FINANCIALLY OPTIMAL CULLING STRATEGIES FOR WESTERN CANADIAN COW-CALF OPERATIONS

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By

HEIDI TYMKO

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ABSTRACT

Canadian cow-calf producers often experience slim margins and focus on reducing costs to maximize their economic profit. This study aims to identify financially optimal breeding female culling strategies using production and financial data from 16 ‘typical farms’ in the Canadian Cow-Calf Cost of Production Network (COP Network). Managing the breeding herd inventory composition through culling and replacement decisions impacts the future cashflows and the value of the herd. Average values from 16 ‘typical farms’ in the COP Network were used to generate four farms with combinations of high and low costs and productivity. Four culling scenarios were looked at in this thesis; the base scenario does not account for wean weight differences based on dam age. Scenarios 1 through 3 vary wean weight based on dam age using the Beef Improvement Federation (2002) factors and price slide adjustments. Replacements come from home-raised heifer calves (Scenario 1 and 3) or purchased bred heifers (Scenario 2). Using these culling and replacement scenarios a net present value (NPV) model is converted to an equivalent annual annuity (EAA). The enterprise profitability analysis assesses the cash flow and returns on assets (ROA) for the cow-calf and home-raise heifer enterprises and whole farm business in three scenarios (1 through 3). This analysis considers the depreciation of breeding females over their productive life, assessing the cash flow and ROA impact of different culling decision rules. When evaluating the ROA, depreciation is considered when calculating the accrual net income. Depreciation is a significant cost when looking at accrual-based income, which is the proper way to measure financial performance when considering investment alternatives. By reducing breeding stock depreciation through lowering heifer development costs, farms can positively impact the net income of the enterprise. The EAA model shows greater EAA valuation for home-raised bred heifers over open females. The enterprise ROA model found the home-raised heifer enterprise to be profitable for the majority of farms. The whole farm business was the most profitable for these same farms, suggesting home-raised bred heifers are more profitable than purchasing bred heifers priced at the Alberta 5-year average price of $1978/hd (CanFax, unpublished data). These models provide a financial perspective on the optimal culling decision based on a farm's costs and productivity, as well as the source of replacements (home-raised or purchased).

Keywords: culling, depreciation, equivalent annuity, net present value, return on assets

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LIST OF ABBREVIATIONS

AU………………………………………………………………………………….…… Animal Unit

BIF…………………………...……. Beef Improvement Federation

CDN COP Network …………………..………. Canadian Cow-Calf Cost of Production Network

EAA…………………………………….……………...……….……….. Equity Annual Annuity

NPV ……………………………………………………………….….…. Net Present Value

TR……………………………….……..……………………………………... Total Revenue

HP……………………………….…..………………………………….....…. High Production

HC…………………………………..………….. High Cost

LP………………………………………………………………..……..……... Low Production

LC………………………,……………..……..…………………………….….….. Low Cost

AVG……………………………………………………………………...…….. Average

Chapter 1 – Introduction

1.1 Background

1.1.1 Canadian Cow-Calf Producers

The first stage of the beef supply chain is the cow-calf producers. There are 3.78 million beef cows on just under 55,000 farms with beef cows within Canada as of January 1, 2022 (Statistics Canada, 2022a). With cow-calf producers being the foundation of the beef supply chain, they typically focus on minimizing costs to increase their net returns. In addition, production efficiency (i.e., wean rate, weight weaned per female[1] exposed) is of immense importance for these producers to improve both profitability and their environmental impact.

Canadian cow-calf producers must make many decisions to manage their herd and ensure it is producing at the optimal level to maximize profits. These decisions include when to retain or cull[2] unproductive cattle and which replacements to obtain to maintain their desired herd size. They face many challenges to ensure their operation achieves their financial and personal goals. According to the Canadian Cattlemen's Association (2020), while the average cow herd size in 2016 consisted of 69 cows; 61% of farms reported having under 48 cows (accounting for 16% of all beef cows in Canada), and 15% of farms reported over 123 cows (accounting for 60% of all beef cows in Canada) (Statistics Canada, 2017). Relative to the U.S. 79% of farms reported having under 49 cows (accounting for 27% of all beef cows in the U.S.), and 10% of farms reported over 123 cows (accounting for 56% of all beef cows in the U.S.) (United States Department of Agriculture, 2017). Cow-calf producers typically raise their own breeding female replacements by

[1] Cows or heifers with the intention to conceive.
[2] Selling breeding stock for slaughter.

keeping 7-month-old heifer[3] calves from their annual calf crop, feeding them over the winter, and breeding them at 14 to 16 months old, to have their first calf at 2 years old. Producers incur significant costs to develop these heifer calves into bred heifers and the females are expected to obtain 8 to 10 calves before the animal is culled for slaughter (beef). As of July 1, 2022, the average market value of a breeding female is estimated at $1,944 per head, suggesting the average herd of sixty-nine cows is valued at $134,136 (Table 1.1) (Statistics Canada, 2022b).

Table 1.1. Canadian Value Per Beef Animal

	Year					
	2017	2018	2019	2020	2021	2022
Beef cows	$1,847	$1,877	$1,732	$1,758	$1,904	$1,944
Beef Heifer for Breeding	$1,822	$1,831	$1,758	$1,790	$1,891	$1,967

Source: Statistics Canada (2022b)

1.1.2 Competitiveness of Cow-calf producers

Across Alberta and Saskatchewan, there are 171 feedlots with a +1000 head capacity for a total capacity of 1,700,300 head; taken together, these two provinces account for 78% of the fed cattle production in Canada (Canfax, 2022a; Canadian Cattlemen's Association, 2020). This limited number of buyers for weaned calves relative to the number of cow-calf operations creates an oligopsony-style market for feeder calves leaving cow-calf producers as price takers. Another reason for cow-calf producers primarily being price takers is the nature of the product they produce; a majority of producers are spring-calving and sell calves via live auction at weaning each fall (Beef Cattle Research Council, 2019). Live auctions mix calves from multiple farm

[3] A bovine aged less than two who has not birthed a calf.

origins (i.e., pre-sort sale), in effect removing farmers' ability to negotiate prices for their weaned calves. Therefore, commercial[4] cow-calf producers produce a homogenous product (weaned calves).

As price takers, cow-calf producers need to focus on reducing costs and improving productivity (conception rate, wean rate, and pounds weaned per female exposed) as a means to maximize herd profitability. Cow-calf producers experience small margins (AgriProfit$, 2022); with little opportunity to influence prices received for calves, they often focus on reducing costs to maximize profits.

1.2 Depreciation

Depreciation can often make up the second-largest expense on cow-calf operations and can be overlooked by producers as it is an amortized non-cash expense over the useful life[5] of an asset (Thomas et al., 2021). Firms must decide when to keep, fix, and replace assets, often comparing if the asset's book value, or purchase price less accumulated depreciation, is greater than the asset's salvage value. Assets such as buildings are often easily valued as they depreciate linearly, making replacement intervals a more straightforward decision. This significant non-cash cost of asset depreciation is an important consideration in the management of agricultural operations; depreciating assets include equipment, buildings, and breeding stock (Griffith et al., 2017). However, breeding stock depreciation is not always included in enterprise analysis budgets; this is the case in the Agri benchmark methodology used by the Canadian COP (CDN COP) Network (Canadian Cow-Calf Cost of Production Network, 2021). Cow-calf producers raising replacement breeding females often can reduce depreciation by lowering heifer replacement development costs

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[4] Cattle crossed between varying breeds and with no pedigree documentation.
[5] A cow's useful life refers to the years she is expected to produce a calf.

such as feed and health programs[6], but minimum requirements are needed to maintain animal productivity. In addition, production parameters, such as increasing female conception rates and the number of replacements kept (replacing open, unsound[7] and death loss cows) will impact replacement heifer costs.

Valuing biological assets such as breeding stock with a more complex depreciation cycle is often more challenging than other assets on a farm, such as tractors and feed wagons. For cow-calf producers, the cowherd is considered a biological asset with infinite useful life; therefore, the cowherd as a whole will not be depreciated (Chartered Professional Accountants Canada, 2020). Although there is the replacement of individual females within a cowherd, often, the herd will maintain an average age. Within the herd, the individual breeding females are recorded as non-current assets and each individual breeding female will either appreciate or depreciate, and the subsequent replacement and culling decision regarding individual animals will impact the overall herd value and profitability of the farm (Turner, et al., 2013). Depreciation negatively impacts accrual net income by raising costs. Through minimizing depreciation costs, producers can aim to optimize one aspect of costs to increase the net income of the farm.

Producers may choose to follow specific culling strategies (commonly culling all unsound and open females), impacting their herd's potential performance and profitability. There is a linkage between the culling strategy, the level of depreciation, and the salvage value of the cow. Among typical farms in Saskatchewan's 2020 Canadian Cost of Production Network (CDN COP Network), depreciation (of buildings and equipment) accounted for an average of 10% of total

[6] Cow-calf health programs include vaccine protocols and unforeseen treatments needed to keep individual animals and the overall herd in healthy condition to produce offspring.
[7] Beef animal who has a physical condition or injury that limits their productivity.

production costs. The CDN COP Network methodology varies in accounting for breeding female costs by not calculating breeding stock depreciation, but instead includes heifer development costs and breeding female purchases as cash costs and the cull sales as revenues; sometimes, there is a depreciation line item, but the costs associated with developing or purchasing replacements and revenues from culls are often not included each year. According to the Western Beef Development Center (2013), breeding stock depreciation totalled $52.47 per cow (8% of total costs) for Saskatchewan farms. As producers want to minimize costs, cow depreciation should be one of their primary focuses.

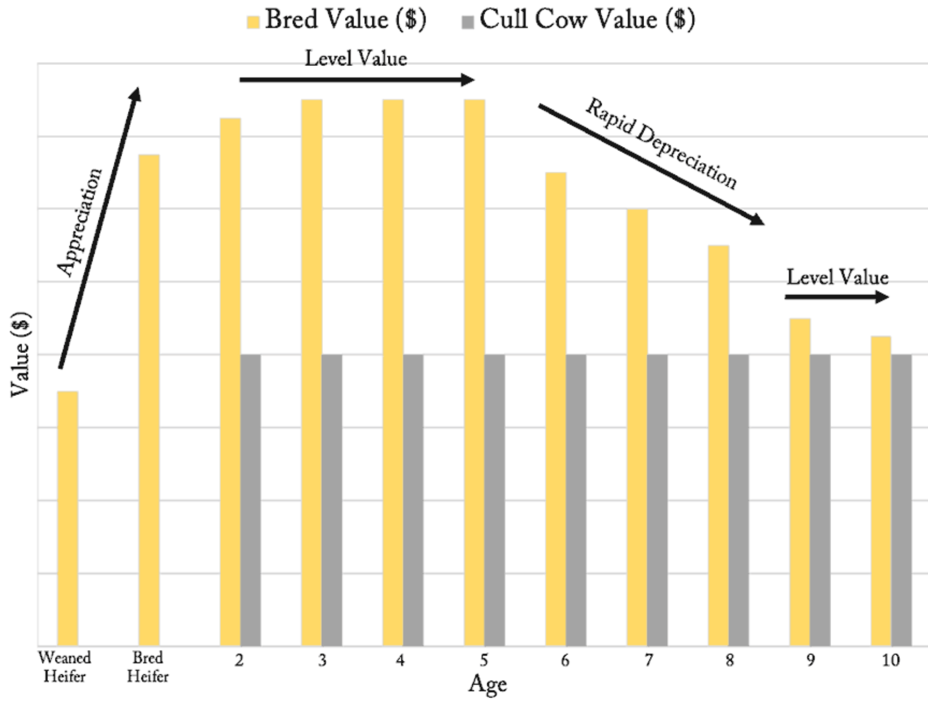
Berger (2014) outlines the three components of cow depreciation: the purchase price or development costs for the bred female, the salvage value at culling, and the productive years in the herd (Equation 1.1). The *Purchase Price* of a bred heifer is the market price to buy a breeding female that will calve in the next six months. The *Development Cost* is the cost to develop a home-raised heifer calf from weaning (seven months of age) until she is confirmed pregnant at 18 months of age. The *Salvage Value* is the market value of the breeding female when she is sold (culled) after being diagnosed as non-pregnant (open) or because of reasons due to health, conformation, or temperament problems. The *Productive Years in the Herd* are the total expected years the cow will produce a weaned calf, where an increase in the number of productive years lowers the annual depreciation. As purchase price (development costs) increase, salvage values decline, or productive years decline, cow depreciation will increase and vice versa.

$$Cow\ Depreciation = \frac{(Purchase\ Price\ or\ Development\ Cost - Salvage\ Value)}{Productive\ Years\ in\ the\ Herd} \qquad (1.1)$$

When a cow is culled for being open (i.e., non-pregnant after breeding) prior to her expected productive years, estimated depreciation from prior years will have understated the true depreciation as the number of actual productive years is less than expected. For example, a rancher may have expected 10 productive years, but culled the cow after she was diagnosed open at age 4 with 3 productive years. Instead of dividing by 10, I now dividing by 3, to represent 3 production years, and that cost difference (less accumulated depreciation) has to be brought forward to the current year.

Thomas et al. (2021) describe that individual female cows do not depreciate in a straight line. Instead, a cow's economic value follows a bell-like curve changing as the cow enters different stages of her life; this can change the market valuation by cow age then impacting the actual salvage value received if the female is sold. Beef cows will appreciate until about three years of age as each year she will typically produce a heavier and more valuable calf that proves her worth as she reaches three years old. The female will then hold her value until six years old. After which, a breeding female will lose value until the age of nine, when her value will stabilize (Figure 1.1) (Thomas et al. 2021). Replacement heifers will replace older aged females within the herd; as females are replaced, the herd will often maintain a stable age, valuing the herd at a stable value based on Thomas et al.'s (2021) values. Therefore, with this replacement and culling cycle, the CPA does not depreciate the entire herd due to having a steady average age and herd value from the overall herd's age distribution (Chartered Professional Accountants Canada, 2020).

Figure 1.1. Cow Valuation Cycle



Source: (Thomas et al. 2021)

1.2.1 Cow Depreciation: Balance Sheet Item

A breeding stock valuation can be found on the balance sheet, where the book value is the cost of the asset minus accumulated depreciation. Producers must estimate the salvage value and useful life of an asset (Barry et al., 2012). This valuation of assets provides producers with a constant valuation of their assets "that does not fluctuate with the market" (Beef Cattle Research Council, 2022). Using management depreciation instead of tax depreciation gives the producer an accurate valuation of net worth and accrual-adjusted net income used on a cost-based balance sheet (Hoffman, 2020). Income Tax depreciation (i.e. Capital Cost Allowance) allows producers to write off asset costs to reduce their taxable income (Farm Business Consultant, 2022; Government of Canada, 2023).

Using cost-based valuation (book value) is recommended for breeding stock and other livestock on the balance sheet, where asset value is the asset's cost minus depreciation calculated (Jones et al., 2020). The accumulated costs from the time of weaning[8] until the point when a replacement heifer is confirmed pregnant and joins the breeding herd are considered the bred heifer's asset value. Prior to joining the herd, a replacement heifer is considered a non-depreciating current asset (Hoffman, 2020). Regarding appreciation of the female's value, for accounting purposes, asset appreciation only applies when the asset is sold, as depreciation expense will not change. By including breeding stock depreciation in a producer's annual budget, they can manage their leverage and interest expense when replacing culled mature female capital assets.

1.3 Culling in Cow-Calf Herds

Producers consider numerous factors when retaining or culling animals. Culling rules are part of an asset replacement strategy, similar to an operation considering repair costs in its strategy for replacing a fully amortized combine. However, while the concept of infinite life is associated with the cowherd as a whole, the replacement and culling of individual females within the herd impacts the herd's overall valuation and the cow-calf enterprise's profitability.

Culling decisions may differ across herd size, operation type, and business phase. For example, commercial producers may choose to cull females if they fail to conceive regardless of age or cull all females exceeding a certain age regardless of pregnancy diagnosis. Purebred producers with large investments in genetic lines may choose to retain open[9] females under five years old who have weaned high-valued seed stock calves in their past years of production. Producers will typically cull all non-pregnant females after pregnancy testing in the fall as these

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[8] Separating a calf from a lactating cow.
[9] Cow or Heifer that did not conceive.

cattle cannot offset their production costs during the winter-feeding season (CanFax, 2011). In addition to culling unbred females, culling reasons include not calving within the desired calving period length, deteriorating health conditions, conformation breakdowns, temperament problems, and age (Pearson, et al., 2019). These culling decisions impact the cash flows and the potential profitability of the herd.

1.4 Brief Introduction to the Literature

Net present value (NPV) analysis has been used extensively in the U.S. cow-calf herd management literature to compare culling strategies, but there is a lack of studies using current Canadian production costs and market prices. A Canadian study is needed to address the differences in climate and the costs associated with maintaining breeding females in western Canada relative to cow herds in the U.S. from previous studies. For example, the CDN COP Network reported 150 to 250 winter feeding days among its benchmark farms (Canadian Cow-Calf Cost of Production Network, 2021a) and AgriProfit$ (2022) reported feeding 3.8 tonnes per cow (5-year average) relative to the average U.S. beef cow eating 1.1 tonnes of hay over a 90-day winter feeding period, feeding 1.1 (Gleason and White, 2019). These differences in feeding length and tonnage are due to climate differences between countries and regions.

One of the NPV analyses done in the U.S. by Ibendahl et al. (2004) converted the NPV equation into a perpetual annuity decision model to compare open cow assets and heifer replacement assets with varying timelines. Mathews and Short (2001) valued cow assets' NPV throughout the price cycle and the effect of genetic improvement on the herd. Meek et al. (1999) constructed a spreadsheet budget NPV model with varying revenue, costs, and performance to evaluate beef females aged one to fifteen. Boyer et al. (2020b) also did a variation of the NPV model but introduced risk-neutral and risk-averse producers; in the model, the authors used a hedonic pricing model to measure the impact of various production factors such as a female's pregnancy status and age on the sale prices of the female. Alternatively, Turner et al. (2013) used a systems dynamic model simulation to simulate varying cow marketing (culling strategies) and heifer replacement scenarios to evaluate the farm's net income and return on investment.

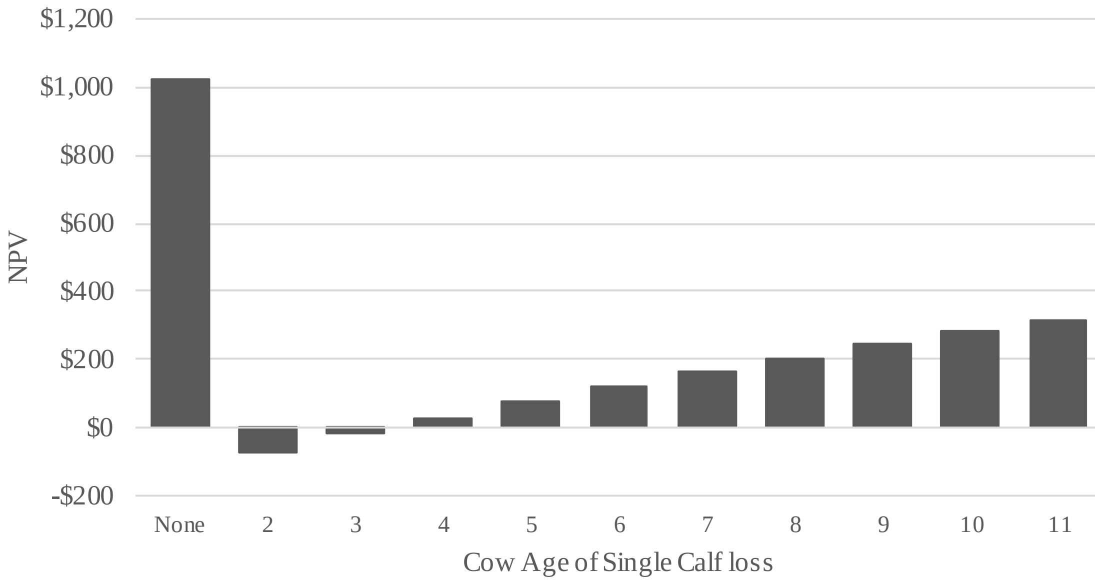
To the best of my knowledge, similar models using Canadian data do not exist. A Canadian analysis will allow producers to compare their strategies to farms with similar cost and productivity structures such as climate and feeding systems as opposed to an analysis using data from the U.S. that may vary more from Canadian farms. In my culling and replacement analysis, I will use a weighted NPV model and herd cashflow simulation model to evaluate three culling scenarios' impact on the individual female's equivalent annual annuity evaluation (EAA) and the herd's profitability, respectively. The NPV model adapted from Ibendahl et al. (2004) allows assets of varying cashflow timelines to be compared, such as an open four-year-old cow and a replacement heifer. The second herd cashflow model motivated by Turner et al. (2013) will illustrate the impact of the chosen culling strategy on the cow-calf enterprise's profitability. Berger (2014) and Thomas et al. (2021) have outlined several culling strategies that minimize cow depreciation. It is unclear in the literature which strategy is optimal for different types of Canadian operations with different cost structures, replacement development costs, production parameters (i.e., calf and cow weight) and sale prices. With a capital investment analysis, a comparison of simulated alternatives to determine which culling strategy optimizes a female's NPV and the cow-calf enterprise's profitability can be completed.

1.4.1 NPV and Cashflows in Cow's Production Years

If producers had perfect knowledge of their individual female's future production each female asset's NPV could be calculated and compared. For instance, if the producer expected a single calf loss from different individual females at different ages, the NPV can be calculated and compared.

Figure 1.2 represents a hypothetical example using average costs from AgriProfit$ (2022) and cattle values from Statistics Canada (2022b). Each column in Figure 1.2 is the NPV for an 11-year-old breeding female with a different age when they failed to wean a single calf. None is the NPV ($1020) when a cow successfully weans a calf every year for 11 years. The other columns represent the NPV for an 11-year-old cow that weans a calf every year except at that age. An 11-year-old breeding female that failed to rebreed at age 2 or 3, but weaned a calf every other year, will have a negative NPV. Eleven-year-old females that were open once at ages 4 through 11 have positive NPVs. The difference in NPV valuation between the cow with no calf losses and a cow open once at age eleven is $704.16 of forgone discounted calf revenue.

Figure 1.2. Perfect Knowledge NPV of Females with Single Calf not Weaned

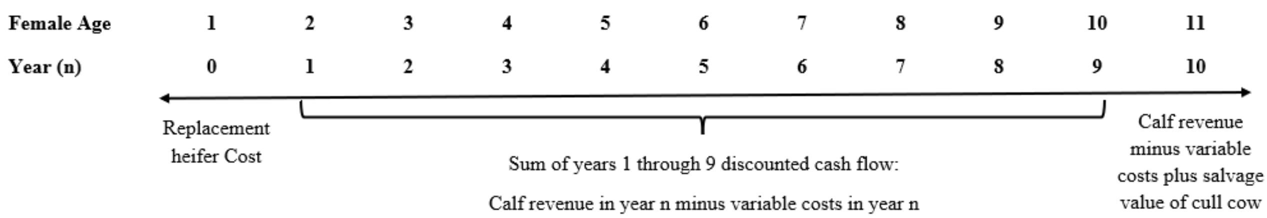


Notes: Replacement heifer costs $1967 (Statistics Canada, 2022b), Calf crop annual value $1147 (Statistics Canada, 2022b), Variable costs $914.67 (AgriProfit$, 2022), 10 production years, and 5% discount rate.

