THESIS

BEEF ON DAIRY ECONOMIC SELECTION INDEX

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2025

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ABSTRACT

BEEF ON DAIRY ECONOMIC SELECTION INDEX

The objective of this study was to create an economic selection index for a beef on dairy crossbreeding system. In an effort to improve overall performance in the system, the index aims to increase profitability. Crossbreeding a beef bull with a dairy female aims to add value to the resulting calf entering the beef supply chain. Historically, dairy animals entering the beef supply chain have mostly been in the form of veal production as diary animals lack the growth and carcass performance characteristics of a beef animal. Data from previous literature as well as some current industry was used to derive a profit equation. The economic values used in the economic selection index were derived using the profit equation. The resulting economic selection index when compared to iGENDEC had a higher response to selection for efficiency traits largely due to the inclusion of average daily gain (ADG). The presented index also showed a positive response to selection for carcass weight (86.07 kg), ribeye area (9.78 sq. cm), and marbling (1.29). The economic index derived in this study can be used to improve the profitability of beef on diary production systems, due to these positive responses to selection.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

The United States' dairy industry has continually evolved and transformed throughout its history. Most innovations came around increasing milk yield and reducing costs. More recently, the dairy industry is adding value in another way, using beef sires in dairy systems, commonly called "beef on dairy", to produce a crossbred calf. Beef on dairy production aims to add value to the excess calves that don't end up in the dairy system, instead they enter the beef system. Historically, dairy animals entering the beef system have mostly been in the form of veal production as dairy animals lack the growth and carcass performance characteristics of a beef animal. The aim of introducing beef genetics for dairy was to decrease this disparity between dairy and beef animals and increase the value of these calves for the dairy selling these animals.

To highlight some of this disparity, a day-old dairy calf is worth between 85 and 125 USD as of 2023. This modern-day dairy calf has low value and is often considered a byproduct of the dairy industry. While its beef on dairy counterpart can be worth 400 USD as a day old (Overland Stockyards Market Reports, 2023). This is around a four-fold increase in value for the dairy producer. Also, dairy type animals consistently receive discounts at the packer. Beef on dairy animals can avoid some of these discounts from select packers by having an Angus phenotype. Foraker et al. (2022) documented that 78% of beef on dairy animals have an Angus phenotype and thus would avoid some of the dairy type discounts. While that only highlights the monetary disparity, disparity among physical characteristics also persists.

Ribeye area, marbling, fat thickness, and yield grade are some of the biggest disparities between beef and dairy animals in terms of carcass traits. A study in 2022 by Foraker et al. presented these disparities as ribeye area of 94.8 cm^2 for beef and 87.5 cm^2 for dairy type, respectively, a marbling score of 447 for beef and 482 for dairy type, fat thickness of 1.31 inches for beef and 0.92 for dairy type, and the percent of total carcasses receiving a yield grade of 1, 12.0% for beef and 7.6% for dairy type. Not all these disparities are at the expense of the dairy animal. Marbling is one area where dairy animals outperform beef animals. In the same study, beef on dairy animals had a ribeye area of 92.2 cm^2, a marbling score of 481, a fat thickness of 1.11 square inches, and 8.1 percent receiving a yield grade of 1. Beef on dairy animals reduced the disparity among all traits. They were also among the best for many of the traits compared to beef.

With beef on dairy systems proving to provide dairy producers with additional value, the focus now is to maximize that value. Because a beef on dairy animal is different from both a dairy and beef animal, they also need different selection criteria for genetic improvement to address the weaknesses in the cross. Both the beef and dairy industry have multiple selection indices to help aid in selection, such as “Dollar Beef” for Angus cattle and “Lifetime Net Merit” for Holstein cattle. Beef on dairy is lacking in the availability of these indexes.

One of the specific indices that Angus Association of America uses is “Dollar Beef” (American Angus Association, 2024). This index includes post-weaning gain (difference from weaning to yearling weight), dry matter intake, carcass weight, ribeye area, marbling, and back fat as component traits. As a terminal index, it includes important traits for producing high quality beef such as carcass weight, ribeye area, marbling, and back fat, with an efficiency trait represented as post-weaning gain together with dry matter intake. This index is also an economic index, meaning that the output value is related to a monetary value. Overall, this index is used by many beef producers and allows them to increase their selection intensity in multiple traits without focusing on just one trait. While it works for situations where Angus are bred to another full beef animal, beef on dairy animals need additional traits to adjust for their dam being a lactating dairy cow.

To account for the dam being a lactating dairy cow, calving ease needs to be added to the index. Calving ease will help control how big the calves are at birth, reducing the incidence of dystocia cases at the dairy. This will help the dairy cow transition into her next lactation with reduced health concerns and allow her to maintain her milk production levels. This is very important as the main purpose of a dairy is to produce milk, not beef.

Average daily gain and dry matter intake need to be included to help overall growth and performance of the beef on dairy calf. This combination helps find the most efficient growing cattle. Only accounting for dry matter intake allows animals that eat a lot but gain weight accordingly to rank highly. Only accounting for average daily gain doesn't discount animals that eat more but grow the same rate as others. Using both together allows individuals who grow more and eat less to rank the highest in this category. The carcass traits are also very important and remain a high portion of the selection criteria for a terminal selection index. These traits determine the value of the product and, overall, the value of the beef on dairy calf.

Overall, the production and use of a selection index for beef on dairy would help dairy producers profit from an otherwise byproduct of the dairy industry. The challenge with the selection of beef on dairy animals is catering to the dairy needs and keeping up with the beef demands. The use of a selection index helps manage both sides while still improving all included traits. The economic index then helps producers select animals that will likely produce offspring that are the most profitable. Using the economic selection index as a tool can greatly benefit the dairy producer and every other producer in the product chain. Therefore, the objective of this study was to create an economic selection index specifically designed for a beef on dairy system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

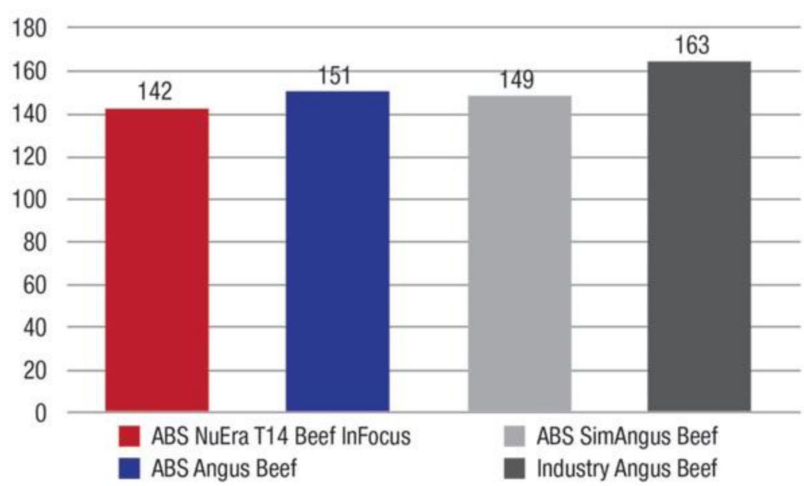
Modern day dairy calves have low value and often are considered a byproduct of the dairy industry. A day-old straightbred dairy calf is worth between 85 and 125 USD (Overland Stockyards Market Reports, 2023) as of August 2023. One opportunity for dairy producers to increase the value of these calves is to produce beef on dairy cross calves. These are created by mating a beef bull to the dairy cow. The resulting calf has a significant increase in value as it avoids the heavy discounts for straightbred dairy animals at harvest. A beef on dairy cross calf can be worth up to 400 USD at one day old (Overland Stockyards Market Reports, 2023). This is around a four-fold increase for the dairy producer.

While these beef on dairy calves have increased value, a dairy still needs to produce its replacement females. This means not every cow in the dairy herd can produce a beef on dairy cross calf. Sexed semen can be used on the high genetic merit heifers to produce the replacement females, allowing the dairy producer to then breed the rest of the herd with beef semen. Selection intensity is then increased as the highest-ranking females will only produce replacement females instead of some having an unwanted male calf. This method maximizes the genetic progress as the selection intensity is increased and minimizes the amount of unwanted straight dairy calves.

2.2 Dairy in Beef

For beef on dairy animals to make it to harvest they have additional steps and time as compared to their pure-bred beef cattle counterparts. In a typical system, these calves will first be transported from the dairy to a calf ranch within the first week of life, then to a feedlot between 400-500 lbs. This addition of the calf ranch phase includes the pressure to produce a product that quickly grows to market size for them to increase per animal value. This pressure is applied in days on feed (DOF). Not only do these new beef on dairy calves need to have good carcass characteristics, but they also need to be efficient and grow quickly (which is desired in beef cattle as well). As seen in the figure below when higher genetic merit beef bulls (defined as having EPDs in a specified range to qualify for a specific program such as ABS NuEra T14 Beef InFocus), are used the calf ranch can see up to an average of 21 less days on feed (Schmidt, 2021). This decrease in days on feed makes the value of these calves grow tremendously as feed prices rise. As these calves grow and are sold to a feedlot, growth traits is still highly valued. However, feedlots want a consistent product that they can market to packers to earn the best price. Incorporating the use of known genetic merit animals produces a more consistent product. Thus, further increasing the need to use evaluated beef bulls on dairies' low-ranking females.

Figure 1: Calf ranch performance – average number of days to reach 400lbs



[1]The type of beef genetics crossed with dairy animals influences the average number of days to reach 400 pounds or market weight for a calf ranch to sell.
[2](Cobank, August 2023)

After the beef on dairy animal moves to the packer, there are many traits that are considered to determine the value of these animals, but often dairy animals receive an automatic discount at the packer. These discounts range from packer to packer but can be significant discounts (10-25 USD per cwt), or even rejection of dairy type cattle (Jibben, 2017). Additional discounts can also be applied not only to the dairy carcass but also the beef on dairy cross. One common discount is liver abscesses. Having a liver abscess not only condemns the liver which had value, it also slows the production line. A severe case of liver abscess can lead to adhesions and condemnation of other high value muscles further decreasing the profits for the packer (Foreman, 2023). Furthermore, while liver abscesses also occur in pure bred beef cattle, they are presented at 20 to 50 percent higher incidence in dairy cattle (Foraker et al., 2022). Other reasons for discounts on the beef on dairy and dairy cattle at the packer are size and weight. Dairy cattle tend to be longer and taller than beef cattle. The carcasses from these can then cause backups while being processed at the packer, due to potential damage to the rail and longer fabrication times (Parish, 2016). The slowing down or even stopping of the rail leads to less profits for the packer (Foraker et al., 2022). Thus, due to the nature of these dairy carcasses the packer imposes a discount to include these slowdowns. Along with these previous discounts, discounts are also applied for red meat yield. Dairy and beef animals having equal live weights will vary at red meat yield. This reduction in red meat yield for the dairy animal is due to a lower live weight to carcass weight ratio, and a lower carcass weight to saleable whole muscle cuts (Foraker et al., 2022). Therefore, dairies strive to produce a product that can avoid these additional discounts. Current selection indices for beef dairy crosses focus mainly on carcass traits (American Angus Association, 2024). These traits are important but neglect other important areas of focus for feedlots, calf ranches, and dairies. Therefore, the inclusion of a comprehensive beef on dairy index could further benefit the dairy and maximize the profits from the beef cross calves.

2.3 Calving Ease and Dystocia

Calving ease is one of the few traits that dairy producers emphasize when breeding beef bulls to their dairy cows. Dairy producers want to make sure that their cow produces a calf without difficulty to begin the next lactation. Calving difficulty can lead to many mishaps and additional stress for the cow such as calf mortality, joint damage, or nerve damage. There are many types of dystocia, and they are divided into two categories: maternal and fetal caused. Fetal caused dystocia is more common and leads to 76 percent of the cases of dystocia in mature cows (Tierarzt et al., 1967). However, in the same study 32 percent of maternal caused dystocia resulted in cow death. This is compared to only 13 percent in fetal caused dystocia (Tierarzt et al., 1967). Regardless of the cause, dairy producers want to reduce the incidence of dystocia.

