from excess AMU generally use the cost of treatment of resistant infections and hospitalizations as the main cost. Meta studies from Gandra et al. (2014), Naylor et al. (2018), and Wozniak et al. (2019) provide a large range in cost estimates from USD$5 per resistant infection to USD$126,856 per resistant infection. Larson (2010) used regression analysis to examine the excess cost of AMR infection treatment over control infection treatment. Variables included level of hospital care, infectious organism type, and infection site, and resulted in an estimate of up to USD$126,856 of additional cost for treating an AMR infection compared to treating a control infection. At a macro level, the cost of additional hospitalizations and other societal costs due to AMR has ranged from USD$2.2 billion to USD$35 billion in the United States (Centers for Disease Control and Prevention, 2019; Thorpe et al., 2018).

While data on hospitalizations and costs is well documented, the literature on the externality cost per unit of AMD used on livestock is sparse. To the author's knowledge, Innes et al. (2020) is the only empirical study on the cost of AMU in livestock and found an external cost of USD$1,532 per kg of fluoroquinolones given to broiler chickens. Four parameters were used to determine the cost of AMR derived from AMU in livestock in the study: the health and economic burden of AMR in humans, AMU in animals, the impact of AMU in animal agriculture on AMR, the fraction of AMR in humans attributed to animal agriculture (Innes et al., 2020). From these parameters, a value of the cost of AMU for any livestock can be provided, regardless of which animal. These parameters present a highly anthropocentric view on the externalities of AMR, where the cost is entirely derived from the additional costs to human health care. This is likely the case because empirical data on human hospitalizations exists and far exceeds the cost of treating sick animals. Chapter 3 will discuss the conceptual framework of AMR externalities as it applies to beef cattle in more detail.

2.5 Summary

Beef cattle production is divided into three stages before slaughter: cow-calf, backgrounding, and feeding. Feedlots purchase calves from cow-calf operations or backgrounders based on specifications from packing plants. Young, freshly weaned calves that arrive at the feedlot from cow-calf operations are at a high risk of morbidity and mortality due to the stress of weaning and transportation. Feedlots often use prophylactic and metaphylactic treatment of AMDs to reduce morbidity and mortality, however, overuse of AMDs causes an increase in AMR, which is a danger to humans and animals.

Preconditioning is a practice designed to prepare calves for the feedlot by reducing the stress from weaning. This can reduce the need for unnecessary AMU upon feedlot arrival, as PC calves will have received booster vaccinations and will be familiar with feeding from bunks. Preconditioning can only be done by the initial cow-calf operators, but these operators are generally price-takers with very tight profit margins. Cow-calf operators are willing to precondition their calves for premiums, but feedlots in Canada have not always been willing to pay additional premiums for fear that PC calves will not remain healthy once they are commingled with other calves. Consumers, on the other hand, have shown a willingness to pay for meat products that are organically raised or produced with reduced AMDs. This suggests that the market for preconditioning as a source of antibiotic-free or -reduced meat exists but has not been fully realized.

The literature on externalities from AMR caused by AMU in livestock has provided several cost estimates at a macro level, but estimating the per unit externality from AMDs remains difficult. The best current estimate of the per kg externality cost from a Class I antimicrobial is approximately USD$1,532.

Chapter 3

Conceptual Framework

The problem faced by beef cattle producers is that there exists a practice that improves calf health during feedlot induction - a time when morbidity and mortality are highest - but the market for weaned calves does not provide enough incentive for its wide-spread adoption. There are some direct benefits to feedlots for purchasing PC calves, but feedlots are not the only beneficiaries from calf health programs. Parties who would receive benefits from preconditioning, but do not compensate the cow-calf operators are benefiting from an externality.

Conceptually, premiums for PC calves are intended to cover the additional costs incurred by cow-calf producers. Yet, there are still additional benefits of PC calves that are not accounted for, such as the reduction in antimicrobial drug (AMD) use and the related decrease in the societal cost of antimicrobial resistance (AMR). Section 2.2.5 introduced the relationship between antimicrobial use (AMU) in cattle production and AMR, and section 2.3.4 described the externalities that result from AMU in livestock production. This chapter will describe externalities resulting from preconditioning in beef cattle production and build the conceptual framework for the analysis of externalities in chapters 4 and 5.

From Gravelle and Rees (2004), "[a]n externality is said to exist if some of the variables which affect one decision-taker's utility or profit are under the control of another decision-taker". Externalities can positively or negatively affect outside parties, and both the production and consumption of a good can create an externality.

By preconditioning calves, cow-calf operators provide benefits to a wide range of groups or individuals who do not pay for these benefits, and thus markets are not producing at socially optimal levels. The most prominent externality is the reduction of the cost of health care associated with AMR, but other externalities may exist. Section 3.1 will provide an overview of how positive externalities are calculated in general terms and section 3.2 will examine potential beneficiaries from preconditioning.

3.1 Externalities

In its most general form, a market has a demand and supply for some good, with demand and supply written mathematically as $Q = f(P)$, where quantity demanded and supplied is a function of the price of the good. The inverse demand and supply written to match traditional graphs is written as $P = f(Q)$. The equilibrium price and quantity will produce the most social welfare by maximizing both consumer and producer surplus.

Externalities can be created through production (supply) or consumption (demand). In both cases, there is a difference between the internalized supply or demand functions and the total supply and demand functions. The internalized functions are called the “private” supply or demand, as only the factors that directly affect the market are considered. The functions that consider external costs and benefits are known as “social” supply or demand, as these functions include all societal costs and benefits.

These general demand and supply functions include attributes that are known to producers and consumers of the good, and are said to be internalized in the transaction, setting the market equilibrium price and quantity. The presence of an externality creates a market failure because the market price is not set at the socially optimal price, and the good is not produced at socially optimal quantities. The presence of an externality means the market will not be maximizing social welfare.

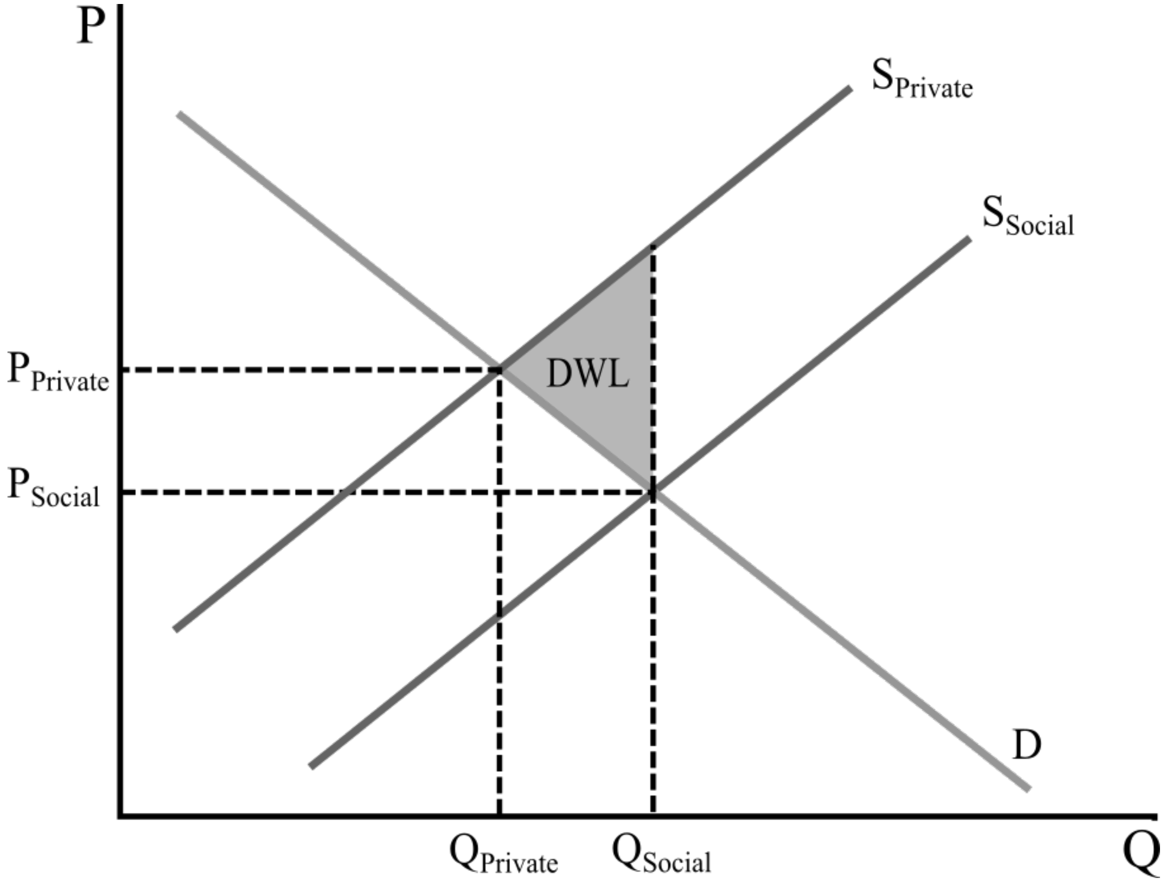
3.1.1 Positive Production Externalities

Positive production externalities reduce the costs of production for other firms. Other firms can include producers of the same good as the firm that produces the externality, or producers of other goods. Collectively, these beneficiaries and their consumers are referred to as society (i.e. the societal costs of production are reduced). A classic small-scale example from Meade (1952) is the interrelated production of beekeepers and apple farmers, but production externalities also include wider reaching social goods, such as research and development, and education. Both of these goods reduce the total costs to other firms (and society at large) by advancing the general level of technology and increasing the productivity of labour.

Overuse of AMDs is an example of a negative supply externality. This incurs a social cost in the form of the cost of developing new antimicrobial drugs to combat AMR, additional health care costs, and increased morbidity and mortality from the loss in effectiveness of existing AMDs. Reducing AMU through production practices that maintain good health would reduce some of these external social costs, and constitutes a positive production externality.

Figure 3.1 shows a market with a positive production externality. When only the private demand and supply ($\mathrm{S}_{\mathrm{Private}}$) are considered, the good will be sold at the private price ($\mathrm{P}_{\mathrm{Private}}$) and private quantity ($\mathrm{Q}_{\mathrm{Private}}$) given the demand for the good (D). An additional supply curve ($\mathrm{S}_{\mathrm{Social}}$) represents the social supply and corresponding reduction in social costs resulting in the production of this good. The social supply curve shows that, because total social costs are lower, the good should be produced in higher quantities ($\mathrm{Q}_{\mathrm{Social}}$) and be sold at lower prices ($\mathrm{P}_{\mathrm{Social}}$). Meade (1952) calls goods that lower the cost of social production "unpaid factors" because the producer of the externality is not compensated by the beneficiary. This constitutes a market failure because the good is both under-produced and over-priced compared to its social optimum. A Dead Weight Loss (DWL) results from the underproduction and

Figure 3.1: Positive Production (or Supply) Externality



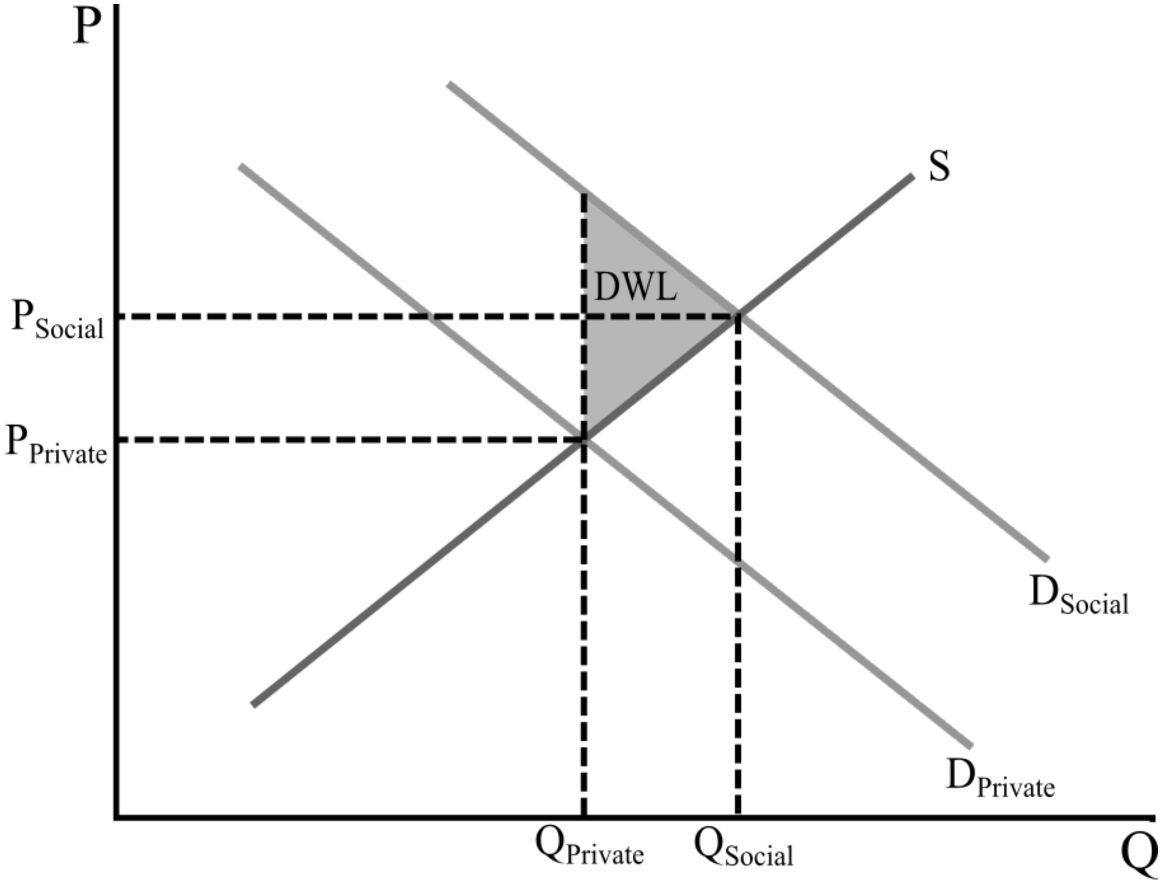
higher price (shaded area in Figure 3.1). The DWL represents the total welfare that could be gained by producing the good at the socially optimal quantity (Q_{Social}).

3.1.2 Positive Consumption Externalities

Positive consumption externalities are created when the consumption of a good creates a benefit to outside parties. The good has attributes that create more benefits than those demanded, and thus creates a larger social demand. Examples include aesthetic improvements to the exterior of a house that increase the value of neighbouring houses and using medications to treat infectious diseases. When a medication is used to treat an infectious agent, it decreases the chances of others becoming sick, which contributes to better health for other individuals.

Figure 3.2 depicts a good with a positive consumption externality. In the case

Figure 3.2: Positive Consumption (or Demand) Externality



of consumption externalities, supply (S) is now unchanged, and the private demand function ($D_{Private}$) includes only the demand from the consumers who purchase the good. If this good has some additional benefits that are not considered in the private transaction, and the producer is unable to collect payment from the beneficiaries, this creates a market failure where the good is under-produced ($Q_{Private}$) and under-priced ($P_{Private}$). The social demand function is introduced (D_{Social}), which represents the demand for the good when all those who benefit are considered. If the full benefits of the good are "internalized", the good will be sold at the socially optimal quantity (Q_{Social}). Similar to the positive production externality, the DWL area represents the total lost benefit in welfare if the good is produced at private demand quantities.

3.2 Preconditioning as a Positive Externality

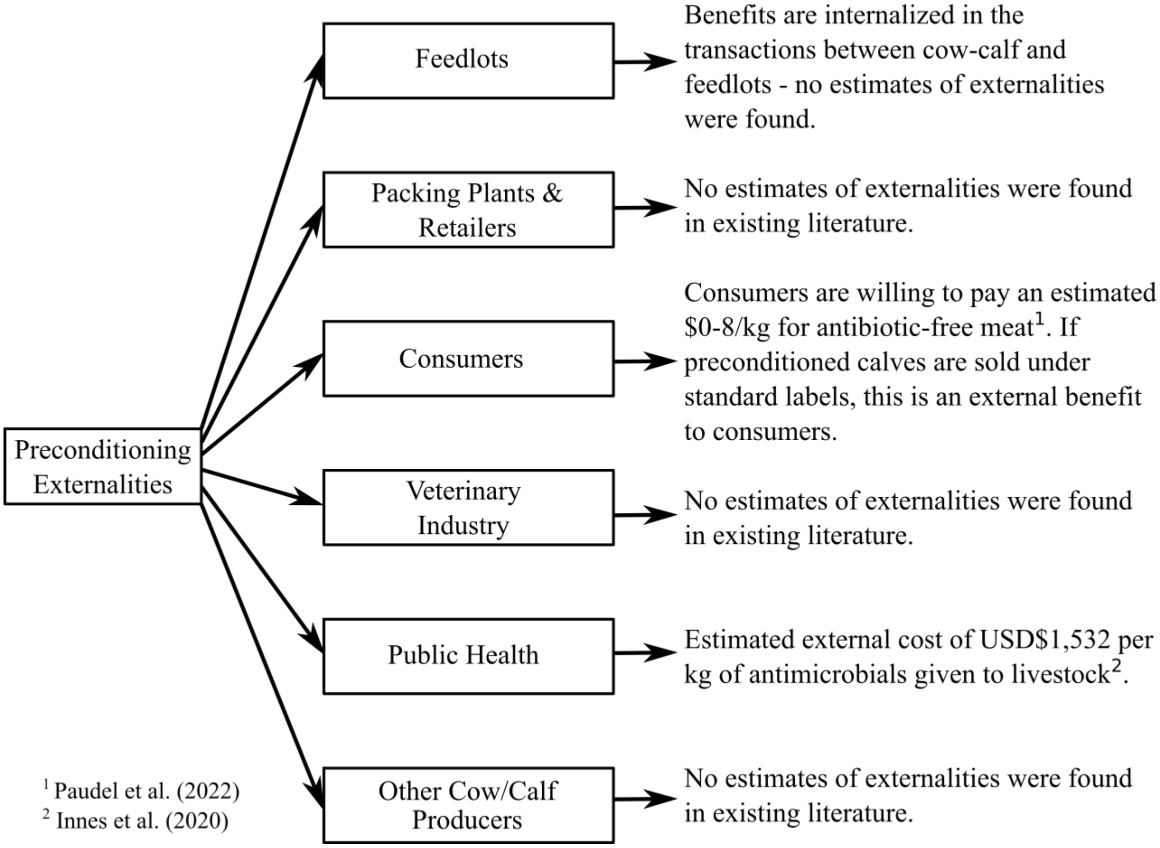
Preconditioning calves may provide both production and consumption externalities depending on the stage of production. Figure 3.3 provides an overview of how externality costs and benefits may be distributed throughout the beef supply chain. Six main beneficiaries are identified as well as a brief description of the estimates of externalities from the literature. These beneficiaries include: feedlots, packing plants and retailers, consumers, the veterinary industry, public health care, and other cow-calf producers. As a caveat, no study was found that explored the direct link between externalities and preconditioning. Therefore, externalities associated with the goals of preconditioning, such as reducing AMU and improving livestock welfare, are used as proxies. Sections 3.2.1 through 3.2.6 describe the externalities that may be present for each group shown in figure 3.3.