Unfortunately, producers do not have perfect knowledge of their female's future production and the NPV of an open female is usually calculated at the time she is open with the remaining production year's discounted cashflows. The new NPV of the open female is then compared to the replacement heifer NPV as an EAA, due to the difference in each asset's timeline (Ibendahl et al., 2004).

A female's NPV is impacted by the discounted net cash flows the female receives over her useful life. Figure 1.3 represents these expected total future discounted cashflows. Unfortunately, it is not perfectly determined if the female will have a calf in each production year. If a calf is not produced in one of the production years (n) the producer will forgo the revenue of the calf but must cover the variable costs if the producer chooses to retain the cow instead of replacing her.

Figure 1.3. Illustrative Cash Flow Timeline



Therefore, with this uncertainty producers will often choose to cull older open cows due to fewer production years remaining to recover variable costs and forgone revenue. Younger open cows may be retained if the EAA of the open young cow is greater than the EAA of the replacement heifer.

1.5 Research Question and Motivation

The goal of this thesis is to provide a financial and economic framework that aids producers in understanding how different breeding female culling and replacement strategies can impact a herd's valuation and the cow-calf enterprise's profitability. Producers must decide whether to develop home-raised heifer calves or purchase bred heifers for replacements and whether to cull open breeding females or give specific females (based on age, past progeny performance, etc.) a second chance. These decisions (and many more) impact the cowherd's productivity and cow-calf enterprise's profitability. Table 1.2 outlines the research problem and potential culling strategies impacting the solution of the research question.

Table 1.2. Research Problem

Economic Problem
Evaluate how culling and replacement strategies impact cow-calf farms' profitability and cashflow.
Culling Strategies
Cull all open females regardless of age
Cull cows before a specific age (8 years old) to increase the salvage value of cows that are leaving the herd
Replace with homegrown heifers versus purchasing bred heifer replacements

This research is of interest to cow-calf producers and beef financial specialists. By modelling culling strategies, financial advisors and producers will be given a set of strategies and a universal calculator generated in Microsoft Excel to best manage their cowherd's replacements and culling practices to optimize the herd's valuation and the cow-calf enterprise's profitability.

1.6 Chapter Summary

The culling and replacement decision process is a critical part of the producer's decision model. Each individual female will depreciate but the overall cow herd carries an average age and will not be amortized. The individual cow culling decisions impact a female's NPV and the overall herd's profitability, therefore, impacting the farm's net worth. Ensuring newly bred heifers and young cows have a higher pregnancy rate is essential as illustrated in Figure 1.2. One lost calf could result in the asset having a negative NPV if the producers had perfect knowledge of the female's future production. Canadian producers experience slim margins, by following optimal culling and replacement strategies enterprise profitability can be increased.

Chapter 2 –
Literature Review

The thesis aims to examine optimal culling and replacement strategies for various types of Canadian cow-calf operations. The existing literature on optimal culling strategies has thus far largely focused on cow-calf operations in the U.S., and there is no academic research using Canadian cow-calf operation data. The literature review will explore culling strategies and models used to determine optimal decisions when culling and replacing females in the herd.

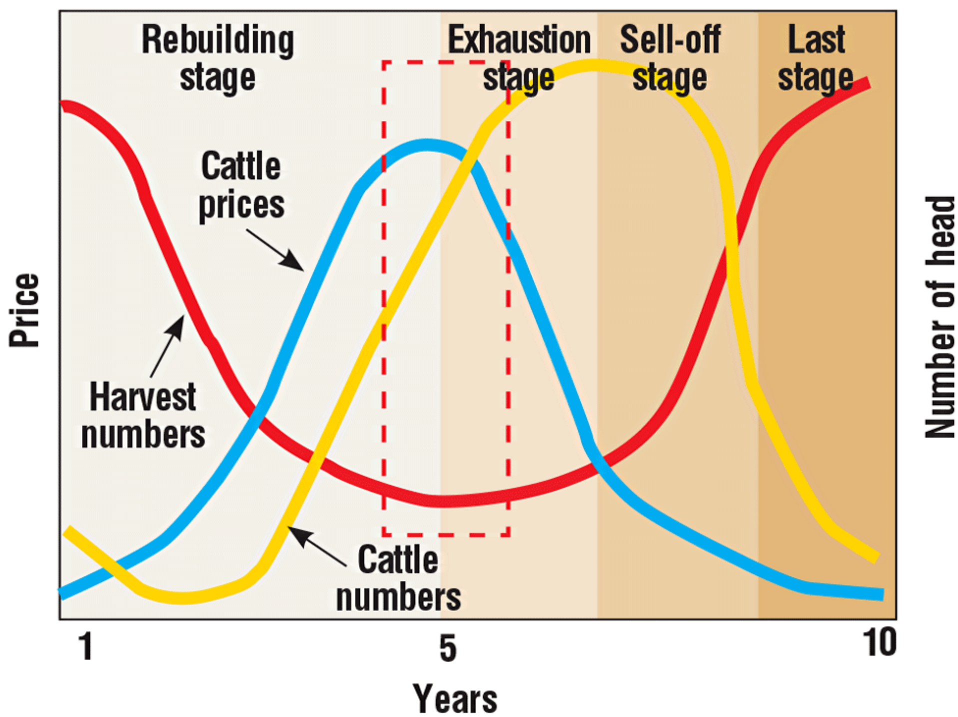
The literature review section will cover five main research areas: the beef cycle's impact on herd inventory management, cow depreciation reduction considerations, replacement and culling decision modelling, optimal replacement and culling strategies, and wrapping up with culling strategy inconsistencies. The first section will address research on the impact of replacement and herd inventory management compared to the national herd inventories. The second section of culling strategies to minimize cow depreciation will relate to the outlined strategies within the primary research objective of optimally managing the cow-calf enterprise's income. The third section will describe a modelling outline to determine the replacement cow's NPV prior to culling as an additional analysis to understand the impacts of culling strategies. The fourth section will review the literature addressing replacement strategies such as culling rate impact on the overall farm's income and herd profitability. Finally, in the fifth section, the inconsistency of replacement and culling strategies will be addressed as there is a variety of culling options, but not all farms follow the same strategy.

Following the discussion of each research area, I will address what is known about culling strategies and minimizing beef cow depreciation and the gaps of knowledge within the current research. I will then briefly discuss the question of how future research can be applied to address gaps in the literature for Canadian cow-calf producers to develop strategies to optimize a herd's valuation and the cow-calf enterprise's profitability, with additional details following in the Methodology section.

2.1 Beef Herd Management During the Cow Cycle

The Beef Cattle cycle id defined as a "biological-economic phenomenon influenced by production, prices and profits" and driven mainly by the national cattle herd inventory (CanFax, 2018, p. 1). The beef cattle cycle is constructed by three phases illustrated in Figure 2.1: expansion (i.e. rebuild stage), peak (i.e. exhaustion stage), contraction (i.e. sell-off stage), and turnaround (i.e. last stage) (Griffith et al., 2017).

Figure 2.1. Theoretical 10-year Cattle Cycle



Source: (Ishmael, 2022)

Within Figure 2.1 a few observations can be made. First, the harvest numbers (red line) track countercyclically to prices (blue line) and the national herd numbers (yellow line) track behind the price cycle. When the expansion phase is at its peak (associated with more retained heifers and fewer culls) there are less cattle marketed leading to higher prices, therefore, producers aim to keep more replacements to capitalize on higher prices in the future when they have a larger calf crop (Griffith et al., 2017; Hamilton & Kastens, 2000). When cattle prices are high, the peak of the expansion phase is often in effect, where producers retain more heifers and cull fewer mature females than usual. Conversely, prices will fall with a larger supply of calves on the market. At the time of expansion, producers often have the opportunity costs of selling heifers at a higher price (Griffith et al., 2017).

According to Griffith et al. (2017), when the contraction phase is often in effect; producers will have a higher culling rate and lower heifer retention rate, leading to more animals being marketed and lower cattle prices. Producers often sell heifer calves as they see less profit in future progeny, decreasing their cowherd inventory for the following years. This reduction in cowherd inventory is often a consequence of fewer calves being marketed in the national herd, then raising prices in the future. These expansion and contraction decisions are made with short-term price information, and there is a need for producers to consider long-term factors to improve their profits (Griffith et al., 2017).

The behaviours of expansion and contraction illustrated by Griffith et al. (2017) are the opposite of most farms' behaviour. This is partly due to the biological lag from raising a heifer to selling her first calf, limiting producers' market power and responsiveness (Griffith et al., 2017; Hamilton & Kastens, 2000). Hamilton and Kastens (2000) outline three producer types: (1) representative producers adjusting their herd inventory with the national aggregative cattle inventory; (2) the constant inventory producers maintaining the same inventory over time; (3) countercyclical producers having an inventory opposite of the aggregate inventory of the nation. If we apply the whole industry's actions in expansion and contraction behaviour illustrated above, when calf supply increases, calf prices decline.

In addition to the countercyclical and constant inventory producers, Fanning et al. (2002) described a third strategy for herd management in the cattle cycle: the dollar-cost averaging, where producers will retain “the same dollar value of replacement heifers each year” (Fanning et al., 2002, p. 132). Producers can better manage cash flows and capitalize on lower-priced heifers producing higher-priced calves in their prime production years as the cattle cycle shifts (CanFax, 2022b). Fanning et al. (2002) used a dynamic optimization model to find the “economically optimal replacement strategies that optimize the net present value of net income and ending inventory value of the cow herd for the study period” (p. 131-132). By using price signals to inform heifer retention, producers can improve herd profitability, assuming they are a cost-minimizing operation (Fanning et al., 2002).

When a producer makes opposite moves to the general industry (countercyclical producer), such as selling more heifer calves at higher prices, they will need to strategically manage cash flow while selling fewer animals at lower prices. This behaviour is known as the ‘market effect’ (Hamilton & Kastens, 2000). Optimally, producers should maximize inventory during profitable periods of the cattle cycle and minimize during unprofitable periods through reduced heifer replacements. However, there are several challenges with adjusting cow numbers to capitalize on the cattle cycle. These challenges include underutilized forage land when the cowherd is liquidated and the impossible perfect prediction of prices (Fanning et al., 2002). For this reason, established producers may choose to focus on maintaining their herd size to reduce cash flow problems and optimally utilize their resources, such as grazing acres. In addition, maintaining a herd size allows a producer to build preferred genetics essential to purebred seed stock and commercial producers (Griffith et al., 2017).

Hamilton and Kastens (2000) describe the decision on culling and retention as an economic decision based on the current and future expected prices and the projected future costs. Through a simulation model using data from U.S. producers from 1974 to 1998 "to calculate net returns from alternative cattle management practices," they found an inverse relationship between deviated net returns and the inventory of the herd (p.90). In addition, it was shown that representative producers in times of high prices hold low inventories, and therefore are incapable of capitalizing on higher prices (Hamilton & Kastens, 2000).

Hamilton and Kastens (2000) describe two factors influencing the cattle cycle; the exogenous shock shifting the demand function and the market timing effect representing the aggregate movement of quantity and price. These factors were separated in the authors' model. Suppose the market results entirely from exogenous shocks. In that case, it is hypothesized that the representative producer is outperforming relative to the producer who has a constant herd inventory. If the market is stable and market timing effects operate through the cycle, constant inventory producers are hypothesized to outperform representative producers. These hypotheses were rejected by the authors' analysis, showing that both exogenous shock and timing effects impact various cattle cycle phases (Hamilton & Kastens, 2000).

In the model, the representative producer outperformed the countercyclical producers by $28.48 per head and the constant inventory producer by $12.55 per head on average (Hamilton & Kastens, 2000). As Griffith et al. (2017) illustrated, herd inventory maintenance might be preferred as it takes less prediction by the producer and full utilization of resources, therefore, promoting economies of scale.

As whole cowherd management is one part of herd management, producers must also know when to retain or replace individual cows as described in the upcoming Culling Strategy Inconsistencies and Cow Depreciation Reduction Consideration sections. The following section analyses several authors' models on individual female culling and replacement decisions that can aid producers in their female culling and replacement decisions.

2.2 Cow Depreciation Reduction Considerations

Individual cow depreciation is calculated by subtracting the female's salvage value from the initial purchase price or development costs (i.e. homegrown replacement) of the female and then dividing it by her productive years in the herd (Equation 1.1) (Berger, 2014). Within Berger's (2014) simple cow depreciation model, there are three main methods for reducing cow depreciation; (1) reducing replacement heifer development costs or purchase price for replacement heifers or cows, (2) increasing the salvage value of cows that are leaving the herd, and (3) increasing the number of years a cow is productive in the herd. Teichert (2020) and Hughes (2013) suggest that producers track replacement heifers in a separate enterprise to better evaluate their development costs. This separation can help producers confirm the costs of home-raised replacements and assess if retaining more opens or having a higher replacement rate is viable.

Pratt (2015) noted that making culling decisions requires skill; producers must judge their animals' conformation and predict the future success of the animal. Producers who intend to extend their female's productive years will have to develop skills and collect data (i.e., treatment records, calving ease, conformation issues, weights) to make an informed decision, select the most appropriate culls and ensure non-culls have the most productive years ahead.

Lower depreciation can be achieved by tracking cow depreciation, optimal marketing of cull cows, reducing costs of replacements, retaining young open females, or keeping productive females longer. However, it is unclear from the above research which of these strategies should be used in a specific production system. Producers have questioned how the cost of developing replacement heifers and the time it takes a cow to pay herself off play into this decision (Ferguson, 2021). Producers also need to consider trade-offs such as their herd's average age, weaning weight expectations, replacement and cull prices, variable costs, and the replacement rate required per year to maintain their preferred herd size. Along with reducing individual female depreciation, the producer must also factor in how the price cycles and cowherd inventory affect these decisions.

2.3 Replacement and Culling Decision Modelling

2.3.1 NPV Replacement Decision Modelling

When considering replacement decisions, an NPV analysis looks at the expected discounted cashflows of an individual female and a replacement female. A NPV should be positive to justify an investment in the asset and two assets NPV with the same timeline can be compared, with the higher NPV asset being a better investment. The calculated NPV values of the females are used to inform the producer regarding the decision to retain or replace an individual cow under a selected scenario.

Mathews and Short's (2001) analysis of beef cow replacement decisions examined the effect of critical assumptions such as genetic improvement in the herd and price cycles on a female's NPV. Within their model, females from a herd were considered to have varying productivity levels depending on their age and genetic factors. Females with superior genetic factors were recognized as advantageous assets in the herd (Mathews & Short, 2001).

Mathews and Short (2001) illustrate that producers have an objective function "to maximize the expected utility of wealth," which is a function of the "utility of wealth for the m^{th} producer and wealth is solely embodied in the cowherd" (p. 194). Here the authors assume that this is the utility function for all producers and that all producers are trying to maximize wealth, however, it may be that producers are trying to maximize something else. The authors evaluate the resulting NPV by altering key variables of the female's NPV under an array of assumptions. The NPV equation (Equation 2.1) represents the nth female at time t, that will be expected to produce calves for J periods in the future. The equation is made up of three parts; first, on the LHS, the "discounted net revenue from all the offspring bred female n will have in her remaining time t," minus the discounted costs of maintaining the cow and discount rate r (p. 196). On the RHS, "the discounted salvage value of the nth breeding female that remains in the herd J periods" and the final variable is "the costs of the nth female up through period just before she enters the herd" (known as the replacement cost or purchase price of the replacement heifer) (p. 196). The $NPV_{n,t}$ decreased with increases in cost and discount rate, and increases with increases in prices (Mathews & Short, 2001).

$$NPV_{n,J,t} = \sum_{j=1}^{J} \frac{\left(R_{n,t+j} - C_{n,t+j}\right)}{\prod_{h=0}^{J-1}(1 + r_{t+h})} + \frac{S_{n,t+J}}{\prod_{j=0}^{J-1}(1 + r_{t+j})} - S_{n,t-1} \tag{2.1}$$

Mathews and Short (2001) constructed several NPV matrices of the females' future production years varying from one to fourteen productive calving periods. Within the model, the authors used both actual prices from the year and cycle for simulated prices. The matrix dimensions were then the prices for the next fourteen years by the production years of the female, making the dimensions either 12 x 14 or 45 x 14 (Mathews & Short, 2001). Using the defined NPV equation (Equation 2.1), the elements from the matrix were calculated. Along with this, there were varying rates of replacement heifers retained for the herd. Heifers with a higher weaning weight are often considered to have greater genetic potential; therefore, it was a key component of the NPV matrices. Finally, through regression techniques, these matrices were summarized (Mathews & Short, 2001).

Mathews and Short (2001) found that females with fewer productive years left have higher NPVs across the two models. Additionally, retaining replacement heifers is beneficial when cow prices are low, and replacement heifers born with the highest weaning weights often have higher NPV than most cows in the herd. In this decision, producers are trading off short-term revenue for a potentially higher NPV of the female with superior genetics compared to older females being replaced. However, it may not be the best decision to sell cows and retain heifers every year due to less discounting implemented on older females than younger females. It was found that 50% of heifers are worth more at weaning than as a replacement (Mathews & Short, 2001).

Mathews and Short (2001) also found that it is more critical to keep females that weaned a calf over culling females that produced a light calf, as any calf will add value. When a female fails to wean a calf, there were few cases when the NPV was high enough to keep her. These cases included positive NPV generally for "10-year-old to 5-year-old cows during 1973, with the highest NPVs for cows with seven years of expected production left" (Mathews & Short, 2001, p. 202).

Ibendahl et al. (2004) used a deterministic and stochastic (with variability in the last 10 years of prices) NPV model to compare replacement decisions for open beef cows based on several factors, including age, calf weaning weights, cow and calf prices, variable costs, and fertility. The researchers calculated and compared the value of the open cow and replacement heifer in two separate sets of equations. Equation set one calculated the NPV of the retained open cow and the value of the replacement heifer. Equation set two placed the values of the females on a common time basis through a perpetual annuity calculation to be compared. Therefore, the value of selling all open cows regardless of age versus retaining open cows till they reach eleven years of age was compared for the decision model (Ibendahl et al., 2004).

When Ibendahl et al. (2004) valued the calf crop, the researchers considered breeding females' peak performance (age four to eleven); the authors estimated young cows (age two to four) that have not reached mature weight to generate lower calf revenues (4% per year) due to lower calf weaning weights. First calf heifers would generate $48 less (12%) calf revenue relative to a mature cow (age four to eleven). Varying calf revenues by cow age captured missed profits when producers replaced open cows in their prime production years with heifers (Ibendahl et al. 2004).

In a sensitivity analysis, Ibendahl et al. (2004) used estimated fertility probabilities based on data from Tronstad et al. (1993) – the probabilities were based on one Arizona operation with individual female records from 1982 to 1989 – to show that as an open cow's fertility decreases, the decision to retain is less optimal unless there are low variable costs of upkeep and a higher risk of first-calf heifers being open. Management decisions can impact fertility, for example, by feeding heifers separately, producers can ensure heifers can obtain their nutritional requirements to promote fertility (Dargatz, 1994). Within the 2014 Western Canadian Cow-Calf Survey (WCCCS), 83% of producers sorted breeding females for winter feeding based on age. This is a recommended practice to ensure younger cows do not get out-competed by older cows for feed Western Beef Development Centre, 2015; Government of Alberta, 2008, p. 128).

Ibendahl et al. (2004) also illustrated in their third sensitivity analysis (varying real discount rates from 4% to 10%) that higher discount rates make the NPV of open cows and replacement heifers similar, making the producer indifferent between retaining and replacing. The authors found that decreasing salvage values leads to a higher probability of producers retaining open cows. The NPV and sensitivity analysis when evaluating assets with different lifespans and a break within revenue due to open cows demonstrated the trade-offs of replacing open cows with a bred heifer versus retaining an open cow. Their results indicate that when feed costs are low, the price differential between cull cows and replacement heifers is high, or the calf crop value is low, retaining open cows can be more desirable, representing less than 15% of the scenarios analyzed (Ibendahl et al., 2004).

An NPV analysis by Meek et al. (1999) constructed a spreadsheet budget with varying revenue, costs, and performance of females ages one to fifteen. The authors found that females retain their highest residual value at four years old, similar to other researchers such as Ibendahl et al. (2004) and Thomas et al. (2021). Females between the ages of two and three typically have greater reproductive failure risk and greater costs, therefore, lowering their NPV (Meek et al., 1999).

In addition, through sensitivity analysis, Meek et al. (1999) adjusted production parameters by 1% to find factors influencing a female's NPV, and the difference in the NPV per cow over their lifetime is known as the shadow price. They found that increasing pregnancy rates resulted in a 1% decrease (14.7% to 13.7%) in open heifers sold. When looking at specific age groups, the shadow price for changing pregnancy rate by 1% is higher for a two-year-old bred heifer (Shadow price of $2.68) than a yearling heifer (Shadow price of $4.30). Through economic sensitivity analysis of production changes, producers can identify production levels that provide maximum return on their investment (Meek et al., 1999).

Boyer et al. (2020b) takes the NPV model a step further by using a hedonic pricing model to measure the impact of various production factors such as a female's pregnancy status and age on the sale prices of the female. The authors used data from heifer and cow sales in Tennessee from 2009 to 2018. The main data limitation was only using the November sale price, making it unable to model for sale price seasonality. The model found that sale prices were highest for four- and five-year-old females four to five months pregnant. Producers can increase the sale prices of their females by marketing five-year-old uniform lots that are four months pregnant. These females are often valued more due to the premium producers placed on bred females and the track record of mature cows weaning past calves. Producers who tolerate less risk may choose to purchase bred females relative to open females (Boyer et al., 2020b).

Using a financial model, Boyer et al. (2020b) created an NPV distribution of the replacement and culling of females of varying ages and pregnancy statuses. They found that the expected NPV was highest ($559/head) for purchased open heifers that were subsequently sold as pregnant nine-year-olds. In contrast, the expected NPV was lowest (-$567/head) when a producer bought a pregnant four-year-old and sold her a year later as an open female. As mentioned above, Berger (2014) suggested increasing cow salvage values to reduce cow depreciation. Boyer et al. (2020b) found that selling bred females when bought as bred females always resulted in a higher NPV; in addition, Boyer et al. (2020b) illustrated that a high NPV resulted from selling a five to nine-year-old bred female over an open twelve-year-old. The authors illustrated that a female overall would increase in price until five years old and then decrease in price as she ages, following a similar bell curve as Thomas et al. (2021) suggested. Ultimately producers can expect a higher NPV when selling bred females with a few more productive years left relative to selling the same female as a mature cull cow for slaughter. Boyer et al. (2020b) found that females take six to eight calves weaned to become profitable. Females lacking reproductive efficiency will often result in a negative NPV, taking away profit from the cowherd.

Regarding producer risk tolerance in choosing replacement and culling decisions, Boyer et al. (2020b) found that risk-averse producers prefer purchasing established females with past weaned calves and selling females at an earlier age of five. Therefore, future cashflows will be discounted less due to a shorter timeline when the cow assets are retained in the herd. Risk-neutral producers prefer purchasing open heifers and selling nine-year-old bred females, following a more extended cow turnaround period in their cowherd (Boyer et al., 2020b).