Two main causes of dystocia are feto-maternal disproportion and fetal malpresentation (Alsahaf et al., 2022). Birth weight and gestation length have been identified as risk factors for feto-maternal disproportion. This type of dystocia occurs when the calf is larger than that mother's pelvic area. Breeding strategies have been implemented using estimated progeny difference (EPD) to help reduce this on farm risk. An EPD is the value that a sire or dam's offspring is expected to express relative to the animals included in the group evaluated. An EPD for birth weight (BW) is commonly used to reduce feto-maternal disproportion. Calving Ease Direct (CED) is also a common EPD used to reduce feto-maternal disproportion as it expresses the difference in unassisted births to first calf heifers. Both the CED and BW EPDs can be helpful when making breeding decisions.

Other species such as swine also experience dystocia in similar ways. Swine tend to have higher rates of dystocia with each farrowing having at least one event 47.2% of the time (Nam et al., 2021) compared to <5% in dairy cattle (Mee, 2008). Even with more cases of dystocia, similar patterns were found in swine and dairy cattle. Dead piglets and piglets with a crown rump length >31 cm was associated with an increased rate of dystocia (Nam et al., 2021). Birth order was also associated with rate of dystocia with dystocia decreasing as order number increased. This follows a similar pattern with dairy cattle as primiparous animals have greater rates of dystocia than multiparous animals. The number of offspring also demonstrates an increased incidence of dystocia in dairy cattle (Mee, 2008). Meaning dairy cattle having twins results in higher dystocia. This would align with 47.2% of farrowing resulting in at least one dystocia event as it is common for swine to farrow multiple offspring at once.

Sheep commonly have twins, triplets, or quadruplets and exhibit the same trends for dystocia. In sheep quadruplets result in a higher chance of a dystocia event when compared to singletons, twins, and triplets (McHugh et al., 2016). However, twins experienced less difficult lambing than singletons and triplets. While this contradicts the dystocia rate in both swine and cattle, the result of increased dystocia in singletons can possibly be attributed to larger birth weight (McHugh et al., 2016). However, birth weight is not the only contributor to increased dystocia risk for singletons as lamb viability and ewe condition may also play an important role (McHugh et al., 2016). A larger birth weight or size at birth would concur with the findings in both cattle and swine and likely plays a role in singleton lamb dystocia. Parity was also shown to play a role in dystocia for sheep. Specifically, first parity ewes had increased risk of dystocia compared to all other multiparous ewes (McHugh et al., 2015). This result is consistent with both cattle and swine.

With the results from these dystocia studies, the use of birth weight and calving ease EPDs is important. Although dystocia will not be eliminated with this selection tool, risk of dystocia can be limited. The use of beef on dairy specifically provides a great example of the balance that needs to be considered when making selection on birth weight or calving ease. The dairy producer wants to ensure no problems when calving to get the cow into lactation as soon as possible with as little risk as possible. Meanwhile, the calf ranch, feedlot, and packer want a calf that will grow and produce a quality product. Too much selection applied to small birth weight and calving ease can forfeit the progress made in growth and meat quality traits, as shown by decrease in average daily gain as birth weight decreases (Smith et al., 1976). Overall, birth weight and calving ease play an important role in the beef on dairy production system and need to be considered when making selection decisions.

2.4 Fertility

Production in dairy and beef herds widely revolves around fertility. Heifers and cows in the dairy system need to establish and maintain pregnancy in a timely matter to maximize milk production. Beef systems need each heifer and cow to produce offspring to sell a calf crop and supply replacements for the next year. It has been shown that heifers that conceive early have an increased productivity and more reproductive success throughout their lifetime (Credille et al., 2023). Although it is the female producing the calf, fertility in both males and females is extremely important. In either a dairy or beef system the most common techniques for insemination are natural service, artificial insemination (AI), in-vitro fertilization (IVF), and embryo transfer (ET). In dairy systems that implement beef on dairy breeding programs, the most common procedure is exposing females to AI, then using natural service if pregnancy was not induced with AI. While that is the most common procedure there is an increased popularity in the use of ET and IVF as these practices become more reliable, and cost effective, again using natural service if pregnancy is not induced.

The previously mentioned techniques of obtaining pregnancy are tools that can be used to implement selection. Not all of these techniques will be successful for every producer. Due to this variance, different traits are of importance when selecting bulls to produce the next generation of offspring. In pasture settings using natural service, bull serving capacity is an extremely useful trait. A previous study showed high serving capacity bulls had an 18.5% higher conception rate, 2.3% higher pregnancy rate, and conception earlier in the mating period than medium serving capacity bulls (Blockey et al., 1978) where serving capacity is measured as number of services completed in a 7.5 hour pasture mating period. Heritability of serving capacity is unknown. While serving capacity was a selection tool for past bulls used for natural service, scrotal circumference can be used for selecting bulls for AI, IVF, ET and still applies for natural service. Previous studies have shown that scrotal circumference is a highly heritable trait with measurements at ages 12 and 18 months having the highest heritability (Quirino et al., 1998). Later studies identified scrotal circumference at 18 months of age being more impactful for selection (Frizzas et al., 2008). These studies also found that there is a positive genetic correlation between scrotal circumference and body weight. This allows for selection to be applied to both scrotal circumference and body weight simultaneously.

Scrotal circumference has been shown to have a significant positive correlation with sperm quality and quantity (Devkota et al., 2007). As a trait being used for fertility, scrotal circumference applies to all techniques mentioned for establishing a pregnancy. The effects of sperm quality on in-vitro fertilization and embryo quality in cattle are unknown. However, sperm quality is known to influence fertilization success and embryo quality in humans (Colaco et al., 2018). There is still more research that needs to be done on sperm quality effects on fertilization success rates and embryo quality. The current literature suggests that improved motility and concentration of sperm results in an increase in fertilization rate, increasing the cleavage and blastocyst rate of the developing embryo, and increasing the rate of implantation in the endometrium (Colaco et al., 2018). The improvement in these traits is positive for the use of scrotal circumference in both IVF and ET, however, future studies on these effects in cattle need to be confirmed by using motility scored semen. While scrotal circumference is important for fertility it also is only a male associated trait.

Selection in cattle systems is mainly focused on sire effects as sires contribute to an increase in selection intensity more than females do typically. This increase in selection intensity is due to the ability of males to have many offspring each year. Females have an impact on genetic progress but at a slower rate over the long term as they typically produce fewer total offspring over their life span. Female fertility is commonly measured with calving interval or days open (Berry et al., 2014). More recent studies have indicated that hip height, heifer conception in first 21 days of exposure, and reproductive tract maturity score could also be used as selection tools for fertility (Credille et al., 2023). Reproductive tract maturity score is taken 33 days prior to breeding. Heifers with a reproductive tract maturity score of 3 or greater presented a 1.4 to 1.67 times greater odds of becoming pregnant than heifers with a score less than 3 in a restricted breeding season. Reproductive tract maturity score is also moderately heritable and could be used for selection (Credille et al., 2023). However, other studies show reproductive tract maturity score to not be significant as it is highly correlated with other reproductive traits such as hip height and age at the beginning of the breeding period. Hip height and age at the beginning of the breeding period both increased the odds of becoming pregnant. Every 2.5 cm increase in hip height increased the odds of heifer pregnancy by 15% in beef replacement heifers. Every one month increase in age at the start of breeding increased the odds of heifer pregnancy by 20%. Hip height could be a selection tool used to account for female fertility based on the recent literature. Pairing hip height and age at the start of breeding with scrotal circumference may currently be the preferred selection tools for fertility in a production setting.

A more recent EPD that is used for fertility in beef and dairy cattle is heifer pregnancy (HP). For beef cattle, heifer pregnancy is reported as a percentage increase in the probability of a sire's daughters becoming pregnancy as first-calf heifers during a normal breeding season (American Angus Association, 2024). Dairy producers use heifer conception rate (HCR) instead of heifer pregnancy. Heifer conception rate is the percentage of inseminated heifers that become pregnant at each service. The EPD HCR represents the percent change in HCR. Both HP and HCR are measures of female fertility and reproductive success.

Fertility and reproductive success are also of great interest to other species in agricultural or production settings. The use of genomics, transcriptomics, proteomic, and metabolomic tools could provide increased knowledge about selection for fertility and reproductive traits. A recent study demonstrated that while reproduction is highly complex and species specific, there could be enough similarities between mammalian species for conserved biomarkers of fertility to be used (Long, 2020). This would allow animal agriculture to use comparative techniques to identify and accurately apply selection to important fertility markers. With fertility and reproduction being complex, there will be a great need to accurately identify several of these markers to accurately apply selection for fertility or reproduction as a whole.

2.5 Heterosis

The increase in performance by outcrossing is simply known as heterosis, or hybrid vigor, has been observed in many species of plants and animals. The mechanism behind heterosis has been in debate since its observation in 1908. It is observationally clear that when cross breeding the F_1 offspring perform significantly better in size, growth, performance, and many other characteristics than do the average of the parents. Meanwhile it seems that heterosis is maximized in the F_1 generation as the F_2 crosses decrease in vigor (East, 1936). Even with this clear observation for over a century, the entirety of heterosis outcomes is not explained. There are generally accepted models on how to calculate heterosis and general principles of additive dominance or gene linkage have been best in describing heterosis. Even these generally accepted heterosis coefficients are being investigated (Vienne et al., 2020). Overall, the measurement of heterosis is the increase in a trait of the F_1 offspring compared to that expressed trait in the best parent or the parent average.

Heterosis has also been shown to possibly be predicted by genetic distance between the mating pairs. This genetic difference was measured using DNA fingerprints in poultry (Haberfeld et al., 1996) and showed the greater genetic distance, or less genetic similarities, between a mating pair the greater heterosis effect. While the exact mechanisms behind heterosis are not completely clear, this ability to measure and predict heterosis can be helpful for selection purposes. The presented heterosis coefficients and other measurements for predicting heterosis have been successfully implemented in several plant species along with poultry, swine, drosophila, and other animal species (Dickerson, 1975).

The incorporation of heterosis in beef on dairy production is important as many different breeds are incorporated in this practice. Some breeds used for beef on dairy include Angus, Charolais, Limousin, SimAngus, Simmental, and Wagyu (Culbertson, 2023). The question of which breed is the best depends on what traits an individual values more in their breeding program. In most cases this revolves around minimizing discounts and maximizing incentives at the packer. Weight, size/length, quality grade, and yield grade are some of the most important traits that contribute to either discounts or incentives. In situations where the calves from the dairy are sold to calf ranches, important traits are birth weight, yearling weight, health traits, dry matter intake, and average daily gain. The dairy also adds fertility as an important trait for sire selection as conception rates are crucial. With all these traits being included, accounting for and maximizing heterosis is necessary. Increase in fertility dui to heterosis is expected around 4% for fertility traits such as calving rate (Bullock, 2019).

2.6 Feed efficiency

A more feed efficient individual can produce or grow at a higher rate while consuming the same amount or less feed than a less feed efficient counterpart. Feed efficiency has been at the forefront of sustainability as a more feed efficient animal has a lower carbon footprint of near 0.32

kg CO_2e / kg dry matter (Rotz et al., 2018). Along with sustainability it also provides a direct benefit to the producer by reducing feed costs and/or days on feed for an individual. With there being multiple benefits for feed efficient cattle it has been intensely researched by nutritionists and geneticists. Focusing on the genetic component of feed efficiency, dry matter intake (DMI) and average daily gain (ADG) are selection tools for more feed efficient cattle. Dry matter intake and ADG have moderate to high heritability of 0.84 ± 0.12 (DMI) and 0.53 ± 0.12 (ADG) respectively (Freetly et al., 2020).