3.2.1 Feedlots

Externalities exist at the feedlot level if feedlots purchase PC calves at the same price as non-PC calves. PC calves theoretically warrant a higher price due to their health benefits. The benefits from PC calves are divided here into savings in health costs and death loss, and savings in labour costs. When a premium is paid for PC calves, it should be equal to the value of these benefits. If PC calves are purchased for a higher price, some or possibly all benefits would no longer be an externality, as the benefits will be internalized in the transaction through the premium. All potential benefits are listed here, as these benefits exist whether a premium is paid or not, therefore they all have the potential of becoming positive externalities.

Savings in health costs is the amount saved per calf if it had been infected, or the reduction in treatment costs. This can apply to any injuries or illnesses, though is most often calculated in relation to BRD. This would likely be a supply-side externality, where the “social” cost would reflect the combined costs of raising beef cattle for

Figure 3.3: Distribution of Externalities from Preconditioning



both cow-calf operators and feedlots. By taking time to precondition calves, health care costs would be reduced for feedlots. Nyamusika et al. (1994) estimated the cost of BRD to be $44 per calf, and Dhuyvetter et al. (2005) used several sources[1] for an estimate of $40 - $60 in BRD related cost savings per preconditioned calf. Hilton et al. (2015) estimated $46.83 - $60.72 in health cost savings from preconditioning. More recently, Lhermie, Verteramo Chiu, et al. (2019), estimated the total loss of a calf's value from BRD at $138 per case, and references two other papers with net losses ranging from $60-$143 per head. All of these estimates are in USD$.

Savings in labour costs represent the increased ease of handling PC calves. Weaned calves that are used to their mothers and have not been handled can be flighty and

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[1] Cravey (1996), Gardner et al. (1996), McNeill et al. (2000), and Roeber and Umberger (2002)

difficult to manage, whereas PC calves have become accustomed to handling. This has been mentioned anecdotally and referenced in previous studies (Dogan & Demirci, 2012; Langley & Morrow, 2010; Taylor, 2011). However, there does not appear to be an attempt to quantify this benefit. If preconditioning does reduce some of the physical work of handling cattle it could be considered a positive production externality, assuming feedlots were not aware of this benefit.

3.2.2 Packing Plants & Retailers

There is no indication from the literature that preconditioning status is considered when packing plants purchase cattle, nor that any higher price exists for PC cattle sold after the packing plant. PC calves may be sold under an "antibiotic free" or "reduced antibiotics" label, and this would internalize the potential benefits.

Most evidence suggests that by the time cattle reach slaughter weight, there is no discernible difference between beef sourced from preconditioned and non-preconditioned cattle (Anderson et al., 2016; Mathis et al., 2009). BRD may (Wilson et al., 2017) or may not (Holland et al., 2010) have an effect on marbling and carcass weight. If BRD does affect carcass value, then an uncompensated reduction in cases of BRD would become a positive externality, but again, no evidence of this was found in the literature.

3.2.3 Consumers

There is an increasing demand for meat products that are produced with social and environmental impacts in mind, and several studies show that consumers are willing to pay for meat from animals produced is a socially or environmentally conscious manner (Galyean et al., 2011; Markus et al., 2011; Stampa et al., 2020). Examples in Canada are Certified Humane and Certified Sustainable labels ("CRSB", n.d.; "Humane Certification", n.d.). From King et al. (2006), beef products labelled with health programs garnered a premium of \$2.47/kg - \$7.91/kg. Schulz et al. (2012)

found that organic beef products sell for \$2.98/kg more, and Ward, Vestal, et al. (2008) found branding associated with health programs sold for up to \$6.20/kg more. All of these studies use scanner data from American grocery stores and values are USD\$. Paudel et al. (2022) estimated a willingness to pay an additional \$2.88 to \$3.46/lb for antibiotic-free meat. Tonsor and Wolf (2011) found that consumers would be willing to pay 20% more for pork and poultry products with production practices labelled. Both of these results are from stated preference surveys (also in USD\$).

Meat products that are labelled with some health or environmental practice and sold at a higher price are taking advantage of this higher demand and reducing the number of "free-riders" who would have paid more (Lusk et al., 2007). In Canada, there has not been any labelling indicating whether the cattle were preconditioned or not, however, beef is sold under "antibiotic free" labels which could consists of PC calves. If PC calves are sold without any specific branding or sold under generic labels, some consumers who would have paid more for humane programs may be gaining an external benefit of up to \$8/kg of beef product.

3.2.4 Veterinary Industry

The veterinary industry responds to changes in treatment needs. Similar to feedlots, there may or may not be a labour cost reduction from animals that are easier to handle, and again, no studies were found that attempted to quantify such a benefit.

3.2.5 Public Health

Section 2.3.4 provided a background for AMR stemming from overuse of AMDs as a negative externality. This is because increased AMR leads to longer hospitalizations from infections and increases the costs of developing new AMDs. Reduction in AMU reduces the instance of AMR, which increases social welfare. AMDs also operate as positive externalities by reducing the number of sick individuals. Several theoretical models have been created to optimize AMU based on these two counteracting externalities (Delmond & Ahmed, 2020; Herrmann & Gaudet, 2009; Horowitz & Moehring, 2004; Laxminarayan & Brown, 2001).

In Canada, approximately 349,000kg of AMDs were sold for use in cattle production in 2021 (CIPARS, 2022). Approximately 1,700kg of these AMDs were Class I drugs, which was an increase of 13% from 2020 (CIPARS, 2022). Tetracyclines are the most commonly used AMD in feedlots, but these are Class III antimicrobials (medium importance to human health). Of some concern is the use of macrolides in feedlots, a Class II antimicrobial (high importance to human health) (Brault et al., 2019). Macrolides such as Draxxin® are used for metaphylactic treatment against BRD upon feedlot arrival.

Innes et al. (2020) provides the most comprehensive empirical analysis of the public health externalities caused by use of AMDs in livestock to this author's knowledge, measuring a cost of US$1,532/kg of fluoroquinolones used in broiler chicken production. In Canada, fluoroquinolones are a Class I AMD (very high importance to human health) (Canadian Animal Health Institute, 2018). In most AMR models, external costs increase at an increased rate with respect to AMU because the percentage of AMR increases as AMU increases. The Innes et al. (2020) external cost value is calculated using an estimated fluoroquinolone resistance rate of 18% in 1999 (Centers for Disease Control and Prevention, 1999). In 2018, the "first-line" antimicrobial resistance rate was estimated at 26% in Canada (Finlay et al., 2019). This would raise the external cost to $4,557/kg of fluoroquinolones[2]. Finlay et al. (2019) warns that the resistance rate of first-line antimicrobials could reach 40% by 2050. If the fluoroquinolone resistance rate reached 40%, the external cost would rise to $42,241/kg of fluoroquinolone applied (Innes et al., 2020).

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[2] "First-line" is defined as "those [antimicrobials] generally first prescribed to treat an infection" (Finlay et al., 2019).

3.2.6 Other Cow-Calf Producers

Cow-calf producers participate in the same markets as one another, and no studies were found that suggest an external cost or benefit from one cow-calf producer on another cow-calf producer from preconditioning, weaning, or other health practices.

3.3 Summary

PC calves produce two main externalities. Members of the public who prefer beef produced with fewer antimicrobials and humanely treated livestock (via reducing stress at weaning) are benefiting from a positive consumption externality if beef produced with these qualities is sold the same price as conventionally raised beef because beef producers are not compensated for this additional good. The other main externality is the benefit to public health from the reduction of AMU in livestock production - mostly in cattle feedlots. Feedlots may pay premiums for the benefits they gain from PC calves, but feedlot operators are unlikely to consider the reduction in public health costs from their own reduction in AMU.

Chapter 4

Data and Empirical Approach

Chapter 4 will describe the cattle data and methods used for the empirical analysis of preconditioning. The description of the data and methods presented here was the economic portion of a larger study of PC calf performance under different commingling scenarios. Section 4.1 describes the cattle and cost data, and section 4.2 describes the general methods for the analysis. Section 4.3 provides the empirical specification for the economic benefits of preconditioning.

4.1 Data

This section describes the data used for the empirical analysis, and a brief description of how the data was obtained. Section 4.1.1 explains the cattle data and the structure of the trial conducted at the University of Calgary and Olds College. Section 4.1.2 will examine the costs for the feedlot portion of the study, as well as the source of cost figures.

4.1.1 Cattle Data

Empirical data were collected and provided by researchers at the University of Calgary and Olds College. The study used 500 spring-born steer calves (mean 614.8 lbs, SE 55.83 lbs) to test feedlot performance of PC calves under varying proportions of commingling with auction sourced calves. Calves were sorted into five pens with a

Table 4.1: Pen Organization.

Pen Name	**No. PC Calves**	**No. AD Calves**	**Total**
0PC	0	100	100
25PC	25	75	100
50PC[1]	50	49	99
75PC[1]	76	26	102
100PC[1]	99	0	99

[1] One calf from each the 50PC pen and 100PC pen wandered into the 75PC pen upon feedlot entry. Researchers elected to allow the calves to stay in their chosen pen rather than risk additional stress on the calves by forcing them to their intended pens.

different proportion of PC calves, ranging from 0% to 100% PC calves, as summarized in table 4.1.

The 250 PC calves used in the study were sourced from the University of Calgary's WA Ranch, a commercial cow-calf operation with 900 Angus-based breeding females. At around 60 days of age, the calves were given a series of vaccinations against clostridial diseases and common BRD pathogens, and surgically castrated. In September 2020, the calves were fenceline weaned for 5 days and given booster vaccinations Bovi-Shield Gold One Shot® (Zoetis Canada, Kirkland, QC) and ULTRABAC® 7/SOMUBAC® (Zoetis Canada, Kirkland, QC). The calves were then moved to a pasture-pen, with feed provided from feed bunks similar to those found in feedlots. The calves were fed a silage-based diet for 45 days before transport to Olds College. Hodder (2022) provides further details on treatments and procedures at WA Ranch.

Researchers at the University of Calgary placed emphasis on preconditioning as a holistic management practice. Calves were interacted with as infrequently as possible to reduce overall stress and to mimic typical ranch practices. Three key intervals were used as interaction times to adhere to this management practice: birth, spring processing, and fall weaning. Interactions outside these three time periods were limited to necessary interventions, such as treating illness or facility repairs.

The 250 calves designated as auction-derived (AD) were purchased from an auction mart in Olds, Alberta. These calves were purchased without knowledge of their source or medical histories and served as a control group to the PC calves. The AD calves represent the majority of feeder cattle purchased by feedlots in Southern Alberta (University of Saskatchewan, 2018).

All 500 calves were the same breed (Angus-cross) and gender (steer). The auction in Olds where the AD calves were purchased is approximately 2km away from the feedlot used in the study to reduce the impact of long transportation routes. PC calves from WA Ranch were transported approximately 65km to the feedlot at Olds.

Calves arrived at Olds College on November 13 and 14, 2020, and the trial ended on December 22 and 23, 2020 (40d). Upon arrival at the feedlot, calves were randomly sorted into five pens of the mixes described in table 4.1. Calves were not given any antimicrobial metaphylaxis upon arrival at the feedlot. Vaccinations consistent with industry standards were administered upon arrival. This included Bovi-Shield Gold One Shot® (Zoetis Canada, Kirkland, QC) and ULTRABAC® 7/SOMUBAC® (Zoetis Canada, Kirkland, QC). Calves were also given IVOMEC® (Boehringer Ingelheimand Canada, Burlington, ON) for parasite control and SYNOVEX® C (Zoetis Canada, Kirkland, QC) growth implant. Researchers weighed each calf upon feedlot entry and at the trial's conclusion. Instances of illness and injury, as well as treatments were recorded, including date, animal temperature, and treatment dosage. Table 4.2 reports the head count for each pen and source over the course of the trial.

Twelve calves did not complete the study. Five were euthanized before the end of the trial due to illness, and a further seven were moved to a separate sick pen for the duration of the study. All but two of these twelve calves were treated at least twice for respiratory illness. All twelve cases of mortality and severe morbidity were AD calves, and all but one were housed in either pen 0PC or pen 25PC.

All calves were fed the same diet consisting of 83.4% barley silage, 9.5% barley grain, 3.3% 32-15 Grower supplement, and 3.8% corn DDGS (46.50% dry matter) for

Table 4.2: Summary of head counts, severe morbidity, and mortality over the trial.

	Head Count Arrival	**Head Count Final**	**Mortalities**	**Moved to Sick Pen**	**Number (%) of Animals Treated for BRD**	**Total BRD Treatments**
Total	500	488	5	7	192 (36.92%)	225
Preconditioned	250	250	0	0	68 (25.18%)	72
Auction-Derived	250	238	5	7	124 (49.60%)	153
Pen 0PC	100	97	3	0	50 (50.00%)	62
Pen 25 PC	100	92	2	6	63 (63.00%)	78
Preconditioned	25	25	0	0	9 (36.00%)	9
Auction-Derived	75	67	2	6	54 (72.00%)	69
Pen 50 PC	99	99	0	0	22 (22.22%)	22
Preconditioned	50	50	0	0	9 (18.00%)	9
Auction-Derived	49	49	0	0	13 (26.53%)	13
Pen 75 PC	102	101	0	1	32 (31.37%)	35
Preconditioned	76	76	0	0	25 (32.90%)	26
Auction-Derived	26	25	0	1	7 (26.92%)	9
Pen 100 PC	99	99	0	0	24 (24.24%)	27

Table 4.3: Total feed offered, weight gain, feed conversion (FC), and dry matter feed conversion (DMFC) by pen.

	Total Feed Offered (lbs)[1]	**Total Weight Gained (lbs)**	**FC (lb as-fed / lb gain)**	**DMFC (lb DM offered / lb gain)**
Total	559,300	40,951	13.66	6.49
Preconditioned	292,998	21,902	13.38	6.36
Auction-Derived	266,302	19,049	13.98	6.65
Pen 0PC	106,500	10,421	10.22	4.86
Pen 25 PC	98,600	3,783	26.06	12.39
Preconditioned	24,650	2,369	10.41	4.95
Auction-Derived	73,950	1,414[2]	52.30	24.87[2]
Pen 50 PC	114,900	10,998	10.45	4.97
Preconditioned	58,030	5,244	11.07	5.26
Auction-Derived	56,870	5,754	9.88	4.70
Pen 75 PC	113,700	7,502	15.16	7.21
Preconditioned	84,718	6,042	14.02	6.67
Auction-Derived	28,982	1,460	19.85	9.44
Pen 100 PC	125,600	8,247	15.23	7.24

[1] Total Feed Offered in mixed pens assumes an equal proportion of feed was consumed by each calf.

[2] Low weight gain and high DMFC is a consequence of 8 calves not completing the trial.

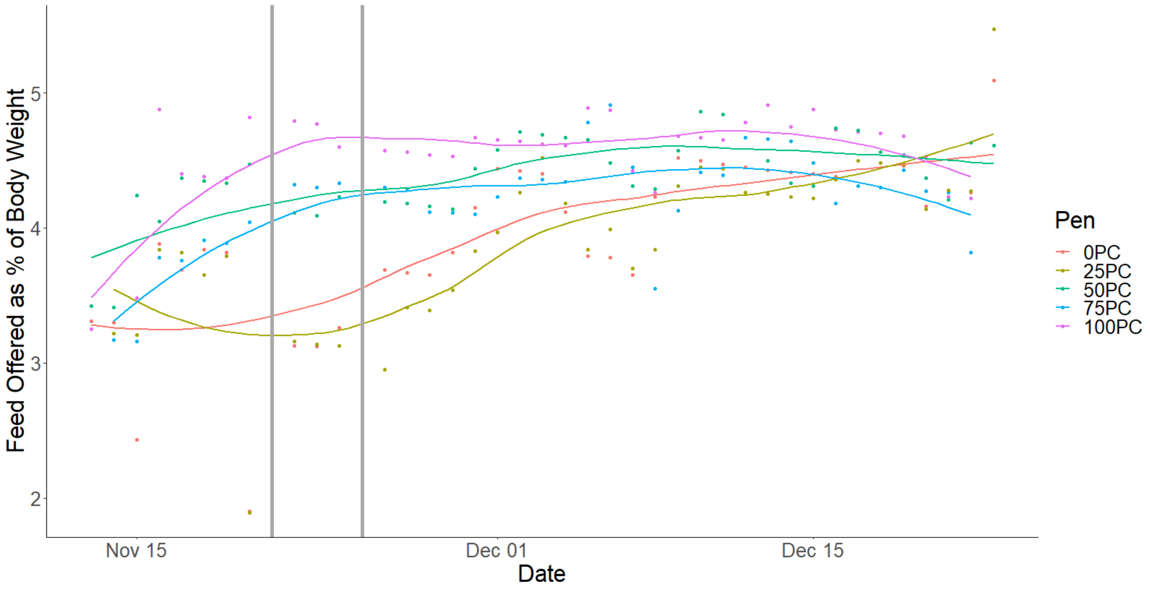
the first 14 days of the trial. For the last 27 days, the diet was switched to 80.03% barley silage, 13.37% barley grain, 3.4% 32-12 grower supplement, and 3.2% corn DDGS mixture (48.09% dry matter). Feed was added to bunks each morning and afternoon, with the amount of feed added depending on the amount remaining in the bunk from the previous feeding time. Daily feed offered was recorded for each pen. Measures of individual feed offered is calculated by dividing the total feed offered for each day by the number of calves in the pen on that day.