2.3.2 Markovian Culling Decision Analysis

Azzam et al. (1990) used Markov chain analysis to estimate the cow herd's age distribution at equilibrium (estimate age distribution of an efficient beef production system) and the average age of culled cows. By depicting the Markov chain as the culling procedure and using data from past literature, the authors gathered "age-specific probabilities for health and reproductive failure" and then used "these probabilities to obtain age distributions in herds under different culling strategies" (p. 5). The Transition Matrix P depicts the Culling strategy, with the elements (p_{ij}) describing the probability of a female to "be retained an additional year ($j = i + 1$) or be replaced by a one-year-old ($j = 1$) heifer" (p. 8). Two assumptions are maintained to ensure "all other elements of P are zero unless replacement animals of any ages are purchased" — one, no purchasing of replacement cows (non-heifers) and two, constant herd size (p. 8). Figure 2.2 depicts the transition matrix used by Azzam et al. (1990).

Figure 2.2. Female Age Distribution Estimate Transition Matrix

$$\mathbf{P} = \begin{bmatrix} .193 & .807 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .153 & 0 & .847 & 0 & 0 & 0 & 0 & 0 & 0 \\ .160 & 0 & 0 & .840 & 0 & 0 & 0 & 0 & 0 \\ .174 & 0 & 0 & 0 & .826 & 0 & 0 & 0 & 0 \\ .161 & 0 & 0 & 0 & 0 & .839 & 0 & 0 & 0 \\ .176 & 0 & 0 & 0 & 0 & 0 & .824 & 0 & 0 \\ .199 & 0 & 0 & 0 & 0 & 0 & 0 & .801 & 0 \\ .279 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & .721 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Source: (Azzam et al., 1990)

Azzam et al. (1990) described numerous culling strategies in their simulation, they included, culling at maximum age, culling based on health alone or health and female open in one year, or health and female open in two consecutive years. The authors then manipulated the transition matrix to match the simulated culling strategy. For example, when culling all females at a maximum age of eight there will be only seven rows and columns in P with p_{71} being one and all other elements in row seven equaling zero, illustrating the female at age eight is replaced by a heifer after being culled.

The following year Azzam & Azzam (1991) used Markovian decision analysis and linear programming to determine "optimal replacement policy (maximizing long-run average net returns) for a specific production environment" (p. 2329). The authors determined if the female should be replaced or retained through the female's age, reproductive status and pregnancy checking season (due to having a dual fall and spring calving season). The transition matrix P in this model represents the probability "that an animal in a certain state i (age x reproductive status x season combination) at time of pregnancy checking will be in state j next time she is checked for reproductive status (nonpregnant, pregnant, or physically unsound)" (p. 2332). Through linear programming the objective function was solved "for each decision made in each state". The authors found the culling policy that maximized the average net returns, in the long run, was culling all open females and having only a spring calving season (Azzam & Azzam, 1991).

2.3.3 System Dynamics Model

Turner et al. (2013) used a system dynamics approach and a larger farm data set (i.e. from Texas A & M University King Farm Institute for Farm Management) from 1996 to 2007 to inform and create a cow-calf model to provide a framework for understanding profitability dynamics in farming. The authors used a simulation model to evaluate the cow-calf farm's net income and return on investment under various marketing scenarios (i.e., 10%, 20% and 30% of cows sold).

Turner et al. (2013) model found that an increased culling rate increased the net income and return on investment of the farm with the three culling levels of high (30%), medium (20%), and low (10%) of the cowherd. As culling rates increased, revenues increased due to increasing cull prices over the period in the model, while costs associated with the herd decreased, therefore increasing the net income of the farm. By selling bred cow's the managers were also able to gain premiums. Within the model, management was rewarded based on net income leading up to 32% of older females being sold as bred females each year (Turner, et al., 2013).

It has been illustrated that culling impacts the overall farm's profitability in the short term. However, it is not revealed in Turner et al. (2013) how increased culling rates affect the productivity and financial success of the cowherd. Turner et al. (2013) described that keeping mature cows leads to advantages such as a heavier weaning weight to generate greater revenue per cow, but a mature female will often fully depreciate not allowing producers to gain higher salvage value (Goehring et al., 1991). Alternately culling a higher rate of mature-bred females could help producers gain premiums on their salvage value during rising markets. These strategies will impact the cowherd's average age, possibly impacting the average pounds weaned. Within Turner et al.'s

(2013) simulation study, it is unclear which strategy leaves producers with higher net income and returns on their investment for the farm.

2.4 Optimal Replacement and Culling Strategies

Through the use of NPV, Markovian analysis and system dynamics modelling, culling and replacement decisions of individuals can be applied to the whole herd for decision analysis. In addition to these models, authors have also analyzed other optimal culling and replacement decisions including age of culling, calving period restriction culling, and culling and replacement based on genetic improvement, all of which are discussed in the following section.

2.4.1 Culling age

Sessim et al. (2020) investigated the optimal culling age for both biological and economic efficiency. Biological efficiency was defined as the "ratio between the production of total live weight and the metabolizable energy consumed over one production cycle" (p. 1). Economic efficiency was defined as "the ratio between gross margin and production area and the ratio between gross margin and number of cows" (p. 1). Finally, bioeconomic efficiency was determined "by a simple linear regression between biological efficiency, economic efficiency per area, and economic efficiency per cow" (Sessim et al., 2020, p. 1).

Sessim et al. (2020) used a dynamic model to compare the bioeconomic efficiency of different cow-calf systems. The cow-calf systems were built from ten cow herds of one thousand head by varying the maximum ages of culling cut-offs ranging from four to thirteen years old, the herd's composition, the number of retained heifers, and the number of weaned calves. The ten herds otherwise had consistent parameters such as the body condition score, mineral and salt offering and vaccination program (Sessim et al., 2020).

In addition, Sessim et al. (2020) described that all opens or females who failed to wean a calf were culled. Heifer replacements were homegrown with no purchased replacements. Sessim et al. (2020) retained the heaviest weaned heifers due to often having an earlier calving date leading to earlier maturity than later-calved heifers. To maintain the herd size, the culling age was a minimum of four to ensure no gradual reduction of the cowherd inventory. The authors described a three-year-old culling; the heifer replacement rate would need to be 52% which is unachievable through non-sexed artificial insemination. The results also illustrated that the replacement rate was higher as the culling age was reduced (Sessim et al., 2020).

Sessim et al. (2020) found in the herd structure sub-model that a higher culling age resulted in higher weaning weight and weaning rate. In contrast, younger culling herds had greater production per animal as more younger females were sold. In the economic sub-model, the lower the maximum culling age, the “higher was the total revenue (TR) of the cow-calf system” (p. 7). However, the cost increased as the maximum culling age was lowered as it often takes more feed to grow young cows who have not reached their mature weight and are lactating. The authors then concluded that an older maximum culling age is more economically efficient. The optimal culling age varies for biological and economic efficiency, with a culling age of four years old and thirteen years old, respectively. Five and a half years old was the maximum culling age that balanced the biological and economic efficiency. Overall, producers with difficulty intensifying feed resources should retain an older maximum culling age due to less nutritional requirements than growing females. In contrast, producers with the opportunity to intensify production should maintain a younger maximum culling age due to younger cows achieving greater productivity (Sessim et al., 2020).

2.4.2 Calving Period and Feeding Program

Frasier and Pfeiffer (1994) used farm data from the Nebraska Sandhills to determine beef herds' optimal replacement management policies using Markovian decision analysis to "reflect the interaction between herd management and culling decisions" (Frasier & Pfeiffer, 1994, p. 1). Within the model, the "expected net return and the probability of transition between states were determined for each state/decision combination" (p. 850). The cows were evaluated with varying body conditions, ages, calving periods, and feeding programs (Frasier & Pfeiffer, 1994).

Frasier and Pfeiffer (1994) found that the ideal management strategy was to optimize feeding for females to maintain an adequate body condition and decrease the calving period length. By having a calving period length criterion, a producer can have a more consistent group of weaned calves to sell, possibly earning premiums. Culling females on the same nutrition plan as the cowherd but failing to calve during the designated period can help producers improve their herd's reproductive characteristics and save resources such as labour during a shortened calving season. These results focused on the cowherd's management and considered the biological relationship between nutrition and performance compared to other studies focusing on cost minimization (Frasier & Pfeiffer, 1994).

2.4.3 Genetic Improvement

Melton (1980) investigated the genetic progress of a cowherd when making culling and replacement decisions. Producers can choose to keep home-raised replacements from the herd or purchase replacements. Purchased replacements have the added benefit of new genetics compared to home-raised replacements that can maintain a cowherd's biosecurity. Often a producer puts a greater value on sire selection and purchasing, but proper cow selection is needed to gain the genetic superiority the bull has to offer. Cows with superior genetics will often be retained in the herd longer, as the author shows these females will have an older optimal replacement age. This is often seen in many established purebred seedstock producers' cow herds (Melton, 1980).

Melton (1980) shows that with no genetic progress, the average age to cull a female is eleven years, where the producer receives an economic benefit from culling at a later age. When genetic progress exists, the culling age is lowered to eight. Superior cows generate $3.24 in additional residual earnings per year compared to the average cow. The author then shows that improvements in genetics should be considered when replacing and culling females (Melton, 1980).

2.5 Culling Strategy Inconsistencies

Within the cow-calf industry, many operations vary in herd size, feed availability, climate, and management practices. Due to the heterogeneity among operations producers often follow different management practices such as culling and replacement strategies to optimize their herd production goals including but not limited to improved genetics, increased weaning weight per female exposed, or calf crop consistency.

McDermott et al. (1992) evaluated the distribution of herd culling rates for 180 Ontario commercial cow-calf herds, with 123 of the herds maintaining individual animal records. They found that culling decisions partly depended on the herd the individual animal belonged to, illustrating that producers have differing preferences for retaining and culling their females, including the decision to cull open females. The authors did not find an apparent reason for the difference in management (McDermott et al., 1992).

Waldner et al. (2009) found that culling odds were greater for females over ten years of age in western Canada. The researchers found that producers culled based on pregnancy status, body condition score, and replacement costs with an optimal age of seven to eight, as cows older than ten years old would likely die on the farm (Waldner et al., 2009).

One of the main strategies researched, and not consistent among producers is culling or retaining open females. Pearson et al. (2019) surveyed ninety-seven cow-calf farms through the Western Canadian Cow-Calf Surveillance Network and found that only 4.2% of producers were unlikely to cull due to a cow being open. A female is most likely to not conceive after having her first calf because she is still growing while raising a calf and being expected to conceive her second calf (Boyle et al., 2020a; Roberts et al., 2015). Through a simulation model, Boyle et al. (2020a) found that retaining an open female is often unprofitable, and producers are better off selling the open rather than rebreeding. Similarly, Mathews and Short (2001) illustrated that a rancher who retained a female who is open one year of her production lifetime, regardless, of age would likely not recover the reduction in NPV compared to a replacement. In contrast, Ibendahl et al. (2004) suggested that retaining opens is preferred to developing replacement heifers if feed costs are low; otherwise, selling the open female is preferred.

Although there are some general agreements on culling decisions, there still is a lack of consistency across farms. Given this lack of consensus, there is a need for culling strategies to be analyzed for Canadian producers. Instead of a single rule of thumb, it may be that different optimal strategies exist due to each operation having unique challenges and advantages, such as production costs and herd productivity, differing in the culling and retention decisions of the cowherd.

With the complex cycle of cow depreciation and valuation, researchers have outlined several strategies to reduce cow depreciation (Berger, 2014; Teichert, 2020). These culling strategies include but are not limited to culling opens or culling once a mature cow reaches a specific age, such as five and a half (Hersom et al., 2018; Sessim et al., 2020).

2.6 Chapter Summary

From the literature, it is known that biological asset management is a complicated and impactful decision for the producer's future success and profitability of the herd. Many producers prefer using different strategies, and there is a lack of consistency across operations. This can be mainly because operations are unique in their resources and goals.

In addition, the cattle cycle and risk tolerance of the producers will impact herd inventory management, such as expansion and contraction of the cowherd. Producers with a strong desire to develop genetics and sell seedstock or who want to utilize resources such as grazing acres optimally may choose to maintain their herd inventory. Maintaining inventory can allow producers to have a steady cash flow and capitalize on higher prices without biological lags. More risk-averse producers may choose to follow a countercyclical cycle where producers make the opposing herd inventory alterations compared to the national aggregate herd level. When estimating the producer strategies, the countercyclical cycle was the best performing in terms of net returns (Hamilton & Kastens, 2000).

Three culling strategies were investigated within the literature: culling age, calving period, and genetic improvement. Sessim et al. (2020) found that five and a half years old was the culling age that balanced the biological and economic efficiency. Frasier and Pfeiffer (1994) found that optimizing feeding for females to maintain an adequate body condition and decrease the calving period was the ideal management strategy. Finally, Melton (1980) showed that improvements in genetics should be considered when replacing and culling females using individual female herd data from a Florida beef herd. These authors have shown that there are many considerations for producers to achieve their optimal culling strategy; it depends on the goals of their cowherd, available resources, and the market.

How to evaluate a breeding female's NPV and how the types of management practices such as culling strategies impact replacement decisions are reviewed extensively using the work of Ibendahl et al.(2004), Mathews and Short (2001), Meek et al. (1999), and Boyer et al. (2020b). However, a more recent and Canadian-based valuation has not been done. Using an adaptation of these authors' NPV valuation and a whole herd simulation model, the proposed research will fill this knowledge gap by comparing different culling strategies' impact on farm financials using Canadian production and financial data.

Chapter 3 –
Data and Methods
3.1 Introduction

Ibendahl et al.'s (2004) NPV valuation model can help us understand and evaluate an individual female's NPV during various stages of her life for Canadian cow-calf herds with variations in production costs and herd productivity. This will help initially determine the NPV of different culling strategies. Through the analysis of trends such as lower calf weaning weights in the cow's first three years of production described in Ibendahl et al.'s (2004) paper, a realistic NPV evaluation for females at varying ages can be better estimated. Data from the CDN COP Network's 'typical farms' can be included in the model to expand the analysis.

In this analysis, I use a deterministic model for a capital investment analysis and will evaluate the different culling strategies outlined later in Table 3.6 across typical operations found by the CDN COP Network. I expect subnormal cash flows and depreciation when analyzing breeding female assets, further complicating these models (Thomas et al., 2021). The capital investment analysis will evaluate the different culling strategies' impact on a farm's cowherd valuation and the cow-calf enterprise's profitability.

3.2 Data Source

This thesis is conducted in partnership with the CDN COP Network to determine financially optimal culling strategies for Canadian cow-calf producers. The primary data source for the model will be the Canadian COP network data managed by CanFax Research Services.

Following the Agri Benchmark methodology, the network generates benchmarks for 'typical farms' (Chibanda, et al., 2020; Canadian Cow-Calf Cost of Production Network, 2021b). Each 'typical farm' is based on actual data provided by three to five operations who share similarities in types of enterprises and profit centres, calving dates, winter feeding strategies, and ecoregions, hence there is variation in productivity (i.e. herd size, feeding methods, wean weights, conception rates, calving rate, death loss) and financials (i.e. feed production costs, prices paid for breeding stock, market prices received, debt, equity, asset base). To date, CanFax has generated 49 'typical farm' benchmarks. Various operation types allow for the analysis of culling and replacement strategies for different types of cow-calf operations across Canada.

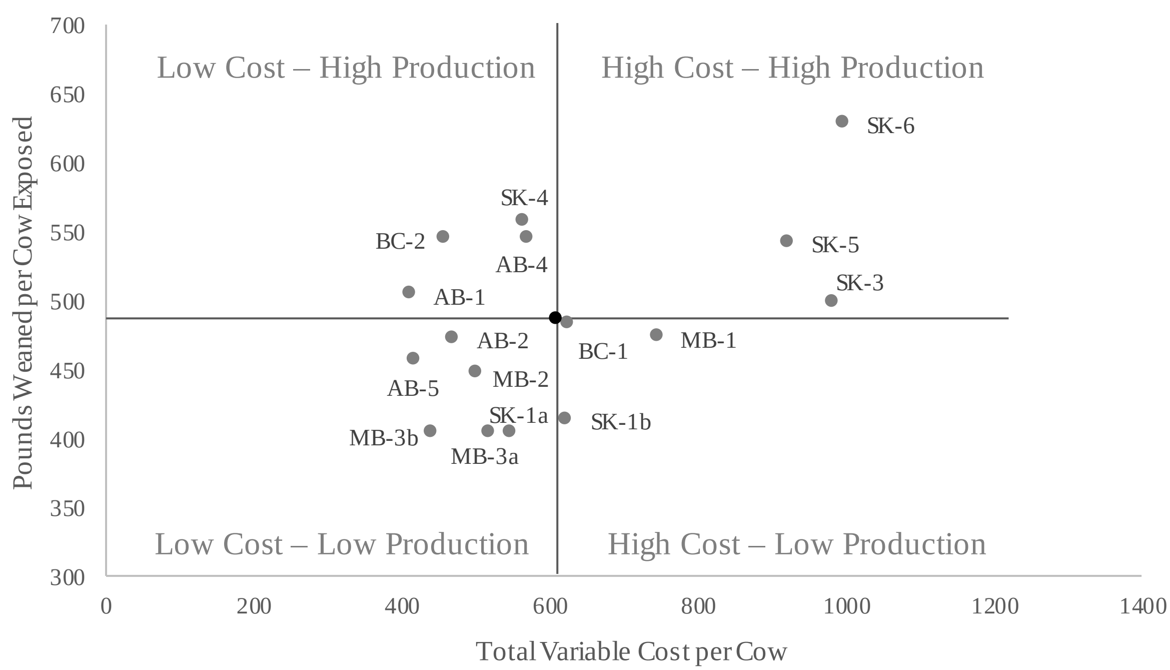
The network only collects herd-level productivity measures; therefore, there are several data limitations, such as the distribution of culling age, open rates, or weaning weight by female age. Therefore, I had to extrapolate how these values change as a female ages. One example of this approximation made in the given CDN COP data is the calculation of grazing costs when developing replacement heifers. The mature cow weight was multiplied by 0.65 as heifers have been shown to weigh 65% of their mature cow weight at puberty and exposure to first breeding (Selk, 2023). To calculate the heifer animal units (AU), I use Equation 3.1 and then divide the heifer weight calculated by one thousand. To find the heifer grazing costs per head Equation 3.2 is followed.

$$AU_{Heifer} = \frac{mature\ cow\ weight\ \times 0.65}{1000} \tag{3.1}$$

$$Grazing\ Costs\ per\ Heifer = \frac{AU_{Heifer} \times days\ on\ pasture}{AU\ days\ per\ acre} \times rental\ cost\ per\ acre\ of\ grassland \tag{3.2}$$

Sixteen of the 18 western Canadian (British Columbia, Alberta, Saskatchewan, and Manitoba) 'typical farms' from the 2021 CDN COP Network cohort will be used to evaluate culling and replacement strategies. Two 'typical farms' were excluded due to missing data needed to calculate breeding and grazing costs. Figure 3.1 is a scatter plot of the variable costs per cow and pounds weaned per cow exposed for the 16 'typical farms.' I use the average values ($610, 487 lb) to separate the 'typical farms' into four quadrants. The costs and production values for the 'typical farms' lying within each quadrant will be averaged to generate four aggregated farms with combinations of high and low costs and production. Creating the quadrants from the pounds weaned per cow exposed and the total variable costs enabled me to capture the two main variables (calf revenue and production costs) affecting the cash flows of the breeding female which will be the focus of the thesis analysis.

Figure 3.1. Scatter Plot of 16 CDN COP Network 'Typical Farms'



The cost and production values for the four farms in the top left quadrant of Figure 3.1 (BC-2, AB-1, AB-4, and SK-4) were the average of the four low-cost and high production (LC-HP) farms in this quadrant. Similarly, values for the three farms in the top right quadrant (SK-3, SK-5, SK-6) were the average of the three high cost and high production (HC-HP) farms in this quadrant. The average cost and production values for the six farms (AB-2, AB-5, SK-1a, MB-2, MB-3a, and MB-3b) in the bottom left quadrant reflect the average of the six low-cost and low production (LC-LP) farms in this quadrant. The average cost and production values for three farms (BC-1, MB-1 and SK-1b) in the bottom right quadrant make up the average of the three high cost and high production (HC-HP) farms in this quadrant. The aggregated values are shown in Table 3.1.1 The specific 'Typical Farm' values can be found in Appendix A.

Table 3.1. Aggregated Values from 'Typical Farms'

	HC-HP	HC-LP	LC-HP	LC-LP
Costs of Production, $/Cow/yr				
Purchased bred Heifer	$1,978.44	$1,978.44	$1,978.44	$1,978.44
Heifer Development Cost	$2,099.03	$1,515.41	$1,617.78 [a]	$1,412.55
Winter Feed Cost	$156.64	$257.10	$146.30	$212.41
Grazing Cost	$326.75	$118.37	$75.63	$70.25
Breeding Cost	$40.42	$33.39	$35.30	$30.24
Other Variable Costs [b]	$481.50	$287.31	$277.49	$197.63
Total Variable Costs	$1005.31	$696.17	$534.72	$510.53
Unpaid Labour	$236.48	$185.95	$269.25	$134.40
Production Parameters				
Weaning Weight	625 lb	537 lb	602 lb	490 lb
Wean Calf Price ($/lb)	$1.99	$2.08	$1.99	$2.26
Cull Cow Weight	1423 lb	1262 lb	1351 lb	1313 lb
Cull Cow Price ($/lb)	$0.81	$0.81	$0.81	$0.81
Capital Structure				
Assets Per Cow ($/Cow) [c]	$17,270.21	$21,008.32	$11,227.13	$28,726.58
Interest Per Cow ($/Cow) [d]	$138.71	$27.21	$71.36	$36.84
WACC [e]	7.47%	7.36%	7.33%	7.36%

[a] The higher heifer development costs for LC-HP relative to HC-LP is due to the LC-HP farm producing heifer feeder calves, therefore raising the opportunity costs for the retained replacement heifer calf. See Table 3.2 for further explanation on the retained replacement heifer calf opportunity cost.
[b] Other variable costs include machinery maintenance and spare parts, water, electricity, fuel, RFID and management tags, veterinary service, medical products, growth hormones, bedding, sales commission, check-off taken at sale, brand inspection, fees for pedigree records, insurance, contract labour, paid labour, and advisor, accountant and legal costs.
[c] Assets per cow was calculated by multiplying total assets by the percent of whole-farm revenue from the cow-calf enterprise divided by the 'typical farms' herd size
[d] Interest per cow was calculated by multiplying total interest on debt by the percent of whole-farm revenue from the cow-calf enterprise divided by the 'typical farms' herd size (see appendix A for 'typical farm' herd sizes)
[e] weighted average cost of capital (WACC)

The heifer development costs were calculated using the same methodology as the replacement heifer calculator by the Western Beef Development Center (2012). To calculate the heifer development costs I consider the opportunity costs of the foregone revenue from choosing to keep the heifer at weaning rather than sell her into the feeder market. Costs for winter feeding, grazing (using Equations 3.1 and 3.2), breeding (from Table 3.1), and total variable costs (from Table 3.1) are included in the heifer development costs from when the heifer is weaned in the fall until she is confirmed pregnant with her first calf the following fall. The development costs are divided by the conception rate so that the bred heifers bear the cost for the heifers that did not conceive. The market value for the open heifers[10] (weight x market price) is then deducted from the development costs. Table 3.2 illustrates the equations used to calculate the heifer development costs reported within Table 3.1.