Dry matter intake is a measurement of feed intake excluding water content. The goal of using dry matter intake as a selection tool is to reduce the amount of feed an individual needs. Reducing feed intake has both sustainability and economic value. Reducing the quantity of feed needed reduces the emissions associated with feeding cattle. Along with less emissions this also saves the producer money on feed costs. However, using just dry matter intake as a selection tool doesn't consider growth rate. If the individual eats less, but has reduced growth rates, the individual loses its emission and economic advantage as it will take more days on feed for this animal to reach the desired slaughter weight.

Average daily gain refers to the average weight an animal gains per day on feed, post weaning. Average daily gain as a trait is independent of feed consumption, when there are no feeding restrictions. An individual that has a high ADG will reach its desired slaughter weight faster, therefore reducing the number of days on feed. A reduction in days on feed also has environmental and economic value. However, there is a similar issue with ADG and DMI. If an individual has a high ADG but eats a lot more feed for the amount of ADG, the environmental and economic value are diminished. Therefore, the use of both DMI and ADG together can help identify animals that are more feed efficient.

Residual feed intake is also a common index used to determine feed efficiency in cattle. RFI is calculated by the difference between actual and expected feed intake. Many studies have been limited in size as RFI is a complex trait and expensive to calculate as is just the DMI measurements. With the available data, RFI has moderate heritability typically ranging from 0.14 to 0.36 and therefore could be used in selection (Crowley et al., 2010; Freetly et al., 2020). While RFI has been shown to reduce feed intake and improve feed efficiency, it is uncorrelated to ADG (Berry et al., 2012). With RFI unrelated to growth, individuals with low feed intake that also have a low growth rate may rank highly in RFI. In a genetic improvement program, to combat this downfall RFI would need to be selected for in addition to other growth traits or indices.

Alternative feed efficiency indices have also been presented such as residual body weight gain (RG), and residual intake and body weight gain (RIG). The RIG is the combination of both RG and RFI (Berry et al., 2012). The combination of both RG and RFI resulted in all animals that ranked highly for RIG having lower DMI and higher ADG than the average. Conversely all lowly ranked RIG individuals had higher DMI and lower ADG than the average (Berry et al., 2012). Selection on DMI, ADG, and body weight also can yield a similar result as RIG due to its selection index methodology. Therefore, selection based off DMI, ADG and BW could be a more applicable way of selecting for feed efficiency in a production system.

2.7 Pulmonary Arterial Pressure

Bovine pulmonary hypertension (BPH) leads to right-sided heart failure and edema in the chest and abdomen often resulting in death. Bovine pulmonary hypertension is also known as high-altitude disease or brisket disease (Neary et al., 2014). These alternative names for BPH come from the historical observation only at high altitudes and visual edema in the brisket region of the animals. Pulmonary arterial pressure (PAP) is a management tool to help identify animals at higher risk with studies showing that there is a significant allelic association with PAP in cattle allowing for positive selection of alleles predisposed to lower PAP (Neary et al., 2014). The use of PAP to aid in selection could help reduce the increase of heart failure and pulmonary hypertension seen in feedlot cattle specifically in the West and High Plains regions. Beef on Dairy cattle would greatly benefit from the use of PAP as many of them are finished at feedlots in these regions but incidence of the problem is relatively sparsely documented, due to cost autopsy for positive diagnosis.

It has been proposed that using a heart score is also a possible measure to develop an EPD that can reduce the risk of heart failure in future generations (Kukor, 2021). As more research and tools are developed there may be a better way to identify animals at risk for heart failure, while also allowing for selection to reduce this risk in future generations. This will have value for feedlots with the hope that a portion of that value could be added to the calves at time of acquisition by the feedlot given they would likely have higher survival rates. As of now the use of PAP is the best accepted way to identify these at-risk animals and allows for genetic selection. Currently there is no breed conversion for PAP that would allow for the comparison of animals across breeds. The creation of such a tool would greatly enhance the ability of selection to be applied to beef on dairy as many other breeds are included. Unless PAP is measured on a group large enough to develop an EPD there would be no way of including PAP in a multi-breed index or selection program. Thus, currently an individual breed index, such as ones offered by breed associations, would be the best way to select for low risk of heart failure or pulmonary hypertension animals to be used in a beef on dairy system.

Selection to reduce heart failure and pulmonary hypertension in feedlot cattle, specifically beef on dairy cattle could help increase the value of beef on dairy calves and avoid costly management on feedlots due to a lower risk of heart failure or pulmonary hypertension as both cause a reduction in performance or even death. The reduction of heart failure or pulmonary hypertension would also reduce costly management practices that go into taking care of these affected or dead cattle. It takes time to separate and care for these affected animals as well as additional time to remove a dead animal from the feedlot pens. This time is valuable on the feedlot as it takes time away from detecting other sick animals, cleaning pens, and other maintenance thereby reducing the efficiency and profitability of the feedlot itself. A reduction in time spent detecting sick animals leads to more sick animals and a negative feedback loop as more animals get sick in turn the reduction in time spent cleaning pens can also lead to disease or other health issues such as injury for those animals. Overall, the ability to select for and reduce the risk of heart failure and pulmonary hypertension is an asset that beef on dairy animals could take advantage of using PAP or possibly other tools developed in the future.

2.8 Indices

The use of an index for genetic selection was first proposed by Hazel in 1943. As described to achieve maximum accuracy three things must be known, relative economic values of the different traits, phenotypic constants, and genetic constants (Hazel, 1943). Within the phenotypic constants, standard deviations for each trait and the correlation amongst traits must be known (Hazel, 1943). Within the genetic constants, the heritability of each trait and the genetic correlations between each pair of traits must be known. (Hazel, 1943). Hazel names these three categories as the selection differential, the multiple correlation between aggregate breeding value and selection index, and genetic variability (Hazel, 1943). Of these three categories the second category of multiple correlation between aggregate breeding value and selection index offers the greatest opportunity to increase progress.

Since Hazel proposed the explanation for a selection index in 1943, other selection indices have been presented. Two indices designed for beef production and increasing overall profit and production were presented by MacNeil et al. (1994) and Newman et al. (1992). MacNeil's selection indices included a total of 18 traits (Table 1) but only 12 traits were evaluated in the terminal production indices. The selection index weights (**b**) were determined using:

$$\mathbf{b}=\mathbf{P}^{-1}\mathbf{Ga} \quad (1\text{-}1)$$

Where $\mathbf{G}$ is an n x m genetic variance-covariance matrix for m traits affecting profitability and n correlated indicator traits, $\mathbf{P}$ is a n x n phenotypic variance-covariance matrix of correlated indicator traits, and **a** is a m x 1 vector of relative economic values derived from literature (MacNeil et al., 1994). Two terminal indices were produced. The first (M3) focused on breeding a terminal sire to heifers focusing on producing progeny with light birth weight to avoid increased labor costs for observing primiparous females at calving and increased neonatal mortality associated with unobserved dystocia. The second (TX) focused on breeding a terminal sire to mature cows 5-9 years of age, to produce progeny with maximum expression of individual heterosis and superior growth rate, feed conversion and carcass composition. (MacNeil et al., 1994). The two indices differed in economic weights, therefore the selection index weights differed. The most extreme difference occurred in birth weight with M3 having a selection index weight of over three times that of the TX. Both indices resulted in an overall economic increase. MacNeil also goes on to state the development of sire and dam lines to fit particular niches is also of interest because of the variety of production and marketing systems that permeate the beef cattle industry. The present research has shown the flexibility of models that can be modified to accommodate differences in breeding herd structure and the biological characters that define profit (MacNeil et al., 1994). Thus, further explains the need to develop an index specific to the breeding objective.

The index presented by Newman in 1992 was developed for general purpose beef cattle in New Zealand. This production system represents the equivalent of a cow-calf operation in the United States which includes profit coming from 18-month steers, surplus heifers, and cull cows.

Being a broad selection index very few traits were included (Table 1). All genetic parameters used were derived from literature. Newman used three different profit functions to determine the value of each trait for steers, heifers, and cull cows. Economic values for each trait were derived by partial differentiation of the three profit functions. Responses to selection were greatest when economic values were calculated on an income and expense per year basis. Growth traits response to selection increased as discounts increased. There was little response to selection for feed intake, but an increasing negative trend as discounting increased. Reduction in economic weight for number of calves weaned per cow and carcass weight increased selection efficiency. When feed intake was removed there was an increased response to selection for growth traits.

Table 1: Traits included in MacNeil and Newman selection Indices.

Traits	MacNeil, 1994	Newman, 1992
Cow wt	X	
Male Fertility	X	
Female fertility	X	
Calf Survival	X	
Weaning wt direct	X	X
Weaning wt maternal	X	X
ADG backgrounding	X	
ADG Finishing	X	
Feed conversion	X	
% A grade	X	
Dressing %	X	
Meat yield	X	
Birth wt	X	X
Day born	X	
ADG Preweaning	X	
ADG Postweaning	X	
Fat depth	X	
Scrotal circumference	X	X
Number of calves weaned per cow		X
Yearling wt		X
Carcass wt		X
Feed Intake		X

An X represents the inclusion of the trait in the index.

While both the MacNeil and Newman indices included several different traits from one another, the main categories of selection remained the same. Growth traits in each study had the highest response to selection, even with using different traits associated with growth. MacNeil's index had a higher increase response to selection for growth traits than Newman, due to the exclusion of feed intake. The biggest difference in the two indices are how they included efficiency traits. Newman only used feed intake and MacNeil used average daily gain and feed conversion. In both cases they missed the complete efficiency representation. As seen in Newman's study, when feed intake is excluded, there is a significant increase in growth traits. The lowly heritable feed conversion also led to zero response to selection. Due to the terminal index not being focused on future generations of offspring, maternal responses were either left out (MacNeil et al., 1994) or had minimal response to selection except for maternal birth weight (Newman et al., 1992). Overall, the two main areas of selection response occurred in growth traits followed by efficiency traits.

With specific concentration on a desired gain index proposed by Yamada in 1975. The proposed desired gain index allows for selection based solely on the breeder's intention. Using this constrained methodology, to keep traits that are already at the desired level steady, the authors reported a 5% lower accuracy in the example provided by Yamada than a traditional selection index (Yamada et al., 1975). This specific desired gains index eliminates all economic weights, which has been a primary difference from other indices meant to maximize economic gain. When economic weights are applied to this specific example, the constraint of zero change in egg weight caused less than a 1% decrease in economic gain (Gibson et al., 1990). While this is a significant finding illustrating the potential to constrain a trait without diminishing economic gain; however, when more than one constraint was applied there was a 15% decrease in economic gain (Gibson et al., 1990). This detrimental effect of having more than one constraint is a major flaw for the use of the desired gain index when holding more than one trait constant is a desire.

More recently economic breeding objectives were compared to those of principles based on organic dairy farming and farmer preferences. The economic index resulted in the most economic gain, but resulted in unfavorable impacts on fertility, disease, and beef production traits (Slagboom et al., 2018). Consequently, the indices based on either organic dairy farming principles or farmer preferences were non-economically sustainable (Slagboom et al., 2018). Therefore, with the inclusion of these results and those previously, a combination of both economic weight and desired traits need to be considered.

References

Alsahaf, A., Gheorghe, R., Hidalgo, A. M., Petkov, N., & Azzopardi, G. (2022). Pre-insemination prediction of dystocia in dairy cattle. *Preventative Veterinary Medicine, 210*(105812).

American Angus Association. (2024). *Value Indexes*. Retrieved August 2024, from Angus: https://www.angus.org/nce/ValueIndexes

Berry, D. P., & Crowley, J. J. (2012). Residual intake and body weight gain: A new measure of efficiency in growing cattle. *J. Anim. Sci.*, 109-115.

Berry, D. P., & Evans, R. D. (2014). Genetics of reproductive performance in seasonal . *American Society of Animal Science, 10*(2527), 1412-1422.

Blockey, M. A., & Galloway, D. B. (1978). Hormonal control of serving capacity in bulls. *Theriogenology, 9*(2), 143-151.

Bullock, D. (2019, September 3). Retrieved from beef-cattle.extension.org: https://beef-cattle.extension.org/genetic-practices-to-improve-beef-cattle-reproduction/

Colaco, S., & Sakkas, D. (2018). Paternal factors contributing to embryo quality. *Journal of Assisted Reproduction and Genetics, 35*, 1953-1968.