Feed conversion (FC), a useful measure of feeding efficiency, is calculated by dividing the total feed offered in a pen by the total weight gained in that pen. This method of calculating FC differs from more precise measurements of FC (Beef Cattle Research Council, 2019), because feed refused (or feed left over at the end of each day) was not recorded. A lower feed conversion is preferable, because these calves need less feed for every pound gained.

Dry Matter Feed Conversion (DMFC) corrects feed conversion for moisture variability in feed stuffs to isolate the consumption of silage, grains, and supplements. DMFC is a useful indicator for comparing the feed conversion for different diets, and is more commonly used in analysis (Beef Cattle Research Council, 2019). In this study, DMFC is calculated by multiplying total feed offered by its dry matter content (46.50% for the first 14 days and 48.09% for the latter 27 days). Average DMFC for Angus steers is around 6 lbs of feed per lb of weight gain, with the desirable range being 4.5 to 7.5 lbs of feed per lb of gain (Byrne, 2018).

Table 4.3 provides a summary of total weight gained, total feed offered, FC, and DMFC by pen and source. Table 4.4 shows the mean individual weights measured at arrival and at the conclusion of the study. Final weights from the twelve calves that either died or were moved to the sick pen are not available. In total, calves gained 40,951 lbs of weight from 559,300 lbs of feed, for a DMFC of 6.49 lbs of dry matter (DM) feed per lb of gain. Calves that completed the study gained an average of just over 99 lbs of weight. PC calves had a slightly lower FC (6.36 vs 6.65), though the difference is not statistically significant (p=0.93). AD calves that completed the study showed larger gains than PC calves, but all PC calves completed the study. All 12 calves (5 deaths and 7 sick pen pulls) that did not complete the 40d trial were AD calves. Pen 50PC saw the largest total gains, while the 25PC pen had the lowest weight gain. This is largely due to the number of severe morbidity and mortality cases in the 25PC pen, which reduced the total weight gained in those pens. However, of the calves where a final weight was recorded, calves in pen 0PC saw the largest mean weight gain (126.32 (SE 35.86) lbs), whereas pen 75PC saw the lowest mean weight gain (80.57 (SE 29.86) lbs). This rapid weight gain for calves in pen 0PC contributed to this pen having the lowest DMFC despite three mortalities, as shown in Tables 4.3 and 4.4.

Figure 4.1: Feed offered as a percent of total body weight for each day



The grey bars show November 21 and November 25. Just over 76% of treatments for BRD were administered between these dates. Total body weight is estimated for each day based on that pen's ADG as only the entry and final weights were recorded.

The literature is mixed as to whether compensatory gain can be regularly expected (Cuevas-Gómez et al., 2020; Klopfenstein et al., 1999; Sainz et al., 1995); however, lighter calves do tend to have more of a compensatory gain upon feedlot entry (Coleman & Evans, 1986). A common strategy amongst feedlot operators is buying young, "green" calves with the hope that they will be more profitable due to compensatory gain (Jim & Gulchon, 1990). Figure 4.1 shows the feed offered as a percentage of total body weight for every day of the trial. Pen 0PC and 25PC saw low feed offered at the start of the trial, then eventually catch up to the other three pens. The early dip in feed offered for these pens coincided with BRD outbreaks (37 treatments in pen 0PC and 42 treatments in pen 25PC between November 21 and November 25). While this study does not analyse compensatory growth, it should be mentioned that this is not a completely unexpected phenomenon. This also suggests that using the data from this study to estimate growth patterns over the course of a full feedlot stay would be inappropriate.

Table 4.4: Mean arrival weight, final weights, and average daily gain (ADG) by pen and source.

	Arrival Weight Mean (lbs)	**Final Weight Mean (lbs)**	**Total Gain Mean (lbs)**	**Average Daily Gain (ADG) (lbs)**
Total	614.80 (55.83)	713.84 (62.85)	99.11 (34.73)	2.52 (0.86)
Preconditioned	626.31 (65.85)	713.92 (67.90)	87.61 (25.57)	2.25 (0.64)
Auction-Derived	603.29 (40.55)	713.75 (57.20)	111.20 (38.80)	2.81 (0.97)
Pen 0PC	609.87 (36.33)	736.16 (58.76)	126.32 (35.86)	3.16 (0.90)
Pen25 PC	620.57 (53.45)	715.65 (65.10)	94.90 (37.26)	2.43 (0.95)
Preconditioned	628.68 (85.58)	723.44 (86.09)	94.76 (32.29)	2.42 (0.82)
Auction-Derived	617.87 (37.64)	712.75 (55.83)	94.96 (39.17)	2.43 (1.00)
Pen50 PC	590.10 (55.49)	701.19 (60.22)	111.09 (25.30)	2.78 (0.63)
Preconditioned	615.64 (65.48)	720.52 (71.50)	104.88 (22.12)	2.62 (0.55)
Auction-Derived	564.04 (23.15)	681.47 (37.41)	117.43 (26.95)	2.94 (0.67)
Pen75 PC	618.67 (62.74)	699.07 (64.89)	80.57 (29.86)	2.12 (0.78)
Preconditioned	621.66 (67.68)	701.16 (69.25)	79.50 (26.34)	2.09 (0.69)
Auction-Derived	609.92 (45.31)	692.72 (50.01)	83.84 (39.13)	2.20 (1.02)
Pen100 PC	634.68 (58.53)	717.98 (59.04)	83.30 (19.86)	2.14 (0.51)

Standard Deviations in brackets. Table does not include the 12 calves that did not complete the study.

ADG was higher overall for AD calves ($p<0.001$), with calves in pen 0PC performing the best (3.16 (SE 0.90) lbs/day) and calves in pen 75PC performing the worst (2.12 (SE 0.78) lbs/day). These values are all lower than the mean ADG of 3.62 lbs/day for Angus steers (Reinhardt et al., 2012).

At the conclusion of the study, the 250 PC calves were sold via electronic auction on December 18, 2020 for \$194.13/cwt with a \$0.08 price slide. There is no indication that PC calves sold for a premium. Therefore, a final sale price for each individual calf, both PC and AD, was assigned using the following formula:

$$Price\ per\ lb = \frac{194.12 + (697 - Final\ Weight) \times 0.08}{100} \tag{4.1}$$

Multiplying the price calculated in Equation 4.1 by the end of trial weight provides a trial ending value for each calf. Calves that died were assigned a trial ending value of \$0. The seven calves moved to the sick pen were given a 5% reduction in the mean calf value, amounting to \$1,285.41 per head[1]. Blakebrough-Hall et al. (2020), Brooks et al. (2011), Cernicchiaro et al. (2013), and Schneider et al. (2009) found an average reduction of 5% of value for cattle treated three or more times for BRD at slaughter[2].

4.1.2 Cost Data

The starting values of the feeder steers was based on average prices reported by Canfax (2020) for 550 lb steers in Alberta for November 2020. The average Alberta feeder steer price in November 2020 - the month the calves were moved to the feedlot at Olds - for a 550lb steer was \$213/cwt. Using a modified version of Equation 4.1, a slide-adjusted price for each feeder calf can be determined[3].

$$Feeder\ Price\ per\ lb = \frac{213 + (550 - Entry\ Weight) \times 0.08}{100} \tag{4.2}$$

Multiplying this price by the entry weight for each calf provides the cost of acquiring the calves for the feedlot.

Table 4.5 shows the ending value, starting value, value added, and net return on a per head basis, and table 4.6 presents the total ending value, starting value, value added, and net return from each pen. Value added is the difference between ending and starting values, and net return is the value added minus costs. Net returns are mostly negative due to the short time period of the study, with the median net return being -\$68.43. Over a longer time period, cattle will gain enough weight to cover the costs of entry processing. Pen *50PC* showed the highest value added and net return

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[1] No final weights were recorded for 7 sick pen calves. A 5% reduction of the mean head value of \$1,353.06 was used.

[2] While not all calves moved to the sick pen in this study were treated three or more times for BRD, the short time period of the study leaves the possibility that future treatments may be required.

[3] Assuming the same 0.08 price slide applied when the PC calves were sold December 18, 2020.

Table 4.5: Summary of Ending and Starting Calf Values, Value Added, and Net Returns ($ per head).

	Ending Value	**Starting Value**	**Value Added**[1]	**Net Return**
Min	0.00	865.00	-1356.78	-1547.49
25th Q	1312.26	1220.66	63.28	-103.30
Median	1379.06	1279.56	96.19	-68.43
Mean	1357.49	1275.17	68.78	-86.26
75th Q	1426.74	1330.20	132.61	-38.24
Max	1579.48	1509.92	266.37	119.04

[1] Value Added = Ending Value - Starting Value

Table 4.6: Total Ending and Starting Calf Values, Value Added, and Net Returns by Pen ($).

Pen	**Ending Value**	**Starting Value**	**Value Added**[1]	**Net Return**
0PC	136,119	126,877	9,242	-8,121
25PC	134,234	128,452	5,783	-11,786
50PC	134,241	122,319	11,922	-4,273
75PC	137,896	130,627	7,270	-9,277
100PC	136,519	129,309	7,209	-9,447

[1] Value Added = Ending Value - Starting Value

Table 4.7: Summary of Costs in the Feedlot Study ($ per head).

	Feed	**Processing**	**Treatments**	**Yardage**	**Marketing**	**Total**
Min	9.42	9.70	0.00	13.42	0.00	32.69
25th Q	63.04	9.81	0.00	53.72	23.60	152.09
Median	63.65	9.83	0.00	53.72	23.60	158.54
Mean	64.80	9.82	16.95	53.72	23.36	168.33
75th Q	67.56	9.84	32.98	55.02	23.60	183.70
Max	71.41	9.91	127.73	55.02	23.60	265.86

due to the high growth rate of the calves and low health costs, whereas pen *25PC* saw the lowest net returns due to death and sickness loss.

Costs associated with feedlot production from this trial are summarized in Table 4.8. Feed costs are the amount paid by Olds College over the course of the trial for the feed. Yardage costs are based on the amount charged by Olds College to the University of Calgary. When adjusted for inflation and currency, the yardage costs are similar to those found in related studies (US$0.47-0.57 in Fernandez and Woodward (1999) and US$0.38-0.75 in Kumar et al. (2012)).

Processing costs are the costs of industry standard feedlot induction treatments. This consisted of Bovi-Shield Gold One Shot® (Zoetis Canada, Kirkland, QC) and ULTRABAC® 7/SOMUBAC® (Zoetis Canada, Kirkland, QC) vaccines, IVOMEC® (Boehringer Ingelheimand Canada, Burlington, ON) dewormer, and SYNOVEX® C (Zoetis Canada, Kirkland, QC) growth implant. Treatment costs include any other treatment provided over the course of the study. A full list of medications used is included in the appendix table B.

Marketing costs include brokerage or commission fees, check-off, brand inspections, insurance, and other sale fees. The amount of $23.60 was the marketing cost of the calves sold at the conclusion of the study. All mortalities were assigned a marketing cost of $0. Figure 4.2 shows the allotment of costs for each pen, and the summary

Table 4.8: Summary of Costs.

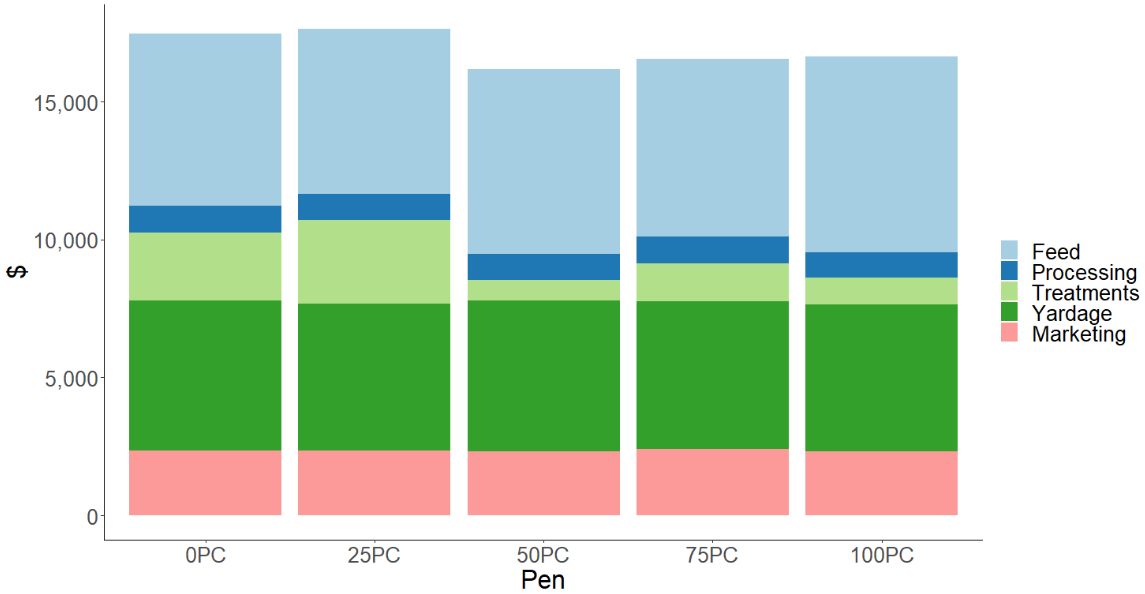
Feed	**($)**
Step 1 Diet	124.36 tonne^{-1}
Step 2 Diet	129.99 tonne^{-1}
Yardage (including Labour)	**($)**
General	1.30 head^{-1} day^{-1}
Processing	**($)**
Bovi-Shield GOLD One Shot	3.63 head^{-1}
Ultrabac 7/ Somubac	1.20 head^{-1}
Ivermectin (Ivomec)	0.01 mL^{-1}
Revalor G (implant)	4.67 head^{-1}
Medication	**($)**
See Appendix for full list	-
Other	**($)**
Marketing	23.60 head^{-1}

Note: See Appendix Table B for full list of medication costs.

Table 4.9: Total Costs by Pen ($).

Pen	**Feed**	**Processing**	**Treatments**	**Yardage**	**Marketing**	**Total**
0PC	6,242 (36%)	982 (6%)	2,419 (14%)	5,432 (31%)	2,289 (13%)	17,364 (100%)
25PC	5,970 (34%)	983 (6%)	2,987 (17%)	5,316 (30%)	2,313 (13%)	17,569 (100%)
50PC	6,688 (41%)	971 (6%)	752 (5%)	5,447 (34%)	2,336 (14%)	16,194 (100%)
75PC	6,430 (39%)	1,002 (6%)	1,356 (8%)	5,351 (32%)	2,407 (15%)	16,546 (100%)
100PC	7,070 (42%)	974 (6%)	962 (6%)	5,316 (32%)	2,336 (14%)	16,658 (100%)

Figure 4.2: Total Costs by Pen.



of total costs is shown in table 4.9, and represented graphically in figure 4.2. Table 4.7 provide summary statistics for the final values of the calves, and each of the costs from the study on a per head basis.

The largest costs were yardage and feed, accounting for 64% - 75% of total costs depending on the pen. This is consistent with most budget estimations for cattle operations (Alberta Agriculture and Forestry, 2020; Fernandez & Woodward, 1999; Pendell et al., 2015). Yardage, marketing, and processing costs are similar for all calves and across all pens, therefore the largest variability in costs is from feed and treatment costs. For instance, pen 25PC has treatment costs nearly 4 times higher than those for pen 50PC. Because of these high treatment costs, pen 25PC had the highest total costs despite the lowest feed and yardage cost.

4.2 Empirical Approach

This section will explain the general methods used for analysis. Several different regressions were chosen depending on data analysis requirements. These were linear, logistical, and Poisson regressions. Regressions are simple yet informative tools for analysis. Regression coefficients estimate the relationship between selected independent variables and a selected dependent variable. In this case, preconditioning status and the pen mixture were the main focus of research. Regressions allowed the preconditioned status and pen mixtures to be isolated from other variables that affect pen performance and health, namely calf weight at feedlot induction.

The data used for this analysis had already controlled for several variables such as gender, location, and breed. In larger analyses of cattle health practices, variables such as location, housing type, breed, sex, and operation size need to be controlled for in order to examine the effects of the practice in question. Large models with dozens of variables are required for these analyses[4]. Too many irrelevant variables reduces the predictive power of independent variables and reduces the accuracy of the model by increasing the likelihood of multicollinearity.

Regression models can only observe relationships within the data set, so random sampling inputs for models are used to estimate relationships in a population where complete population data is difficult to acquire. In this case, individual calf data is used to model the effects of preconditioning to then estimate population effects and externality costs for Alberta and Saskatchewan.

Breusch Pagan tests for heteroskedasticity were conducted for each regression, and robust standard errors are used where noted in order to correct for heteroskedasticity. Robust standard errors are also used for each Poisson regression in order to ensure the mean is equal to the variance. Variance Inflation Factors (VIFs) provide measures for multicollinearity. The VIFs were observed for each model, but no models showed strong signs of multicollinearity (VIF scores were >5 in every model).

R-squared and F statistics are shown to report on model fitness (Verbeek, 2017). R-squared measures the proportion of the variance of the independent variable that is

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[4] Cernicchiaro et al. (2012) and Irsik et al. (2006) are examples of regressions analysing cattle health practices with a large number of independent variables.

explained by the dependent variables. An R-squared score of 0 indicates none of the variation in the dependent variable is explained by the independent variables, while an R-squared of 1 suggests that all the variance in the dependent variable is explained by the dependent variable. Adjusted R-squared is also included, as R-squared scores tend to increase as more variables are added, and the adjusted R-squared corrects for additional variables. F statistics test the joint significance of all variables, with the null hypothesis being all independent variable coefficients are zero. If the F-statistic is not statistically significant, this suggests that the model has no predictive value.