Table 3.2. Heifer Development Cost Calculation

Variable	Equation
Heifer Opportunity Cost	= average heifer wean weight × average heifer feeder price
Heifer Development Costs Not Adjusted for Conception	= heifer opportunity cost [a] + heifer winter feed cost + heifer grazing cost + total variable costs + breeding costs
Heifer Development Costs Adjusted for Conception	= (heifer development costs [b]) / (conception rate [c])
Open Rate	= 1- conception rate
Credit from Sale of Opens	= ((open rate × number of heifers [d]) × (cull heifer market value [e] × cull heifer weight [f])) / (conception rate × number of heifers)
Development Heifer Costs	= heifer development costs adjusted for conception - credit from sale of opens

[a] The heifer opportunity cost is based on the market value had the heifer need sold as a feeder, however, heifers selected for replacement are of higher quality and therefore may have sold at a premium to the feeder price.
[b] Heifer development costs include heifer winter feed (see Appendix A), heifer adjusted grazing (see Appendix A) and total variable costs.
[c] Conception rate is equal to the calves alive after 24 hours of birth per 100 exposed (see Appendix A). This was used because pregnancy rates were not collected in the CDN COP Network data.
[d] Number of heifers was calculated by multiplying the heifer retention rate (see Appendix A) by the herd size of the 'typical farm' (see Appendix A).
[e] Price per pound for cull heifers 12 to 24 months old (see Appendix A).
[f] Weight for cull heifers 12 to 24 months old (see Appendix A).

[10] The Alberta 'typical farms did not provide heifer weight and prices for open cull heifers 12 to 24 months old. The 12-to-24-month old cull heifer weight was estimated as 85% of the cull cow weight and the >24 month old cull heifer price per pound was used.

The purchased bred heifer price[11] ($1978/head) is the five-year (2018-2022) average price for bred heifers in Alberta as reported by Canfax (unpublished data). The total assets per cow were calculated as the total assets for the operation multiplied by the percent of whole-farm revenue generated by the cow-calf enterprise and then divided by the herd size. The weaned calf price[12] was estimated using CanFax's (unpublished data) five-year (2018 to 2022) average prices in October and November for different weight classes of feeder steers and heifers. It was important to use prices from different weight classes because feeder prices fluctuate with the weight of the calf; lighter calves tend to sell for a higher price per pound relative to heavier calves. In addition, the cull cow prices[13] were sourced from CanFax (unpublished data) D1-D2 five-year (2018 to 2022) average from the average monthly (September, October, November and December) prices given for Alberta. The prices from the months of September, October, November and December were chosen as this is after cows wean their calves and when they are pregnancy checked before being sold if found open.

The low-cost (LC) operations have several advantages such as reduced winter feed costs from homegrown hay, in addition to a smaller amount of purchased feed supplements such as minerals, pellets and salt blocks. For grazing costs, the higher amount of animal unit days per acre and lower pasture rental rates contribute to lower costs. Low breeding costs are a result of a lower bull culling rate and a lower purchase price for breeding bulls. Alternatively, high cost (HC) farms often rely on purchased hay for winter feed, leading to costs being relatively higher compared to homegrown feed. The HC farms had fewer animal unit days per acre and rented a larger portion of their grazing acres, therefore, grazing costs are higher. The breeding bull purchase costs were

[11] Data provided by CanFax Monthly Alberta Bred Heifer Prices from 2012 to 2022.
[12] Data provided by CanFax Weekly Alberta and Saskatchewan Feeder Prices from 2018 to 2023.
[13] Data provided by CanFax Monthly D1-D2 and D3 Alberta Cow Prices from 2018 to 2022.

higher raising the breeding costs. Finally, the HC farms have higher costs towards outsourced paid labour compared to the LC farms that rely mainly on family labour.

3.2.2 Calf Wean Weight Adjustments by Cow Age

Only the average wean weight for steers and heifers was collected for the CDN COP Network. Due to this limitation, animal science research will be used to adjust average weaning weights to wean weight by cow age in order to calculate a female's estimated discounted cashflows by cow age (Rumpf & Van Vleck, 2004). Average wean weights will be used to create wean weight by dam age. Gould (2015) states that a two-year-old female's calf weaning weight is sixty pounds less than a mature cow's calf. The Beef Improvement Federation (BIF) has standard age-of-dam adjustment factors for birth and wean weights (Beef Improvement Federation, 2002). Average wean weight from CDN COP Network data between steers and heifers will be assumed as the weights from five- to ten-year-old dams. Table 3.3 shows the weaning weight adjustments in pounds by age of the dam and sex of the calf. The model does not discern between steer and heifer calves so steer and heifer adjustment factors are averaged and the average value is used to adjust the average wean weight. For example, the weaning weight for a calf born from a two-year-old dam will be determined by subtracting 57 lb from the average wean weight.

Table 3.3. Calf Weaning Weight Adjustment by Cow Age

Age of dam (years)	Steer	Heifer	Average
2	60.0	54.0	57.0
3	39.9	35.9	37.9
4	20.1	18.1	19.1
5 - 10	0.0	0.0	0.0
≥11	20.1	18.1	19.1

Data from this table is adapted from (Beef Improvement Federation, 2002)

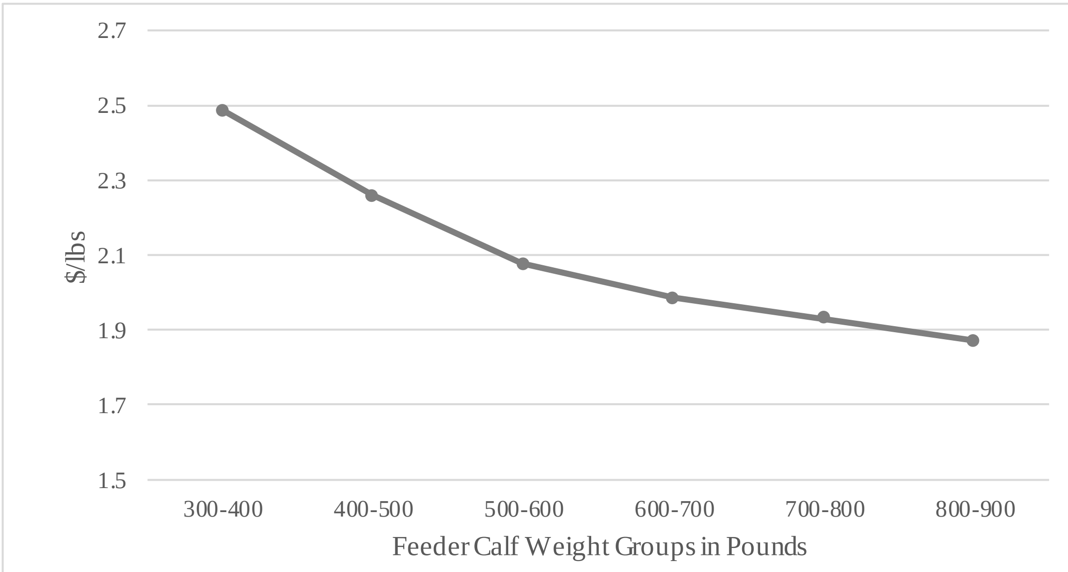
3.2.3 Calf Price Slide

As the weight of feeder cattle increases, the price per unit ($ per cwt) decreases. For example, the five-year (2018-2022) average October and November price for 450 lb feeders from Saskatchewan and Alberta was $225.87 per cwt[14] while the average price for 550 lb feeders was $207.73 per cwt[15], a difference of $18.14 per cwt (CanFax, unpublished data) (Figure 3.2). The October and November months were chosen as these are the common months' spring calving herds sell weaned calves. The adjustment in price as animal weight changes is commonly referred to as the "price slide" (Government of Alberta, 2023). Lighter calves tend to have a higher selling price per pound relative to heavier calves (Ritten et al., 2018). The price slide will be used to adjust the market value for weaned calves in the model.

Using the five-year October and November Saskatchewan and Alberta average prices between steers and heifers reported from CanFax (unpublished data) (Figure 3.2). As seen in Figure 3.2 as calves weigh more at weaning their price per pound decreases and the difference between prices decrease as calves enter heavier wean weight categories. The price spread between each one-hundred-pound weight class is shown in Table 3.4.

[14] Data provided by CanFax Weekly Alberta and Saskatchewan Feeder Prices from 2018 to 2023.
[15] Data provided by CanFax Weekly Alberta and Saskatchewan Feeder Prices from 2018 to 2023.

Figure 3.2. Average Western Canada Feeder Calf Prices from 2018 to 2022



Data from this table is from CanFax (unpublished data) Weekly Alberta and Saskatchewan Feeder Prices from 2018 to 2023

Table 3.4. Price Slide for Feeder Calves in Western Canada

Weight	Price ($/lb)	Price Slide ($/lb)[a]
350	2.49	
450	2.26	-0.23
550	2.08	-0.18
650	1.99	-0.09
750	1.93	-0.05

Data from this table is from CanFax (unpublished data) Weekly Alberta and Saskatchewan Feeder Prices from 2018 to 2023
[a] Price slide equals 100 lb weight feeder price – 100 lb weight lighter feeder price (ex. price slide from 350 lb to 450 lb calf is $2.26 - 2.49 = -0.23$)

I used Equation 3.3 to find the price adjustment for a calf. I take the price slide per pound from Table 3.4 and the average weaning weight adjustment from Table 3.3. For example, a calf from a two-year-old first-calving heifer will weigh 57 lb lighter. If the calf weighed 400 lbs the market price will be \$0.13 per lb $((57/100) \times 0.23)$ higher than a weaned calf from a mature cow (aged 5-10) of the same hundred-pound weight class.

$$Calf\ Price\ per\ pound\ Adjustment = \left(\frac{Average\ Weaning\ Weight\ Adjustment}{100}\right) \times Price\ Slide \quad (3.3)$$

Using these adjustments on the given weaning weights and prices slides will help analyze the effect of the dam's age on discounted cashflows – specifically the differences in productivity (wean weight) and resulting calf revenues – at different stages of the female's productive life.

3.2.4 Cull Cow Price Slide

The letter grades D1 to D4 are used to grade cull cows in Canada (Beef Cattle Research Council, 2023; King's Printer for Ontario, 2022). As a cow ages, changes in fat colour, fat abundance and muscling change the grade and price received. Grade D1 is reserved for cows with excellent muscling, and firm white or amber-coloured backfat less than 15 mm in thickness. Grade D3 is for cows with deficient muscling with less than 15 mm of backfat. To account for cow grade deterioration as cows age, the cull price of the cow's later stages of production is adjusted.

The difference between monthly prices for D1-D2 and D3 cows in Alberta as reported by CanFax (unpublished data) was used to estimate a price adjustment for cows over age nine in the model (Table 3.5). The assumption made for the analysis is cows aged nine and older will be valued eleven cents below the per pound cow cull price (\$0.81 - \$0.11 = \$0.70 per lb).

Table 3.5. Alberta Monthly D3 to D1-D2 Price Differences

	Year					
	2018	2019	2020	2021	2022	Monthly Average
Sep	-0.10	-0.10	-0.09	-0.09	-0.14	-0.10
Oct	-0.11	-0.11	-0.10	-0.10	-0.13	-0.11
Nov	-0.10	-0.10	-0.11	-0.09	-0.12	-0.10
Dec	-0.10	-0.11	-0.11	-0.10	-0.12	-0.11
				Five-year average		-0.11

Data from this table is from CanFax (unpublished data) Monthly D1-D2 and D3 Alberta Cow Prices from 2018 to 2022.
Note: These are the rounded prices to the nearest cent

3.3 Culling Strategies

The base and three alternative culling strategies outlined in Table 3.6 will be analyzed. In the base scenario and Scenarios 1 and 2, I assume cows are sold at age 11, and under Scenario 3, I assume cows are sold at age 8[16]. The base case will reflect no difference in the cash flow of cattle by age, using the given average value provided by the COP Network, while the three alternative scenarios will vary production and cash flow by cow age.

[16] Females in Scenario 3 are assumed to be sold at the given cull D1-D2 price (shown in Table 1) this will contrast the D3 price given to cows aged 9 and older.
I do not the data for bred 8-year-old cow prices and this would be a complex addition to my models to estimate which of the eight-year-old cows are bred. However, show by Boyer Griffith and DeLong (2020) and Turner et al. (2013) selling bred females can increase the selling price and I would expect giving bred eight-year-olds leaving the herd a higher price would increase the profitability of the farm.

Table 3.6. Culling and Replacement Strategy Models

Model name	Culling Strategy description	Assumptions
Base	Cull for fertility issues including open, abortion, and no calf weaned. Cows can also leave the herd due to death with no salvage value generated.	No Production and price differences by cow age Home-raised Replacements
Scenario 1	Cull for fertility issues including open, abortion, and no calf weaned. Cull cows aged 11 after the calving cycle. Cows can also leave the herd due to death with no salvage value generated.	Production and price differences by cow age Home-raised bred Replacements
Scenario 2	Cull for fertility issues including open, abortion, and no calf weaned. Hard cull cows aged 11 after the calving cycle. Cows can also leave the herd due to death with no salvage value generated.	Production and price differences by cow age Purchased bred Replacements
Scenario 3	Cull for fertility issues including open, abortion, and no calf weaned. Cull cows aged 8 after the calving cycle. Cows can also leave the herd due to death with no salvage value generated.	Production and price differences by cow age Home-raised bred Replacements

Scenario 1 reflects a common strategy of culling all breeding females with fertility problems and replacing them with home-raised replacements. This scenario is often more optimal for low-cost operations as home-raised replacements will be cheaper than purchasing bred heifers as in Scenario 2. Scenario 3 is similar to Scenario 1, but cows are sold at age eight (regardless of pregnancy diagnosis) instead of age eleven. This may reflect a farm with a lower cattle longevity or producers culling earlier to obtain a higher salvage value for their cow assets.

3.4 Chapter Summary

Using the CDN COP Network data, 16 of the western Canadian 'typical farms' cost and production values from the same quadrant were averaged, these values will be used for both the EAA ad ROA analysis. The CDN COP data used within this thesis has several limitations due to being average aggregated data from multiple cow-calf operations. Due to these limitations, several assumptions had to be made. These assumptions include generating calf weaning weights by dam age using BIF (2002) age adjustment factors, applying a calf price slide to reflect the price adjustment when weaning weights adjust, and a cull cow price slide for cows aged nine or older. These adjustments allow cash flows by cow age to be adjusted to reflect differences in productivity and market price affecting the female assets.

Finally, four strategies were outlined with one base model using the average data (no adjustments for dam age) and the three scenarios incorporating price and weight variations as the dam ages using the assumptions described above. By using the dam age adjusted production and cost values we can better estimate the expected future cashflows for each female asset within the individual NPV and enterprise profitability models to determine optimal culling and replacement decisions for varying cow-calf operations.

Chapter 4 –

Methodology

4.1 Individual Cow NPV Decision Model

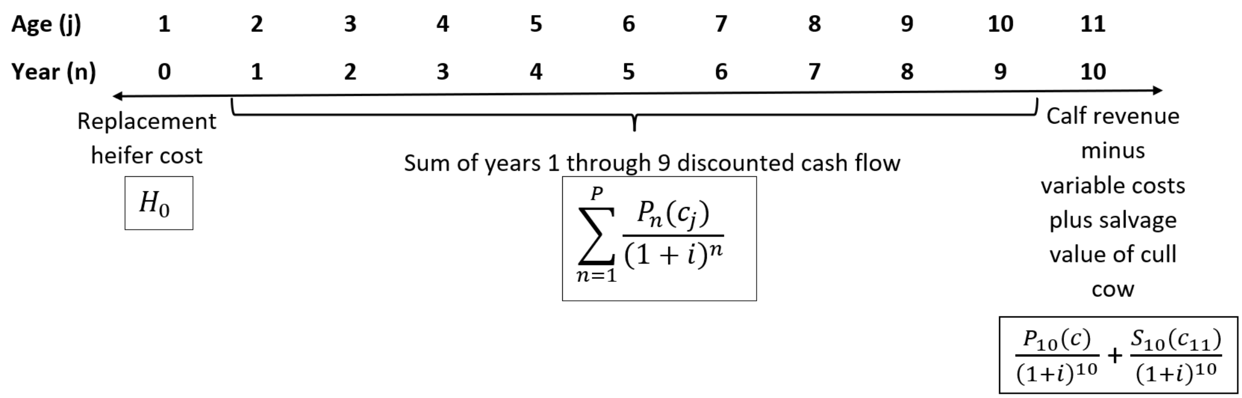
Within a cowherd, the NPV of the individual females can be calculated using Equation 4.1, which has been adapted from Ibendahl et al. (2004).

$$NPV(cow) = -H_0 + \sum_{n=1}^{P} \frac{P_n(c_j)}{(1+i)^n} + \frac{S_n(c_j)}{(1+i)^n} \tag{4.1}$$

In Equation 4.1, $NPV\,(cow)$ represents the net present value of the cow. The initial purchase or development cost of the bred heifer is denoted by H_0. P represents the total productive years of the cow. $P_n(c_j)$ is the net payment received in year n from the cow at age j and further broken down into the revenue minus the variable costs ($rev(c_j)) - (vc(c_j))$ for the cow at age j. The discount rate is represented by i and $S_n(c)$ denotes the salvage value received in year n for the cow age j when sold.

Within a cow's lifespan, she is predicted to have as many calves as her productive years (P). Figure 4.1 represents the discounted cashflows of a cow till age eleven, producing a calf each of her ten productive years. Ranchers will not receive any revenues tied to a particular animal till the females are half age. For example, a first calf heifer will not earn revenue till age two and a half when the calf is weaned and sold.

Figure 4.1. Timeline of Cow's Predicted Cashflows



Unfortunately, Figure 4.1's depiction is not always an accurate representation of the cow's cashflows due to the producer's non-perfect knowledge of their female's future productivity. To reflect a more accurate valuation based on the probability of varying scenarios for the breeding female asset Equation (4.2.2 below is used and represents the adjusted NPV calculation when a cow is retained (Option 1).

4.1.1 Probability Weighted Scenario

The Weighted NPV allows for multiple cashflow scenarios for a single asset (Davies, Goedhart, & Koller, 2012). As noted above, like many biological assets, cows are unpredictable assets that can follow any one of multiple cash flow streams. Equation 4.2 below illustrates varying probabilities of each scenario multiplied by its corresponding cash flow stream for a retained open cow.

$$NPV(retain\ open\ cow) =$$

$$prob(weaned\ calf) \times \left(\sum_{n=1}^{P} \frac{-RI - \left(vc\left(c_j\right)\right)}{(1+i)^0} + \frac{P_n\left(c_j\right)}{(1+i)^{n-on}} + \frac{S_n\left(c_j\right)}{(1+i)^{n-on}} \right) +$$
$$prob(open) \times \left(\sum_{n=1}^{P} \frac{-RI - \left(vc\left(c_j\right)\right)}{(1+i)^0} + \frac{-\left(vc\left(c_j\right)\right)}{(1+i)^1} + \frac{P_n\left(c_j\right)}{(1+i)^{n-on}} + \frac{S_n\left(c_j\right)}{(1+i)^{n-on}} \right) + \quad (4.2)$$
$$prob(unsound) \times \left(\sum_{n=1}^{P} \frac{-\left(vc\left(c_j\right)\right)}{(1+i)^{n-on}} + \frac{S_n\left(c_j\right)}{(1+i)^{n-on}} \right) +$$
$$prob(death) \times \left(\sum_{n=1}^{P} \frac{-\left(vc\left(c_j\right)\right)}{(1+i)^{n-on}} \right)$$

Where $NPV(retained\ open\ cow)$ represents the NPV of the retained open cow. on is the production year the cow was open and P represents the productive years of the cow. RI represents the reinvestment cost of retaining the open cow instead of selling her at the D1-D2 cull price. Therefore, RI will equal the cull cow weight multiplied by the D1-D2 price of $0.81/lb (CanFax, Unpublished). The probability the cow weans a calf in all other years of production ($Prob(weaned\ calf)$), the probability the cow is open a second time ($Prob(open)$), the probability of a cow being unsound (any physical confirmation breakdowns limiting the female's production) and sold ($prob(unsound)$), and the probability of death of the cow ($prob(death)$) are represented by each representative NPV calculation to find the weighted scenario of the NPV of the cow.

Figure 4.2 illustrates the cashflows of Option 1 (retain open cow timelines). The first timeline represents the discounted cashflows of a cow calving in all other production years after being open a single time. The second timeline represents the discounted cashflows of a cow not calving after the last year of being open but calving all other production years after. The third timeline represents the discounted cashflows of a cow sold for being unsound. Finally, the fourth timeline represents the discounted cashflows of a cow's death after being open the prior year.

Figure 4.2. Timeline of Cashflows Option 1

	Age (j)								
	3	4	5	6	7	8	9	10	11
	Year (n)								
	2	3	4	5	6	7	8	9	10
(weaned calf)	$\frac{-RI-(vc(c}{(1+i)^{2-}}$			$\sum_{n=0}^{P}\frac{P_n(c_i)}{(1+i)^{n-2}}$					$\frac{P_{10}(c_{11})}{(1+i)^{10-2}}+\frac{S_{10}(c_{11})}{(1+i)^{10-2}}$
(open again)	$\frac{-RI-(vc(c}{(1+i)^{2-}}$	$\frac{-(vc(c_4))}{(1+i)^{3-2}}$			$\sum_{n=0}^{P}\frac{P_n(c_i)}{(1+i)^{n-2}}$				$\frac{P_{10}(c_{11})}{(1+i)^{10-2}}+\frac{S_{10}(c_{11})}{(1+i)^{10-2}}$
(unsound)	$\frac{-(vc(c_3))}{(1+i)^{2-2}}+\frac{S_2(c_3)}{(1+i)^{2-2}}$		Zero Cash flow generated years (n) 4 through 10						
(death)	$\frac{-(vc(c_3))}{(1+i)^{2-2}}$		Zero Cash flow generated years (n) 4 through 10						

The probability for each outcome (open again, unsound, death) by cow age is informed by the CDN COP network data, Waldner et al. (2019) and Tronstad et al. (1993). Tronstad et al. (1993) probabilities are based on one Arizona operation with individual female records from 1982 to 1989 and provided probability change by cow age to inform the rate of change of each scenario as females reach and surpass maturity. Table 4.1 reports Tronstad et al.'s (1993) probabilities of a cow having a weaned calf, being open, being unsound or death of the cow.

Table 4.1. Probabilities by Age for Open Females with Calf

Cow age	Prob (live calf)	Prob (open)	Prob(unsound)	Prob(death)
3	81.95%	14.59%	1.40%	2.06%
4	80.80%	14.59%	1.86%	2.75%
5	79.33%	14.59%	2.65%	3.43%
6	77.52%	14.59%	3.77%	4.12%
7	75.39%	14.59%	5.21%	4.81%
8	72.94%	14.59%	6.98%	5.49%
9	70.15%	14.59%	9.08%	6.18%
10	67.04%	14.59%	11.51%	6.87%
11	63.59%	14.59%	14.26%	7.55%

Data from this table is from Tronstad et al. (1993, p. 29)

The CDN COP network does not collect probabilities by cow age, therefore the death rate and the inverse of the calve alive after 24 hours (as the open rate) reported by the COP Network were assumed to pertain to 5-year-old cows. The probability of death and open rates were informed by an average of all 16 operations from the CDN COP Network data. Outside published sources such as Tronstad's (1993) (based on 7 years of individual cow records from a single Arizona farm) and Waldner et al., (2019) were used to further generate the probability tables rate of change by cow age and inform the unsound rates. Tronstad's (1993) probabilities were different from the ones based on the CDN COP Network because Tronstad's (1993) data were from a single herd, in alternative terrain (Arizona range), and from an earlier time frame (1982-1989).