Credille, B. C., Duggin, J. D., Jones, A. L., Nyhuis, G., Fontes, P. L., Jr, R. L., & Berghaus, R. D. (2023). *Physical traits, performance data, and reproductive tract maturity score can be used to predict fertility and likelihood of early conception in beef replacement heifers consigned to a heifer development prgram in southeastern United States.* 1193-1199: JAVMA.

Crowley, J. J., McGee, M., Kenny, D. A., Jr., D. H., Evans, R. D., & Berry, D. P. (2010). Phenotypic and genetic parameters for different measuers of feed efficiency in different breeds of irish performance-tested beef bulls. *J. Anim. Sci.*, 885-894.

Culbertson, R. (2023, Feburary). Retrieved from ebeef.org: https://ebeef.ucdavis.edu/sites/g/files/dgvnsk7331/files/inline-files/Factsheet2_2023.pdf

Devokota, B., KOSEKI, T., MATSUI, M., SASAKI, M., KANEKO, E., MIYAMOTO, A., . . . MIYAKE, Y.-I. (2008). Relationships among age, body weight, scrotal circumference, semen quality and peripheral testosterone and estradiol concentrations in pubertaal and postpubertal holstein bulls. *J. Vet. Med. Sci.*, 119-121.

Dickerson G.E., & DB, L. (1975). Breed, heterosis, and environmental influences on growth and puberty in ewe lambs. *American Society of Animal Science, 41*(1), 1-9.

EAST, E. M. (1936). Heterosis. *Genetics*, 375-397.

Foraker, B. A., Ballou, M. A., & Woerner, D. R. (2022). Crossbreeding beef sires to dairy cows: cow, feedlot, and carcass performance. *Translational Animal Science*, 1-10.

Foraker, B. A., Frink, J. L., & Woerner, D. R. (2022). Invited review: a carcass and meat perspective of crossbred beef x dairy cattle. *Translational Animal Science*, 1-7.

Foreman, J. H. (2023, May). *Liver Abscesses in Cattle*. Retrieved from MSD Veterinary Manual: https://www.msdvetmanual.com/digestive-system/hepatic-disease-in-large-animals/liver-abscesses-in-cattle

Freetly, H. C., Kuehn, L. A., Thallman, R. M., & Snelling, W. M. (2020). Heritability and genetic correlations of feed intake, body weight gain, residual gain, and residual feed intake of beef cattle as heifers and cows. *Journal of Animal Science, 98*(1), 1-6.

Frizzas, O. G., Grossi, D. A., Buzanskas, M. E., Paz, C. C., Bezerra, L. A., bo, R. B., . . . Munari, D. P. (2008). Heritability estimates and genetic correlations for body weight. *Animal*, 347-351.

Gibson, J., & Kennedy, B. W. (1990). The use of constrained selection indexes in breeding for economic merit. *Theoretical and applied genetics*, 801-805.

Haberfeld, A., DUNNINGTON, E. A., SIEGEL, P. B., & HILLEL, J. (1996). Heterosis and DNA Fingerprinting in Chickens. *Poultry Science*, 951-953.

Hazel, L. N. (1943). The genetic basis for constructing selection indexes. *Iowa Agricultural experiment station*, 476-490.

Jibben, B. (2017, January 16). *Dairy herd*. Retrieved from Dairy herd: https://www.dairyherd.com/news/large-holstein-steer-discounts-seen-packers-reduce-slaughter

Kukor, I. M., Thomas, M. G., Enns, R. M., Holt, T., Speidel, S. E., Cleveland, M. A., . . . Ellis, G. B. (2021). Sire differences within heart and heart fat score in beef cattle. *Translational Animal Science*, S149-S153.

Long, J. A. (2020). The 'omics' revolution: Use of genomic, trascriptomic, proteomic, and metabolomic tools to predict male reproductive tratis that impact fertility in livestock and poultry. *Elsevier B.V.*, 1-13.

MacNeil, M. D., & Newman, S. (1994). Selection indices for Canadian beef production using specialized sire and dam lines. *Canadian Journal of Animal Science*, 419-424.

McHugh, N., Berry, D. P., & Pabiou, T. (2015). Risk factors associated with lambing triats. *The Animal Consortium*, 89-95.

Mee, J. (2008). Prevalence and risk factors for dystocia in dairy cattle: A review. *The Veterinary Journal*, 93-101.

Nam, N. K., & Sukon, P. (2021). Risk factors associated with dystocia in swine. *Veterinary World*, 1835-1839.

Neary, M. T., Neary, J. M., Gretchen K. Lund, Holt, T. N., Garry, F. B., Mohun, T. J., & Breckenridge, R. A. (2014). Myosin heavy chain 15 is associated with bovine pulmonary arterial pressure. *Pulmonary Vascular Research Institute*, 496-503.

Newman, S., Morris, C., Bake, R., & Nicoll, G. (1992). Genetic improvement of beef cattle in New Zealand: breeding objectives. *Livestock Production Science*, 111-130.

Overland Stockyard. (2023). Retrieved August 2023, from https://www.overlandstockyard.com/market-reports

Parish, D. J. (2016). Beef Grades and Carcass Information. Mississippi State University Extension.

Quirino, C., & Bergmann, J. (1998). Heritability of Scrotal Circumference Adjusted and Unadjusted for Body Weight in Nellore Bulls, using univariate and bivariate animal models. *Theriogenology*, 1389-1396.

Rotz, C. A., Asem-Hiablie, S., Place, S., & Thoma, G. (2018). Environmental footprints of beef cattle production in the United States. *Elsevier Ltd.*, 1-13.

Schmidt, M. (2021, March 23). *agproud*. Retrieved from www.agproud.com/articles/34854-beef-on-dairy-crossbred-calves-through-the-supply-chain

Slagboom, M., Wallenbeck, A., Hjortø, L., Sørensen, A. C., Rydhmer, L., Thomasen, J. R., & Kargo, M. (2017). Simulating consequences of choosing a breeding goal for organic dairy production. *J. Dairy Sci.*, 11086-11096.

Smith, G. F. (1976). A Genetic Analysis of Maturing Patterns in Straightbred and Crossbred Hereford, Angus and Shorthorn Cattle. *Journal of Animal Science, 43*, 389-395.

Tierarzt, V. Sloss, & Johnston, D. E. (1967). The Causes and Treatment of Dystocia in Beef Cattle. *Australian Veterinary Journal, 43*, 13-21.

Vienne, D. d., & Fiévet, J. B. (2020). The Pitfalls of Heterosis Coefficients. *Plants*, 875-883.

Yamada, Y. (1995). Are economic selection indices always superior to a desired gains index? *Theor Appl Genet*, 655-658.

Yamada, Y., YOKOUCHI, K., & NISHIDA, A. (1975). Selection Index when Genetic gains of individual traits are of primary concern. *Japan J Genetics*, 33-41.

CHAPTER 3

BREEDING OBJECTIVE AND PROFIT EQUATION

3.1 Introduction

The beef on dairy production system is theoretically simple but complex in application. To account for as many of the factors that play a role in the final product and value of the beef on dairy animal as well as the costs associated with raising a beef on dairy animal to harvest, a profit function as well as literature values were used to estimate economic weights for economically relevant traits. Use of a profit equation allows the product system to be expressed mathematically regarding revenue and costs associated with production. To develop a profit equation, the breeding objective must first be determined as it contains the list of traits that influence the system's profitability. This chapter will define the production system and breeding objective, outline the included economically relevant traits, and construct the profit equation.

3.2 Beef on Dairy Production System

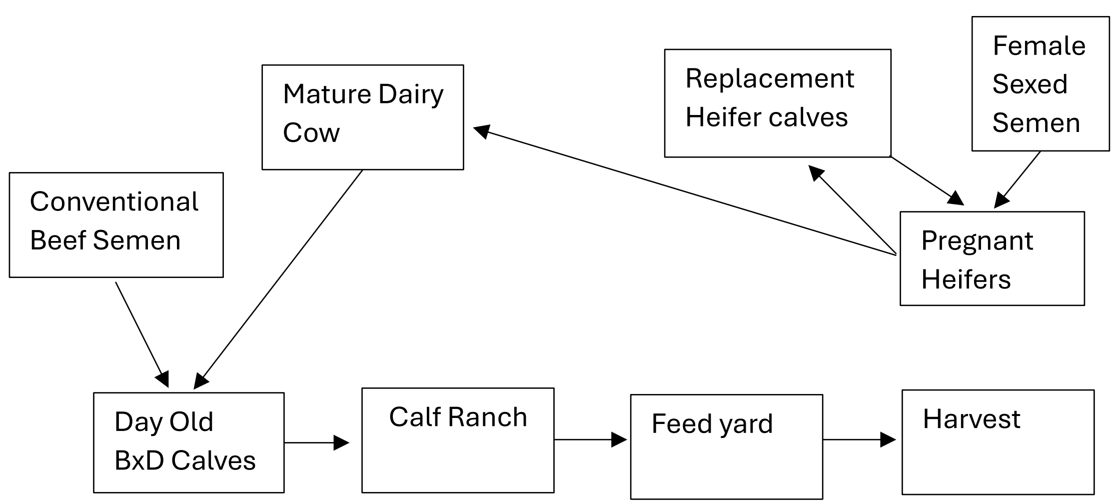
The production system for beef on dairy is unique as it combines aspects of both the dairy, such as year round breeding and the widespread use of artificial insemination, and beef operations, such as raising and finishing cattle for harvest. However, unlike both operations, beef on dairy offspring are completely terminal. Beef on dairy is implemented on dairy farms and consists of breeding older, non-primiparous cows with beef semen from a beef seedstock system. A beef seedstock system produces genetics for commercial cattle producers in the form of bulls or semen.

For this study, the focus is on a system that uses conventional beef semen on mature dairy females that are not going to produce replacement dairy females. This dairy herd is constant in size and produces its own replacement females through using sexed semen on high genetic merit heifers. The use of sexed semen in the dairy to dairy matings this allows for 80 percent of the herd to be bred to conventional beef semen with a projected 94.5% conception after three inseminations (Kniffen, 2022). All resulting beef on dairy calves are sold at a day of age and transported to a calf ranch to be raised until they reach 180 – 270 kgs at approximately one year of age. The calves are then transported to a feed yard to be finished for about 167 days (Foraker et al., 2022). All animals are then harvested, and carcasses evaluated and priced. The beef on dairy production system is shown in Figure 3.1.

3.3 Breeding Objective

A breeding objective is a list of traits that present the best way of achieving goals set forth by the company. The beef on dairy system's breeding objective is to produce a calf that will ultimately have high-quality beef, similar to a beef calf, but doesn't affect the cow's milk production by having calving difficulty. Overall, beef on dairy allows for profit from the mother producing milk while the beef on dairy calf is now also more profitable in the beef sector for calf ranches, feedlots, and packers. Therefore, the breeding objective consists of terminal traits but will also include a maternal purpose trait, direct calving difficulty. All of which will have economic values estimated.

Figure 3.1 Beef on Dairy Production System



3.4 Economically Relevant Traits

All included economically relevant traits are the focus of selection using economic selection indices as records are weighted by their economic values and heritability (Vleck, 1993). Economic weights for a single trait may vary between systems due to geographical reasons, management differences, or level of production (Dechow, 2024). For example, dry matter intake is an economically relevant trait that relates to feed costs (Dechow, 2024). The feed costs in a desert region will be different than the feed costs in a more tropical region, due to feed availability and quality. These two regions will also often have different feed stuffs incorporated into their ration likely based on what is available. For this study, we are assuming all animals are raised in the same management system and the same location, so the economic variation between regions is not included. Due to the same management system, fixed costs related to management, such as vaccination protocols, labor, marketing, and transportation costs, are assumed to be the same from year to year and, therefore, left out of the profit equation. Table 3.1 indicates the economic value for variables included in the profit equation.