The Akaike Information Criterion (AIC) and Schwarz Bayesian Information Criterion (BIC) are also measures of model fitness included in Poisson and logit regression results. Models with lower AIC and BIC scores are preferred, as these models will explain the most variation with the least number of variables (Verbeek, 2017). BIC punishes additional variables more than AIC.

Lastly, a budget sensitivity analysis was used to examine cow-calf producers' profitability under preconditioning. The aim of this analysis was to test the robustness of a cow-calf producer's budget under different scenarios to understand incentives for cow-calf producers and to test for when premiums may be necessary.

4.2.1 Linear Regression Model

Linear regression models use the ordinary least squares (OLS) method to estimate relationships between a set of variables. OLS creates the best linear unbiased estimator for a function of the form:

$$y_i = \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK} + \varepsilon_i$$

by minimizing the sum of the squared error terms (ε_i) of the function. The left-hand side y_i is the observed independent variable, $x_{i2} \cdots x_{iK}$ are the observed dependent variables, and ε_i is unobserved and referred to as the error term. The assumptions of OLS, or the Gauss-Markov conditions, are as follows (Verbeek, 2017):

- The expected value of the error term is zero.
- The error terms and independent variables are not correlated.
- Homoskedasticity (i.e. the error terms have the same variance).
- The error terms are not correlated.

Linear regression models are used in this thesis to model ADG, DMFC, value added, net return, and health costs.

4.2.2 Logistical Regression and Probit Models

A major limitation of the linear regression model is that it is not designed to model binary dependent variables or probabilities (Verbeek, 2017). Binary dependent variables show how independent variables affect the probability of the dependent variable occurring. Depending on the data, linear regressions may estimate probabilities less than 0 or greater than 1. If a binary dependent variable uses the same functional form as a linear regression:

$$y_i = \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK} + \varepsilon_i$$

and if the expected value of y_i is calculated assuming an error term of zero:

$$E(y_i|x_i) = 1 \cdot P(y_i = 1|x_i) + 0 \cdot P(y_i = 0|x_i)$$

$$E(y_i|x_i) = P(y_i = 1|x_i) = \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}$$

the independent variables are implied to be a probability for the expected value of y_i. This may not be desirable if probabilities can only be bound between 0 and 1.

Another problem arising from modelling binary dependent variables with a linear regression is that the assumption that the error term is not correlated with the independent variables is violated, because the error term also now has two outcomes with probabilities defined as:

$$P(y_i = 1|x_i) = P(\varepsilon_i = 1 - \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}|x_i) = \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}$$

$$P(y_i = 0|x_i) = P(\varepsilon_i = 0 - \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}|x_i) = 1 - (\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})$$

Logistical regression models (or logit models) and probit models avoid the limitations of the linear regression by restricting the independent variables between 0 and 1 by creating a non-linear transformation using a logistic function or a normal distribution function, respectively, such that:

$$P(y_i = 1|x_i) = F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})$$

A likelihood function of N observations can be constructed with this probability that y_i is equal to 1:

$$L(\beta_1, \cdots, \beta_K) = \prod_{i=1}^{N} [F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})]^{y_i} [1 - F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})]^{1-y_i}$$

and the log version as:

$$\begin{aligned} \ln(L(\beta_1, \cdots, \beta_K)) &= \sum_{i=1}^{N} y_i \ln(F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}) \\ &+ \sum_{i=1}^{N} (1 - y_i) \ln(1 - F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})) \end{aligned}$$

The maximum of this log-likelihood function is then found with software programs that find the β parameters that maximize the function. This is referred to as maximum likelihood estimation (MLE) (Verbeek, 2017). While both the logit and probit models are calculated the same way using the MLE method, the probit model's cumulative density function is defined as an integral that does not have a solution, whereas the cumulative density function of the logit model is explicitly written as:

$$F(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}) = \frac{\exp(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})}{1 + (\exp(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}))}$$

This allows an explicit probability of events given by independent variables to be calculated in the logit model, which is why it is the preferred model in this thesis. Rearranging this function gives:

$$\ln \frac{p_i}{1 - p_i} = \beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}$$

This shows how the β parameters reflect a change in the log-likelihood that y_i is equal to 1 given a one unit change in the corresponding x variable.

The probability of calf treatment for BRD is modelled using the logit model.

4.2.3 Poisson Regression

Another limitation of linear regression models is that coefficients are estimated assuming a normal distribution. Using a linear regression model for small integer count data may result in negative estimated dependent variables, which may not make sense in the context of the count. Common examples are in health economics, where treatment data may only consist of a few doses and a negative treatment dose is not possible, or when dependent variables are skewed (Hutchinson & Holtman, 2005).

Poisson regressions also use MLE method similar to the logit model. Because the goal is to ensure y_i is non-negative, the expected value of y_i given the independent variables uses this form (Verbeek, 2017):

$$E(y_i|x_i) = \exp(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})$$

This expected value for y_i is then substituted as λ in the Poisson distribution to provide a distribution for the probabilities of y_i:

$$P(y_i = y|x_i) = \frac{e^{-\lambda}\lambda_i^y}{y_i!},\ y = 0, 1, 2, \ldots$$

An important feature of the Poisson distribution is that the expected value of y_i (or λ) and the variance of y_i are the same. Computing robust standard errors ensures that the standard errors conform to this requirement.

The log-likelihood function that will be maximized, which is derived from the above distribution is:

$$\begin{aligned}\ln(L(\beta_1, \cdots, \beta_K)) = \sum_{i=1}^{N} [&-\exp(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}) \\ &+ y_i(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK}) - \ln(y_i!)]\end{aligned}$$

The β parameters are derived from the maximum likelihood function of this form. To interpret the coefficients, it is best to return to the expected value of y_i and measure a change in a variable x_{ik}:

$$\frac{\partial E(y_i|x_i)}{\partial x_{ik}} = \exp(\beta_1 + \beta_2 x_{i2} + \cdots + \beta_K x_{iK})\beta_k$$

or for the semi-elasticity:

$$\beta_k = \frac{\partial E(y_i|x_i)}{\partial x_{ik}} \frac{1}{E(y_i|x_i)}$$

This is equivalent to the log likelihood change of an increase in x_{ik}. The exponent of β_k provides the Incidence Rate Ratio (Verbeek, 2017):

$$\frac{\partial E(y_i|x_{ik}+1), x*_i}{E(y_i|x_i), x*_i} = \exp(\beta_k)$$

This measures the change in incidence rate from a one unit increase in x_{ik}. Poisson Regressions are used in this thesis to analyse count data for BRD treatments and used to calculate the externalities associated with overuse of AMD.

4.2.4 Budget Sensitivity Analysis

Budget sensitivity analyses (or What-if analyses) are used to examine the effects of changes in cost, price, revenue, or return variables on others. It allows researchers to see the effects of these changes in isolation or with other effects combined, and test for input robustness. The basic structure includes relevant factors that determine revenue, costs, and returns, and provide a range of scenarios from alterations of these factors.

This method of analysis is useful because of its flexibility. Data can be combined from a range of sources and can range in complexity. A budget sensitivity analysis will be used to evaluate the cow-calf producer's decision whether to precondition their calves. Because this decision ultimately rests with the cow-calf producer, it is important to understand how changes in key factors such as feed cost, ADG, or death loss will affect influence the profitability of preconditioning. Both Dhuyvetter et al. (2005) and Schunicht (2017) used this method to analyse cow-calf producer profitability.

4.3 Empirical Specification

This section will explain the methods used to evaluate the impacts of preconditioning on feedlot performance and BRD morbidity, and the cow-calf producer's decision whether to precondition their calves. Each analysis will use different methods with the ultimate goal of evaluating downstream benefits of preconditioning to feedlot owners, whether performance is lost when commingling is introduced, and the theoretical reduction in externalities from AMD use.

4.3.1 Feedlot Performance

The first analysis will examine differences between PC and non-PC calves with respect to feedlot feeding performance. Because feedlot revenue is based almost entirely on the cattle's ability to efficiently gain weight, it is unlikely that owners will purchase PC calves if they show signs of decreased feeding performance or weight gain. This is especially pertinent when commingling is introduced. Feedlot owners may be hesitant to purchase PC calves if expected benefits are lost when they are mixed with non-PC calves.

The two main metrics for measuring cattle feeding and growth are ADG and DMFC. DMFC is preferred over feed conversion (FC) because it corrects for different feed moisture contents. These two metrics are commonly used for analysis of feedlot profitability (Cernicchiaro et al., 2012; Dennis et al., 2020; Langemeier et al., 1992). Albright et al. (1994) and Dennis et al. (2018) provide intuition for ADG and DMFC as metrics of profitability. Albright et al. (1994) found that 92 to 94% of the variability in cost of gain is related to the price of feed, feed conversion, and ADG. A modified form of the net return functions from Dennis et al. (2018) show how these two metrics affect feedlot profitability:

$$\begin{aligned} Net\ Return = Total\ Revenue - Feeder\ Cattle\ Purchase\ Cost \\ -Yardage\ Cost - Feed\ Cost - Health\ Cost - Interest\ Cost \end{aligned} \tag{4.3}$$

where

$$Total\ Revenue = Fed\ Price \times Finishing\ Weight \times (1 - Shrink) \tag{4.4}$$

$$\begin{aligned} Feed\ Costs = Feed\ Price \\ \times Feed\ Conversion \times (Finishing\ Weight - Intake\ Weight) \end{aligned} \tag{4.5}$$

Equation 4.5 shows how FC affects feed costs. With ADG calculated as:

$$Average\ Daily\ Gain = \frac{Finishing\ Weight - Intake\ Weight}{Days\ on\ Feed} \tag{4.6}$$

Reorganizing equation 4.6 and substituting finishing weight in the total revenue equation shows total revenue as a function of average daily gain:

$$\begin{aligned} Total\ Revenue = Fed\ Price \times (1 - Shrink) \\ \times (Average\ Daily\ Gain \times Days\ on\ Feed + Intake\ Weight) \end{aligned} \tag{4.7}$$

A high ADG will either achieve a higher finishing weight or reach a certain finishing weight sooner, ultimately increasing total revenue or reducing yardage and feed costs. The average ADG for Angus steers is around 3.5 lbs per day (Reinhardt et al., 2012). Cattle with a low DMFC require lower feed intake for weight gain, reducing the amount of feed required to gain weight, however, DMFC is more closely related to genetics rather than external factors (Goddard et al., 2011; Richardson et al., 1996).

Feed conversion is calculated as:

$$Feed\ Conversion = \frac{Feed\ Offered\ (as\ fed)}{Final\ Weight - Entry\ Weight} \tag{4.8}$$

and DMFC as:

$$Dry\ Matter\ Feed\ Conversion = \frac{Feed\ Offered\ (dry\ matter)}{Final\ Weight - Entry\ Weight} \tag{4.9}$$

Previous studies on the effect of preconditioning on FC has shown mixed results, with some finding a decreased FC in PC cattle (Avent et al., 2004), and others finding no difference between PC and non-PC cattle (Irsik et al., 2006).

Ranchers perceive PC calves to have higher ADG than non-PC calves Avent et al. (2004), and there is some evidence that preconditioning is positively linked to ADG (Daniels et al., 2000; Sowell et al., 1998; Sowell et al., 1999). Healthy calves spend more time feeding; therefore, preconditioning is expected to have a positive relationship with ADG because the calves have already been taught to feed from a bunk, are expected to remain healthy, and should show fewer signs of stress such as pen wandering.

Table 4.10 lists the variables and expected results from the ADG and DMFC regressions. Lighter calves entering the feedlot are expected to have lower ADG and higher DMFC (Cernicchiaro et al., 2012; Dennis et al., 2020). While PC calves are expected to show higher ADG, the literature is mixed on the impact of preconditioning

Table 4.10: Expected signs for average daily gain (ADG) and dry matter feed conversion (DMFC) regressions.

	ADG	DMFC
Entry Weight	+	-
Auction-Derived (AD)	ref[1]	ref
Preconditioned (PC)	+	±
Pen 0PC	ref	ref
Pen 25PC	+	±
Pen 50PC	+	±
Pen 75PC	+	±
Pen 100PC	+	±
AD · *Pen* 25*PC*	ref	ref
PC · *Pen* 25*PC*	+	±
AD · *Pen* 50*PC*	ref	ref
PC · *Pen* 50*PC*	+	±
AD · *Pen* 75*PC*	ref	ref
PC · *Pen* 75*PC*	+	±
Average Daily Gain	Dep.	
Dry Matter Feed Conversion		Dep.

[1] Reference category

on DMFC. PC or pen status could have a positive or negative relationship with DMFC. To this author's knowledge, no prior studies have examined the effects of commingling different proportions of PC calves on ADG and DMFC. Findings from Step et al. (2008) suggest that ADG will be higher as the proportion of PC calves in a pen increases, though differences in ADG were minimal near the end of that study. Given these expected results ADG and DMFC, value added and net returns are also expected to have a positive correlation with preconditioning status.

The general regressions use a similar structure to those found in Irsik et al. (2006) and Cernicchiaro et al. (2012). Irsik et al. (2006) use mortality, entry weight, and dummy variables for mixed pens, heifers, sale quarter, region, preconditioning, and feed type. Cernicchiaro et al. (2012) used distance travelled, region, steers, entry weights, cohort size, season, and year, as well as interaction terms between distance travelled and all other variables to observe each effect mixed with distance travelled on profit metrics. In the current study, all price, location, gender, and feed variables are held constant, allowing preconditioning to be observed in isolation with weight and commingling data.

The general linear regression estimation for the ADG uses the following form:

$$\begin{aligned} ADG = \beta_0 + \beta_1 \ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ +\beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ +\beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.10}$$

The log form of entry weight was chosen to estimate the change in ADG from a 1% increase in entry weight. There is no difference in value or the statistical significance of any variable when the linear form of entry weight is used, and all F-stats are identical. Polynomial regression forms were also tested to observe a potential peak in dependent variables from entry weight. The following form was used for ADG as an example:

$$
\begin{aligned}
ADG = \beta_0 + \beta_1 Entry\ Weight + \beta_2 Entry\ Weight^2 + \beta_3 PC + \beta_4 Pen25PC \\
+\beta_5 Pen50PC + \beta_6 Pen75PC + \beta_7 Pen100PC + \beta_8 PC \times Pen25PC \\
+\beta_9 PC \times Pen50PC + \beta_1 0PC \times Pen75PC + \varepsilon
\end{aligned} \tag{4.11}
$$

Some statistical significance was found using the polynomial form of entry weight on ADG, but it did not improve model fitness compared to the natural logarithm form. The same functional form for ADG was used for DMFC:

$$
\begin{aligned}
DMFC = \beta_0 + \beta_1 \ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\
+\beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\
+\beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon
\end{aligned} \tag{4.12}
$$

Final weight cannot be included as a variable for either feeding metric because ADG is calculated by subtracting the entry weight from the final weight and dividing by the days on feed, and DMFC uses final weight to calculate weight gain. If final weights were included, all variance in ADG and DMFC would be explained by entry weight and final weight alone. Because ADG and DMFC is calculated using final weights, and no final weight was recorded for the 12 calves that did not complete study, regressions with different final weight values for these 12 calves. The first series of models excluded these 12 calves, the second series used an assigned final weight of zero for these 12 calves, and the third series assigns an ADG of zero[5].

Two additional general linear models were used to estimate the economic value of PC calves: an added value model and a net return model. Added value is the final value for each calf minus the starting value of each calf. Net return is value added minus all costs associated with raising each calf. Net return has been used to examine returns of different feeding practices and prices (Albright et al., 1994; Mark et al., 2000). Table 4.5 provides individual summary statistics for both value added and net

---

[5] This third series only applies to ADG - a DMFC of 0 implies the calf ate nothing at all (which theoretically could happen, but was not observed in this study), while a gain of 0 (where Final Weight = Entry Weight) returns an undefined DMFC.

return. As with the previous model estimations, final weight is not included because entry weight and final weight together explain most of the variance:

$$\begin{aligned} Value\ Added = \beta_0 + \beta_1 \ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ + \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ + \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.13}$$

$$\begin{aligned} Net\ Return = \beta_0 + \beta_1 \ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ + \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ + \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.14}$$

4.3.2 Health Costs

This series of regressions will examine the effects of preconditioning on direct health costs to feedlot owners and AMU. Four series of models are used in this analysis: a general linear regression for health costs, a Poisson regression for BRD treatment count, a logit regression for whether a calf was treated for BRD or not, and a logit regression for whether a calf was treated twice or more for BRD. All series in this section follow a similar structure to the feedlot performance series, where Model 1 will only include weights as independent variables, Model 2 introduces a dummy variable for preconditioning, Model 3 adds dummy variables for each pen, and Model 4 includes all independent variables shown in the following equations.

The first series is general linear model with the following structure:

$$\begin{aligned} Health\ Costs = \beta_0 + \beta_1 ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ + \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ + \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.15}$$

Health costs have previously been used in analyses of feedlot risk and health management (Belasco, 2008; Dennis et al., 2020). In Section 4.1, health costs were shown to be the highest source of cost variability in this study. The aim of this series is to observe the effect of preconditioning on health costs, and whether the PC calves maintain a health cost reduction in the different pen compositions.

The second and third series of use logit regressions with a binary dependent variable for treatment status, with treatment defined as 1 and no treatment defined as 0 for each individual calf. A feedlot owner's decision to purchase PC calves can be viewed as not only a function of the value of the PC calves, but also as a function of how many PC calves will be in each pen and whether the calves' performance will decline if they only make up a small proportion of calves in that pen (i.e. worsened health due to commingling).

$$\begin{aligned} Treated\ for\ BRD = \beta_0 + \beta_1 ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ + \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ + \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.16}$$

$$\begin{aligned} Treated\ for\ BRD\ 2X\ or\ More = \beta_0 + \beta_1 ln(Entry\ Weight) + \beta_2 PC + \beta_3 Pen25PC \\ + \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC + \beta_7 PC \times Pen25PC \\ + \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.17}$$

The cow-calf producer's decision and the feedlot purchaser's decision can be understood by this equation:

$$Pr(BRD_1) \times Cost\ of\ Treatment + Cost\ of\ PC \leq Pr(BRD_2) \times Cost\ of\ Treatment \tag{4.18}$$

reordered so the cost of PC is on one side:

$$Cost\ of\ PC \leq [Pr(BRD_2) - Pr(BRD_1)] \times Cost\ of\ Treatment \tag{4.19}$$

where $Pr(BRD_1)$ is the probability of a PC calf becoming ill from BRD, and $Pr(BRD_2)$ is the probability of an AD calf becoming ill from BRD. If the cost of preconditioning is less than or equal to the difference between the non-PC probable cost of treatment and the PC probable cost of treatment, then there is an incentive for PC calves to be produced.