The average, high and low production probabilities for a mature cow at age five for open and death loss were informed by the 16 western Canadian 'typical farms' from the CDN COP Network data. Among the 16 'typical farms', cow death loss ranged from 0.9% to 2.0%, the culling rate ranged from 6% to 17.5%, calves alive after 24 hours ranged from 87% to 96%, and the weaning rate ranged from 82% to 93%. Waldner et al., (2019) reported an average open rate for cows to be 6.8% and heifers 9.7%. Heifers, therefore, have approximately a 3% higher open rate than mature cows. I will assume the open rate probability will be 3% greater for first-calving 2-year-olds and lowers by 1% each year till the female reaches maturity at age five. The rate of change in open rates for ages 5 to 11 and the rate of change in the death rates for all cow ages was informed by Tronstad et al. (1993). The average unsound rate by cow age was taken directly from were informed by Tronstad et al. (1993). I assumed the low production unsound rate to be 1% greater and the high unsound rate to be 1% less with the same variation in cow age from Tronstad et al. (1993) original unsound rates by cow age. For 2-year-old cows, I assumed the same unsound and death rates as three-year-old cows as these values were not provided by Tronstad et al. (1993) shown in Table 4.1. The remaining probability estimated was the probability of a cow having a weaned calf, this was calculated by subtracting one from the summation of the open, unsound and death rates.

Due to production probabilities varying from each cow herd, Table 4.2, Table 4.3 and Table 4.4 illustrate three levels of production probabilities used for the individual weighted NPV analysis. These levels of probabilities are used as a robustness test to assess how the production probabilities can impact the breeding female's valuation and the herd's profitability. Due to the probability being assumed from the CDN COP network, Waldner et al. (2019), and Tronstad et al.

(1993) creating ambiguity, the three-level sets will help assess the impact of productivity levels on the culling and replacement financial models later shown in the result sections.

Table 4.2. Average Production Assumed Probabilities by Cow Age

Cow Age	Prob (live calf) [a]	Prob (open)[b]	Prob(unsound) [c]	Prob(death) [d]
2	86.00%	11.41%	1.35%	1.24%
3	87.00%	10.41%	1.35%	1.24%
4	87.54%	9.41%	1.81%	1.24%
5	87.56%	8.41%	2.65%	1.38%
6	85.75%	8.41%	3.77%	2.07%
7	83.62%	8.41%	5.21%	2.76%
8	81.17%	8.41%	6.98%	3.44%
9	78.38%	8.41%	9.08%	4.13%
10	75.26%	8.41%	11.51%	4.82%
11	71.83%	8.41%	14.26%	5.50%

[a] Known as wean rate
[b] Known as open rate
[c] Known as unsound rate
[d] Known as death rate

Table 4.3. High Production Assumed Probabilities by Cow Age

Cow Age	Prob (live calf)	Prob (open)	Prob(unsound)	Prob(death)
2	92.29%	6.60%	0.35%	0.76%
3	93.29%	5.60%	0.35%	0.76%
4	93.83%	4.60%	0.81%	0.76%
5	93.85%	3.60%	1.65%	0.90%
6	92.04%	3.60%	2.77%	1.59%
7	89.91%	3.60%	4.21%	2.28%
8	87.46%	3.60%	5.98%	2.96%
9	84.67%	3.60%	8.08%	3.65%
10	81.55%	3.60%	10.51%	4.34%
11	78.12%	3.60%	13.26%	5.02%

Table 4.4. Low Production Assumed Probabilities by Cow Age

Cow Age	Prob (live calf)	Prob (open)	Prob(unsound)	Prob(death)
2	79.79%	16.00%	2.35%	1.86%
3	80.79%	15.00%	2.35%	1.86%
4	81.33%	14.00%	2.81%	1.86%
5	81.35%	13.00%	3.65%	2.00%
6	79.54%	13.00%	4.77%	2.69%
7	77.41%	13.00%	6.21%	3.38%
8	74.96%	13.00%	7.98%	4.06%
9	72.17%	13.00%	10.08%	4.75%
10	69.05%	13.00%	12.51%	5.44%
11	65.62%	13.00%	15.26%	6.12%

The alternative Option 2 represented by Equation 4.3 illustrates an open cow being replaced by a home-raised or purchased bred heifer. Similar, to the NPV of the retained cow in Equation 4.2 the weighted average NPV is calculated of the heifer either calving all production years ($Prob(weaned\ calf)$), the probability the heifer is open ($Prob(open)$), the probability of the heifer being unsound and sold ($prob(unsound)$), and the probability of death of the heifer

$(prob(death))$ are represented by each NPV calculation to find the weighted scenario of the NPV of the heifer.

$$\begin{aligned} NPV(heifer) = {} & prob(weaned\ calf) * \left(-H_0 + \sum_{n=1}^{P} \frac{P_{n-rn}(h)}{(1+i)^{n-rn}} + \frac{S_{n-rn}(h_j)}{(1+i)^{n-rn}}\right) \\ & + prob(open) * \left(-H_0 + \sum_{n=1}^{P} \frac{-\left(vc(h_j)\right)}{(1+i)^{0}} + \frac{P_{n-rn}(h)}{(1+i)^{n-rn}} + \frac{S_{n-rn}(h_j)}{(1+i)^{n-rn}}\right) \\ & + prob(unsound) * \left(-H_0 + \sum_{n=1}^{P} \frac{-\left(vc(h_j)\right)}{(1+i)^{n-on}} + \frac{S_n(h_j)}{(1+i)^{n-on}}\right) \\ & + prob(death) * \left(-H_0 + \sum_{n=1}^{PCO} \frac{-\left(vc(h_j)\right)}{(1+i)^{n-on}}\right) \end{aligned} \tag{4.3}$$

In Equation 4.3, $NPV(heifer)$ represents the net present value of the replacement heifer, rn is the year the cow is replaced with the heifer and P represents the total productive years. H_0 represents the initial development cost for the Home raised Heifer or the purchase price of the purchased bred heifer. $P_n(h_j)$ is the net payment received in year n from the replacement heifer at age j, and is further broken down into the revenue minus the variable costs ($rev(h_j)) - (vc(h_j))$ for the replacement heifer at age j. $S_n(h_j)$ denotes the salvage value received in year n for the replacement heifer when sold as a cull cow at age j. Equation 4.3 illustrates the cashflows from a replacement heifer of Option 2, with the first timeline showing the heifer calving every production year. The second timeline illustrates the heifer being open in her first production year. The third timeline represents the discounted cashflows of a heifer sold for being unsound. Finally, the fourth timeline represents the discounted cashflows of a heifer's death.

Figure 4.3 Timeline of Cashflows for Replacement Heifer Option 2

	Age (j)									
	2	3	4	5	6	7	8	9	10	11
	Year (n)									
	3	4	5	6	7	8	9	10	11	12
(weaned calf)	$-H_3 + \frac{P_{3-3+1}(h_2)}{(1+i)^{3-3}}$				$\sum_{n=0}^{P}\frac{P_{n-3+1}(h_j)}{(1+i)^{n-3}}$					$\frac{P_{10}(h_{11})}{(1+i)^{13-3}} + \frac{S_{10}(h_{11})}{(1+i)^{13-3}}$
(open)	$-H_3 + \frac{-(Vc(h_2))}{(1+i)^{3-3}}$				$\sum_{n=0}^{P}\frac{P_{n-3+1}(h_j)}{(1+i)^{n-3}}$					$\frac{P_{10}(h_{11})}{(1+i)^{13-3}} + \frac{S_{10}(h_{11})}{(1+i)^{13-3}}$
(unsound)	$-H_3 + \frac{S_3(h_2)}{(1+i)^{3-2}}$			Zero Cash flow generated years (n) 4 through 12						
(death)	$-H_3$			Zero Cash flow generated years (n) 4 through 12						

4.1.2 Equivalent Annual Annuity

The NPVs ($NPV(heifer)$ and $NPV(retain\ open\ cow)$) have different production timeline lengths, so before they can be compared I converted them to equivalent annual annuities (EAA). Using Equations 4.4 and 4.5 I calculate the constant annual cash flow generated by the female over its useful life if it was an annuity (Ross et al., 2002). However, if two females have the same number of production years left a NPV comparison would be adequate.

$$EAA(cow) = \frac{i \times NPV(retained\ open\ cow)}{(1-(1+i)^{-(PCO)})} \quad (4.4)$$

$$EAA(heifer) = \frac{i \times NPV(heifer)}{(1-(1+i)^{-(PH)})} \quad (4.5)$$

If the $EAA(retained\ open\ cow)$ is greater than the $EAA(heifer)$ retaining the open cow is more desirable for the farm. If the $EAA(retained\ open\ cow)$ is less than the $EAA(heifer)$ then retaining the open cow is less desirable for the farm. PCO represents the production years left for the open cow and PH represents the total production years of the heifer.

As illustrated in this section, the NPV analysis can help producers evaluate the discounted cashflows and decisions regarding their female assets when there is uncertainty or failure of production within the female's useful life. By estimating the discounted future cashflows the female's value to the overall cow herd is calculated and can be compared to see if she will be a profitable asset to the farm. Producers can then better decide when to retain profitable assets and replace assets with more profitable counterparts.

4.1.3 Discount Rate Based on Capital Structure

Using the Weighted Average Cost of Capital (WACC) we can determine a unique discount rate for each 'typical farm' based on its capital structure. Stowe et al.'s (2007) WACC equation is shown below (Equation 4.6) (p. 111).

$$WACC = \frac{MV(Debt)}{MV(Debt) + MV(Equity)} R_d(1 - Tax\ rate) + \frac{MV(Equity)}{MV(Debt) + MV(Equity)} R_e \qquad (4.6)$$

The market value of debt and market value of equity is represented by $MV(Debt)$ and $MV(Equity)$, respectively. With R_d representing the cost of debt and R_e representing the cost of equity. The calculation for the cost of debt is illustrated in Equation 4.7 (Stowe et al., 2007).

$$R_d = \frac{Total\ Interest\ on\ Debt}{Total\ Debt} \tag{4.7}$$

The capital asset pricing model (CAPM) is used to calculate the cost of equity shown in Equation 4.8 (Stowe et al., 2007, p. 48). The cost of equity will be used in the WACC Equation 4.6.

$$R_e = R_F + \beta_L (MR - R_F) \tag{4.8}$$

Where R_F is the risk-free rate of return. MR is the market rate of return. The risk-free rate of return (R_F) is the yield of a 10-year Canadian treasury bond. Similarly, the market rate of return (MR) is set to the 10-year average for the Canadian S&P/TSX 60 index. In terms of beta, the levered beta (β_L) is calculated using the Hamada equation (Equation 4.9) (Topyan, 2021).

$$\beta_L = \beta_U \left(1 + (1 + T) \times \frac{D}{E}\right) \tag{4.9}$$

The unlevered beta (β_U) represents an "asset's sensitivity to returns on the market portfolio" (Stowe et al., 2007, p. 48). For this analysis, we will assume unlevered beta to be one. T represents the corporate tax rate of the Canadian Province and the farthest RHS term $\left(\frac{D}{E}\right)$ is the debt-to-equity ratio from the benchmark farm.

4.2 Enterprise Culling and Replacement Profitability Model

After evaluating the individual female's EAA, the home-raised bred heifer enterprise, cow-calf enterprise and whole farm Business (cow-calf and home-raised replacement heifer) cash flow and profitability will be assessed for one year. By following the culling strategies listed in the section above (Table 3.6) the whole herd cow numbers (Table 4.5) were estimated. The herd in this model is assumed to stay a fixed size. As there cannot be partial cow assets the cow category numbers were rounded to whole numbers, and some rounding errors resulted in a few extra or fewer cattle compared to the 250-head assumption. All cows aged ten will be assumed final age and culled for Scenarios 1 and 2, and cows aged eight will be assumed final age and culled for Scenario 3. The heifer calves retained from the herd were chosen based on heifer calf availability by cow age varying from 0% to 16% of the heifer calf crop by cow age group. Producers may choose to keep heifers from older mature cows with superior genetics but for my analysis, I choose based on heifer availability across cow ages.

The average, high, and low production probabilities outlined in Table 4.2, Table 4.3, and Table 4.4 will directly influence the cow numbers in each category of the herd and the average probabilities from Table 4.2 will be used for the main analysis. The cash flows from the different categories of females (Table 4.6) will be calculated generating the herd's net income; then the Return on Assets (ROA) will be evaluated to inform the farm's profitability and compare strategies. For the ROA calculation, the assets per cow from Table 3.1 will be assumed, multiplying the assets per cow by the rounded herd size to get the total assets. To calculate the ROA, I divide the net income[17] from the cash flows by the total calculated assets (Barry et al., 2012, p. 49). For the home-raised heifer Scenarios 1 and 3, there will be two ROAs calculated, one for the cow-calf enterprise and one for the home-raised heifer enterprise. Therefore, the ROAs for the cow-calf enterprise for Scenarios 1 and 2 with home-raised heifers and purchased heifers,

[17] Total Interest was added, and Total unpaid labour was subtracted from net income in the ROA calculation. Interest per cow and unpaid labour per cow can be found in Table 3.1.

respectively, will be similar to the cash ROA but be different for the accrual ROA due to different levels of depreciation used between home-raised and purchased breeding females. The whole farm business (cow-calf and home-raised heifer enterprise) ROA will be calculated for Scenarios 1 through 3 where the profit (gain or loss) from the heifer enterprise subtracted from the bred heifer price ($1978) is the additional investment costs of the 2-year-old breeding females entering the cow herd. The farms in Scenario 2 will be forging the costs of raising bred heifers and the gains or losses from the heifer enterprise in the whole farm model due to purchasing all their bred heifers. For the cow-calf enterprise and whole farm business, the additional investment costs for the 2-year-old breeding females entering the cow herd will be $1978[18] across all Scenarios.

An ROA using the cash-based net income (Equation 4.10) and an ROA using the accrual net income (Equation 4.11) will be calculated. The accelerated depreciation of the females calculated using Equation 1.1 will be included to calculate the accrual net income. This will illustrate the impact of a female's valuation adjustments on the farm's profitability.

$$ROA = \frac{Net\ income + total\ interest - \ unpaid\ labour}{Total\ \ Assets} \tag{4.10}$$

$$ROA\,(accrual) = \frac{Net\ income + total\ interest - \ unpaid\ labour - annual\ cow\ depreciation}{Total\ Assets} \tag{4.11}$$

[18] For purchased bred heifer the transportation costs are not added to the purchase cost of $1978.44 due to transportation costs specific for purchased bred heifer transportation not given in the CDN COP network data. For an individual producer purchasing a bred heifer the transportation costs should be added in to the purchase price for 2-year-olds entering the cow-herd.

Table 4.5. Herd Numbers by Cow Category

Cow Category	Calculation for the number of head
Heifer	= Retained Heifer Calves
Retained Heifer Calves	= Calving Cows – weaned sale feeder heifers – weaned steers
Weaned Steers or Heifers	= Calves × 0.5
Weaned Sale Heifers	= Weaned Heifers– (Total Retained Heifers × Heifer Calf Retention Rate [a])
Total Retained Heifers	= Death Loss + Unsound + Cull with Calf Loss
Death Loss [b]	= Cow Herd × Death Rate
Unsound [c]	= Cow Herd × Unsound Rate
Cow with Weaned Calf	= ((Cow Herd – Death Loss – Unsound) × Wean Rate) – Retained Heifer Calves
Cow with Retained Calf	= Retained Heifer Calves [a]
Cull with Calf Loss	= Cow Herd – Calving Cows
Cull with weaned Calf (at final age)	= ((Cow Herd – Death Loss – Unsound) × Wean Rate) – Retained Calves
Cull with Retained Calf (at final age)	= Retained Calves

[a] The heifer retention rate varied from 0% to 16% depending on heifer calf availability in each cow age group and the heifer retention rate used for each age group summated to 100%.
[b] Assumed cows who died did not wean a calf
[c] Assumed cows found unsound did not wean a calf

Table 4.6. Cash Flow by Cow Category

Cow Category	Calculation for Cash flow
Heifer	= Heifer Transfer Price [a] - Heifer Development Costs
Death Loss	= - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Unsound	= (Cull Cow Weight × Cull Cow Price) - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Cow with Weaned Calf	= (Wean Calf Weight × Wean Calf Price) - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Cow with Retained Calf [b]	= (Wean Calf Weight × Wean Calf Price) - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Cull with Calf Loss	= - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Cull with Weaned Calf (at final age)	= (Wean Calf Weight × Wean Calf Price) + (Cull Cow Weight × Cull Cow Price) - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)
Cull with Retained Calf (at final age) [c]	= (Wean Calf Weight × Wean Calf Price) + (Cull Cow Weight × Cull Cow Price) - (Winter Feed Costs + Grazing Costs + Breeding Costs + Other Variable Costs)

[a] Heifer transfer price is equal to the purchased bred heifer price of $1978.44.
Note: For the cow-calf enterprise, first-calving heifers entering the cow-calf herd as bred heifers will also incur costs of $1978.44 in addition to their other cash flows. For the whole farm business, first-calving heifers entering the cow-calf herd as bred heifers will also incur costs of $1978 - individual heifer profit from heifer enterprise for home-raised bred heifers in addition to their other cash flows.
[b] Cow with Retained Calf has the same calculation as Cow with Weaned Calf because the retained calf is sold into the heifer enterprise for development as a replacement.
[c] Cull with Retained Calf has the same calculation as Cull with Weaned Calf because the retained calf is sold into the heifer enterprise for development as a replacement.

4.3 Chapter Summary

The first NPV decision model calculated the weighted NPV of cows and heifers that may be entering one of four varying probability scenarios (weaned calf, open, unsound, and death). These weighted NPV equations will allow varying probabilities to be used to calculate the expected valuation of individual animals as producers do not have perfect information on the future productivity of the breeding female assets. The use of an EAA will then allow heifer replacements and an open cows' valuation to be compared to allow the producer to see which asset (bred heifer or open cow) has a higher valuation reflecting a potentially greater net cash flow generated from the higher valued asset. I compared the EAA of individual females from various costs and productivity of the farms and culling strategies to evaluate the ideal retain or cull decision of an individual open cow asset.

The enterprise profitability model will calculate a single year's profits from the various culling strategies with a fixed herd size (replacements equalling culls and cattle who left the herd) for the home-raised bred heifer enterprise, cow-calf enterprise and whole farm business. The ROA is calculated from the average assets per cow, the herd size and the herd's net income. The ROA of the various farms' cost of production and productivity and culling strategies can be compared to evaluate the ideal culling and replacement strategy for the overall herd. The NPV EAA model and enterprise ROA model illustrate the contrast between the individual female and whole herd inventory culling and replacement decisions.

Chapter 5 –
Results

5.1 Introduction

The scenarios described in Chapter 3 (Table 3.6) were analyzed using the models outlined in Chapter 4. Two models were reviewed in this thesis: an individual EAA valuation and an enterprise ROA analysis. Prior to analyzing the two models, I calculated depreciation for breeding stock at various ages using Equation 1.1. I will use the estimates in the ROA analysis when calculating profitability using an accrual-based approach.

The first analysis outlines the valuation of individual females and compares them to similar breeding females with varying production years. The analysis outlines the preference for replacing open cows with a home-raised heifer. The purpose of this analysis is to provide a financial estimate of the impacts of varying culling and replacement decisions on the valuation of breeding cow assets.

The second analysis considers the cash flows of the entire herd and evaluates the revenue impacts of retaining home-raised heifers versus replacing them with purchased bred heifers and receiving all the weaned heifer calf revenue. The model revealed higher profits are received from replacing the herd with home-raised bred heifers relative to purchased bred heifers. The purpose of this analysis is to provide a financial estimate of the impacts of varying culling and replacement decisions on the herd's cash flow and profitability.

5.2 Results

5.2.1 Breeding Female Depreciation

Using Equation 1.1 the depreciation based on the number of production years was calculated for home-raised bred heifers (Table 5.1) and purchased bred heifers (Table 5.2). Home-raised bred heifers and purchased bred heifers were found to depreciate for all farms. For both replacements, the annual depreciation will increase as the production years decrease illustrating the accelerated value effect when culling breeding animals earlier. The depreciation of home-raised heifers was highest for the HC-HP farm, as higher costs farms had the highest heifer development costs. Home-raised heifer depreciation was lowest for the LC-LP farms as the heifer development costs were low and the salvage value was lower than high production operations. As shown in Figure 5.2, depreciation of purchased bred heifers is highest for low-production (HC-LP and LC-LP) operations as the cost of purchased bred replacements was held constant at $1978.44[19] (CanFax, unpublished data). These values will affect the accrual calculation of ROA in the enterprise profitability model described in a later section.

Table 5.1. Home-Raised Heifer Depreciation

	Production Years									
Farms ID	10	9	8	7	6	5	4	3	2	1
HC-HP	$95	$105	$118	$135	$158	$189	$237	$315	$473	$946
HC-LP	$49	$55	$62	$70	$82	$99	$123	$164	$246	$493
LC-HP	$52	$58	$65	$75	$87	$105	$131	$175	$262	$524
LC-LP	$35	$39	$44	$50	$58	$70	$87	$116	$175	$349

[19] Data provided by CanFax Monthly Alberta Bred Heifer Prices from 2018 to 2022.

Table 5.2. Purchased Bred Heifer Depreciation

	Production Years									
Farms ID	10	9	8	7	6	5	4	3	2	1
HC-HP	$83	$92	$103	$118	$138	$165	$206	$275	$413	$826
HC-LP	$96	$106	$119	$137	$159	$191	$239	$319	$478	$956
LC-HP	$88	$98	$111	$126	$147	$177	$221	$295	$442	$884
LC-LP	$92	$102	$114	$131	$153	$183	$229	$305	$458	$915

5.2.2 EAA Model

Table 5.2 represents the difference in EAA between the heifer and open cow at ages two through ten assuming average production probabilities (Table 4.2) were used to calculate the weighted NPV of each breeding female. It is assumed all weaned calves in the NPV model are sold at the given market price shown in Table 3.1 and not retained for replacement. A negative number indicates the optimal valuation comes from retaining an open cow while a positive number means replacing the cow with a heifer replacement results in a higher breeding female valuation (higher EAA) based on the estimated discounted cash flows. The model illustrated all open females should be replaced with a bred heifer.