3.5 Profit Equation

For this study, the profit equation will be broken down into two parts, pre-harvest and post-harvest, then combined later. All economically relevant and indicator traits listed in table 3.1 will be included in the profit equation. This will then be used to determine the economic weights used in the selection index for a one-unit increase in each trait of interest. In a beef on dairy system the main economic drivers are production costs, feed efficiency, carcass weight, yield grade, and quality grade. The profit equation will be built using the components that comprise these economic drivers.

3.5.1 Pre-harvest Profit Equation

The purpose of this section is to account for the differences between animals in the growing phase that affect the overall profitability of the animal. This section will include the economically relevant traits: calving difficulty (CD), dry matter intake (DMI), and average daily gain (ADG). Calf ranch feed cost (CRFC), feed yard feed cost (FFC), calf ranch housing cost (CRHC), feed yard housing cost (FHC), calf ranch entry weight (CREW), feed yard entry weight (FEW), and finished live weight, as a product of carcass weight (CW) and dressing percentage (DP), will also be included in this section. Calving is the beginning of the entire process and is determined by calving difficulty

Table 3.1 Profit function variables

Variable	Variable indication	Variable value
Calving Difficulty Value ($)	CDV	-7.51[1]
Calving Difficulty	CD	*
Calf Ranch Feed Cost ($/kg)	CRFC	0.05[2]
Feed yard Feed Cost ($/kg)	FFC	0.06[5]
Calf Ranch Housing Cost ($/day)	CRHC	0.97[2]
Feed yard Housing Cost ($/day)	FHC	0.88[2]
Calf Ranch Entry Weight (kg)	CREW	36[2]
Feed yard Entry Weight (kg)	FEW	181[3]
Days on Feed (Days)	DOF	167[6]
Carcass weight (kg)	CW	*
Dressing Percent (%/100)	DP	0.60[6]
Dry Matter Intake (kg)	DMI	*
Average Daily Gain (kg)	ADG	*
Carcass weight value ($/kg)	CWV	1.30[7]
Fat ($/mm)	FAT	*
Yield Grade 1 Premium ($/kg)	YGP	0.03[7]
Yield Grade Premium Difference ($/kg for an increase by 1)	YGPD	-0.016[7]
Marbling Score	MARB	*
Marbling Score Value ($/kg for an increase by 1)	MSV	0.102[7]
Average Marbling Score	AVG_{MARB}	5.58[7]

Values estimated from: [1] *(Berry, et al., 2019)*, [2] *(Dicostanzo, 2023)*; [3] *(Schmidt, 2021)*; [4] *(USDA Livestock, 2023)*; [5] *(Waggoner, 2024)*; [6](Foraker et al., 2022); [7]Caviness, JBS, and Cargill (2023). * Represents economically relevant traits.

and calving difficulty cost. It accounts for the economically relevant trait calving difficulty, which is necessary for producing a calf without affecting the dam's lifetime milk production. The cost of calving difficulty is represented in the profit function as:

$$\mathrm{CDC}=\mathrm{CD}*\mathrm{CDV} \tag{3-1}$$

Where CDC is the calving difficulty cost. CD is calving difficulty, expressed as an average calving difficulty where 1 is no difficulty and 5 is extreme difficulty, and is an economically relevant trait included in the selection index. CDV represents the calving difficulty value which is set at -7.51 USD for this study (Berry et al., 2019). Following the beef on dairy production system (Fig. 3.1), these calves are shipped at a day of age to a calf ranch. This is where costs associated with individuals at the calf ranch occur. These costs include the calf ranch feed cost (CRFC) and calf ranch housing cost (CRHC). For this study, CRFC is priced at 0.05 USD per kilogram of feed, and CRHC is priced at 0.97 USD fixed per day (Dicostanzo, 2023). Dry matter intake and average daily gain are used to determine the number of days on the calf ranch, and, therefore, overall costs. The parameters for number of days on the calf ranch is the difference between feed yard entry weight (FEW) and calf ranch entry weight (CREW), then divided by ADG. The calf ranch feed cost total is represented in the profit function as:

$$\mathrm{CRFCt}=\mathrm{CRFC}*\mathrm{DMI}*\frac{FEW-CREW}{ADG} \tag{3-2}$$

The FEW is the weight at which the calves are no longer on the calf ranch but have arrived at the feed yard, typically between 200 kgs and 270 kgs. Calf ranch housing cost total is represented in the profit function as:

$$\mathrm{CRHCt}=\mathrm{CRHC}*\frac{FEW-CREW}{ADG} \tag{3-3}$$

At the feed yard, feed and housing costs occur and work within a similar parameter as feed costs determined by the difference between FEW and CREW, then divided by ADG. For this study, FFC is priced at 0.29 USD per kilogram (Waggoner, 2024), and FHC is priced at 0.88 USD per day (Dicostanzo, 2023). The parameter is the difference between feed yard entry weight and finished live weight (FLW). Finished live weight is the function:

$$\mathrm{FLW}=\frac{CW}{DP} \tag{3-4}$$

The feed yard's total feed costs are represented in the profit function as:

$$\mathrm{FFCt}=\mathrm{FFC}^{*}\mathrm{DMI}^{*}\mathrm{DOF} \tag{3-5}$$

Where FFC represents the cost of one kilogram of feed at the feed yard. The use of DMI is to determine the total kilograms of feed per day an individual eats. Multiplying FFC by DMI produces the feed cost per day. Multiplying that value by total days at the feed yard results in the total feed yard feed cost (FFCt). Total days on feed is represented by DOF.

Feed yard housing cost total is represented in the profit function as:

$$\mathrm{FHCt}=\mathrm{FHC}^{*}\mathrm{DOF} \tag{3-6}$$

Where FHC is the daily feed yard housing cost. That is then multiplied by the total days on the feedyard which is represented as DOF.

Combining these equations to represent the pre-harvest part of the profit function (PH) as:

$$\mathrm{PH}=\mathrm{CD}\text{-}\mathrm{CRFCt}\text{-}\mathrm{CRHCt}\text{-}\mathrm{FFCt}\text{-}\mathrm{FHCt} \tag{3-7}$$

3.5.2 Post-harvest Profit Equation

The post-harvest profit equation accounts for the overall value of the carcass. Carcass weight is used to determine the base price of the carcass where yield grade and quality grade are then used as a premium/discount to add value to superior carcasses or reduce the value of inferior carcasses. The values used for a base price per pound and the premiums associated with yield and quality grade vary depending on the grid on which the carcass is being evaluated. For this study, an average of three grids, sourced from Caviness (personal communication/proprietary information, 2023), JBS (proprietary information, 2023), and Cargill (proprietary information, 2023), was used. For direct application, the base price and premiums should be adjusted to fit the specific grid in question and also adjusted as prices change over time. Averaging the three proprietary grids provided a more generalized assessment of potential selection index performance across the range of grid systems evaluated. These three sources of information were averaged and are presented below.

Base carcass price is set as a price per pound of carcass (2.86 USD per pound, Caviness, JBS, and Cargill, 2023) and is referred to here as the carcass weight value (CWV). The difference in base carcass price between two carcasses is a function of the carcass weight. The carcass base value (CBV) is then represented in the profit equation as:

$$CBV = CW * CWV \tag{3-9}$$

The carcass yield grade is used to mark premiums for carcasses. It demonstrates the percentage of closely trimmed boneless retail cuts from the loin, round, rib, and chuck (USDA,2024). Yield grade is calculated numerically and have possible scores ranging from 1 to 5. A yield grade of one indicates the highest-yielding carcass, while a yield grade of 5 indicates a carcass with the most fat trim. A premium is an additional amount paid per kilogram for carcasses that have desired characteristics. Discounts are deductions in price per kilogram for carcasses that have undesired characteristics. Premiums are applied to yield grades 1 and 2 while yield grades 4 and 5 are discounted. For the purpose of this study, we will focus on yield grade 3 and below as there are numerically very few yield grades 4 and 5 for beef on dairy carcasses (Foraker et al., 2022). Yield grade 1 premium was $0.15 USD per kilogram. Yield grade 2 premium was $0.08 USD per kilogram (Caviness, JBS, and Cargill, 2023). The yield grade equation was (NDSU, 2024):

$$YG=2.5+[(2.5*FAT/2.54)+(0.2*KPH)+(0.0038*CW/0.45)-(0.32*REA/6.45)] \quad (3\text{-}10)$$

Above, FAT represents adjusted fat thickness, at the 12th rib, in cm, and KPH stands for kidney, pelvic, and heart fat percentage. Due to the negligible impact on the overall yield grade and lack of data for KPH in beef on dairy animals, the value for KPH was held constant at 3.5 percent (Burdine, 2006) for this study. Therefore, the final yield grade equation used was:

$$YG=3.2+(2.5*FAT/2.54)+0.7+(0.0038*CW/0.45)-(0.32*REA/6.45) \quad (3\text{-}11)$$

Above, CW represents carcass weight in kilograms, and REA represents ribeye area in square centimeters. Yield grade consists of three economically relevant traits: FAT, CW, and REA. All three are included in the selection index, and economic weights will be calculated from the overall profit equation. To include the premium for yield grades 1 and 2, the yield grade value equation is:

$$YGV= YGP+YGPD*(YG-1) \quad (3\text{-}12)$$

Where YGV is the yield grade value or the premium per kilogram of carcass. YGP represents the yield grade premium for a yield grade of one. YGPD represents yield grade premium difference, which is the difference in premium for a one-unit increase of yield grade. To get the overall increase in carcass value due to yield grade:

$$CYGV=CW*YGV \quad (3\text{-}13)$$

Where CYGV is carcass yield grade value. This is the final value that will be used to represent yield grade in the profit equation.

The quality grade is the third and final piece of the post-harvest income equation. Quality grade reflects the expected tenderness, juiciness, and flavor of meat and was developed by the United States Department of Agriculture (USDA, 2017). Carcasses from animals of this age can generally receive one of three USDA quality grades: Prime, Choice, and Select. Choice is often broken into two sections, upper 2/3 and lower 1/3. Due to the lack of availability of this differentiation in this study, all grades of Choice are considered as the same category. A grade of Prime represents the expected best eating experience, followed by Choice, and then Select. There are other quality grades called: Standard, Commercial, Utility, Cutter and Canner. These quality grades were numerically very low in our study field data (presented in chapter 4), representing only 0.2% of the harvest, and may be attributable to management factors unrelated to genetic improvement (Foraker et al., 2022). For these reasons, these outcomes were omitted. Leaving only the possibility of USDA quality grades of Prime, Choice, and Select. There is a premium for Prime, which can vary depending on the grid used. The value used for this study was calculated as an average across grids from Cargill (proprietary information, 2023), Caviness (proprietary information, 2023), and JBS (proprietary information, 2023), resulting in a value of $0.55 USD per kilogram of carcass as the difference between choice and prime. Choice has no premium or discount associated with the quality grade. Select grade results in a discount that also varies depending on the grid used. For this study the Select discount was calculated as an average across grids from Cargill, Caviness, and JBS, resulting in a value of -$0.22 USD per kilogram of carcass as a deviation from the Choice grade.

The assessment of USDA quality grade is somewhat subjective and relies on the individual visually grading the carcass. These trained graders use intramuscular fat score and carcass maturity to determine the overall quality grade. For this study, the animals should receive similar, if not identical, carcass maturity scores due to their age and identical management. The intramuscular fat score would then be the primary driver in determining the difference in USDA quality grade among the individual carcasses. Marbling score is the trait indicated by intramuscular fat and is an economically relevant trait. The traditional equation for USDA quality grade is:

$$QG=OM+MARB \quad (3\text{-}14)$$

OM represents overall maturity and is omitted in this study. There are some beef on dairy production systems, such as grazing or grass fed, that could go over the 30-month maturity score, however, they are outside the scope of this system. MARB represents marbling score. Therefore:

$$QG=MARB \quad (3\text{-}15)$$

To account for the premium for USDA QG Prime, the discount for USDA QG Select, and no change in price for USDA QG Choice, the quality grade value (QGV) was calculated by increasing the proportion of Prime graded animals by 1% and determining the resulting average change in price for all animals. Overall, the shift in the distribution will allow for a value that accounts for the average change in price when increasing quality grade as a categorical and non-linear trait (Zeng, 2013). The resulting QGV is 1.34×10^{-2} USD per change in marbling score that results in 1% more animals grading Prime. The change in marbling score representing 1% increase in animals grading Prime is 0.06. Therefore, the marbling score value (MSV) represented as a one-unit change from the mean in marbling score is 2.24×10^{-1} USD.