4.3.3 AMU Externalities

The next series of models uses Poisson regressions to understand how preconditioning and pen composition affects the likelihood that BRD treatment is needed. Because of the low count data (BRD treatment ranges from 0 to 3), a Poisson regression is more appropriate than a linear regression as negative BRD treatments are not possible. Previous studies have used a similar negative binomial regression approach for BRD morbidity (Cernicchiaro et al., 2012; Cernicchiaro et al., 2013).

$$\begin{aligned} BRD\ Treatment\ Count &= \beta_0 + \beta_1 Entry\ Weight + \beta_2 PC \\ +\beta_3 Pen25PC &+ \beta_4 Pen50PC + \beta_5 Pen75PC + \beta_6 Pen100PC \\ +\beta_7 PC \times Pen25PC &+ \beta_8 PC \times Pen50PC + \beta_9 PC \times Pen75PC + \varepsilon \end{aligned} \tag{4.20}$$

An alternate functional form with pen proportion as a continuous variable is also used for externalities to be applied:

$$\begin{aligned} BRD\ Treatment\ Count &= \beta_0 + \beta_1 Entry\ Weight + \beta_2 PC \\ +\beta_3 Pen\ Proportion &+ \beta_4 Pen\ Proportion \times PC + \varepsilon \end{aligned} \tag{4.21}$$

With this form, the parameter β_3 measures the change in expected BRD count from a 0% PC pen to a 100% PC pen. The effect of proportions between 0 and 1 can be calculated by multiplying a proportion and β_3. Similar to the interaction variables in the previous functional form, β_4 will measure the effect of PC calves and pen proportion.

The cost of externalities can then be applied to the log-likelihood changes to BRD treatments. Changes in the likelihood of BRD treatments will be applied to an hypothetical 1,000 head feedlot to examine the externality costs. The change in externality cost from 0% PC calves at fall intake to 100% PC calves will also be calculated used the expected BRD treatment counts from the Poisson regression.

Chapter 5

Results and Discussion

This chapter is divided into four sections. Section 5.1 presents the results from five feedlot performance models. Each model in this section is a general linear model focusing on a different metric for feedlot performance: average daily gain (ADG), Dry Matter Feed Conversion (DMFC) with outliers included, DMFC with outliers excluded, value added, and net return. The purpose of this section is to examine the ability of PC calves to efficiently gain weight, and the value of PC calves compared to AD calves irrespective of health benefits and externalities. Section 5.2 examines these health benefits. Three models are used, beginning with a general linear model examining the direct health costs of the calves in the study. Two logit models are then used to measure changes in probability of a calf requiring treatment for BRD. Section 5.3 uses Poisson model to calculate the expected number of BRD treatments for PC and AD calves to which the externality cost can be applied. Finally, section 5.4 is a budget sensitivity analysis of a cow-calf operation adopting preconditioning. The aim of the analysis is to estimate whether profits may be anticipated for a cow-calf operator producing PC calves, and at what price or premium a cow-calf operation can be profitable.

5.1 Results from Feedlot Performance

All models in the feedlot performance section follow the same format. Model 1 for each is a general linear model with an intercept and the natural logarithm of feedlot arrival weight as the only independent variable. This measures the relationship between calves' starting weights and their performance. Specifically, the coefficient represents the unit change to the dependent variable from a 1% increase in calf arrival weight. Model 2 adds a dummy preconditioned variable, with 1 for preconditioned (PC) and 0 for auction-derived (AD) calves. This measures the change in the dependent variable if the calf was preconditioned. Model 3 adds a dummy variable for each pen, with Pen *0PC* as the reference pen. Each of these dummy variables measures the change in the dependent variable based on which pen a calf was housed compared with a calf housed in pen *0PC*. The purpose of these variables is to control for unknown differences in each pen, and identify a pattern of performance as more PC calves are added. Finally, Model 4 in each analysis adds three interaction variables[1]. These interaction variables measure the effect of PC calves on the dependent variable specific to that pen, and together with the PC dummy variable measures the effect of pen mixture and PC. For example, if feedlot owners' concerns that mixing PC calves with non-PC calves will reduce their performance is correct, we should see a decrease in ADG and/or an increase in DMFC between *PC*50PC* and *PC*25PC*. If the PC calves are not affected by commingling, there should be no difference between these interaction coefficients. Standard errors are in brackets beneath each coefficient.

Table 5.1 shows the outcome of the ADG regressions. The results for the effect of entry weight on ADG are the opposite of what has been reported in the literature. The results in Model 1 suggest a 1% increase in entry weight would decrease ADG by 0.85 lbs, though the effect is reduced from Model 1 to Model 4 as more variables are

---

[1] The interaction variable *PC*75PC* measures the change in preconditioned status in the *75PC* pen, however this coefficient could not be estimated in any model likely due to co-linearity. It was included for completeness.

Table 5.1: Results from four Average Daily Gain (ADG) (lbs) models.

	Model 1	Model 2	Model 3	Model 4
Intercept	7.97***	4.62*	3.59	3.14
	(2.70)	(2.61)	(2.53)	(2.56)
ln(Entry Weight)	-0.85**	-0.28	-0.07	0.00
	(0.39)[A]	(0.08)	(0.39)	(0.40)
PC		-0.55***	-0.16	-0.11
		(0.08)	(0.10)	(0.18)
25PC			-0.68***	-0.72***
			(0.11)	(0.12)
50PC			-0.30**	-0.22
			(0.12)	(0.14)
75PC			-0.92***	-0.96***
			(0.13)	(0.17)
100PC			-0.86***	-0.91***
			(0.15)	(0.21)
PC*25PC				0.10
				(0.25)
PC*50PC				-0.20
				(0.24)
PC*75PC				NA
				NA
Observations	488	488	488	488
R-squared	0.01	0.11	0.22	0.22
Adj. R-squared	0.01	0.10	0.21	0.21
F-stat	4.07	28.78	22.40	17.00
Prob(F-stat)	0.04	0.00	0.00	0.00

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

[A] Robust S.E. to correct for heteroskedasticity.

added. Most findings from the literature observed better feedlot performance from calves that are heavier upon arrival. Heavier calves are less likely to be sick and more likely to feed consistently. However, the short time frame for the current study and the feeding behaviour observed (seen in figure 4.1) suggest that some compensatory gain from lighter calves was present. The fit of the models (measured by F-statistic and R-squared) increases after the PC dummy variable is introduced in Model 2.

The results from the PC dummy variable also run contrary to expected results. In Model 2 the PC dummy variable is negative and statistically significant, suggesting that a calf's PC status had a larger impact on ADG than a calf's entry weight. The expected ADG for a PC calf is 0.55 lbs/day less than an AD calf. As discussed in section 4.1.2, this may be due to some compensatory gain from lighter calves, but also may be due to the sickest calves being removed from the analysis. The PC dummy variable is negative in Models 3 and 4 as well, though not statistically significant in those cases. Previous studies have observed either no difference between PC and control calves, or higher ADG from PC calves, so Models 3 and 4 would be considered consistent with the literature. Once pen coefficients are included, the PC variable becomes less statistically significant.

Every pen coefficient has a negative and statistically significant relationship with ADG compared to the AD reference category in Models 3 and 4, except Model 4 pen *50PC*. From these results, calves in a pen made up entirely of non-PC calves would gain nearly a pound a day more than calves in a pen with a majority of PC calves (pens *75PC* and *100PC*) without considering calf source. The results also show somewhat decreasing performance as pens increase the number of PC calves. The ADG coefficient decreases from -0.68 to -0.86 between pens *25PC* and *100PC*. Some of these differences may be attributed to the pens themselves. For example, pen *0PC* and pen *25PC* had the fewest number of calves complete the trial, which may have afforded the remaining calves more bunk space to access feed.

PC calves show a negative relationship with ADG in all cases except the interaction

Table 5.2: Results from eight alternative Average Daily Gain (ADG) (lbs) models that include missing values.

	Model 1		Model 2		Model 3		Model 4	
	0 FW	0 ADG	0 FW	0 ADG	0 FW	0 ADG	0 FW	0 ADG
Intercept	19.65	8.23***	25.27	5.79**	18.07	4.05	14.42	3.28
	(16.61)	(2.92)	(16.81)	(2.90)	(17.24)	(2.81)	(17.37)	(2.83)
ln(Entry Weight)	-2.78	-0.90**	-3.72	-0.49	-2.48	-0.15	-1.91	-0.03
	(1.94)[A]	(0.40)[A]	(2.36)[A]	(0.45)	(2.16)[A]	(0.44)	(2.07)[A]	(0.44)
PC			0.94*	-0.41***	1.04	-0.05	0.63	-0.03
			(0.54)[A]	(0.08)	(0.53)[A]	(0.11)	(0.76)[A]	(0.19)
25PC					-2.14***	-0.81***	-2.63***	-0.89***
					(1.24)[A]	(0.12)	(1.43)[A]	(0.13)
50PC					0.02	-0.27**	0.65	-0.13
					(0.69)[A]	(0.14)	(0.62)[A]	(0.15)
75PC					-0.95	-0.93***	-0.65	-0.95***
					(0.79)[A]	(0.15)	(0.97)[A]	(0.19)
100PC					-0.95	-0.87***	-0.56	-0.90***
					(0.78)[A]	(0.16)	(0.98)	(0.23)
PC*25PC							2.32	0.27
							(1.51)[A]	(0.28)
PC*50PC							-0.79	-0.28
							(0.76)[A]	(0.26)
PC*75PC							NA	NA
							NA	NA
Observations	500	500	500	500	500	500	500	500
R-squared	0.00	0.01	0.01	0.05	0.03	0.17	0.04	0.18
Adj. R-squared	0.00	0.01	0.01	0.05	0.02	0.16	0.02	0.17
F-stat	1.15	3.90	2.49	14.13	2.69	17.10	2.50	13.46
Prob(F-stat)	0.28	0.05	0.08	0.00	0.01	0.00	0.01	0.00

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

[A] Robust S.E. to correct for heteroskedasticity.

*PC*25PC*, though this is not statistically different from zero. The pen interaction variables measure the total effect when added together, so PC calves in a pen of 25% PC calves would have a mean ADG adjustment of -0.01 and PC calves in a pen of 50% PC calves would have a mean ADG adjustment of -0.31. Again, this contrasts with the expectation that PC calf performance would increase as more PC calves are added, as this shows the opposite. However, neither the PC dummy variable nor the interaction variables are statistically different from 0 in Model 4, so the effects of PC status are inconclusive in Model 4.

The results from the ADG models show better feeding performance from non-PC calves (specifically those that completed the trial) and inconclusive effects from commingling, suggesting that PC calves may not be affected by the mix of cattle in their pens, but their ability to gain weight lagged behind the non-PC calves. This contrasts findings from Hilton et al. (2015) and Irsik et al. (2006) where PC calves had similar or better ADG than control calves.

As previously mentioned, there are two factors that may have increased ADG for calves in pens *0PC* and *25PC* - the duration of the study and the removal of severe cases of morbidity. The short time period of this trial likely skewed feeding results in favour of non-PC calves, as there were some indications of compensatory gain that are unlikely to continue beyond 40 days. It is also important to note that ADG for calves pulled from pens *0PC*, *25PC*, and *75PC* were not included in the first series (Table 5.1) as no final weights were recorded for these calves. This will have likely raised the expected ADG for the AD calves that completed the study.

Two alternatives are included in Table 5.2 that address the calves without final weights. The models listed under *0 FW* adjust the final weights of calves that did not complete the study to zero, resulting in a negative ADG for those 12 calves. The models listed under *0 ADG* adjusted the ADG of those 12 incomplete calves to zero. The *0 ADG* models have the same signs for every variable and do not change the interpretation of any parameter. Adjusting final weights to zero, however, does flip the PC dummy variable from negative to positive in Models 2 through 4. In the *0 FW* cases, Models 1 and 2 do not have significant F-statistics, meaning the entire models are not statistically significant. The F-statistics for Models 3 and 4 of the *0 FW* also remain low. In general, while ADG gives some insight into feedlot performance, it can be inflated by missing values, and there is no agreed-upon method of including missing values.

Table 5.3 shows the results from the Dry Matter Feed Conversion (DMFC) regressions. F-statistics are not statistically significant for all four models in the series, meaning all variables together are not statistically different from zero. R-squared values are also close to zero, suggesting feed conversion is not greatly explained by PC status or pen. The result is somewhat expected because there are no intra-pen differences in feed intake recorded, and all calves were assumed to have consumed an equal portion of the feed offered in their pen.

Unlike ADG, where few outliers are possible, results from DMFC may be skewed by extreme outliers. When calculating DMFC, the denominator is the total weight gained by that calf. This means that DMFC values approach infinity as weight gained approaches zero. For example, one calf lost 14 lbs over the course of the study, which corresponds to a DMFC of -32.18, and another calf only gained 2 lbs, corresponding to a DMFC of 259.51. This value is over 20 standard deviations above the mean value. Both of these calves were treated twice for BRD. The result is several values that are highly inflated compared to the mean, which will reduce the predictive ability of OLS regressions by increasing residuals.

To reduce the noise from these large outliers, the DMFC regression was run again with outliers over 3 standard deviations away from the mean removed. Table 5.4 shows results from this adjusted DMFC regression. Four values were removed for a total of 482 observations. Similar to the ADG models, the relationship between entry weight and DMFC is the opposite of what was expected, where entry weight and DMFC share a positive relationship in all four models, though entry weight is

Table 5.3: Results from four dry matter feed conversion (DMFC) (lbs) models with outliers included.

	Model 1	Model 2	Model 3	Model 4
Intercept	35.24	35.57	51.03	53.13
	(39.60)	(40.29)	(41.69)	(42.11)
ln(Entry Weight)	-4.42	-4.48	-6.81	-7.14
	(6.17)	(6.30)	(6.50)	(6.57)
PC		0.05	-0.03	-2.43
		(1.17)	(1.64)	(2.97)
25PC			-0.16	-0.46
			(1.90)	(2.02)
50PC			-2.25	-2.75
			(2.02)	(2.27)
75PC			-0.18	1.65
			(2.18)	(2.88)
100PC			0.41	2.82
			(2.42)	(3.47)
PC*25PC				3.53
				(4.20)
PC*50PC				3.38
				(3.92)
PC*75PC				NA
				NA
Observations	486	486	486	486
R-squared	0.00	0.00	0.01	0.01
Adj. R-squared	0.00	0.00	-0.01	-0.01
F-stat	0.51	0.26	0.50	0.50
Prob(F-stat)	0.47	0.77	0.81	0.86

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 5.4: Results from four dry matter feed conversion (DMFC) (lbs) models with outliers greater or less than 3 standard deviations from mean excluded.

	Model 1	Model 2	Model 3	Model 4
Intercept	-11.68	-4.76	-0.01	1.21
	(9.15)[A]	(8.73)[A]	(8.64)[A]	(9.46)[A]
ln(Entry Weight)	2.79	1.62	0.74	0.55
	(1.43)[A]	(1.37)[A]	(1.35)[A]	(1.47)[A]
PC		1.15***	0.01	0.32
		(0.33)[A]	(0.46)[A]	(0.75)[A]
25PC			1.88***	2.07***
			(0.74)[A]	(0.82)[A]
50PC			0.63	0.47
			(0.53)[A]	(0.58)[A]
75PC			2.16***	1.92**
			(0.61)[A]	(0.80)[A]
100PC			2.71***	2.40**
			(0.66)[A]	(0.87)[A]
PC*25PC				-1.03
				(1.54)[A]
PC*50PC				-0.01
				(0.88)[A]
PC*75PC				NA
				NA
Observations	482	482	482	482
R-squared	0.01	0.03	0.08	0.08
Adj. R-squared	0.00	0.03	0.07	0.07
F-stat	2.44	7.24	6.95	5.33
Prob(F-stat)	0.12	0.00	0.00	0.00

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

[A] Robust S.E. to correct for heteroskedasticity.

not statistically different from 0 in any model.

The PC dummy variable is introduced in Model 2, and shows an increase of 1.15 lbs of feed for one lb of gain if the calf has been preconditioned. While the literature shows little evidence of relationship between PC and DMFC (Irsik et al., 2006), a statistically significant positive result is unexpected. Once pen dummy variables are introduced in Models 3 and 4 however, the PC dummy variable has a much lower and less statistically significant effect on DMFC.

As for the pens, each pen shows a higher and statistically significant (with the exception of pen *50PC*) effect on DMFC, compared to the reference pen *0PC*. Excluding pen *50PC*, DMFC increased as the proportion of PC calves in a pen increased. That is, in Model 3, DMFC is expected to increase by 1.88 lbs for a calf in a 25% PC pen, 2.16 lbs for a calf in a 75% PC pen, and 2.71 lbs for a calf in a 100% PC pen.

With the interaction variables included in Model 4, the total effect of PC calves in pen *25PC* is negative, while PC calves in pen *50PC* are still positive. If PC calves were to improve performance as proportion of PC calves in a pen increases, the interaction variable between PC and pen *50PC* would be less than the interaction variable between PC and pen *25PC*.

The results from ADG and DMFC models show calf performance decreases as the number of PC calves in a pen increases, and in both cases PC dummy variables indicate a lower performance for PC calves. However, as a measure of the effect of commingling, the interaction variables show little consistency or statistical significance, suggesting PC calves' performance is not affected by their pen-mates. These results also contradict Hilton et al. (2015) and Irsik et al. (2006) where the relationship between DMFC and PC was not significant, and where ADG and PC was positive. However, both of these studies used larger datasets for their analyses.