Table 5.3. Equivalent Annual Annuity Difference Between Heifer and Open Cow

	Difference in Equivalent Annual Annuity by Age of Open Cow [a]								
	Age Cow Open								
Farms ID	2	3	4	5	6	7	8	9	10
Base – Home-raised bred Heifer and 10 production years (no adjustments for dam age)									
HC-HP	$53	$65	$80	$100	$129	$168	$226	$319	$500
HC-LP	$112	$123	$138	$157	$187	$226	$281	$367	$529
LC-HP	$135	$147	$163	$186	$220	$265	$327	$422	$594
LC-LP	$143	$154	$169	$190	$221	$262	$319	$405	$563
Scenario 1 – Home-raised bred Heifer and 10 production years									
HC-HP	$28	$35	$51	$74	$107	$151	$216	$327	$536
HC-LP	$75	$82	$98	$120	$153	$196	$257	$358	$544
LC-HP	$79	$87	$103	$129	$167	$217	$286	$397	$596
LC-LP	$92	$98	$114	$137	$172	$217	$280	$383	$566
Scenario 2 – Purchased bred Heifers and 10 production years									
HC-HP	$41	$49	$65	$87	$120	$165	$230	$341	$550
HC-LP	$5	$13	$29	$50	$83	$126	$187	$288	$474
LC-HP	$24	$32	$48	$74	$112	$162	$231	$342	$541
LC-LP	$7	$13	$29	$52	$87	$133	$196	$298	$481
Scenario 3 – Home-raised bred Heifer and 7 production years									
HC-HP	$36	$56	$92	$151	$252	$452			
HC-LP	$97	$116	$151	$205	$298	$478			
LC-HP	$103	$122	$158	$217	$319	$512			
LC-LP	$119	$136	$170	$224	$317	$495			

Note: A negative value means retaining an open cow is more profitable and a positive number means it is more profitable to replace an open cow with a bred heifer.
[a] Assuming Average Production Probabilities by Cow Age (Table 4.2)[20]

[20] The results table for the EAA differnace between replacment heifers and open breeding females using Tronstad's (1993) production proabilities (Table 4.1) is avaliable in Appendix B.

EAA Difference Base Scenario

In the base case, there is no age variation in cash flow (i.e., same wean weight regardless of cow age). Base scenario results show as open cows are older the replacement decision is significantly more profitable than retaining the open. As high as $596 per year higher annual EAA valuation for replacement heifers over retained open 10-year-old cows for the LC-HP farms. Across all operations, the maintenance cost for open females and those with no revenue will be unable to recuperate costs for the year, which often makes the replacement decision more profitable. LP operations with lower weaning and cull weights have lower EAA differences suggesting a lower revenue from feeder calves and the salvage value would make the producer closer to being indifferent between retaining and replacing open females relative to the LC-HP operations.

EAA Difference Scenario 1

Recall that Scenario 1 represents culling all opens and replacing them with home-raised replacements. Similar to the base scenario, all open females should be replaced with a home-raised bred heifer. However, the LC operation has the greatest difference in EAA across open cow ages with the greatest difference for 10-year-old cows. These LC operations have a low-cost advantage of raising efficient home-raised replacements and then raising the replacement heifer EAA valuation relative to the HC operations. The EAA difference for all operations peaks for open cows aged 10 when it is significantly more profitable to replace the open cow with a home-raised bred heifer (ranging from an annual valuation of approximately $540 to $600 greater). These cattle have the least amount of production years to recover their lost revenues, therefore, a new replacement heifer asset is preferred while the producer can receive the salvage value from the open cow. The EAA difference between home-raised heifers and open 9- to 10-year-old cows is significantly more than earlier ages partly due to a lower salvage value (D3 price = $0.70/lb) obtained for these cows.

EAA Difference Scenario 2

Scenario 2 is similar to Scenario 1 but instead of replacing opens with home-raised replacements, bred heifers are purchased at $1948 (5-year Alberta average) (CanFax, unpublished data). The results for Scenario 2 start to show replacing younger open 2- and 3-year-old cows for the LP operations is slightly less profitable but the producers are nearly indifferent between retaining and replacing these open cows. Again, open 10-year-olds have the highest different in EAA valuations, but the difference is relatively lower (ranging from $474 to $550) than Scenario 1 with home-raised replacement heifers. Therefore, home-raised bred heifers are the better replacement option for low costs operations.

EAA Difference Scenario 3

Scenario 3, similar to Scenario 1, has home-raised replacements but has 7 production years. The results also illustrate a greater EAA valuation for replacement heifers over open females of all ages (2 to 7). As the open female is older the difference in EAA increases due to less production year to recover the lost revenue from a missing weaned calf.

Indifference Heifer Cost Scenario 1

Table 5.4 displays the bred heifer price when the producer will be indifferent between retaining the open cow and replacing it with a purchased bred heifer. The indifference costs for replacement bred heifers in Scenario 2 follows a similar trend to Scenario 1 home-raised bred heifers indifference costs. The indifference price for purchased bred heifers is slightly lower than the indifference costs of home-raised bred heifers. Overall, the results show producers are willing to pay more for heifers before they are indifferent between replacing or retaining an open female.

displays the home-raised heifer development costs for Scenario 1 when the producer will be indifferent between retaining the open cow and replacing her with a home-raised bred heifer. The LP farms have a lower indifference cost for bred heifers compared to the HP farms. As farm costs increase and productivity decreases, the heifer development costs also have to lower for producers to be indifferent between retaining and culling open females. For Scenario 1, the replacement heifer costs can be significantly higher (as high as $5,833 for the HC-HP farms) when producers are indifferent between the decision to retain an open 9- and 10-year-old cows or replace her. Illustrating the point further that older open cows should not be retained in the herd.

Table 5.4. Home-Raised Heifer Cost Indifference Decision for 10 Production Years

	Age Cow Open								
Farms ID	2	3	4	5	6	7	8	9	10
HC-HP	$2,291	$2,346	$2,454	$2,612	$2,841	$3,152	$3,604	$4,375	$5,833
HC-LP	$2,039	$2,091	$2,203	$2,356	$2,582	$2,884	$3,312	$4,017	$5,318
LC-HP	$2,174	$2,225	$2,340	$2,519	$2,785	$3,135	$3,620	$4,400	$5,795
LC-LP	$2,053	$2,096	$2,207	$2,370	$2,613	$2,931	$3,374	$4,089	$5,369

Note: The listed development costs for the given home-raised heifer replacements when the producer will be indifferent between retaining the open cow or replacing the open cow with a home-raised heifer. If the replacement bred heifer cost is higher then listed above the producer will prefer to retain the open cow and if the replacement bred heifer cost is lower then listed above the producer will prefer to sell and replace the open cow.

Indifference Heifer Price Scenario 2

Table 5.5 displays the bred heifer price when the producer will be indifferent between retaining the open cow and replacing it with a purchased bred heifer. The indifference costs for replacement bred heifers in Scenario 2 follows a similar trend to Scenario 1 home-raised bred heifers indifference costs. The indifference price for purchased bred heifers is slightly lower than the indifference costs of home-raised bred heifers. Overall, the results show producers are willing to pay more for heifers before they are indifferent between replacing or retaining an open female.

Table 5.5. Purchased Heifer Price Indifference Decision for 10 Production Years

	Age Cow Open								
Farms ID	2	3	4	5	6	7	8	9	10
HC-HP	$2,263	$2,317	$2,424	$2,580	$2,805	$3,112	$3,560	$4,321	$5,761
HC-LP	$2,013	$2,065	$2,176	$2,327	$2,550	$2,848	$3,271	$3,968	$5,252
LC-HP	$2,147	$2,197	$2,311	$2,487	$2,751	$3,096	$3,575	$4,345	$5,723
LC-LP	$2,027	$2,070	$2,180	$2,340	$2,580	$2,895	$3,333	$4,038	$5,302

Note: The listed prices are the given bred heifer replacement when the producer will be indifferent between retaining the open cow or replacing the open cow with a purchased bred heifer. If the replacement bred heifer price is higher then listed above the producer will prefer to retain the open cow and if the replacement bred heifer price is lower then listed above the producer will prefer to sell and replace the open cow.

Indifference Heifer Price Scenario 3

Table 5.6 displays the Scenario 3 home-raised heifer development costs when the producer will be indifferent between retaining the open cow and replacing her with a home-raised heifer. The cost trend is the same as Scenarios 1 and 2.

Table 5.6. Home-Raised Heifer Cost Indifference Decision for 8 Production Years

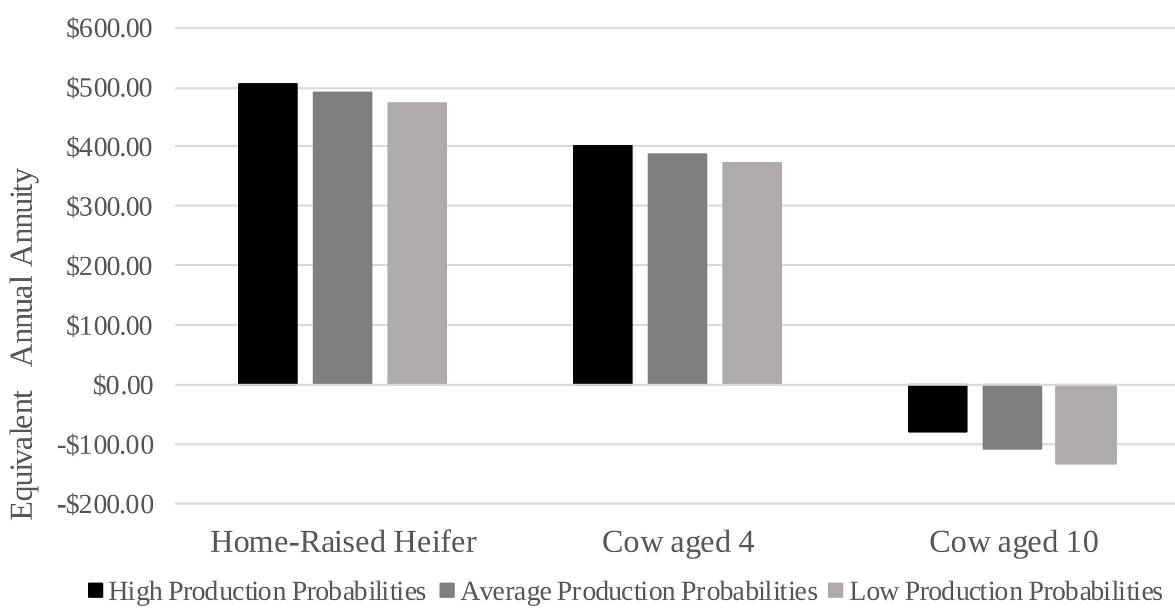
	Age Cow Open					
Farms ID	2	3	4	5	6	7
HC-HP	$2,291	$2,400	$2,595	$2,909	$3,454	$4,524
HC-LP	$2,039	$2,139	$2,330	$2,620	$3,123	$4,091
LC-HP	$2,174	$2,276	$2,471	$2,790	$3,339	$4,380
LC-LP	$2,053	$2,143	$2,328	$2,620	$3,123	$4,078

Note: The listed prices are the given bred heifer replacement when the producer will be indifferent between retaining the open cow or replacing the open cow with a purchased bred heifer.

Production Probability Impact on EAA

As the production probabilities are adjusted, the value of the EAA declines for the LC-HP farms when using low production probabilities and rises when using high production probabilities (Table 5.1). The spread between the EAA probabilities also increased as the cow ages, as illustrated in Figure 5.1. As the difference between high to average to low production probability changes, there is a difference in EAA of approximately $15 for 4-year-old cows and a difference of approximately $27 for 10-year-old cows. A higher weaning rate with lower open, death and unsound rates results in a higher weighted NPV of the breeding female asset. The difference in the probability effect on age was mainly due to the probability of age adjustments as older cows had a higher risk of death or becoming unsound relative to younger female assets.

Figure 5.1. LC-HP Farms EAA with Varying Production Probabilities Scenario 1



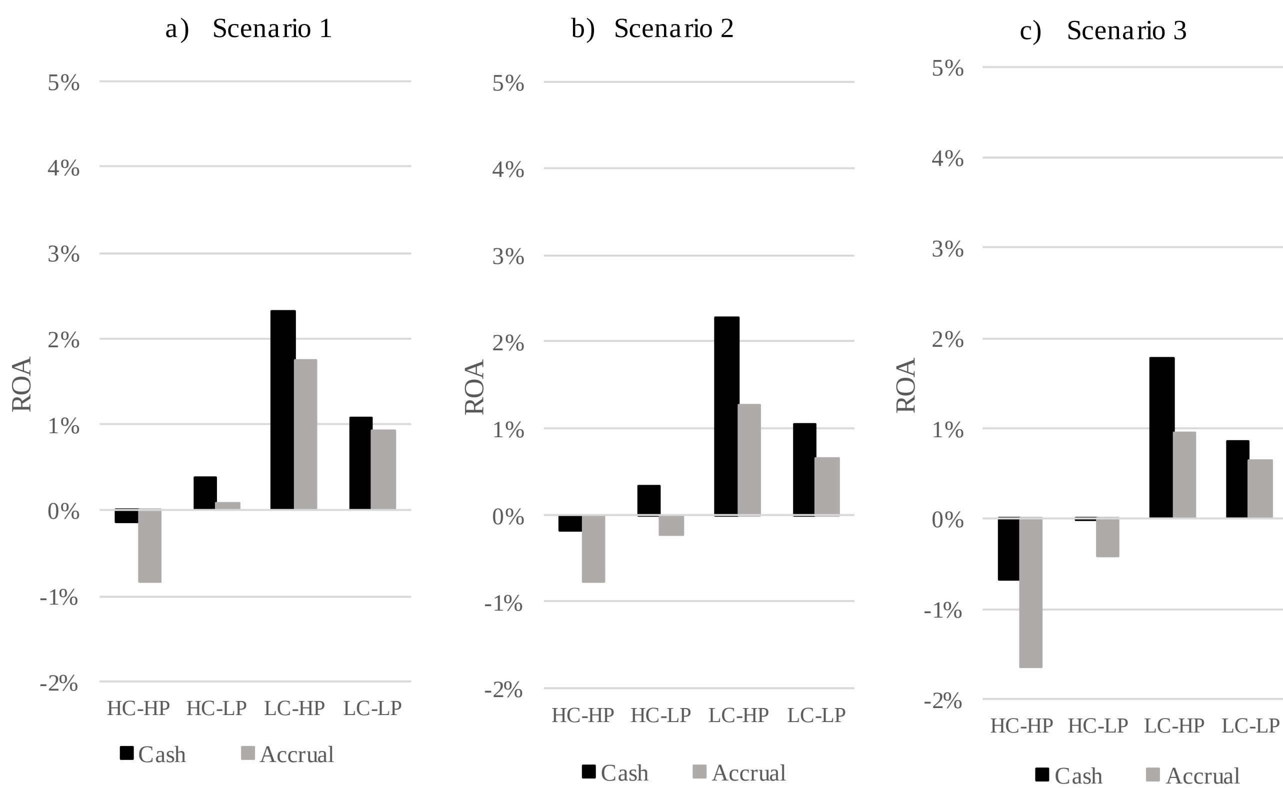
5.2.3 Enterprise Profitability

The following enterprise ROA model calculated the profitability of the cow-calf enterprise, home-raised bred heifer enterprise, and whole farm business.

Cow-Calf Enterprise Model

As shown in Figure 5.2 (assuming average production probabilities from Table 4.2) the ROA is positive for the majority of farms for the cow-calf enterprise. As expected, low-cost operations have a higher ROA than high cost operations. In addition, higher production parameters (i.e., HP operations) also raise the ROA.

Figure 5.2. Cow-Calf Enterprise ROA with AVG Production



Investigating Figure 5.2, the majority of farms had profitable cow-calf enterprises. The HC-HP operation had negative profitability for all scenarios 1 through 3. When considering the accrual ROA, the subtracted depreciation lowered the profitability and made the HC-LP farms for Scenarios 2 and 3 unprofitable relative to their cash net income ROA. For the cow-calf enterprise the most profitable farms in the whole herd strategy model are LC-HP farms with the culling and replacing Scenario 1 producing a cash net income ROA of 2.33% and accrual net income ROA of 1.74%. The least profitable farms are HC-HP farms with the culling and replacing Scenario 3 producing a cash net income ROA of -0.68% and accrual net income ROA of -1.65%. The greater difference between the two ROAs is due to the higher replacement heifer costs of purchased bred heifers costing $1,978.44 (CanFax, unpublished data) relative to home-raised bred heifers then raising depreciation costs for the accrual ROA. When using an accrual approach, considering the accelerated depreciation of culling at different ages, the ROA for the most profitable farm decreased by 0.59% and the least profitable decreased by 0.96%. The decrease is due to females depreciating in the herd.

When adjusting for production levels, the ROA for the cow-calf enterprises decreased with LP probabilities (Table 4.4) and increased with HP probabilities (Table 4.3). The difference in ROA between the LP and HP probabilities varies from 0.13% to 0.42% when considering only cash flow (Figure 5.3) and 0.17% to 0.56% when considering the accrual method (Figure 5.4) for Scenario 1. The difference in ROA between the LP and HP probabilities varies more for Scenario 2; ROA was significantly less from 0.20% to 0.59% when considering only cash flow (Figure 5.5) and 0.29% to 0.83% when considering the accrual method (Figure 5.6).

Figure 5.3. Cow-Calf Cash ROA With Varying Probabilities in Scenario 1

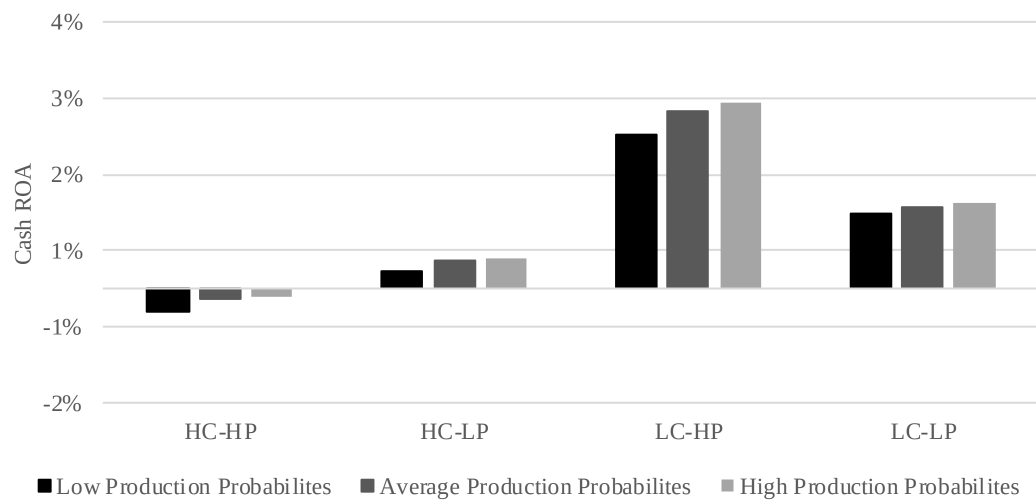


Figure 5.4. Cow-Calf Accrual ROA With Varying Probabilities in Scenario 1

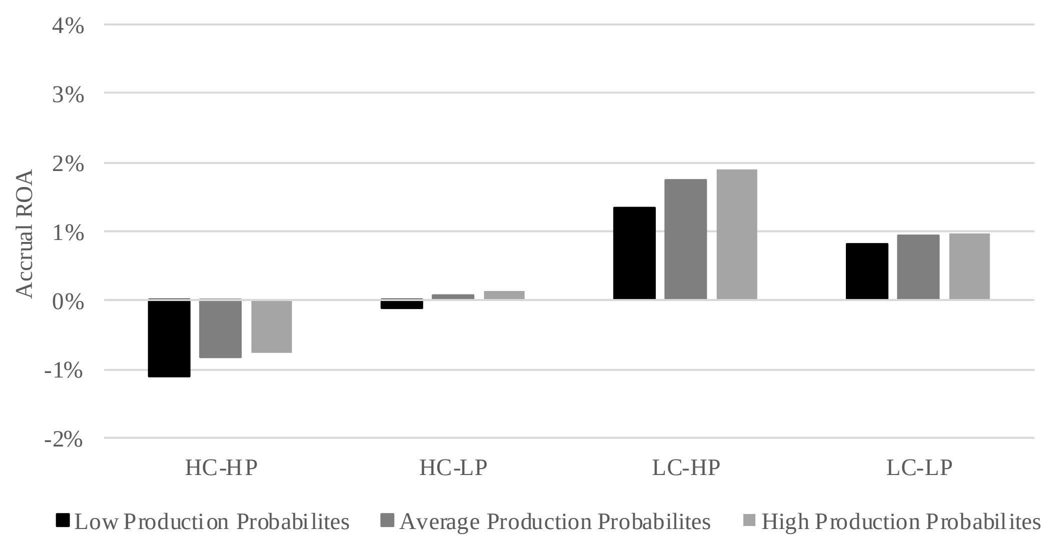


Figure 5.5. Cow-Calf Cash ROA With Varying Probabilities in Scenario 2

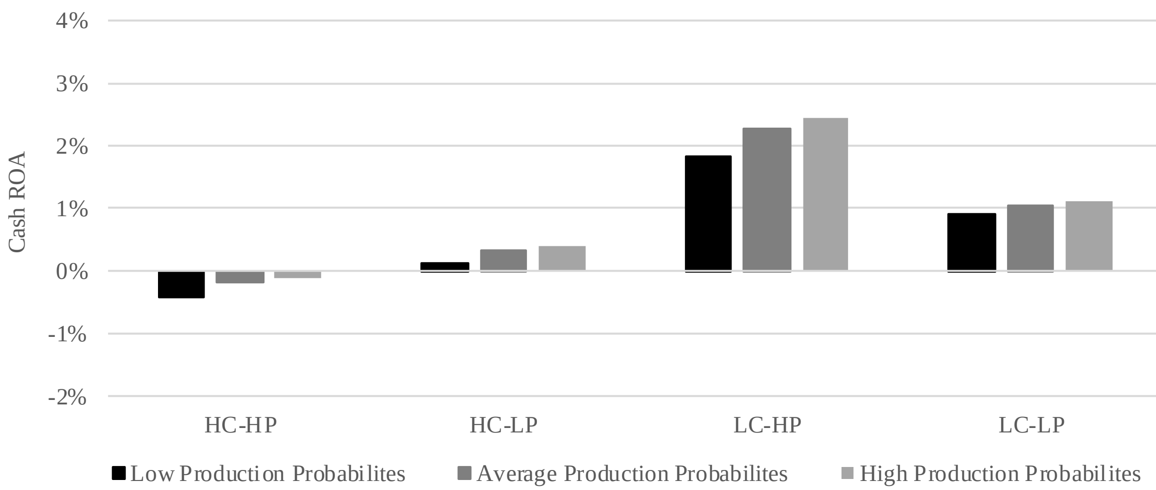
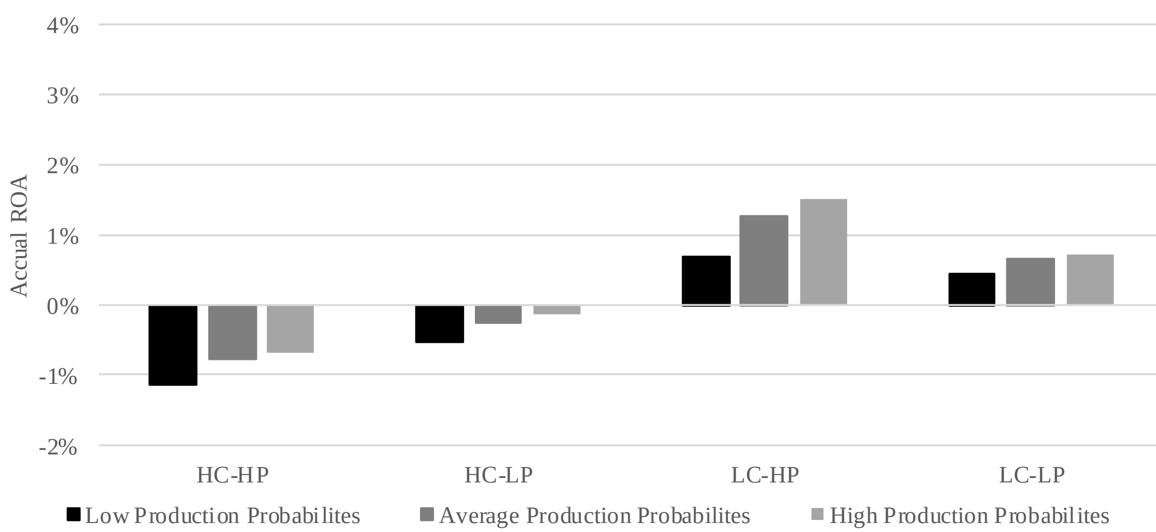