To get the overall increase in carcass value due to quality grade:

$$CGQV=CW*MSV*(MARB\text{-}AVG_{MARB}) \quad (3\text{-}16)$$

Where CGQV is the carcass quality grade value. CW is the carcass weight of the individual. MSV equals the constant 2.24×10^{-1} USD. MARB is the marbling score of the individual. AVG_{MARB} is the constant 5.58 derived from an average marbling score of 27,327 beef on dairy animals as summarized in Chapter 4.

The complete profit equation can then be defined as:

$$P=PH+CBP+CYGV+CQGV \tag{3-17}$$

Where P represents profit, PH is the pre-harvest equation, CBP is the carcass base price, CYGV is the carcass yield grade value, and CQGV is the carcass quality grade value.

3.6 Results and Discussion

All economically relevant traits that are included in this specific economic selection index will be included as phenotypic data. The economic weight of each trait was determined using a profit equation in which all traits were set to their mean values; the resulting change from a one-unit increase in a given trait was taken as its economic value, following the approach of Rewe et al. (2004). The mean, standard deviation, and heritability of animal performance traits were obtained from the literature, with values presented in Table 4.1. Using data from an actual operation would be more ideal and should be considered in future studies. Using data from an actual operation would also allow the profit equation to represent the system better as all parameters could be defined and management differences could be accounted for.

The profit equation presented in this chapter was derived to represent a general outline of a beef on dairy system. Due to the generality of the system used, many management-related costs were left out or assumed to be the same among farms, as the selection index derived using the profit equation will be demonstrated on simulated herds instead of real herds. Assuming the same management related costs, the difference in values resulting from the profit equation and selection index will be represented as differences due to genetics, not management differences.

The overall use of the profit equation will be beneficial in developing the overall selection index. To continually represent changes in the industry, the profit equation presented would need to be updated over time as costs, revenues, and animal performance change. Additionally, for a specific operation, this general profit equation would need to be adjusted to represent the specific operation best.

Further the inclusion of death/loss would more accurately represent a complete system, with the possibility of genetic traits such as PAP then becoming economically relevant. The adaptation of the profit equation over time is necessary to develop economic weights that represent current markets.

3.7 Conclusion

The general beef on dairy system is explained through the profit equation. Economic weights can then be determined for the economically relevant traits that selection can be applied as desired through an economic selection index. Different beef on dairy systems may be similar but not exact. Therefore, each system should adjust the profit equation as the economic weights for the same trait may vary among systems. With this adjustment animals should only be ranked with the index and profit equation for the system they are in. Likewise, animals from separate systems cannot be compared using the same economic selection index.

3.8 References

Berry, D. P., Amer, P. R., Evans, R. D., Byrne, T., Cromie, A. R., & Hely, F. (2019). A breeding index to rank beef bulls for use on dairy females to maximize profit. *J. Dairy Sci*, 102:10056-10072.

Burdine, K. (2006). Understanding beef carcass data reports. *The Beef Site*. Accessed 2024 https://www.thebeefsite.com/articles/750/understanding-beef-carcass-data-reports/

Dechow, C. D. (2024). Effects of genetic and environmental trends from 1970 to 2020 on farm efficiency estimated with a whole farm modeling system. *J. Dairy Sci.*(in press).

Devokota, B., Koseki, T., Matsui, M., Sasaki, M., Kaneko, E., Miyamoto, A., … Miyake, Y.-I. (2008). Relationships among age, body weight, scrotal circumference, semen quality, and peripheral testosterone and estradiol concentrations in pubertal and postpubertal holstein bulls. *J. Vet. Med. Sci.* 70:119-121.

Dicostanzo, A. (2023). Thinking about backgrounding calves in the fall. *Drovers*. Accessed 2024. https://www.drovers.com/news/beef-production/thinking-backgrounding-calves-fall

Foraker, B. A., Ballou, M. A., & Woerner, D. R. (2022). Crossbreeding beef sires to dairy cows: cow, feedlot, and carcass performance. *Transl. Anim. Sci.* 6(2):txac059. https://doi.org/10.1093/tas/txac059

Foraker, B. A., Frink, J. L., & Woerner, D. R. (2022). Invited review: a carcass and meat perspective of crossbred beef x dairy cattle. *Transl. Anim. Sci.* 6(1):txab177. https://doi.org/10.1093/tas/txab177

Kniffen, D. M. (2022). Reproduction by the numbers. *PennState Extension*. Accessed 2024. https://extension.psu.edu/reproduction-by-the-numbers

NDSU. (2024). Yield grades and carcasses. *North Dakota State University*. Accessed 2024. https://www.ndsu.edu/agriculture/ag-hub/ag-topics/livestock/beef/production/yield-grades-carcasses

Rewe, T. O. (2004). Development of breeding objectives for production systems.

Schmidt, M. (2021). Beef-on-dairy crossbred calves throught the supply chain. *agproud*. Accessed 2023. www.agproud.com/articles/34854-beef-on-dairy-crossbred-calves-through-the-supply-chain

USDA. (2024). Beef grading. USDA Beef Research. Accessed 2024. https://www.beefresearch.org/resources/product-quality/fact-sheets/beef-grading

USDA Livestock, Poultry and Grain Market News. (2023). *National Dairy Comprehensive Report - Monthly.* St. Joseph, MO: USDA.

Vleck, L. D. (1993). *Selection index and introduction to mixed model methods.* CRC Press.

Waggoner, J. (2024). *Kansas Feedlot Performance and Feed Cost Summary.* K-State Research and Extension.

Zeng, X. (2013). Beef cattle maternal and terminal economic selection indices. Fort Collins, Colorado: Colorado State University.

CHAPTER 4

ECONOMIC VALUES

4.1 Introduction

Economic values quantify the contribution of economically relevant traits within a production system. These values indicate the relative economic importance of each trait in both magnitude and direction. Estimating economic values involves inserting population means for economically relevant traits into the profit equation and applying partial differentiation to determine the economic value for a unit change in an economically relevant trait. This chapter will present the economic values for the beef on dairy production system described in Figure 3.1 using the profit equation described in Equation 3-17.

4.2 Economic Value of Continuous Traits

Economic values for continuous traits are derived using partial profit function differentiation (Rewe, 2004). The partial differentiation of the profit function yields economic values that reflect a unit change in economically relevant traits. This method allows for the derivation of many variables from a single profit equation. The partial derivative measures how a function changes as one variable changes while all others remain constant. The profit equation is the function used. In this study all economically relevant traits not being calculated at the time were held constant at their population means found in the literature. The respective trait being calculated will then have its value changed by a one phenotypic standard deviation increase to determine its economic value. For example the profit equation with all economically relevant traits at their respective means is 505.43. When changing only calving difficulty by one standard deviation the output of the profit equation is 501.34. Meaning the resulting difference of -4.09 is the economic value used for calving difficulty. The means of all traits for which economic values will be calculated are listed in Table 4.1.

4.3 Economic Value of Categorical Traits

While most economically relevant traits in the profit equation are continuous, some are categorical, such as yield grade and quality grade. As these traits impact the overall economic value of an individual, they should still be included in the index despite the economic value not always changing due to a phenotypic unit change. Due to categorical traits having an optimum range, where a specific outcome is more desired, we can infer that there is a relationship between their population mean and economic value (Kluyts et al., 2007). An example would be calving difficulty. Calving difficulty is a categorical trait that is related to growth traits as well as dystocia. The optimal level occurs in the middle where the extremes may have negative economic impacts. For instance, calving difficulty scores of 1 can result in calves that are too small, whereas scores of 5 may be associated with the death of the calf or dam. There is also an assumption of an unobserved, underlying, normal distribution of breeding value in which the trait has categorical thresholds to determine the phenotype (Koots et al., 1994). Therefore, this distribution can be used to determine the economic value. This is calculated as the difference between the original distribution and the distribution after a one percent change.

4.4 Economically Relevant Traits

Not all traits measured in the production system are economically important. Likewise, not all traits for which selection is desired have economic implications. Such traits may still be included due to a preserved benefit that may become economically relevant in the future. Over time, these economically relevant traits may change. Currently, pulmonary arterial pressure (PAP) is the only trait that is included in the selection index that is not economically relevant at the time of this study. Pulmonary arterial pressure is included due to its importance in determining an individual’s risk of brisket disease/heart failure, and could potentially have an economic value in the future as it relates to heart failure and death in feedlot animals (Kukor et al., 2022).

Table 4.1. Genetic parameters for economic relevant traits and PAP

Trait	μ_{Trait}	σ^2_P	h^2	σ_A
Calving Ease	1.56	0.61	0.23	0.37
Dry Matter Intake	3.68 (kg)	5.44	0.84	2.14
Average Daily Gain	1.05 (kg)	0.42	0.53	0.47
Marbling	5.58	1.39	0.34	0.69
Ribeye Area	97.16 (sq. cm)	2.64	0.29	0.88
Carcass Weight	393.13 (kg)	11,835	0.35	64.36
FAT	1.34 (cm)	0.034	0.35	0.11
PAP	45.55 (mm Hg)	110.25	0.30	5.75

[1]Parameters are from previous literature: (Saad et al., 2020), (Freetly et al., 2020), (Cockrum et al., 2019), (Neary et al., 2013), (Ladeira et al. 2021), (Zuin et al., 2012), and (Martin et al., 2021).

All genetic parameters of traits used in this study came from previous literature except for marbling, which came from a dataset that included marbling scores on over 27,329 Angus Holstein crossbred cattle carcasses harvested in 2023 (Table 4.1). In future studies using a select beef on dairy production system would be best to determine all genetic parameters as they may be different than full bred beef animals. Other factors that are not included in the selection index but are included in the profit equation such as feed costs will vary seasonally and between beef on dairy systems. Values that vary over time should be adjusted as they change. The values of all costs or revenues in this study were determined from a national average, or closest to that, among known beef on dairy production systems in 2023 (USDA Livestock, 2023 and Dicostanzo, 2023).

The unique beef on dairy system allows for increased selection intensity on a smaller number of traits as compared to indexes that include maternal traits given the retention of replacement females. As a completely terminal production system where no replacements are needed, the meat production traits are higher in economic ranking when compared to other systems that have replacements (Zeng, 2013). Other cattle production systems are therefore, unable to maximize beef production traits due to reproductive and other needs. With this increased selection intensity for terminal traits due to minimizing maternal traits, the economic values for each terminal trait are inflated when compared to other maternal systems in previous literature.

Examples of inflated selection index weights for terminal indices when compared to their maternal counterparts are shown by MacNeil et al. (1994) and Zhang et al. (2020). MacNeil presented index weights for a maternal line along with two terminal lines. Traits such as birth weight, average daily gain, and dam weight resulted in an increased selection index weight for the terminal index by 0.253 (-0.333 and -0.080, maternal vs terminal), 37.843 (-5.620 and 32.223, maternal vs terminal), and 0.024 (-0.013 and 0.011, maternal vs terminal), respectively. This change in selection index weight is expected as the purpose for the index changes. Terminal indices are more directed to carcass characteristics and put no emphasis on maternal traits. Another example of this in a sheep population is presented by Zhang et al. (2020) resulting in an increase again in birth weight and average daily gain, while also showing an increase in other traits such as milk yield and scrotal circumference. Zhang also presented a reduction of index weight in the terminal index for calving ease and stayability when compared to the maternal index weights. The difference of overall selection goals between maternal and terminal systems is the main driver of differing selection index weights as shown by inflated values of terminal traits for the terminal index. Therefore, the presented index may have inflated values of terminal traits compared to other maternal indexes.