Two more series will directly analyse economic values from the study. Table 5.5 shows the results from value added and net returns. Both of these series are exhibited together, as there are no differences in coefficient sign and significance. Model fit

Table 5.5: Results from Value Added (VA) and Net Return (NR) models.

	Model 1		Model 2		Model 3		Model 4	
	VA	NR	VA	NR	VA	NR	VA	NR
Intercept	1471.46***	1265.94***	1484.35***	1332.40***	1247.89***	1034.24**	1178.27**	947.53**
	(316.65)[A]	(317.90)[A]	(464.26)	(464.99)	(347.53)[A]	(348.06)[A]	(343.18)[A]	(344.86)[A]
ln(Arrival Weight)	-216.39***	-210.65***	-218.57***	-221.87***	-180.22**	-173.98**	-169.36**	-160.45**
	(49.62)[A]	(49.78)[A]	(72.53)	(72.64)	(54.32)[A]	(54.41)[A]	(53.65)[A]	(53.92)[A]
PC			2.16	11.13	6.61	14.30	-1.76	-1.39
			(13.32)	(13.34)	(10.86)[A]	(11.15)[A]	(11.92)[A]	(14.94)[A]
25PC					-33.51	-37.57	-42.96	-50.58
					(33.37)[A]	(33.03)[A]	(36.62)[A]	(36.08)[A]
50PC					18.28	24.67	30.14	39.24
					(25.74)[A]	(25.98)[A]	(25.41)[A]	(25.69)[A]
75PC					-24.11	-18.48	-17.98	-6.95
					(26.35)[A]	(26.86)[A]	(27.11)[A]	(28.59)[A]
100PC					-19.48	-22.01	-11.51	-6.83
					(26.76)[A]	(27.13)[A]	(27.65)[A]	(29.26)[A]
PC:25PC							45.54	66.90
							(30.81)[A]	(31.45)[A]
PC:50PC							-14.33	-12.22
							(14.23)[A]	(17.00)[A]
PC:75PC							NA	NA
							NA	NA
Observations	500	500	500	500	500	500	500	500
R-squared	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.04
Adj. R-squared	0.02	0.02	0.01	0.01	0.02	0.03	0.02	0.03
F-stat	9.24	8.71	4.62	4.70	2.82	3.27	2.35	2.89
Prob(F-stat)	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.00

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

[A] Robust S.E. to correct for heteroskedasticity.

(based on F-stat) decreases as more variables are included, and pen entry weight is the only statistically significant variable in both series. The coefficients for entry weight show how much value added or net return changes from a 1% increase in calf weight. The net return and value added results follow a pattern with the previous regressions, as a lower entry weight corresponded with better performance in both the ADG and DMFC series. Calves that are heavier on entry also present a higher feeder purchase cost and therefore and higher starting value. The results confirm the overall findings from this study that AD calves started lighter and were able to gain weight faster and more efficiently than PC calves, even when losses are included.

These results contradict much of the previous literature, where calves that are heavier at feedlot induction are more likely to have higher returns (Hilton et al., 2015; Irsik et al., 2006; Mitchell et al., 2018). As summarized by Peel and Riley (2018), calf weight and profitability are highly dependent on feed prices, which are not captured by this model. Feedlot operators will aim to purchase heavier calves when feed prices are high and lighter calves when feed prices are low. In addition, the short duration (40d) of this study makes it difficult to determine profitability for calves in the long run after a full feedlot stay.

All pens with the exception of the *50PC* pen show a lower value added and net return compared to the *0PC* reference pen. The coefficients are increasing in most cases (Model 3 for net return is the exception), which was the opposite pattern seen in the ADG and DMFC series, where performance decreased as number of PC calves increased.

Value added and net return models show a positive relationship with the PC dummy variable in Models 2 and 3. The coefficient is slightly higher in the net return models, suggesting that PC calves have lower costs than non-PC calves. The PC dummy variable in Model 4 for both series shows a negative relationship with value added and net return, but the interaction between PC and the *25PC* pen is positive. As with the ADG and DMFC series, PC performance decreases in the interaction variables, where *PC*25PC* is greater than *PC*50PC*.

DMFC, Value Added, and Net Return regressions were all run with a polynomial entry weight variable with the same form the second ADG series (4.11), however, this was not statistically significant in any of these models.

In summary, all five series presented in this section show no evidence of PC calves outperforming AD calves. Contrary to most findings in the literature, lighter calves performed better than heavier calves, which may be attributed to compensatory gain by these lighter calves. By feed and gain metrics (Tables 5.1, 5.3, and 5.4), PC calves performed worse, and by valuation metrics (Table 5.5), PC calves were not different from AD calves. This analysis supports feedlot owners' hesitancy to purchase PC calves.

5.2 Results from Health Costs

In the previous section, PC calves did not perform better than AD calves, and by some metrics performed worse. While these are the primary incentives for feedlot owners, there is a societal benefit in the form of a reduction in externalities from AMR. This section will analyse these health benefits with three main questions in mind: (1) are the total health costs of PC calves lower than AD calves?; (2) are PC expected to have fewer treatments for BRD, and subsequently reduce the amount of antimicrobial drugs (AMDs) needed for feeder cattle?; and (3) is the probability of being treated for BRD different when commingling is introduced?

The first series of models examines the health care costs from all calves in the study. Table 5.6 shows the results from the health costs models. The F-stat of Model 1 is not significant, and the intercept and entry weight variable are not significant in any model, which suggests there is no relationship between calf entry weight and health costs. The intercept and entry weight coefficient switch signs in Model 2, further confirming this lack of relationship.

Introducing the PC dummy variable lowers expected health costs by $13.86 per

Table 5.6: Linear Regression Models with health cost as the dependent variable ($).

	Model 1	Model 2	Model 3	Model 4
Intercept	36.36	-46.44	44.91	64.09
	(65.36)^{A}	(75.26)	(75.39)	(75.28)
ln(Entry Weight)	-3.02	10.96	-3.23	-6.22
	(10.20)^{A}	(11.76)	(11.75)	(11.74)
PC		-13.86***	-8.57***	-0.34
		(2.16)	(2.94)	(5.17)
25PC			7.87**	11.87***
			(3.33)	(3.48)
50PC			-12.38***	-15.43***
			(3.63)	(4.07)
75PC			-4.47	-10.57**
			(3.90)	(5.01)
100PC			-5.79	-13.90**
			(4.36)	(6.10)
PC*25PC				-24.02***
				(7.37)
PC*50PC				-2.40
				(6.94)
PC*75PC				NA
				NA
Observations	500	500	500	500
R-squared	0.00	0.08	0.14	0.16
Adj. R-squared	0.00	0.07	0.13	0.15
F-stat	0.06	20.65	13.21	11.78
Prob(F-stat)	0.80	0.00	0.00	0.00

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

^{A} Robust S.E. to correct for heteroskedasticity.

head in Model 2, but this decreases to \$8.57 in Model 3. This variable is highly significant in Models 2 and 3. In Model 4, the PC variable is no longer significant, but still shows a negative correlation with health costs.

With the exception of pen *25PC*, all pens have a negative relationship with health costs, and all pen effects are statistically significant in Model 4. The coefficient for pens *50PC* to *100PC* are relatively stable, suggesting that a reduction in per head health costs is possible by adding PC calves up to a certain proportion.

The interaction variable *PC*25PC* is lower than *PC*50PC*. The combined effect from adding the coefficients pen *25PC* and *PC*25PC* is net reduction in health costs of \$12.15, compared to a net reduction of \$17.83 from the combined coefficients *50PC* and *PC*50PC*. These are both similar to the net reductions of \$10.57 and \$13.90 per head from pen *75PC* and pen *100PC*, respectively.

Three conclusions can be drawn from this series of results: PC calves have lower health costs, pens with more than 25% PC calves have reduced health costs, and PC calves have lower health costs even if they form a minority of calves in the pen. This reduction in health care costs is the major benefit of preconditioning advertised to feedlot operators; however, results from net returns in Section 5.1 may cast some doubt as to whether this benefit alone is valuable. The results here show a consistent reduction in health care costs of \$10.57 - \$17.83 per PC calf, regardless of pen-mates. While this amount is not negligible, it can be easily erased from a rise in feeder calf procurement costs or feed costs. This is a very similar finding to Jim and Gulchon (1988), where the benefit exists, but might be overstated.

The logistical regression analysis examines the probabilities associated with requiring a BRD treatment, and how preconditioning will affect this probability. Table 5.7 shows the results from a logistical regression for treated versus not treated. The dependent variable is 1 if treated for BRD and 0 if not treated. Positive coefficients represent an increase in the log-odds ratio of a calf requiring treatment for BRD, and negative coefficients represent a decrease in the log-odds of treatment.

Table 5.7: Logistic regression with the dependent variable as treated or not treated for BRD.

	Model 1	Model 2	Model 3	Model 4
Intercept	1.84*	1.35	3.00**	3.06**
	(1.04)	(1.08)	(1.21)	(1.20)
Entry Weight (cwt)	-0.38**	-0.23	-0.49**	-0.50***
	(0.17)	(0.18)	(0.19)	(0.19)
PC		-0.94***	-0.49*	0.34
		(0.19)	(0.28)	(0.51)
25PC			0.72**	0.99***
			(0.30)	(0.33)
50PC			-1.16***	-1.25***
			(0.34)	(0.39)
75PC			-0.40	-1.01**
			(0.36)	(0.49)
100PC			-0.55	-1.37**
			(0.42)	(0.60)
PC*25PC				-1.83**
				(0.71)
PC*50PC				-0.61
				(0.71)
PC*75PC				NA
				NA
Observations	500	500	500	500
AIC	663.89	641.57	614.71	611.48
BIC	672.32	654.22	644.21	649.41
Pseudo R-squared	0.01	0.08	0.16	0.18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

An increase in the weight of calf at feedlot entry decreases the log-odds that BRD treatment will be needed. This is statistically different from zero in every model except Model 2, where only the PC variable is statistically significant, and is also consistent with findings from the literature, where lighter calves are more likely to be infected with BRD upon arrival at the feedlot (Sanderson et al., 2008; Wilson et al., 2017).

The PC variable shows a decrease of 0.94 in log-odds of BRD treatment in Model 2. By applying the function for *Prob(BRD Treatment)* to Model 2, a probability for PC vs non-PC calves requiring treatment for BRD can be found:

$$Prob(BRD\ Treatment) = \frac{1}{1 + e^{-(1.35 - 0.23 Entry\ Weight - 0.94 PC)}} \tag{5.1}$$

This results in a 48% probability that an AD calf will need to be treated for BRD versus a 27% probability that a PC calf will need to be treated assuming a mean entry weight of 614lbs.

When pen variables are included, similar results to the health cost series are observed. The *25PC* pen is the only pen performing worse than the *0PC* reference pen due to the high number of treatments in that pen. All pen coefficients are statistically significant in Model 4. While there is a decrease in log-odds of treatment from pen *50PC* to pen *100PC*, both are lower than pen *75PC*, so there does not appear to be a constant downward trend in log-odds. This suggests that once PC calves form at least 50% of the calves in a pen, increasing the number of PC calves has less of a health impact on other calves.

Interaction variables in Model 4 show a large decrease in the log-odds for PC calves in the *25PC* pen of 1.83. There is less of a decrease in log-odds for PC calves in the *50PC* pen, and the coefficient is not statistically significant. This shows that PC calves can remain healthy in mixed pens where the probability of a calf requiring treatment is higher. Similar to the previous health cost models, these results show that PC calves remain healthy regardless of commingling mixture.

Table 5.8: Logistic regression with the dependent variable as treated or not treated for BRD 2 or more times.

	Model 1	Model 2	Model 3	Model 4
Intercept	-3.07	-5.52**	-2.15	-2.14
	(2.09)	(2.67)	(2.83)	(2.87)
Entry Weight (cwt)	0.05	0.55	-0.01	-0.01
	(0.34)	(0.44)	(0.46)	(0.47)
PC		-2.14***	-2.58**	-1.83
		(0.57)	(1.08)	(1.25)
25PC			0.69	0.73
			(0.45)	(0.45)
50PC			-16.62	-17.37
			(1015.80)	(1536.29)
75PC			-0.08	-0.29
			(0.72)	(0.81)
100PC			1.31	0.57
			(1.28)	(1.42)
PC*25PC				-16.26
				(2150.79)
PC*50PC				1.84
				(2161.75)
PC*75PC				NA
				NA
Observations	500	500	500	500
AIC	230.94	212.26	204.03	206.86
BIC	239.37	224.91	233.53	244.79
Pseudo R-squared	0.00	0.11	0.20	0.20

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

While one treatment for BRD is undesirable, there are generally few negative consequences by the end of the feedlot stage for cattle sold under generic labels[2]; however, more than one treatment is far more likely to reduce the value of the animal once it reaches slaughter (Brooks et al., 2011; Holland et al., 2010; Schneider et al., 2009). A logistical regression was used to examine the probabilities of a feeder calf requiring multiple BRD treatments, with the results shown in table 5.8. The dependent variable is whether a calf is treated for BRD two or more times, with 1 signifying the animal was treated twice or more and 0 signifying zero or only one treatment. In total, 27 calves were treated twice for BRD and 3 were treated three times (6% of the study herd), and only 4 of these 30 calves were PC calves.

Entry weight is not a statistically significant variable in any of the models, and moves from positive log-odds to negative as more variables are added. The PC variable is significantly different from zero in Models 2 and 3, and shows a decrease in the log-odds in Models 2, 3, and 4. All other pen and interaction variables are not statistically significant, with some showing a high amount of variability (highlighted by some standard deviations being over 1000). This is due to the low number of calves that were treated multiple times. In fact, pen *100PC* shows an increase in the log-odds of multiple BRD treatments being needed, while pens 50PC and 75PC are negative. The results suggest that commingling likely has no effect on the reduction of the probability that PC calves will need multiple treatments for BRD.

Applying equation 5.1 to Model 2 from table 5.8 produces a probability of 10.4% that an AD calf will require two or more treatments, and a probability of 1.4% for PC calves. For a comparison, Johnson and Pendell (2017) estimated 2.3% of calves would become chronically ill. However, the label "chronically ill" applies to calves treated 3 or more times, so the estimates from the current study do not align exactly with that paper. Over a full feeding term, some of the calves treated twice may require more treatments, and others will recover fully. Nonetheless, PC calves

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[2] Calves given at least one AMD treatment can no longer be sold as "antibiotic free".

are estimated to have a treatment probability that is lower than the estimate from Johnson and Pendell (2017), indicating a reduction in chronic BRD cases results from preconditioning.

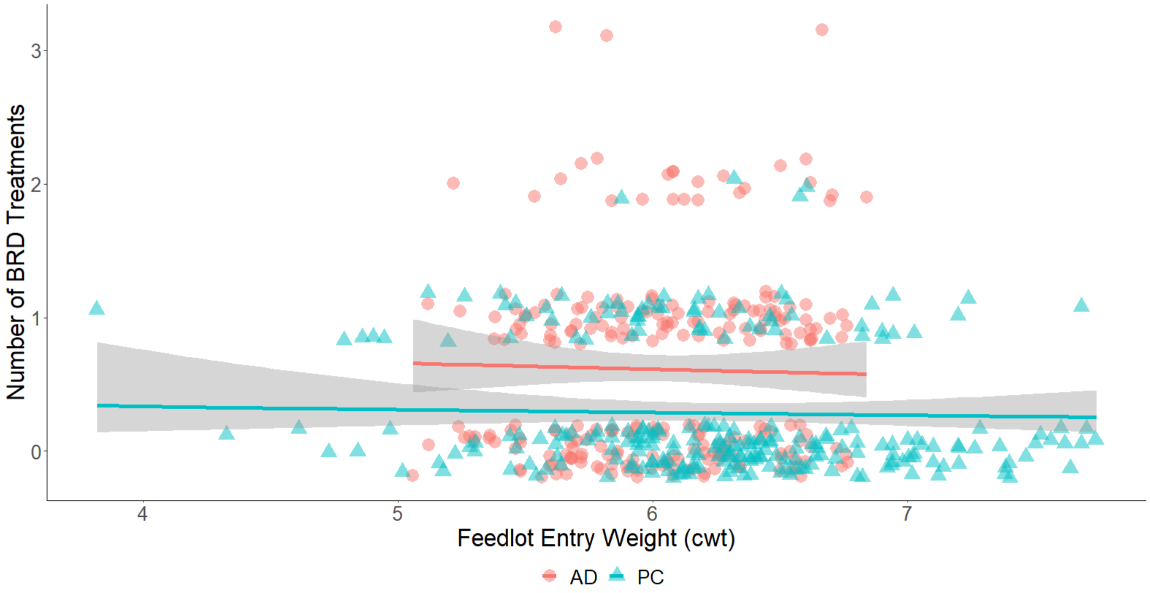
From all four series, PC calves would be expected to outperform AD calves in health measures, and provide a large reduction in the number of BRD treatments. There is no evidence that PC calves become less healthy when commingled with AD calves, and PC calves perform well in health metrics even when they are the minority in a pen. However, these are the well-known benefits of preconditioning, and these benefits alone have not been able to achieve widespread adoption.

5.3 Externalities of BRD

The next objective is to quantify the potential externality reductions from PC calves. Table 5.9 shows the results from the Poisson regressions for BRD count with both the log likelihood (LL) coefficients and the results converted into Incidence Rate Ratios (IRR). For the LL coefficients, a one unit change in the variable corresponds to a log count change of that coefficient. For example, in Model 1, the expected log count for a one cwt (or 100 lb) increase in feedlot entry weight is -0.20. This corresponds with an 0.82 IRR, meaning that a one cwt increase in weight leads to an 18% decrease in BRD treatments. Entry weight has a negative relationship with BRD count in every model, and at statistically significant levels in Models 1, 3, and 4. Again, this is consistent with findings from the literature, where lighter calves are more likely to be infected with BRD upon arrival at the feedlot (Sanderson et al., 2008; Wilson et al., 2017). This is also intuitive because heavier calves usually come from either backgrounding or preconditioning.