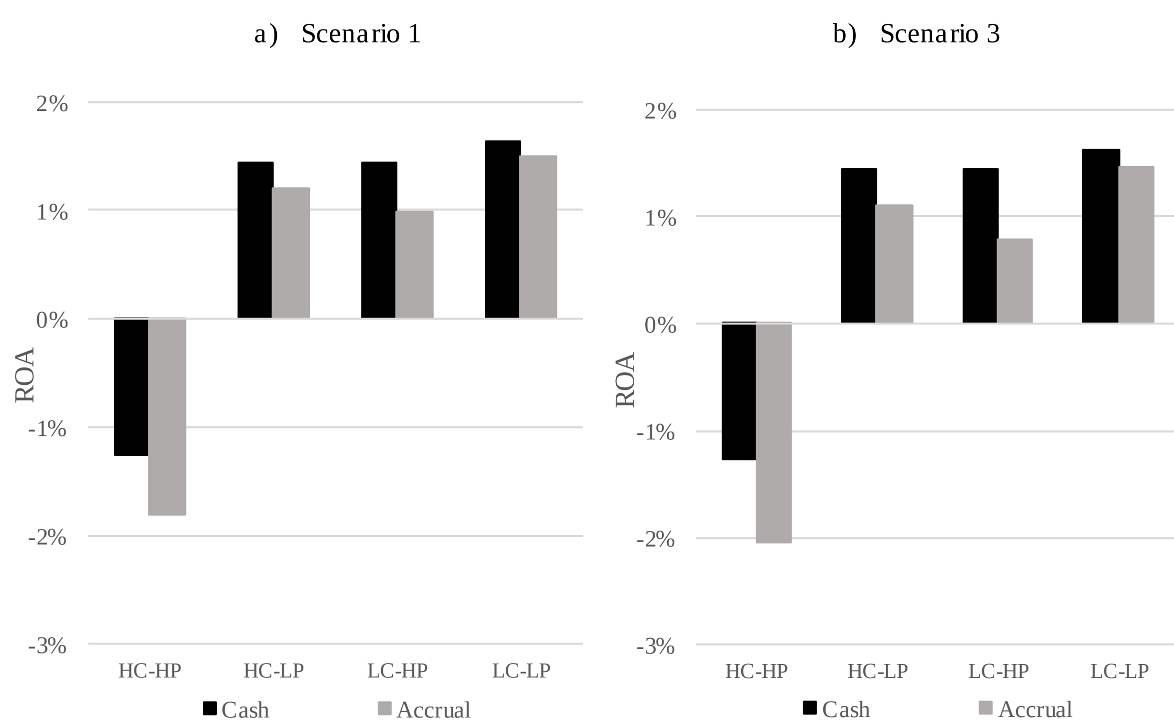
Figure 5.6. Cow-Calf Accrual ROA With Varying Probabilities in Scenario 2



Home-Raised Bred Heifer Enterprise

For the home-raised replacement heifer enterprise, the ROA was estimated for Scenario 1 (10 production years) and Scenario 3 (7 production years) assuming average production. The only unprofitable replacement heifer enterprise is the HC-HP operations for both Scenarios 1 and 3 with a cash flow ROA of -1.26% and an accrual ROA of -1.81% and -2.05% for Scenario 1 and Scenario 3, respectively (Figure 5.7). The difference in the accrual ROA is due to the rounding error difference for replacement heifers needed for each Scenario and the subtracted total depreciation from the net income. Overall, the LC and HC-LP farms with lower costs relative to the HC-HP farms have positive profits from the replacement heifer enterprise and should replace cattle leaving the herd with the farm's home-raised bred replacement heifers. These farms illustrate a low-cost advantage in developing home-raised bred heifers.

Figure 5.7. Replacement Heifer Enterprise ROA with AVG Production



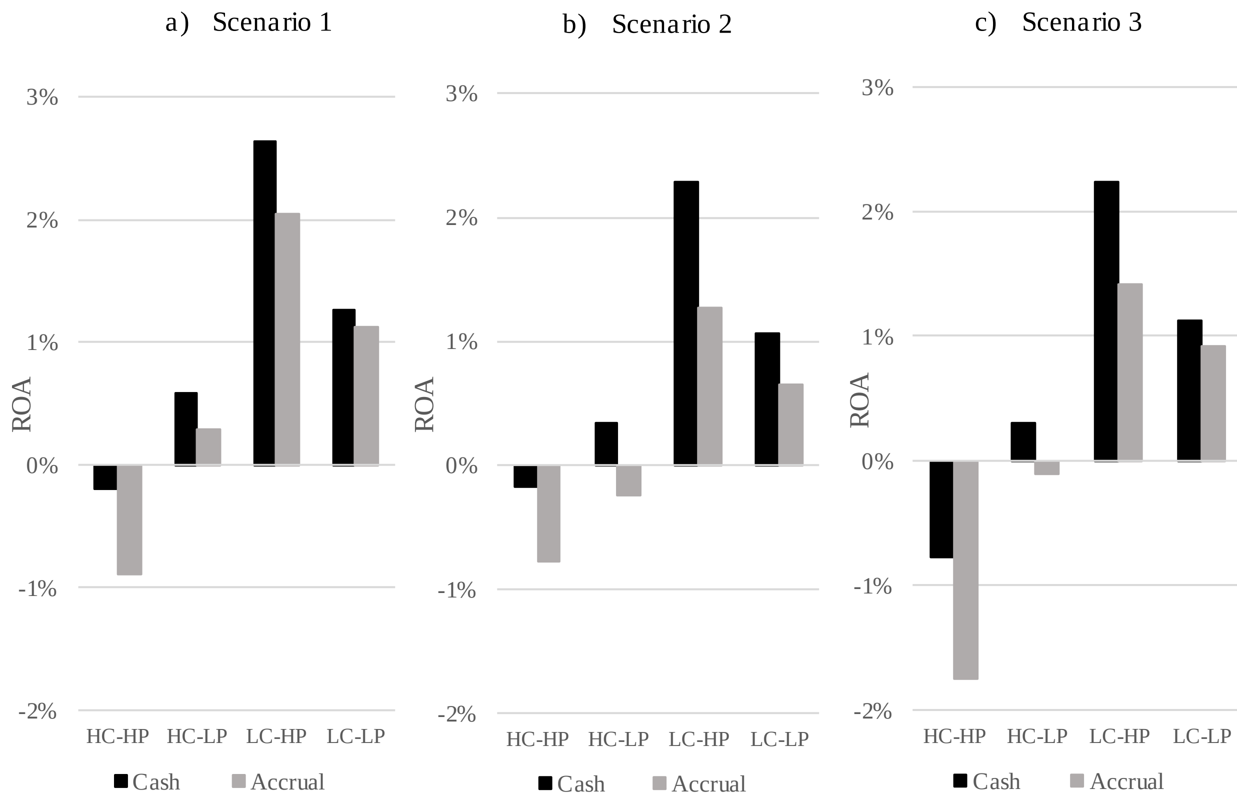
Whole Farm Business Model

The whole farm business combines the heifer and cow-cow enterprises' cashflows to represent the whole farm. The 2-year-old additional cashflow of the bred heifer investment subtracts the gains or loss from the individual breeding female from the heifer enterprise (ex. for LC-HP farm the bred heifer investment cost is $1978.44 - $360.66 = $1617.34). Therefore, farms that efficiently raise bred heifers will be recognized in the whole farm ROA similar to the heifer enterprise ROA.

Illustrated above the HC-HP operations have negative profitability as predicted from the cow-calf (Figure 5.2) and heifer (Figure 5.7) enterprises. The HC-LP operation for Scenario 3 has a negative accrual ROA relative to the cash net income ROA. Similar to the cow-calf enterprise ROA the LC-HP operation has the highest cash income ROA of 2.64% and accrual ROA of 2.05% for Scenario 1 (Figure 5.8). The LC-LP farms had the lowest annual depreciation per breeding female across all varying years of production. Although the LC-LP farms have the lowest heifer development cost helping them receive a greater profit for bred home-raised heifers entering the cow-calf enterprise the LC-HP farms generate a greater revenue due to greater overall production. Although it is important to manage costs impacting heifer replacements (i.e., winterfeed and grazing) greater production increased the overall herd's profit more.

Referring back to Figure 5.2 Scenario 2, this would also be considered the whole farm business as the bred heifers are purchased with no additional enterprise developing heifers. Therefore, Scenario 2 in Figure 5.2 is the same line graph as Scenario 2 in Figure 5.8. For Scenario 2 the LC-HP farms were the most profitable with a cash net income ROA of 2.28%.

Figure 5.8. Whole Farm Business ROA with AVG Production



When adjusting for production levels, the ROA for the whole farm businesses decreased with LP probabilities (Table 4.4) and increased with HP probabilities (Table 4.3). The difference in ROA between the LP and HP probabilities varies from 0.13% to 0.42% when considering only cash flow and 0.17% to 0.56% (Figure 5.9) when considering the accrual (Figure 5.10) method for Scenario 1. The difference in ROA between the LP and HP probabilities varies more for Scenario 3; ROA was significantly less from 0.20% to 0.59% when considering only cash flow (Figure 5.11) and 0.24% to 0.77% when considering the accrual method (Figure 5.12).

Figure 5.9. Whole Farm Cash ROA With Varying Probabilities in Scenario 1

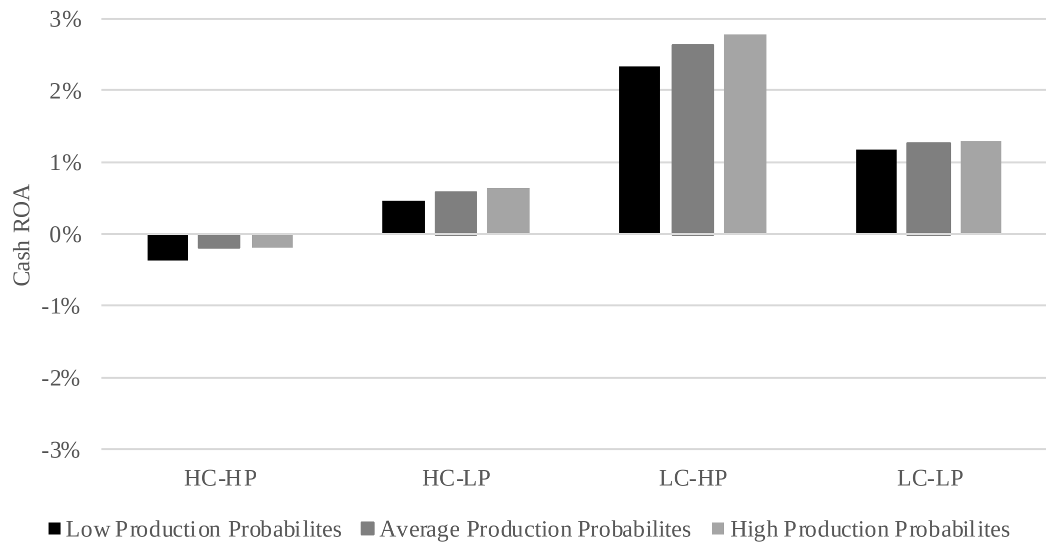


Figure 5.10. Whole Farm Accrual ROA With Varying Probabilities in Scenario 1

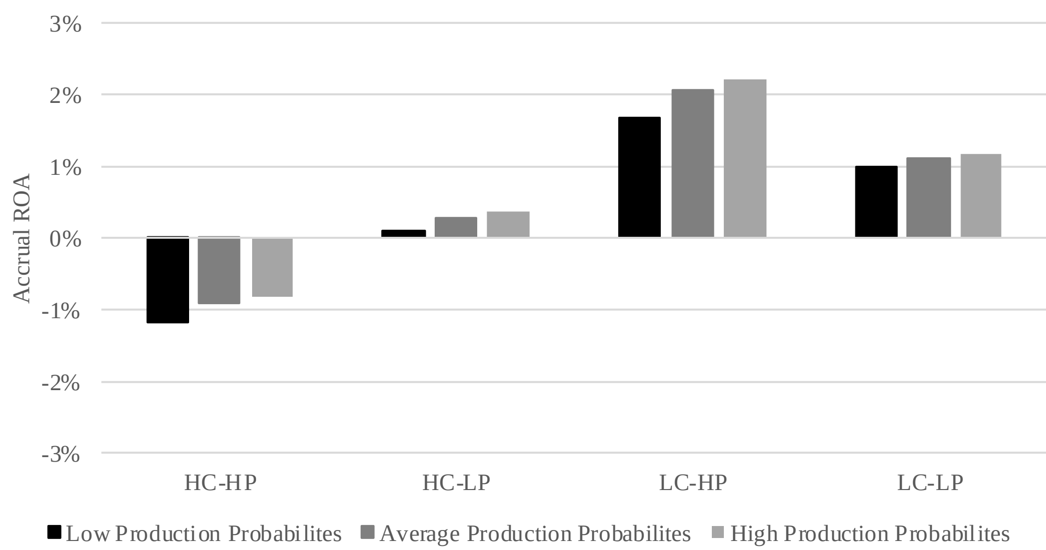


Figure 5.11. Whole Farm Cash ROA With Varying Probabilities in Scenario 3

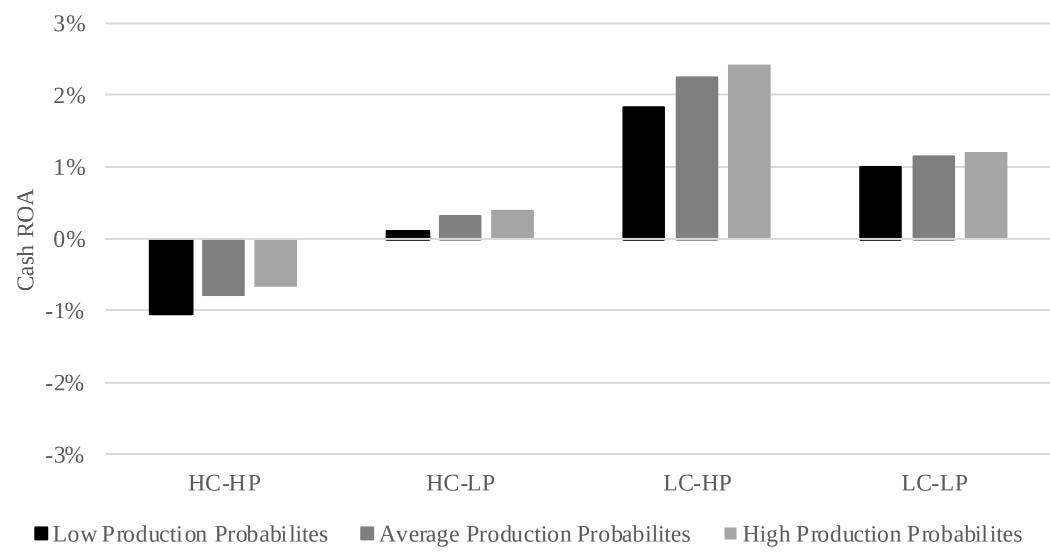
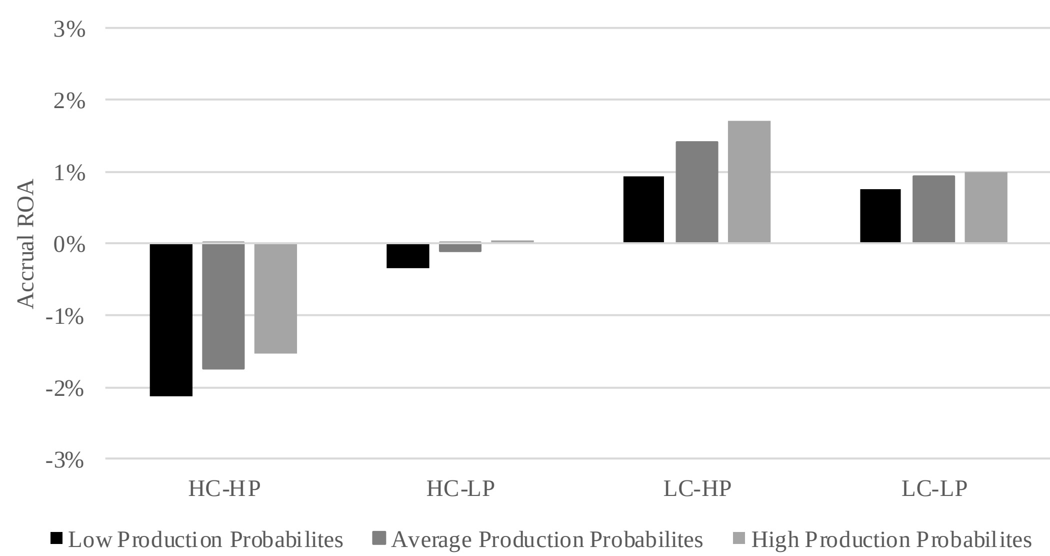


Figure 5.12. Whole Farm Accrual ROA With Varying Probabilities in Scenario 3



5.2.4 Managerial Implications

Overall, there were many significant differences, given the assumptions in the model, between EAAs with an indefinite decision to cull older open cows. The producer who can not afford newly purchased bred heifers due to liquidity limitations or chooses to not follow the above EAA decision model directly by retaining younger open females will not significantly alter their future potential cashflows. However, the larger preference in Table 5.3 to replace open cows shows that producers may want to follow the general rule to cull all open females as many producers often do. Perhaps, the 'producer eye' can help aid in the decision of retaining open females with superior genetics that improve feed and fertility efficiency and produce heavier calves. Producers could also cull females with obvious unproductive features, such as females with udder and milking issues leading to lower calf weaning weights. Producers may also choose to retain a female who failed to wean a calf due to unforeseen circumstances such as severe weather events or calf death due to predators making the cow not at fault. Producers can help optimize positive cashflows by retaining open females with greater genetic potential relative to poor-performing open females.

Although there are preferred culling and replacement decisions shown by the models, a producer's available capital to invest in new livestock and pay to maintain open females may not be available. Producers who do not have the liquidity may have to sell open females who may have a higher NPV if kept relative to a replacement bred heifer. Alternatively, producers also may have to sell more heifers then desired reducing their replacement heifer options due to feed shortages from drought and higher maintenance costs of cattle. Producers have to assess their resources and their spare liquidity to ensure these culling and replacement decisions work for their operation. The current high price environment strategy suggests producers should cull all open females and replace them with bred heifer replacements. For producers with home-raised heifer replacements, this means losing out on some higher feeder prices but capitalizing on higher cull cow prices. The producer then must ensure the revenue is enough to support the operation of the farm. Producers choosing to purchase bred heifers will have to ensure the available capital can cover the price and number of desired heifers. Producers may then choose to have a portion of purchased and home-raised bred heifers to ensure they can afford all the desired replacements needed.

The heifer development costs will also impact the replacement decision, as LC operations were more profitable and had higher EAA valuations for all breeding females. By managing costs such as winter feed, producers can lower their heifer development costs to make replacing a more profitable option. In my model, my heifer development costs consider the opportunity cost of selling the heifer at her feeder value and this should also be considered especially during high prices during the cow cycle (referred to in section 2.1 of the literature review) of higher prices. Producers can then adjust their heifer retention rates based on feed availability and feeder market prices to ensure they optimize their farm's resources and the herd's profitability.

The majority of cow-calf producers raise their own replacement heifers rather than purchase bred heifers (University of Saskatchewan, 2018; National Animal Health Monitoring System, 2009). Producers have many considerations when deciding on the source of their replacements. The decisions can be financially based including cashflow availability and interest in short-term loans for purchased replacements and convenience-based including genetic improvements, biosecurity of the herd, and replacement temperament (Whittier, 2001; Schulz & Gunn, 2014). In an optimal scenario purchasing replacements from a single reliable source with the producer's desired genetics could limit the impact of biosecurity hazards and other convenience factors (Whittier, 2001).

Producers could choose to vary herd inventory with the cattle inventory and price cycle. The non-fixed herd inventory could allow more flexibility to retain a higher proportion of heifers when prices are low and sell a greater number of replacements when feeder prices rise taking on a countercyclical approach to manage their herd inventory. However, producers should also ensure their resources such as land and equipment for grazing and winter feed production are used efficiently to keep the cost per cow low as the low-cost operation had greater valuations and profitability in the two models.

The depreciation costs of the breeding females lowered the profitability of the cow-calf enterprise, heifer enterprise and whole farm business. LC operations were able to lower depreciation costs affecting the accrual net income through having lower heifer development costs. However, a greater reduction of depreciation was found with farms with lower production (i.e., lower wean weights) due to a smaller difference between the female's initial and salvage value. Although breeding female depreciation can be minimized, minimizing the costs may have negative implications on the female productivity of generating greater revenue through heavier calves and a heavier cull weight. As seen the LC-HP farms using the accrual ROA were found to have greater profit for the cow-calf enterprise despite having higher overall depreciation per home-raised breeding female relative to the LC-LP farms. Although the LC-LP farms had the advantage of having lower depreciation and lower heifer development costs due to a lower opportunity cost of selling heifer calves as feeders they were still not the most profitable.

5.3 Chapter Summary

Overall, low-cost operations with higher production values had higher EAA valuations for breeding females and greater profitability. In my model, I categorized high production operations as those with above average pounds weaned per cow exposed. Typically, moderate framed cows producing calves with a high weaning weight are highly productive hence saving costs through needing fewer resources, this can be said for the case of our LC-HP farms having the highest weaned weight to cow cull weight ratio of 45%. In contrast, high cost operations experience lower EAA breeding female valuations with the HC-HP farms experiencing negative EAA valuation for all females across Scenario 1 through 3, illustrating the importance of managing costs to improve the profitability of the cow-calf enterprise. Producers have a higher difference in EAA valuation between replacement heifers and 10-year-old open cows. These results do not fully reflect Ibendahl et al. (2004) and Meek et al. (1999) results, where there can be missed profits when open cows are replaced in their prime production years with bred heifers.

The enterprise ROA model provided a profitability measure of the cow-calf enterprise for Scenarios 1 through 3, the home-raised replacement enterprise for Scenarios 1 and 3, and the whole herd enterprise for Scenarios 1 through 3. Recall the cow-calf enterprise ROA for Scenario 2 is equivalent to the whole farm business ROA. The results illustrated a profitable heifer enterprise for the majority of farms with the exception of the HC-HP farms with the highest total variable costs. This same farm (HC-HP) was the only non-profitable cow-calf enterprise using the cash ROA, however, using the accrual ROA the HC-LP farms were also unprofitable for some of the scenarios.

The results provided the general trends of culling and replacing preferences from the use of ‘typical farms’ average prices and production values. These results provide a financial perspective and decision tool for the estimated future discounted cash flows of individual breeding females and the profitability of the cow herd. These differences point to a difference in the immediate view of the herd inventory management decision and do not directly reflect a long-term decision model.