In this study the two traits that had the greatest impact on the overall profit and consequently have the highest and lowest economic weight are ADG ($408/kg/day) and DMI (-$238/kg/day) respectively. These two traits are also among the highest-ranking economic traits in other production systems, including the native beef and sheep production systems reported by

MacNeil et al. (1994) and Zhang et al. (2020), respectively. These two traits function by minimizing production costs while also influencing some post-harvest carcass traits. Following those two traits, CW ($46.7/kg) and MARB ($44.4/Marbling Score) are the next highest and positive ranking traits included in the selection index. Both traits are tied directly to carcass value. Carcass weight is the basis of minimum price for a carcass. Premiums are also applied as a per cwt basis, making carcass weight important in the overall value of the carcass even for premiums CW is not directly influencing. The final two traits are FAT and CE, which still have an increased influence on profit when compared to other systems. However, in this production system, they are the lowest two ranking traits as they influence less streams of revenue or costs than the other stated traits.

All selection index weights were calculated using equation (5-2), as presented in Chapter 5. All selection index weights, and economic values are presented in Table 4.2.

Table 4.2. Selection index weights and economic value for each trait

Trait[1]	Selection Index Weight	Economic Value
CD (SD Calving Difficulty)	-3470	-$4.09
DMI (kg/day)	-811	-$238
ADG (kg/day)	-3216	$408
MARB (Marbling Score)	-118	$44.4
REA (sq. cm)	-503	$1.69
CW (kg)	30.5	$46.7
FAT (cm)	-2395	-$2.57
PAP (mmHg)	22.2	$0

[1] CE: Calving Ease, DMI: Dry matter intake, ADG: Average daily gain, MARB: Marbling score, REA: Ribeye area, CW: Carcass weight, FAT: Fat thickness, PAP: Pulmonary arterial pressure.

4.5 Conclusion

Profitability is the primary focus of a beef on dairy system. Therefore, identification of traits that most influence profit is necessary. In this completely terminal system, there is a limited number of traits that influence profit. The use of the economic value derived in this chapter for each trait determines the weighting of selection pressure for each trait. This weighting, due to profitability maximizes the overall profit when selecting for all these traits at one time. While there are many traits that an individual gets evaluated on, not all have an economic impact or can be recorded. As more research and data is collected on groups of individuals, more traits may be identified or become economically important. Due to the complete terminal system, economic weights for terminal traits were shown to have a higher economic value (MacNeil et al., 1994; Zhang et al., 2020). The selection of several traits at once is an effective way to improve efficiency of selection and can improve multiple traits at one time.

4.6 References

Cockrum, R. R., Speidel, S. E., Crawford, N. F., Zeng, X., Blackburn, H. D., Holt, T., ... Thomas, M. G. (2019). Genotypes identified by genome-wide association analyses influence yearling pulmonary arterial pressure and growth traits in Angus heifers from a high-altitude beef production system. *Livestock Science,* 224, 75-86.

Freetly, H. C., Kuehn, L. A., Thallman, R. M., & Snelling, W. M. (2020). Heritability and genetic correlations of feed intake, body weight gain, residual gain, and residual feed intake of beef cattle as heifers and cows. *Journal of Animal Science,* 98(1), 1-6.

Kluyts, J., Neser, F., & Bradfield, M. (2007). Derivation of economic values for the Simmentaler breed in South Africa. *South African Society for Animal Science, 37*(2), 107-121.

Koots, K., Gibson, J., Smith, C., & Wilton, J. W. (1994). Analyses of published genetic parameter estimates for beef production traits. *Animal Breeding Abstracts,* 62(5), 309-338.

Kukor, I. (2022). *FEEDLOT HEART DISEASE: UNDERSTANDING HEART SCORE AND ITS RELATIONSHIPS TO ECONOMICALLY RELEVANT TRAITS.* Fort Collins.

Ladeira, G. C., Paiva, J. T., Oliveira, H. R., Carrara, E. R., Pilonetto, F., Freitas, F. A., . . . Gaya, L. d. (2021). Random-efect meta-analysis of genetic parameter estimates . *Tropical Animal Health and Production, 53*(420).

MacNeil, M. D., & Newman, S. (1994). Selection indices for Canadian beef production using specialized sire and dam lines. *Canadian Journal of Animal Science*, 419-424.

Martín, N., Coleman, L., López-Villalobos, N., Schreurs, N., Morris, S., Blair, H., . . . Hickson, R. (2021). Estimated Breeding Values of Beef Sires Can Predict Performance of Beef-Cross-Dairy Progeny. *Frontiers in Genetics, 12*.

Neary, J. M., Gould, D. H., Garry, F. B., Knight, A. P., Dargatz, D. A., & Holt, T. N. (2013). An investigation into beef calf mortality on five high-altitude ranches that selected sires with low pulmonary arterial pressures for over 20 years. *Journal of Veterinary Diagnostic Investigation, 25*(2), 210-218.

Rewe, T. O. (2004). *DEVELOPMENT OF BREEDING OBJECTIVES FOR PRODUCTION SYSTEMS* .

Saad, H. M., Thomas, M. G., Speidel, S. E., Peel, R. K., Frasier, W. M., & Enns, R. M. (2020). Differential response from selection for high calving ease vs. low birth weight in American Simmental beef cattle. *Journal of Animal Science, 98*(7).

USDA Livestock, P. a. (2023). *National Dairy Comprehensive Report - Monthly.* St. Joseph, MO: USDA.

Zeng, X. (2013). Beef Cattle Maternal and Terminal Economic Selection Indices. Fort Collins, Colorado: Colorado State University.

Zhang, X., & Amer, P. (2020). A new selection index percent emphasis method using subindex weights and genetic evaluation accuracy. *J. Dairy Sci.*, 5827-5842.

Zuin R.G., ME, B., SL, C., GC, V., DG, G., DA, G., . . . DP, M. (2012). Genetic analysis on growth and carcass traits in Nelore cattle. *Meat Science, 91*(3), 352-7.

CHAPTER 5

SELECTION INDEX

5.1 Introduction

The final step is constructing the selection index using the parameters determined in the previous chapters. The use of economic weights and genetic parameters will be the driving force of the selection index. The breeding objective will be the focus of using the selection index and the corresponding selection index and economic weights used will reflect the direction of selection. This chapter covers the construction of the selection index and the corresponding change when compared to other terminal selection indices.

5.2 Materials and Methods

5.2.1 Developing Selection Index

The general selection index was first presented by Hazel in 1943 as:

$$I=b_1X_1+b_2X_2+\ldots+b_nX_n \quad (5\text{-}1)$$

Where ***I*** represented the index value, ***b*** represented the selection index weight for a given trait and, **X** represented the information used for selection on a given trait. Information that can be used for selection includes phenotypic, estimated breeding values (EBVs), or expected progeny differences (EPDs). The vector **b** can be represented as:

$$\underline{b}=P^{-1}R\underline{v} \quad (5\text{-}2)$$

Where **P** was a (co)variance matrix for evaluated traits. A **P** matrix accounts for phenotypic variance within and the genetic covariance between the included traits, where the diagonals are the phenotypic variance within a trait and the off diagonals are the genetic covariance between two respective traits. The **R** matrix indicates the genetic relationship within a population and was a (co)variance matrix for weighted traits. A **R** matrix accounts for the genetic variance within and the phenotypic covariance between the included traits, where the diagonals are the genetic variance within a trait and the off diagonals are the phenotypic covariance between two respective traits. The R matrix indicates the phenotypic relationship within a population and $\mathbf{v}$ is the vector of economic weights. For this study there are 8 evaluated traits included in the index and 7 weighted traits as shown in table (5.1). An evaluated trait is any trait that is included in the index. A weighted trait is any trait that has an economic weight. Therefore, P is an 8x8 (co)variance matrix. R is an 8x7 (co)variance matrix. v is a 7x1 vector. b is an 8x1 vector.

Table 5.1. Evaluated and Weighted Traits

Description	Included Traits[1]
Evaluated	CE, DMI, ADG, PAP, MARB, REA, CW, FAT
Weighted	CE, DMI, ADG, MARB, REA, CW, FAT

[1] CE: Calving Ease, DMI: Dry Matter Intake, ADG: Average Daily Gain, PAP: Pulmonary Arterial Pressure, MARB: Marbling score, REA: Ribeye Area, CW: Carcass Weight, FAT: Fat thickness

5.2.2 Genetic (co)variance Matrix

The development of the genetic (co)variance matrix is essential for estimation of selection index weights. The resulting genetic (co)variance matrix will be used for both the P and R matrices. The P matrix's diagonal was the first line on the diagonal of Table 5.3, while the R matrix's diagonal was the second diagonal of Table 5.3. The R matrix also included the off diagonals of Table 5.3. Genetic parameters used for this study were determined through literature. Calving difficulty came from 16 different beef breeds, including Angus, Simmental, and Charolais among others, (Jamrozik et al., 2014; Berry et al., 2019; Saad et al., 2020; and Negreiros et al., 2023). Dry matter intake and average daily gain were converted to kg per day and came from different beef crossbred populations including Angus, Hereford, and Charolais (Freetly et al., 2020; Uskenov et al., 2024; Tedeschi et al., 2015; Negreiros et al., 2023). Pulmonary arterial pressure came from Angus heifer and bull populations and were recorded in mmHg (Cockrum et al., 2019; Neary et al., 2013; Briggs et al., 2020). Marbling score genetic (co)variance came from Angus and Simmental crossbreed, Charolais, Simmental, and other beef breed populations (Mader et al., 2009; Tedeschi et al., 2015). Ribeye area came from Nellore, Angus, Charolais, and Simmental population, with all units converted to square centimeters (Zuin et al., 2012; Negreiros et al., 2023; Tedeshi et al., 2015; Briggs et al., 2020). Carcass weight came from Angus, Charolais, Simmental, and beef on dairy populations, with all units being converted to kilograms (Okut et al., 2013; Martin et al., 2021; Negreiros et al., 2023; Mader et al., 2009; Briggs et al., 2020; Tedeschi et al., 2015). Backfat thickness came from beef on dairy, Angus, and Charolais populations, with all units converted to centimeters (Martin et al., 2021; Negreiros et al., 2023; Mader et al., 2009; Briggs et al., 2020; Tedeschi et al., 2015). Ideally, these genetic parameters would be derived directly from beef on dairy crossbred populations; however, due to a lack of data, genetic parameters that were derived from beef breeds that are also used in beef on dairy crossbreeding were used instead.

Marbling mean and phenotypic variance were not determined using literature as the dataset was available for this study. The mean and phenotypic variance of MARB was determined using a dataset containing beef on dairy animals (n=27,329) from multiple different herds, all using Angus sires on Holstein dams, which were harvested at multiple different packers in the United States. All animals were identified using electronic identification ear tags and had sire recorded. The marbling score of each animal was recorded and linked to the electronic ear tag. The genetic parameters are shown in tables 4.1 and 5.3 and are based on findings in literature as described above.

Table 5.3. Phenotypic variance, (on diagonal), genetic variance (on diagonal, 2[nd] line) and genetic covariance (above diagonal) between traits in selection index.

Trait[a]	CD	DMI	ADG	MARB	REA	CW	FAT	PAP
CD	0.61 0.14	0	0.3	0.49	8.55	41.85	-0.72	-0.2
DMI		1.12 0.94	0.27	0.23	3.96	15.84	0.36	-1.15
ADG			0.086 0.045	0.07	1.68	7.56	0.08	-0.78

MARB				1.37 0.47	3.24	4.86	0.74	-0.65
REA					16.90 4.90	186.0	5.40	-11.2
CW						2435 852.27	11.4	-50.4
FAT							.219 0.052	-1.12
PAP								110.25 33.08

[a] CE: Calving Ease, DMI: Dry matter intake, ADG: Average daily gain, MARB: Marbling score, REA: Ribeye area, CW: Carcass weight, FAT: Fat thickness, PAP: Pulmonary arterial pressure.