The PC variable has a negative relationship with BRD count as well in Models 2 and 3, but Model 4 shows a coefficient for PC that is not statistically different from zero. PC interaction variables *PC*25PC* and *PC*50PC* are also negative. Both of these results are similar to the findings from the previous health cost model. The

Figure 5.1: Expected BRD count from calf source and weight.



IRR of the PC variable in Model 2 shows that PC calves are expected to have an IRR for BRD treatments that is 53% lower than AD calves, and Model 3 shows an expected reduction in the IRR by 37%. For Model 2, at the mean weight of 614lbs, the expected count of BRD treatments for AD calves is 0.61, while the expected count for PC calves is 0.29. Figure 5.1 is a scatter-plot that shows the relationship between calf weight and expected BRD treatment count for each source (PC and AD) from Model 2. The fitted lines show that expected BRD treatments decrease as entry weight increases, but the expected number of treatments is lower for PC calves compared to AD calves at any weight.

Only pen *25PC* showed an increase in the LL, which is statistically significant in both Models 3 and 4. Pen *25PC* had the highest number of BRD treatments. Pen *50PC* is the only pen that shows consistent negative LL that is statistically significant, and pens *75PC* and *100PC* show negative LL compared to the 0PC reference pen.

The interaction variables show that PC calves in mixed pens also have negative LL, and statistically significant for PC calves in pen *25PC*. Similar to the previous series on health costs, PC calves reduced health costs and lowered LL for the number

Table 5.9: Poisson regression of BRD counts listed as log likelihoods (LL) and Incidence Rate Ratios (IRR).

	Model 1		Model 2		Model 3		Model 4	
	LL	IRR	LL	IRR	LL	IRR	LL	IRR
Intercept	0.39	1.48	-0.05	0.96	1.06	2.89	1.16*	3.18*
	(0.60)	(0.88)	(0.71)	(0.68)	(0.66)	(1.90)	(0.68)	(2.17)
Entry Weight (cwt)	-0.20**	0.82**	-0.07	0.93	-0.25**	0.78**	-0.27**	0.76**
	(0.10)	(0.08)	(0.12)	(0.11)	(0.11)	(0.08)	(0.11)	(0.09)
PC			-0.75***	0.47***	-0.46***	0.63***	0.01	1.01
			(0.13)	(0.06)	(0.17)	(0.10)	(0.39)	(0.40)
25PC					0.35**	1.42**	0.42***	1.52***
					(0.15)	(0.21)	(0.15)	(0.22)
50PC					-0.89***	0.41***	-0.97***	0.38***
					(0.23)	(0.09)	(0.27)	(0.10)
75PC					-0.26	0.77	-0.59	0.56
					(0.22)	(0.17)	(0.37)	(0.21)
100PC					-0.30	0.74	-0.77*	0.46*
					(0.28)	(0.20)	(0.45)	(0.21)
PC*25PC							-0.94**	0.39**
							(0.47)	(0.18)
PC*50PC							-0.27	0.76
							(0.55)	(0.42)
PC*75PC							NA	NA
							NA	NA
Observations	500		500		500		500	
AIC	857.26		830.87		809.72		809.94	
BIC	865.69		843.52		839.22		847.87	
Pseudo R-squared	0.01		0.07		0.14		0.15	

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Note: Robust S.E. used to maintain distribution assumption that mean and variance are equal.

Table 5.10: Alternative Poisson regression of BRD counts - where pen proportion is a continuous variable - listed as log likelihoods (LL) and Incidence Rate Ratios (IRR).

	Model 1		Model 2	
	LL	IRR	LL	IRR
Intercept	0.24	1.27	0.51	1.66
	(0.71)	(2.02)	(0.75)	(2.11)
Entry Weight (cwt)	-0.10	0.91	-0.13	0.88
	(0.12)	(1.12)	(0.12)	(1.13)
PC	-0.46**	0.63**	-0.98**	0.37**
	(0.17)	(1.18)	(0.34)	(1.40)
PC Proportion	-0.58**	0.56**	-0.93***	0.39***
	(0.24)	(1.27)	(0.32)	(1.37)
PC Proportion*PC			0.98	2.65
			(0.54)	(1.71)
Observations	500		500	
AIC	828.23		827.49	
BIC	845.08		848.56	
Pseudo R-squared	0.08		0.09	

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Note: Robust S.E. used to maintain distribution assumption that mean and variance are equal.

of BRD treatments.

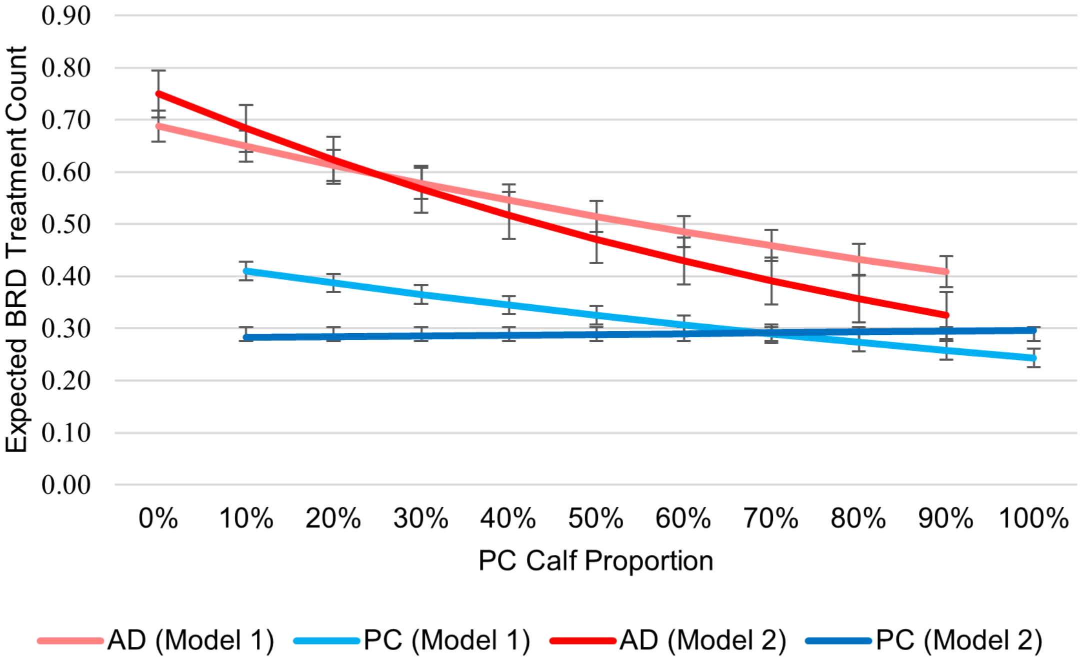
Observing the AIC and BIC, Models 3 and 4 are a better fit than Models 1 and 2, and Model 3 slightly edges out Model 4. The findings from table 5.9 suggest that pen differences are important, but commingling is not.

Table 5.10 presents the results from an alternative Poisson model, where pen dummy variables are replaced with a continuous PC proportion variable. The PC Proportion variable ranges from 0 to 1, so the coefficient measures the change from a pen with no PC calves to a pen entirely made up of PC calves. The reduction in the IRR of BRD treatments is expected to fall by 44% in Model 1 and 61% in Model 2 as pens move from zero PC calves to 100% PC calves.

In these two models, entry weight still has a negative LL relationship with expected BRD treatment count, but is not statistically significant. PC status results in a 37% reduction in IRR of BRD treatments in Model 1, and a 63% reduction in Model 2. However, in Model 2, the *PC Proportion*PC* variable shows a positive relationship with expected BRD treatment count, though not statistically significant. Figure 5.2 depicts the expected BRD treatment count for a calf based on source and pen proportion using the data from table 5.10. This shows how PC calves perform consistently, regardless of the proportion of PC calves in the pens, and AD calves are expected to have fewer BRD treatments as the proportion of PC calves increases.

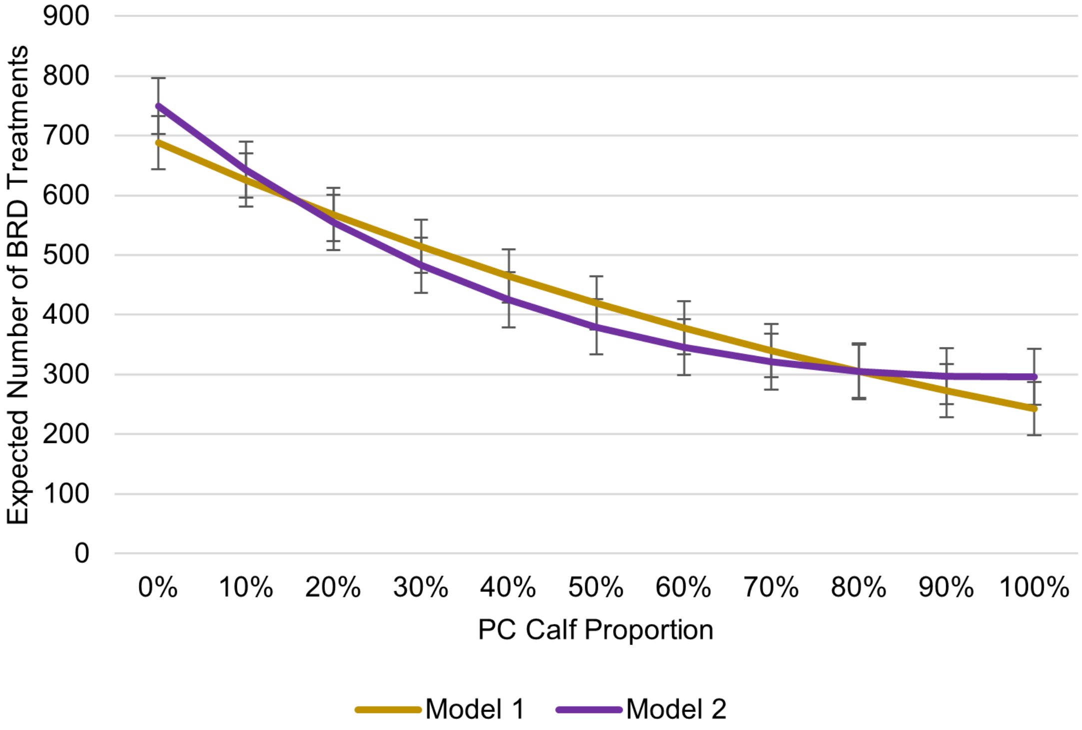
Applying these expected counts to a hypothetical feedlot with a 1000 head intake shows the expected number of treatments for BRD a feedlot would expect given the different proportions of PC calves. Figure 5.3 shows the decrease in expected number of treatments as proportion of PC calves increases. Model 1 predicts a linear decrease in the expected number of treatments from 688 to 243 as PC proportion increases from 0% to 100%. Model 2 predicts a decrease at a decreasing rate such that there is almost no difference in the expected number of treatments in pens with 80-100% PC proportion. Model 2 implies that purchasing only a handful of PC calves can provide benefits in terms of treatment reduction and externality reduction. Both models are

Figure 5.2: Expected BRD count for each source using results from the alternative Poisson regression.



Note: Bars indicate 95% confidence interval.

Figure 5.3: Expected BRD treatments for hypothetical 1000 head feedlot using results from the alternative Poisson regression.



Note: Bars indicate 95% confidence interval.

included because Model 2 allows for diminishing returns.

Finally, a treatment cost for each expected BRD case and the externality cost from the use of the AMD can be calculated based on the expected number of treatments from this hypothetical feedlot. The mean dose of Draxxin® used to treat BRD during the study was 6.83mL, and the per mL cost is CAD$4.85 for a mean cost of $33.13 per treatment. A dose of 6.83mL of Draxxin® contains 683mg of tulathromycin. Assuming the externality cost of USD$1,532/kg of fluoroquinolones from Innes et al. (2020) (or CAD$1,992/kg using the mean exchange rate of 1.3 in 2021), the externality cost associated with each treatment for BRD is USD$1.05 (or CAD$1.36). Table 5.11 shows the total treatment costs and externalities associated with expected BRD treatments in the different pen mixes, all in CAD$.

At the regional scale, the 5-year average feedlot placement in Alberta and Saskatchewan

Table 5.11: Total expected BRD treatment costs and externalities associated with BRD treatments for a hypothetical 1000 head feedlot.

	Model 1			**Model 2**		
PC Proportion	**Treatment**	**Externality**	**Total**	**Treatment**	**Externality**	**Total**
0%	\$22,796	\$936	\$23,732	\$24,838	\$1,020	\$25,858
10%	\$20,718	\$851	\$21,569	\$21,306	\$875	\$22,181
20%	\$18,802	\$772	\$19,574	\$18,381	\$755	\$19,136
30%	\$17,037	\$700	\$17,736	\$15,993	\$657	\$16,649
40%	\$15,410	\$633	\$16,043	\$14,078	\$578	\$14,656
50%	\$13,913	\$571	\$14,484	\$12,580	\$517	\$13,097
60%	\$12,535	\$515	\$13,050	\$11,450	\$470	\$11,920
70%	\$11,269	\$463	\$11,732	\$10,644	\$437	\$11,081
80%	\$10,105	\$415	\$10,520	\$10,123	\$416	\$10,538
90%	\$9,037	\$371	\$9,408	\$9,852	\$405	\$10,256
100%	\$8,057	\$331	\$8,388	\$9,800	\$402	\$10,202

Note: Assumes a mean cost of \$33.13 per BRD treatment and an externality cost of \$1,992/kg (USD\$1,532/kg) of antimicrobial drug.

between October and December is approximately 745,000 head (Canfax, 2020), and consists mostly of recently weaned spring-born calves. Applying the same externality costs to the regional feedlot intake produces a total externality cost of \$697,320 - \$759,900[3] from BRD treatments alone, assuming no PC calves are sourced. If 50% of the fall feedlot intake calves were preconditioned, the expected externality cost would decrease to \$385,165 - \$425,395 - a 39-49% decrease. If all calves entering the feedlot were preconditioned, this would further decrease the expected externality cost to \$246,595 - \$299,490 - a 61-65% decrease.

The resistance rate of bacteria plays an important role in the calculation of AMR externalities. The externality costs presented above assume a resistance rate of 18%. At the 26% resistance rate estimated by Finlay et al. (2019), the externality cost

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[3] $(745{,}000/1000) \times 936 = Range\ Minimum; (745,000/1000) \times 1020 = Range\ Maximum$

per kg of AMD increases to \$4,557, and the total externalities rise to \$2,074,419 - \$2,260,262 per year. In a worst-case scenario, resistance rates rise to 40% by 2050 (Finlay et al., 2019), and AMU does not significantly change, the externality cost per kg of AMD increases to \$42,241, with a total externality cost of around \$20 million per year from feedlot BRD treatments alone. This demonstrates the magnitude of the feedback loop of increased AMR from increased AMU.

An important consideration is that the externality costs assume the same individual treatment for BRD cases as the University of Calgary study. In reality, metaphylaxis is more commonly used to treat BRD for feedlot intakes, especially for young, high-risk calves (Brault et al., 2019). Therefore, it is possible that the true externality costs are higher, depending on the drugs used for metaphylaxis. Another consideration is that fluoroquinolones are a Class I AMD in Canada, whereas macrolides are a Class II AMD (Canadian Animal Health Institute, 2018). Therefore, the externality from the use of Draxxin® and other macrolides is likely lower than the estimated \$1,532/kg used here. On the other hand, the externality cost is highly dependent on the resistance rate for the bacteria being treated, so this could be a consideration for future research.

These cost estimates rely on two major assumptions: (1) non-PC calves will benefit from commingling with PC calves, and (2) all BRD cases will occur in the first 40 days. There is some precedent with this commingling phenomenon in the calf feeding literature. Neave et al. (2018) and Costa et al. (2016) found that pen-mates do matter, and "trainer calves" (calves or cattle that are used to feeding from bunks) are effective at making new calves comfortable with feeding, while Gibb et al. (2000) and Loerch and Fluharty (2000) found mixed results, with some minimal benefits in the short term from "trainer calves". As for the time frame, Buhman et al. (2000) found that 91% of BRD cases occur within the first 27 days upon feedlot arrival, and Edwards (1996) and Loneragan et al. (2001) report the majority of deaths occur within the first 45 days. This would suggest that treatment and externality costs could be slightly higher (by approximately 9%) than these featured in table 5.11.

5.4 Cow-Calf Budget Analysis

Sections 5.1 and 5.2 examined preconditioning from the feedlot perspective, but give little insight into the benefits of preconditioning for the cow-calf producer. Weight measures and health impacts are valuable metrics for determining feedlot performance and profitability, but ultimately do not affect the cow-calf producer's bottom line. This section will examine the cow-calf producer's decision whether to precondition or not using a budget sensitivity analysis, with the aim of quantifying a break-even price and premium. The price or premium would be the minimum needed for a cow-calf producer to break even under a range of scenarios.

Following Dhuyvetter et al. (2005) and Schunicht (2017), a baseline budget in five comparison scenarios for the costs and returns associated with producing PC calves is shown in table 5.12. For the base scenario, a standard weaning price (row 4: \$209.2/cwt) is based on the October slide-adjusted price for 5-600 lb steers in 2020 (Canfax, 2020). This price is \$0.8/cwt lower than the 5 year average between 2015 and 2020, which provides a good benchmark for other price scenarios. The base PC Price (row 14: \$193.6) is the November price for 6-700 lb steers in 2020 (Canfax, 2020). The price selections account for the difference in prices due to market timing and weight following a course of preconditioning. The Price High scenario uses the highest October price paid for steers since 2012 (row 4: \$244.7, 2015), and the Price Low scenario uses the lowest October price for 550 lb steers in Alberta since 2012 (row 4: \$139.2, 2012) (both in 2020 CAD\$) (Canfax, 2020; Government of Alberta, 2022). The November prices that followed each October price in 2015 and 2012 is the PC Price (Row 14) for each.

Body weights (row 1: 544.0) and ADG (row 9: 2.186) are the mean values from the 45d preconditioning at WA Ranch. Shrink rates are set at 4% (row 2) and 2.5% (row 11) for non-PC and PC calves, respectively. Shrink percentage is higher for

Table 5.12: Cow-Calf Producer Budget Analysis.