Chapter 6 –

Summary and Conclusions

6.1 Summary

The objective of this thesis was to estimate the optimal culling and replacement strategies for western Canadian cow-calf operations. The individual culling and replacement decisions impact the EAA analysis, affecting the long run valuation of the cow-calf enterprise, and the profitability of the cow-calf and replacement home-raised heifer enterprise. Producers often choose to focus on managing costs to ensure their operations break even or make profits, but herd inventory management and culling decisions based on cow age can directly impact profitability as shown in my model's results.

The data used in the models were provided by the CDN COP Network managed by CanFax. Data from the 'typical farms' within the CDN COP Network was aggregated to find different cost and performance groups to examine how farm costs and production variation may affect culling and replacement strategies. The 'typical farms' were categorized on high and low cost and production values using data from 16 of the western Canadian 'typical farms' from the CDN COP Network.

All replacement heifers were found to depreciate as their development or purchase price was greater than their final salvage value. As production years lessened due to culling at an earlier age the value of the annual depreciation increased. Depreciation can be a significant cost when looking at accrual-based income and for home-raised heifers, depreciation was highest for the HC operations relative to the LC operations. For purchased heifers, the LP farm had greater depreciation values than the HP operations. By reducing breeding stock depreciation costs by lowering heifer development cash costs, farms can positively impact the net income of the enterprise. Cow depreciation adjusts as the productive years of the female contract or extend. Producers may choose to cull earlier to receive a higher salvage value but accelerating the depreciation of the breeding female.

In the working models developed in this thesis, four strategies were analyzed. In the base case, operations culled all opens and there was no age differentiation with regards to production measures, and the farms used home-raise replacement heifers to maintain the herd size. In scenario 1, the ranch culled all opens and all cows at age 11, while having age differentiation in production and cash flow and also using home-raised replacement heifers to maintain the herd. In Scenario 2, the farms also culled all opens and cows aged eleven, while also accounting for age differentiation in production and cash flow and using purchased bred replacement heifers. Finally, in Scenario 3, the farms culled all opens and cows aged eight while having age differentiation in production and cash flow and used home-raised replacement heifers. The scenarios allowed cash flow to vary as cows aged, with the mature cow weight reached at age four (Ibendahl et al., 2004; Sessim et al., 2020). Younger cows often wean lighter calves generating less revenue relative to a mature cow counterpart (Ibendahl et al., 2004).

Using the methods outlined by Ibendahl et al., (2004) I created an individual open cow culling or retention model. I used a weighted NPV approach to evaluate breeding female retention and culling decisions based on estimated discounted future cashflows of varying aged breeding females. Following the NPV calculation, I employed EAA analysis to account for differing timelines created by the retain versus cull decision (such as would be created when an open four-year-old and an open heifer were compared in the model). The higher EAA reflected the more profitable decision when considering the long-term valuation of the enterprise under the culling strategies listed above. Overall, for the operations analyzed, all open females should be sold and replaced, especially older open cows for all scenarios and farm production probability levels (low (Table 4.4), average (Table 4.2) and high (Table 4.3)).

The second model was inspired by Turner et al., (2013) and utilized an enterprise ROA model of the various culling strategies by estimating the cash flow and accrual-based income of the cow-calf herd and the home-raised replacement heifer enterprise. In the model, the size of the herd was assumed to stay fixed (250 cows) with cattle leaving the herd being replaced by home-raised bred heifers or by purchased bred heifers. The majority of the scenarios were profitable with the LC-HP whole farm businesses following Scenario 1 being the most profitable for all production probability levels (low (Table 4.4), average (Table 4.2) and high (Table 4.3)).

A sensitivity analysis was conducted for both models by varying the production probabilities between low (Table 4.4), average (Table 4.2) and high (Table 4.3) for the weighted NPV calculations and the herd cow category numbers for the cow herd and replacement heifer inventory calculations. The results provided a set of estimated cash flows for the different strategies and farms with varying costs and productivity structures. Overall, my thesis utilizes a financial approach and perspective to examine culling and replacement decisions across a range of cow-calf operations in a western Canadian context. The use of 16 'typical farms' allows for the inclusion of general trends of when to cull versus retain an open cow, and in the enterprise ROA model, what strategies will result in higher profitability from the cow-calf enterprise and home-raised replacement heifer enterprise, and whole farm business.

6.2 Limitations

The models developed yielded results that reflect the trends of data collected from the CDN COP Network, and as a result, may not reflect an individual producer's cow-calf herd. By using aggregate data from the western CDN COP Network 'typical farms' there is a limitation in utilizing these results for a complete decision analysis on a specific individual enterprise. Therefore, a cow-calf operation using their own herd production and cost data may not gather the same results as our model using aggregated data. This results in my first limitation of utilizing average herd data not fully reflecting an individual producer's cow-calf enterprise's ideal culling and replacement model. By using the model for an individual herd, the producer could have a better understanding of their unique challenges and opportunities when considering the financial decisions of culling and replacement strategies. For example, assets per cow may decrease slightly when herds are larger due to economies of scale, hence raising the ROA. In my whole herd with herd size adjustments (small: 150, average: 250 and larger: 350) the ROA is the same for operations because the ratio of net income to total assets was the same. Computing results for a large number of operations would be helpful for producers to match their operations, however, this would not be easy to draw general trends of the culling strategies' impact on estimated cash flow and profitability as displayed in the results.

With aggregate data, various assumptions had to be made to ensure that cash flows by cow age could be estimated. This included adjusting production probabilities and calf weaning weight by cow age, including price slides on feeder calf prices and cull cow prices based on cow grade. These adjustments add ambiguity to the results and therefore the general trends are referenced. For example, having cow weights by age would help estimate cow grade as lighter weights could indicate a lower body condition score and more accurately estimate the salvage value of the culled female. By using herd data with individual breeding female identification, the weaning weight by dam age and production probabilities such as death rate and open rates can be accurately evaluated reflecting the specific farms' cashflows.

6.3 Conclusions

Anecdotal evidence shows producers often follow general rules when culling and replacing breeding females. These include culling all open breeding females or giving young (ages 2 through 4) open breeding females a second chance (due to females still growing to their mature weight). The models analyzed in this thesis focus on the financial decision of culling and replacement decisions for producers. Based on the EAA model's results producers need to assess the cashflow potential of the open breeding female before making a final decision, producers who choose to keep older open females will miss out on the greater revenue potential of replacing her with a bred heifer. The price environment will also affect the culling decision as a high price environment indicates to cull open cows of all ages and a low-price environment will suggest to retain more younger open females (see Appendix C) to gain a higher breeding female valuation.

The EAA value for open cows in low-cost operations favours replacing open cow assets when evaluating individual culling and replacement decisions. Older females ages 9 and 10 have the lowest EAA valuation exhibiting a strong indicator to replace these females with a bred heifer. The younger open females culling decision however can be impacted by the price environment such as their initial investment cost and salvage value when diagnosed as non-pregnant. Producers in a high price environment who have low heifer development costs should cull all young open females. However, some LP farms with purchased bred heifer replacement as their only option were close to the indifferent decision of retaining the open female due to the higher initial investment cost of the replacement.

The ROA model estimated higher profitability for the whole farm business following Scenario 1 with home-raised replacements over Scenario 2 with purchased bred heifer replacements. The LC-HP overall whole farm business for Scenario 1 was the most profitable due to generating greater revenue from higher weaning and cull weights while efficiently raising bred heifers. For the replacement heifer enterprise's profitability, LC operations obtained greater profit than HC operations. This was due to a lower opportunity cost for feeder heifers from the LP farms relative to the HP farms. The HC-HP operation was not efficient at raising bred heifers due to high variable costs to raise and maintain cattle, receiving negative profit from the home-raise bred heifer enterprise and the cow-calf enterprise.

Although there are general decision rules the producer must assess the price environment for culls and feeders, their variable costs, available liquidity, and future productivity of the breeding female at each age before culling a breeding female. Along with the producer's eye evaluating the cow's confirmation, a financial perspective can help producers generate greater cashflows of the breeding female assets and profitability from the overall cow-calf herd.

Glossary

Cow beef female bovine has who calved

Cow-calf beef female bovine with calf on the side

Cow herd a group of cows

Cull an asset the producer intends to sell

Females or breeding females female bovines of any age with the intention to be bred

Health program Cow-calf health programs include vaccine protocols and unforeseen treatments needed to keep individual animals and the overall herd in healthy condition to produce offspring.

Heifer bovine aged less than two who has not birthed a calf

Replacement heifer a heifer intended to replace a cow in the cowherd

Home-raised replacement heifer a heifer produced by a cow herd and kept for breeding

Bred heifer a heifer who is confirmed pregnant and will calf in the next calving season

Open a cow or bred heifer who failed to conceive or had a miscarriage

Wean to separate a calf from a lactating cow

Calf crop the total weaned calves produced by the cow herd

Commercial Cattle crossed between varying breeds and with no pedigree documentation.

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Appendix A: Western Canadian 'Typical Farm' Data

Table A.1. HC-HP 'Typical Farms'

Farm ID	SK-3	SK-5	SK-6	HC-HP
Cost of Production				
Purchased Bred Heifer	$1,978.44	$1,978.44	$1,978.44	$1,978.44
Pregnancy Rate	8%	8%	8%	
Heifer Retention Rate	13%	15%	15%	
Feeder Heifer Price ($/lb)	$1.78	$2.04	$1.72	
Heifer Wean Weight (lb)	549	595	686	
Heifer winter feed cost ($/heifer)	$106.06	$50.17	$506.03[a]	
Heifer Grazing cost ($/heifer)	$397.59	$102.75	$136.82	
Cull Heifer Price ($/lb)	$1.59	$1.51	$1.51	
Cull Heifer Weight (lb)	1109	1274	1246	
Heifer Development Cost	$1,758.23	$2,016.95	$2,521.91	$2,099.03
Winter Feed Cost	$147.36	$149.75	$172.82	$156.64
Grazing Cost	$611.67	$158.08	$210.50	$326.75
Breeding Cost	$53.25	$32.43	$35.57	$40.42
Other Variable Costs	$221.94	$611.63	$610.92	$481.50
Total Variable Costs	$1,034.22	$951.89	$1,029.81	$1,005.31
Unpaid Labour	$274.23	$311.42	$123.80	$236.48
Production Parameters				
Herd Size	245	135	135	
Weaning Weight	558	611	708	625
Wean Calf Price ($/lb)	$1.95	$2.09	$1.85	$1.96
Cull Cow Weight	1304	1499	1466.	1423
Cull Cow Price ($/lb)	$0.65	$0.82	$0.68	$0.72
Capital Structure				
Assets per cow	$31,091.25	$17,400.31	$3,319.07	$17,270.21
Interest Per cow	$68.13	$293.18	$54.82	$138.71
WACC	7.37%	7.52%	7.51%	7.47%

[a] Extremely high winter feed cost due to pellet supplement costing $372 per head for heifers.

Table A.2. HC-LP 'Typical Farms'

Farm ID	BC-1	SK-1b	MB-1	HC-LP
Cost of Production				
Purchased Bred Heifer	$1,978.44	$1,978.44	$1,978.44	$1,978.44
Pregnancy Rate	12%	13%	8%	
Heifer Retention Rate	14%	19%	13%	
Feeder Heifer Price ($/lb)	$1.81	$2.03	$1.86	
Heifer Wean Weight (lb)	584	482	510	
Heifer winter feed cost ($/heifer)	$196.57	$155.67	$112.86	
Heifer Grazing cost ($/heifer)	$10.84	$83.25	$136.73	
Cull Heifer Price ($/lb)	$1.61	$1.78	$1.65	
Cull Heifer Weight (lb)	1063	1058	1063	
Heifer Development Cost	$1,701.36	$1,271.25	$1,573.61	$1,515.41
Winter Feed Cost	$186.54	$396.66	$188.10	$257.10
Grazing Cost	$16.68	$128.07	$210.36	$118.37
Breeding Cost	$17.44	$40.36	$42.37	$33.39
Other Variable Costs	$419.33	$97.07	$345.52	$287.31
Total Variable Costs	$639.99	$662.16	$786.34	$696.16
Unpaid Labour	$338.93	$84.51	$134.42	$185.95
Production Parameters				
Herd Size	65	350	320	
Weaning Weight	594	487	530	537
Wean Calf Price ($/lb)	$1.89	$2.24	$2.00	$2.04
Cull Cow Weight	1250	1287	1250	1262
Cull Cow Price ($/lb)	$0.74	$0.77	$0.75	$0.75
Capital Structure				
Assets per cow	$8,623.65	$2,947.62	$51,453.70	$21,008.32
Interest Per cow	$8.15	$42.46	$31.03	$27.21
WACC	7.30%	7.44%	7.35%	7.36%

Table A.3. LC-HP 'Typical Farms'

Farm ID	BC-2	AB-1	AB-4	SK-4	LC-HP
Replacement Heifer-Specific Values					
Purchased Bred Heifer Price	$1,978.44	$1,978.44	$1,978.44	$1,978.44	$1,978.44
Pregnancy Rate [a]	4%	9%	5%	4%	
Heifer Retention Rate	10%	12%	9%	9%	
Feeder Heifer Price ($/lb)	$1.83	$1.90	$2.16	$1.79	
Heifer Wean Weight (lb)	580	587	610	570	
Heifer winter feed cost ($/heifer)	$278.93	$81.52	$91.24	$23.25	
Heifer Grazing cost ($/heifer)	$15.08	$39.49	$57.21	$124.80	
Cull Heifer Price ($/lb)	$1.56	$1.29	$1.38	$1.61	
Cull Heifer Weight (lb)	1146	1137	1155	1040	
Heifer Development Cost	$1,712.71	$1,493.74	$1,849.69	$1,414.99	$1,617.78
Cost of Production ($/Cow)					
Winter Feed Cost	$79.18	$135.87	$152.06	$218.07	$146.30
Grazing Cost	$23.20	$60.75	$88.01	$130.56	$75.63
Breeding Cost	$10.19	$45.02	$43.04	$42.93	$35.30
Other Variable Costs	$353.18	$213.55	$328.52	$214.71	$277.49
Total Variable Costs	$465.75	$455.20	$611.63	$606.28	$534.71
Unpaid Labour	$244.78	$98.56	$136.57	$597.08	$269.25
Production Parameters					
Herd Size	90	212	54	120	
Weaning Weight (lb)	584	598	627	598	602
Wean Calf Price ($/lb)	$1.97	$1.87	$2.29	$1.89	$2.00
Cull Cow Weight (lb)	1338	1406	1359	1300	1351
Cull Cow Price ($/lb)	$0.66	$0.82	$1.06	$0.65	$0.80
Capital Structure					
Assets per cow	$16,668.29	$3,020.25	$13,497.67	$11,722.30	$11,227.13
Interest Per cow	$63.09	$50.67	$43.24	$128.44	$71.36
WACC	7.39%	7.25%	7.41%	7.28%	7.33%

[a] Calves alive after 24 hours of birth per 100 exposed was used as the pregnancy rate and open rate.

Table A.4. LC-LP 'Typical Farms'

Farm ID	AB-2	AB-5	SK-1a	MB-2	MB-3a	MB-3b	LC-LP
Cost of Production							
Purchased Bred Heifer	$1,978.44	$1,978.44	$1,978.44	$1,978.44	$1,978.44	$1,978.44	$1978.44
Pregnancy Rate	12%	13%	13%	7%	6%	6%	
Heifer Retention Rate	9%	8%	19%	10%	10%	10%	
Feeder Heifer Price ($/lb)	$2.03	$2.11	$2.04	$2.03	$2.05	$2.05	
Heifer Wean Weight (lb)	536	521	456	463	437	437	
Heifer winter feed cost ($/heifer)	$107.80	$104.73	$158.44	$129.27	$98.31	$106.67	
Heifer Grazing cost ($/heifer)	$61.65	$41.37	$55.37	$47.40	$33.03	$35.16	
Cull Heifer Price ($/lb)	$1.64	$1.48	$1.78	$1.53	$1.53	$1.53	
Cull Heifer Weight (lb)	1137	1039	1058	1081	1190	1190	
Heifer Development Cost	$2,016.95	$1,500.08	$1,302.32	$1,263.53	$1,227.95	$1,209.36	$1,420.03
Winter Feed Cost	$138.34	$174.55	$242.37	$279.59	$246.76	$192.86	$212.41
Grazing Cost	$94.85	$63.64	$85.18	$72.92	$50.81	$54.09	$70.25
Breeding Cost	$55.44	$47.58	$13.30	$25.64	$19.69	$19.80	$30.24
Other Variable Costs	$235.43	$175.97	$218.79	$147.14	$218.12	$190.31	$197.63
Total Variable Costs	$524.06	$461.74	$559.65	$525.29	$553.38	$457.06	$510.53
Unpaid Labour	$44.66	$49.34	$282.74	$279.73	$73.44	$76.50	$134.40
Production Parameters							
Herd Size	280	221	350	225	270	270	
Weaning Weight	554	544	465	487	444	444	490
Wean Calf Price ($/lb)	$2.12	$2.21	$2.25	$2.08	$2.24	$2.24	$2.19
Cull Cow Weight	1338	1222	1245	1272	1400	1400	1313
Cull Cow Price ($/lb)	$0.97	$0.87	$0.77	$0.67	$0.80	$0.80	$0.81
Capital Structure							
Assets per cow	$14,588.38	$6,719.49	$3,673.08	$1,793.53	$71,477.78	$74,107.51	$28,726.58
Interest Per cow	$15.74	$6.25	$23.10	$76.12	$5.46	$94.36	$36.84
WACC	7.29%	7.37%	7.36%	7.45%	7.34%	7.35%	7.36%

Appendix B: EAA Using Tronstad et al.'s (1993) Probabilities

Table B.1 below illustrates the difference between using the average production probability provided in Table 4.1 and Tronstad et al.'s (1993) production probabilities from Table 4.1.

Table B.1. Tronstad Probabilities EAA Difference Between Heifer and Open Cow

	Difference in Equivalent Annual Annuity by Age of Open Cow [a]								
	Age Cow Open								
Farms ID	2	3	4	5	6	7	8	9	10
Base – Home-raised bred Heifer and 10 production years (no adjustments for dam age)									
HC-HP	$50	$65	$84	$107	$138	$180	$241	$340	$533
HC-LP	$110	$123	$142	$166	$197	$237	$295	$386	$558
LC-HP	$132	$146	$168	$196	$232	$279	$344	$443	$626
LC-LP	$141	$153	$174	$200	$232	$275	$334	$425	$592
Scenario 1 – Home-raised bred Heifer and 10 production years									
HC-HP	$28	$38	$58	$84	$118	$165	$234	$350	$570
HC-LP	$75	$84	$105	$131	$165	$210	$274	$379	$574
LC-HP	$79	$89	$111	$142	$181	$233	$305	$421	$629
LC-LP	$91	$99	$121	$149	$185	$232	$298	$404	$596
Scenario 2 – Purchased bred Heifers and 10 production years									
HC-HP	$39	$50	$69	$95	$130	$177	$245	$361	$581
HC-LP	$3	$13	$33	$59	$93	$138	$202	$308	$503
LC-HP	$22	$32	$54	$85	$124	$176	$248	$364	$572
LC-LP	$5	$13	$35	$63	$99	$146	$212	$318	$510
Scenario 3 – Home-raised bred Heifer and 7 production years									
HC-HP	$37	$60	$102	$168	$275	$486			
HC-LP	$97	$119	$160	$221	$319	$509			
LC-HP	$103	$125	$169	$236	$343	$545			
LC-LP	$118	$138	$179	$241	$339	$525			

Note: A negative value means retaining an open cow is more profitable and a positive number means it is more profitable to replace an open cow with a bred heifer.
[a] Assuming Tronstad et al.'s (1993) Production Probabilities by Cow Age (Table 4.1).

Appendix C: EAA Analysis Under Historical Low-Price Cycle

Here I will illustrate the impact of a low-price cycle by adjusting various prices for a sensitivity analysis to compare the original EAA difference Table 5.3 utilizing higher 2018 to 2022 prices. I adjusted the bred heifer purchases price to be $990.43 (2008-2012 western Canadian average), the D2 price $0.54 (2008 to 2012 September through December average), and the feeder prices using Saskatchewan feeder 2008 to 2012 October and November average prices (shown in the table below) (CanFax, unpublished). All other variables for the new analysis remained the same (Table 3.1).

Table C.1. 2008 to 2012 Price Slide for Feeder Calves in Saskatchewan

Weight	Price ($/lb)	Price Slide ($/lb)[a]
350	1.38	
450	1.31	-0.08
550	1.21	-0.10
650	1.14	-0.07
750	1.10	-0.05

Data from this table is from CanFax (unpublished data) Weekly Saskatchewan Feeder Prices from 2008 to 2012

[a] Price slide equals 100 lb weight feeder price – 100 lb weight lighter feeder price (ex. price slide from 350 lb to 450 lb calf is $1.38 - 1.31 = -0.08$)

This sensitivity analysis will illustrate how prevailing cattle prices influence the retain and replace decision of open cows. The Table below shows the results using the 2008 to 2012 prices described above.

Table C.2. Low Cattle Price EAA Difference Between Heifer and Open Cow

	Difference in Equivalent Annual Annuity by Age of Open Cow [a]								
	Age Cow Open								
Farms ID	2	3	4	5	6	7	8	9	10
Base – Home-raised bred Heifer and 10 production years (no adjustments for dam age)									
HC-HP	-$112	-$105	-$98	-$91	-$81	-$66	-$41	$6	$109
HC-LP	-$33	-$27	-$20	-$11	$1	$19	$45	$90	$183
LC-HP	-$23	-$16	-$8	$3	$19	$41	$72	$121	$218
LC-LP	-$4	$2	$10	$20	$34	$54	$82	$128	$217
Scenario 1 – Home-raised bred Heifer and 10 production years									
HC-HP	-$95	-$90	-$81	-$71	-$58	-$38	-$5	$58	$188
HC-LP	-$34	-$29	-$20	-$9	$6	$28	$60	$120	$237
LC-HP	-$37	-$32	-$22	-$9	$10	$36	$74	$140	$262
LC-LP	-$18	-$14	-$5	$7	$25	$49	$84	$146	$260
Scenario 2 – Purchased bred Heifers and 10 production years									
HC-HP	$62	$68	$76	$86	$100	$120	$152	$216	$346
HC-LP	$39	$44	$53	$64	$79	$101	$134	$194	$310
LC-HP	$51	$56	$65	$79	$98	$124	$162	$228	$350
LC-LP	$41	$45	$54	$66	$84	$108	$143	$204	$318
Scenario 3 – Home-raised bred Heifer and 7 production years									
HC-HP	-$124	-$111	-$92	-$61	-$8	$103			
HC-LP	-$44	-$33	-$14	$15	$65	$167			
LC-HP	-$48	-$37	-$17	$15	$70	$178			
LC-LP	-$23	-$14	$5	$34	$85	$185			

Note: A negative value means retaining an open cow is more profitable and a positive number means it is more profitable to replace an open cow with a bred heifer.
[a] Assuming Average Production Probabilities by Cow Age (Table 4.2).

Producers in a low-price environment have a variation in culling decision options relative to the high price environment results shown in Table 5.3. In the high price environment, all opens should be culled regardless of age. However, with a lower-cost environment younger open females with the option of home-raised bred heifer replacements should often be retained. HC operations with higher are better off retaining opens at later ages relative to LC operations. This is due to LC farms having lower heifer development costs than replacing more open cows at earlier ages relative to

HC farms. As well HP operations should retain open females at later ages relative to LP operations in the low-price environment. Therefore, the lead driver in the retain or replace EAA model is the cull and calf prices impacting the future discounted cashflows of the breeding females.