		Base	Price High	Price Low	Low Cost	High Cost	Low ADG
A.	Traditional management income						
1	Weaning Body Weight (lbs)	544.0	544.0	544.0	544.0	544.0	544.0
2	Shrink	4.00%	4.00%	4.00%	4.00%	4.00%	4.00%
3	Sale Body Weight (lbs/head)	522.2	522.2	522.2	522.2	522.2	522.2
4	Weaning price[A] ($/cwt)	$209.2	$244.7	$139.2	$209.2	$209.2	$209.2
5	Price slide ($/cwt)	$20.0	$20.0	$20.0	$20.0	$20.0	$20.0
6	Gross revenue ($/head)	$1,121.52	$1,307.02	$755.85	$1,121.52	$1,121.52	$1,121.52
B.	Preconditioning management income						
7	PC Start Body Weight (lbs)	544.0	544.0	544.0	544.0	544.0	544.0
8	Preconditioning Time (days)	45	45	45	45	45	45
9	ADG (lbs/day)	2.186	2.186	2.186	2.186	2.186	1.093
10	PC End Body Weight (lbs)	642.4	642.4	642.4	642.4	642.4	593.2
11	Shrink	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
12	Death loss[B]	0.25%	0.25%	0.25%	0.25%	0.25%	0.25%
13	Sale Body Weight (lbs/head)	626.3	626.3	626.3	626.3	626.3	578.4
14	PC price[A] ($/cwt)	$193.6	$233.3	$127.7	$193.6	$193.6	$193.6
15	Price slide ($/cwt)	$10.0	$10.0	$10.0	$10.0	$10.0	$10.0
16	Gross revenue ($/head)	$1,195.74	$1,444.54	$783.53	$1,195.74	$1,195.74	$1,131.92
C.	Preconditioning costs ($/head)						
17	Interest (4%)	$4.22	$4.22	$4.22	$3.17	$5.28	$4.22
18	Health supplies and medicine	$6.06	$6.06	$6.06	$6.06	$6.06	$6.06
19	Death loss	$2.99	$3.61	$1.96	$2.99	$2.99	$2.83
20	Labor and equipment	$14.85	$14.85	$14.85	$14.85	$14.85	$14.85
21	Feed, hay, and pasture	$79.20	$79.20	$79.20	$52.80	$105.60	$79.20
22	Marketing costs[C]	$5.47	$5.47	$5.47	$5.47	$5.47	$5.47
23	Total cost	$112.79	$113.41	$111.76	$85.34	$140.25	$112.63
24	Cost per day	$2.51	$2.52	$2.48	$1.90	$3.12	$2.50
D.	Comparison: traditional vs preconditioning						
25	Traditional gross revenue ($/head)	$1,121.52	$1,307.02	$755.85	$1,121.52	$1,121.52	$1,121.52
26	Preconditioning gross revenue ($/head)	$1,195.74	$1,444.54	$783.53	$1,195.74	$1,195.74	$1,131.92
27	Increased revenue ($/head)	$74.22	$137.52	$27.68	$74.22	$74.22	$10.40
28	Preconditioning costs ($/head)	$112.79	$113.41	$111.76	$85.34	$140.25	$112.63
29	Net return from preconditioning ($/head)	-$38.57	$24.10	-$84.08	-$11.11	-$66.02	-$102.23
30	Return on costs (line 28 ÷ line 22)	-34.19%	21.25%	-75.23%	-13.02%	-47.08%	-90.76%
31	Break-even price ($/cwt)	$199.7	$229.4	$141.2	$195.3	$204.1	$211.2
32	Break-even premium ($/cwt)	$6.2	-$3.8	$13.4	$1.8	$10.5	$17.7

[A] Canfax (2020); [B] Murray et al. (2016) and Stokka (2010); [C] Dhuyvetter et al. (2005)

Unless otherwise indicated, figures are from Olds College or WA Ranch the non-wean (non-PC) calves to reflect the expected weight loss due to the stress of weaning and is in line with industry rates. Both of these values come from sale receipts during the trial. Death loss is included for the chance that a calf may die during the preconditioning phase. The loss of 0.25% has been used as a figure for PC mortality (Dhuyvetter et al., 2005), and studies of calf mortality at the cow-calf stage suggest a mortality rate of around 0.25% for a 45-day period (Murray et al., 2016; Stokka, 2010).

Costs are estimated through a combination of similar studies in the literature and costs paid during the preconditioning phase of the trial. Booster vaccinations (row 18) are the approximate costs paid by the trial researchers for the last round of vaccinations at weaning. Labour and equipment (row 20) is the approximate cost of weaning equipment plus the per head labour cost for additional work such as feeding, applying nose paddles, fence repairs, manure removal, and other tasks. Feed, hay, and pasture costs (row 21) are those paid during the trial[4]. Marketing costs are an approximation of additional marketing costs for PC calve (not all marketing costs). Marketing costs are taken from Dhuyvetter et al. (2005) adjusted for inflation and currency.

Beginning in Part A, row 6 lists the expected gross revenue from traditionally weaned calves. Row 16 lists the expected gross revenue from a PC calf after a 45-day preconditioning period. Part C lists out the costs with the total cost of preconditioning listed on row 23. Part D compares the financial performance between PC and traditionally weaned calves.

In the base scenario (Base column), a farmer is expected to increase revenues by \$74.22, with the total costs of preconditioning coming in at \$112.79, leading to a \$38.57 loss per head. A premium of \$6.2/cwt would cover this cost difference, and, as highlighted in the literature review, such premiums do not always exist in Canada.

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[4] Feed costs are the costs of feeding cattle, whereas yardage costs are the costs of machinery and facilities associated with feeding cattle.

As the price increases in the high price scenario (Price High column), the increased revenue easily covers the cost of preconditioning, with an expected net return of \$24.10. In this scenario, even if the price drops from \$244.7/cwt in October to a value greater than the break-even price of \$229.4/cwt while the calf is being preconditioned, it will still be profitable to precondition a calf. The negative break-even premium suggests that no premium is needed when prices are high. However, in the Low Price scenario, premium of at least \$13.4/cwt is needed to cover the additional costs of preconditioning.

The Low Cost and High Cost scenarios are intended to reflect the changing input price of feed. As previously discussed, feed is the biggest cost to calf producers, and in the base scenario represents just over 70% of the total preconditioning cost. The Low Cost scenario lowers the cost of feed (row 21) by 33% and the High Cost scenario raises the cost of feed by 33%. In the Low Cost scenario, a premium of just \$1.8/cwt is enough to break-even, whereas in the High Cost scenario, a premium of \$10.5 is required. This shows the importance of lower input costs for cow-calf operations in their decision whether to precondition.

The Low ADG scenario reduces the ADG by 50%. This column is intended to highlight differences in PC profitability for calves that do not gain weight as efficiently[5]. This scenario shows how weight gain affects preconditioning profitability, as net returns are \$102.54 less than in the base scenario, meaning farmers would need to be heavily reliant on a large premium of at least \$17.7/cwt to break even.

This budget sensitivity analysis highlights how prices, costs, and weight gain affect the decision to precondition. Farmers who are unable to keep costs manageable or maintain high weight gain for their calves will be unlikely to precondition their calves without strong financial incentives from feedlot owners. For feedlot owners, large premiums need to be paid to cow-calf operations for preconditioning, especially

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[5] Lower ADG can be related to genetics or environmental factors, but can also represent calves that need to travel further distances to markets/feedlots and therefore have a higher shrink factor.

when input costs are high and/or prices are low. This would likely require some additional premium from consumers and/or packing plants, for example an antibiotic-free premium on beef.

5.5 Summary

Two conclusions are drawn from the empirical analysis of feedlot performance; PC calves do not perform better than AD calves, and PC calves perform consistently regardless of the proportion of PC calves in a pen. This analysis suggests there are no incentives for feedlots to pay a premium on PC calves based on feedlot performance alone.

The analysis of feedlot health costs and externalities showed a decrease in health costs, the probability of BRD treatment, and the expected count of BRD treatments from PC calves. The pen interaction variables (notably *PC*25PC*) showed that PC calves always had a decreased risk of BRD and lower health costs, regardless of pen mix. This contradicts a common belief that PC calves will have reduced rates of BRD if they are the minority of calves in a pen.

Applying an externality cost to expected BRD treatments, the externality cost from AMR due to BRD treatments in Alberta and Saskatchewan is estimated to be \$697,320 - \$759,900 per year. If all calves in Alberta and Saskatchewan were preconditioned, this would decrease the estimated externality cost by over \$450,000 per year.

Finally, the cow-calf budget sensitivity analysis showed that cow-calf operations would almost always require premiums in order to break-even after preconditioning, in some cases up to \$13.4 - \$17.7/cwt. As discussed above, feedlots generally do not see enough direct benefits to justify such a high premium, so premiums would likely need to come from consumers and packing plants.

Chapter 6

Conclusions

The purpose of this thesis was to understand why preconditioning has not been widely adopted in Canada. Two main barriers to adoption are suggested: market failure due to uncompensated externalities, and feedlot owners who fear that premiums will be wasted if PC calves do not remain healthy when commingled with conventionally raised calves. Previous studies compare the feedlot performance of PC calves and control calves at the feedlot (Church, 1988; Hentzen et al., 2020; Lalman & Mourer, 2017), or cow-calf profitability (Dhuyvetter et al., 2005; Schunicht, 2017), but to this author's knowledge, no previous study has examined the reduction in AMR externalities as a result of adopting preconditioning. Only one empirical study on PC calves commingled with control calves was found (Step et al., 2008), but this only examined a 50-50 mixed pen.

Three main approaches were used to evaluate these barriers: feedlot performance, health costs and externalities, and cow-calf profitability. Regression analyses were conducted using data from a University of Calgary and Olds College feedlot study for feedlot performance, and health costs and externalities, while data from the preconditioning portion of the study was used to evaluate cow-calf profitability. For cow-calf profitability, a budget sensitivity analysis was conducted using data from the preconditioning portion of the University of Calgary study, as well as data from previous similar studies.

The results from the feedlot performance analysis showed that PC calves performed similar to AD calves in DMFC, value added, and net returns, but performed worse than AD calves in terms of ADG, though this particular metric may have been affected by some compensatory gain. In the short term, ADG may be low for calves that are sick upon arrival at the feedlot, then rise sharply for a few days or week before falling again to a standard ADG over the long term feeding period. Commingling was not found to have affected PC calf performance in any pen.

The health cost and externality results showed that PC calves were significantly healthier than AD calves based on health care costs ($8.57 - $13.86 lower), probability of BRD morbidity (approximately 21 percentage points lower), and expected count of BRD treatments (37 - 53% lower). PC calves also maintained lower health costs and BRD treatment counts in all pens, suggesting that PC calves will perform consistently and stay healthy regardless of their pen-mates. The externality cost reduction associated with the complete adoption of preconditioning in Alberta and Saskatchewan was estimated to be just over $450,000 per year.

Finally, the cow-calf budget analysis suggested that premiums for preconditioning were almost always necessary, unless feeder calf prices happen to be very high. A premium of at least $6.2/cwt would be needed for cow-calf producers to break even at average prices, and large premiums of $13.4 - $17.7/cwt would be needed to ensure cow-calf producers are consistently profitable, even when calf prices are low or input costs are high.

6.1 Implications

Several implications can be drawn from this empirical analysis. First, the additional costs of preconditioning for a cow-calf operation are on average higher than the direct benefits a feedlot owner will receive from PC calves. Results from feedlot performance showed there was statistically no difference in net returns between PC and non-PC calves, and health cost savings were $8.57-$13.86 per PC calf. The base scenario for the cow-calf producer showed a premium of \$6.2/cwt (just under \$40 per head at the mean weight) was required to break even. As long as metaphylaxis remains inexpensive, this confirms the intuition behind feedlots purchasing cheap, young calves. Metaphylactic treatment would need to become less desirable to feedlot owners in order to justify the premiums. This could come in the form of a Pigouvian tax on AMDs, thus increasing the per unit cost of AMDs and incentivizing feedlot owners to find alternatives to large-scale AMU (Giubilini et al., 2017). A tax on beef is a similar solution, but by directly lowering demand for the final product - beef. Another alternative is to create a monopoly for AMDs, either through patents or property rights (Horowitz & Moehring, 2004). This would increase the price for AMDs through a policy mechanism different from taxation. Finally, increased demand from consumers for antibiotic-free beef and commitment from retailers to provide these beef products could increase the demand for preconditioning if packing plants sought more cattle that were raised without antibiotics.

The second implication from this study is that the reduction in externalities presently created by AMU in feedlots is also not enough to justify preconditioning. However, rising AMR rates would greatly increase the externality costs of AMU in feedlots, and likely the incentives to adopt preconditioning. The externality cost in the form of costs to human health care created by AMU in feedlots was estimated to be just over \$800,000 in Alberta and Saskatchewan. If every calf entering a feedlot in Alberta and Saskatchewan was preconditioned, the reduction in the human health care externality was estimated to be up to \$450,000 per year, which averages to approximately \$0.60 per head. This average is well below the \$6.2/cwt premium estimated for cow-calf producers to break even, meaning a subsidy for preconditioning on the basis of health care savings would likely be much larger than the reduction in the externality. As AMR rates increase, so do the externalities associated with AMR, and externality costs of up to \$20 million a year from a 40% resistance rate could justify a subsidy.

The third implication is the belief that PC calves will lose their health advantage when mixed in with non-PC calves was not shown to be true in this analysis. None of the results showed any negative correlation to commingling. These findings suggest that feedlots should purchase PC calves if the health cost saving benefits are greater than the additional cost of purchasing PC calves.

The fourth implication is that more vertical integration between cow-calf producers, feedlots, and packing plants could be used to ensure the incentives exist for preconditioning at all levels of production, similar to auctions in the USA. This includes changing auction structure for less mixing, more online auctions, certifications for preconditioning, or sale agreements between different producers. Consumer demand for antibiotic free or organic meat exists in Canada, and can justify these changes. Additional costs paid by consumers must pass through packing plants to the feedlots and cow-calf operators in order for preconditioning to be economically viable.

6.2 Limitations

A major limitation of the data is the short time span of the study. While compensatory growth may not be a guarantee, a longer study would have been able to confirm whether the higher ADG observed in the AD calves was sustainable or not for a full feedlot stay. A longer study would have also provided a more full accounting of all costs, as the costs for feedlot processing look substantial after 40 days, but would likely be very marginal after several months. This time period, however, is the idea time to analyse health impacts, as the vast majority of morbidity and mortality occurs within the first few weeks of feedlot arrival.

Feeding data was also not precise, as feed offered was the only marker of feed intake. While this wasn't a huge problem for small pens, it does make it difficult to extrapolate feeding patterns from the data.

All calves were assumed to have the same market value and prices were estimated based on weight alone. In reality, prices can vary substantially based on location and date, and some additional factors may also affect the final price of a calf. Meat properties at slaughter would have provided a better indication of calf value and quality from preconditioning.

As previously highlighted, the calculation for the externalities associated with AMDs in livestock is based on a Class I AMD in the United States. While the methods used by Innes et al. (2020) suggest that the value can be applied to other AMDs given to livestock, a better estimation from Class II AMD data in Canada would have been desirable. Theoretically, an estimation could be made based on the number of AMR hospitalizations from of any infections where the resistance originated from a feedlot. The method used by Innes et al. (2020) was to observe the difference between hospitalizations before and after a change in policy of AMDs give to broiler chickens. A more accurate assessment of externality costs specific to Canada is possible, but a challenge requiring expertise from multiple fields.

6.3 Future Considerations

A larger study with significantly more calves and/or pen replication, likely looking at many farms, would be better suited to evaluate mortality. None of the PC calves and 5 AD calves died during the trial, but this was not enough of a sample size to properly evaluate the effect of preconditioning on mortality.

Future studies on preconditioning could gather more accurate feeding data using GrowSafe Systems®, which measures individual feed intake. This could provide a better measure for feed conversion and cost of feeding.

Future research is needed to more accurately calculate the externality cost associated with AMR stemming from AMU at feedlots in Canada. This is the best way of either assigning taxes or property rights for AMDs, or calculating the value of antibiotic-free calves in order to reduce market failure from externalities. Future research could also examine resistance rates in pathogens and how much this increases externalities over time.

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Appendix

A Feedlot Diet Costs by Ingredient & Ration

Table A: Feed cost data.

Step 1 Diet	**(46.50% Dry Matter)**		
Ingredient	**Ration**	**Cost/Tonne**	**Cost/Tonne**
Barley Silage	83.40	$70.00	$58.38
Barley Grain	9.50	$253.00	$24.04
32-15 Grower Supp	3.30	$776.00	$25.61
Corn DDGS	3.80	$430.00	$16.34
Total	100		$124.36
Step 2 Diet	**(48.09% Dry Matter)**		
Ingredient	**Ration**	**Cost/Tonne**	**Cost/Tonne**
Barley Silage	80.03	$70.00	$56.02
Barley Grain	13.37	$253.00	$33.83
32-12 Supp M440	3.40	$776.00	$26.38
Corn DDGS	3.20	$430.00	$13.76
Total	100		$129.99

B Health Product Pricing

Table B: Treatment cost data.

Product	**Price (VAT not Included)**	**Volume (mL)**	**Price (VAT included)**
Baytril	\$303.45	250	\$1.27/mL
Biomycin	\$88.00	500	\$0.18/mL
Draxxin	\$1,154.54	250	\$4.85/mL
Exceed	\$413.20	100	\$4.34/mL
Fenicyl			\$1.07/dose
Meloxicam Oral	\$310.00	1000	\$0.31/mL
Metacam	\$447.12	250	\$1.88/mL
Oxyvet	\$55.30	250	\$0.23/mL
Resflor	\$298.02	250	\$1.25/mL
Bovi-Shield GOLD One Shot			\$3.63/dose
Ivomec (under brand name Solmectin)	\$233.00	2000	\$0.01/mL
Revalor G			\$4.67/dose
Ultrabac 7/ Somubac			\$1.20/dose