The covariance between PAP and CD was not reported in previous literature. For this study the covariance was estimated using the covariance between calving difficulty and birth weight, then birth weight and PAP. Covariance between calving difficulty and birth weight was reported in literature as -0.66 (Saad et al., 2020). Birth weight and PAP covariance was reported as 0.15 (Crawford et al., 2016). Given these two correlations, a correlation of -0.2 between calving difficulty and PAP was assumed for this study (M. Enns, personal communication).

5.2.3 Response to Selection

Estimating the response to selection is crucial in determining the effects of the selection index. The equation for estimating response to selection is presented by Van Vleck (1993):

$$\Delta T = D[\underline{\mathbf{b}}`\mathbf{P}\underline{\mathbf{b}}]^{\frac{1}{2}} \qquad (5\text{-}3)$$

Where D was selection intensity and equal to 1 standard deviation, and ΔT was the change in net merit where net merit was represented as the total expected economic response due to the economic values that were used. For this study, selection intensity is assumed to be equal to 1 standard deviation - the highest 38% percent are chosen (Bourdon, 2000). Expected changes in individual additive genetic value (S_g) for each trait included in the selection index is calculated as (Bourdon, 2000):

$$S_g = i\frac{\boldsymbol{b}`\boldsymbol{R}}{\sqrt{\boldsymbol{b}`\boldsymbol{R}\boldsymbol{v}}} \quad (5\text{-}4)$$

Where S_g represented the expected changes in the additive genetic value, and i was selection intensity (set as one), b was a vector of selection index weights, R was a (co)variance matrix as described in Chapter 5.2.1, and v was a vector of economic weights.

5.2.4 Index Comparison

To compare the presented index with other work, a direct comparison of economic weights, predicted genetic improvement, and the inclusion or exclusion of traits are important. While economic weights depend on the breeding objective and production system, iGENDEC (Beef Improvement Federation, 2025) and the presented index have common breeding objectives and criteria. Previous indices have been compared even when they differ in traits included in the index as presented by Newman (1992). The predicted genetic improvement for given traits as well as overall results of selecting using the indices can be compared.

The referenced iGENDEC refers to the BIF iGENDEC that is sponsored and operated by the Beef Improvement Federation (BIF). This version is an updated version to the original open source iGENDEC project released under the MIT open-source license. Using the Beef on Dairy version of the software, 15 traits are included: USREA (Ultrasound Ribeye Area), USIMF (Ultrasound Intermuscular Fat), USFAT (Ultrasound Fat), HCW (Hot Carcass Weight), REA (Ribeye Area), FAT (Fat thickness), MS (Marbling Score), BW (Birth Weight), WW (Weaning Weight), YW (Yearling Weight), FI (Feed Intake), MW (Mature Weight), STAY (Stay ability), HP (Heifer Pregnancy), and CD (Calving Difficulty).

Among the listed traits, six are also included in the presented index. The two traits that are in the presented index that are not represented in iGENDEC are ADG and PAP. Hot carcass weight is equivalent to carcass weight (CW), marbling score is equivalent to MARB, and feed Intake is equivalent to dry matter intake (DMI). Thus, predicted genetic improvement for these common traits can be compared as well as the overall results selecting using the indices.

5.3 Results and Discussion

5.3.1 Selection Index Weights

Weights for all 8 traits included in the selection index are in Table 4.2. These selection index weights are represented as the $\underline{b}$ vector in Equation (5-2). The economic value for PAP is 0 as there is currently no economic estimate of economic impact when selecting for or against PAP. In the future, additional data may result in a measurement of economic impact for PAP, likely through its relationship with death in the feedlot. However, PAP measurements at 14 months of age have recently been correlated with heart scores in beef animals (Kukor, 2022). Heart scores included in breeding decisions minimizes the potential risk of pulmonary hypertension in feedlot cattle reducing early feedlot death (Kukor, 2022). Selecting for lower heart scores will most likely not decrease favorable carcass characteristics at a drastic rate while improving cardiovascular fitness (Kukor, 2022). The inclusion of PAP due to its relationship to heart scores and its economic impacts due to heart health, therefore, could have some quantifiable economic impact in the future. In that case the economic value for PAP will need to be adjusted. All other traits' selection index weight will be influenced, in both magnitude and direction, by their respective economic weight. Likewise, economic values are variable and can be adjusted for any of the traits if needed. These adjustments may need to be made over time as economic values change such as cattle prices or feed costs. Traits with higher economic values or larger genetic variance are expected to have the greatest response to selection.

5.3.2 Response to Selection

The economic value response to selection is indicated in table 5.4. The response to selection when the economic value for each trait is changed by 10% is also located in table 5.4. These values indicate the expected change in response to selection when, selection intensity is one standard deviation and all economic values are increased or decreased by 10%, represented as ΔT (Zeng, 2013).

Table 5.4. Expected Response to selection with original, +10% and -10% economic values.

	Original EV	+10% EV	-10% EV
ΔT	2001.41	2201.55	1801.27

5.3.3 Genetic Gain

Expected genetic gain per generation was calculated for each trait. This is represented as S_g in previous equations. The resulting values are expected genetic gain due to selection for each trait after one generation using 1 standard deviation of index value. The values are presented in table 5.5.

Table 5.5. Expected genetic gain due to selection for each trait after one generation.

	CD	DMI	ADG	MARB	REA	CW	FAT	PAP
S_g	0.17	0.77	0.48	1.29	9.78	86.07	0.03	-2.26

There were expected genetic changes that are undesirable when compared to the profit equation. However, the index aims to maximize overall net merit. The undesirable changes are minimal and necessary to achieve a larger desirable change in other traits that lead to a higher net merit. An example of this is CD (0.17 calving difficulty), DMI (0.77 kg dry matter intake), and FAT (0.03 cm of backfat) are expected to change in an undesired way. Due to CD being represented on a 1-5 scale where 1 is no assistance needed; lower CD is desired in this case as opposed to the Angus EPD where a greater calving ease is desired. A positive increase in CD, DMI, and FAT is likely due to their correlations with ADG, REA, and CW. There were desirable changes in ADG (0.48 kg), MARB (1.29), REA (9.78 sq. cm), CW (86.07 kg), and PAP (-2.26 mmHg). The overall change in net merit is expressed in table 5.4 and shows a large positive change in net merit. The economic selection index considers all relationships between traits and maximizes net merit. Not every herd or system is going to be identical and because of these differences the selection index would be most impactful when using genetic parameters determined from the specific herd the index is to be applied. Therefore, the index derived in this study may have differing results among herds or systems even though they are similar. The selection index derived in this study used genetic parameters and economic costs from multiple systems that were similar but not identical. A future study would benefit from having all data points included in the profit equation and genetic parameters from the same herd or farm.

5.3.4 Index Comparison

To put this index in context a comparison between the index and other indices can be achieved using correlation. The correlations were done in RStudio using the following equation from Bourdon (2000):

$$r = \mathbf{v}'\mathbf{G}^{*}\tilde{\boldsymbol{v}}[\mathbf{v}'\mathbf{G}\mathbf{v}]^{-1/2}[\tilde{\boldsymbol{v}}'\tilde{\boldsymbol{G}}\tilde{\boldsymbol{v}}]^{-1/2} \quad (5\text{-}1)$$

Where r is the correlation between the two indices, **v** is a vector of economic weights, **G** is a genetic (co)variance matrix between traits of each index, and ~ represents the referred to index of a given matrix or vector. Two commonly used indices in the industry currently are $B and $G from the American Angus Association. Where $B includes ADG (represented as weaning to yearling gain differences), DMI, CW, REA, MARB, and FAT, and $G includes CW, REA, MARB, and FAT. As a representation of both carcass and feedlot traits the $B index is used. The $G index only includes carcass traits. The index presented in this study had a correlation of 0.42 with an index only including the traits in $G and 0.43 with an index only including the traits in $B. This moderate to strong positive correlation means that selection for the presented index would also lead to an increase in net merit described in both the $G and $B indices. The presented index is still different from $B and $G and it would provide beef on dairy producers with another option when selecting for their specific breeding objectives.

In comparison with iGENDEC, when using the same index weights for both indices, and only index weights are included for traits that are included in both indices, both magnitude and direction of predicted additive genetic gain were similar for all traits except for DMI, MARB, REA, and Fat. The predicted additive genetic gain for DMI were 0.77 kg and 0.19 kg for the presented index and iGENDEC, respectively. The difference in these results is worth further investigation. This result could be due to the inability to accurately predict DMI in the beef on dairy industry as both indices used literature to determine the genetic (co)variance matrix. Actual individual phenotypic DMI data on beef on dairy cattle in the described production system would be ideal and may produce a more accurate prediction for DMI. This strategy presents challenges as it is not always economically viable.

Similarly, REA differed in magnitude with predicted additive genetic gain of 9.78 sq. cm and 2.43 sq. cm for the presented index and iGENDEC respectively. This magnitude difference could be influenced by several factors including the presence of interaction with other traits included in each index. For example, REA has a strong genetic correlation with ADG which is present in this study but excluded in iGENDEC. When using a different set of selection index weights the same results occurred, with REA having a predicted additive genetic gain of 11.5 sq. cm and 2.71 sq. cm for the presented index and iGENDEC respectively. Due to similar results, using a separate set of economic values determined by iGENDEC the differences in DMI and REA are a result of differences between the indices. The economic values, while having an impact on overall additive genetic gain, did not change the relationship between the results of the two indices. This trend is also seen when comparing MARB and FAT between the two indices. This outcome was also observed by Newman (1992) when comparing indices.

The overall outcome of selection is similar in both indices with both indices showing an increase in overall weight and size as evidenced by large increases in both CW and REA. Conversely the index presented in this study focuses more on overall efficiency when compared to iGENDEC. This is largely due to the inclusion of ADG, rather than feed intake alone. The result is iGENDEC having higher additive genetic gain in CW when compared to the presented index by 8.06 kg. While there is a difference in CW gain, both indices can be advantageous depending on the specific production system and their economic pressures. For example, if feed cost is not a concern iGENDEC will help increase growth more than the presented index. When a system is more heavily impacted by feed costs, the proposed index could be a better option to improve efficiency over maximizing growth. This is similar to results from Newman (1992) when food conversion efficiency was included and CW response to selection was 0.137 standard deviation units, compared to 0.308 standard deviation units when excluded. Both indices will lead to desirable outcomes in a dairy breeding system.

To improve upon the presented index comparison and a challenge facing all beef on dairy indices would be availability and reliability of data. As previously mentioned, many trait estimates were derived from previous literature not a specific beef on dairy production system. The presented index would gain from having estimates of genetic and phenotypic values derived from a beef on dairy production system. This change could also lead to better estimates of all traits but specifically traits like DMI that are more difficult and costly to calculate.

5.4 Conclusion

The economic index derived in this study can be used to improve the profitability of beef on dairy production systems. This is due to the resulting positive impact on economic value presented in table 5.4. The selection index can be used even as economic values change and even shows an increase in profit when all economic values decrease 10%. Additional traits may be of interest and add value based on the grid the animals are marketed on. In these cases, the presented index should be adjusted to include these additional traits to maximize economic value.

The presented study assumes that genetic parameters obtained apply to the entire population of cattle used in beef on dairy production systems. These genetic parameters may vary over time as selection is applied and therefore the selection index should be updated over time to reflect these genetic changes in the population. Likewise, as economics vary the profit equation and therefore, economic weights, should also be adjusted over time to reflect those changes.

5.5 REFERENCES

Beef Improvement Federation. 2025. iGENDEC [Web-based decision support tool]. Beef Improvement Federation. Accessed 2025. https://igendec.beefimprovement.org/

Berry DP, Amer PR, Evans RD, Byrne T, Cromie AR, Hely, F. 2019. A breeding index to rank beef bulls for use on dairy females to maximize profit. *J. Dairy Sci*, 10056-10072.

Bourdon RM. 2000. *Understanding Animal Breeding.* 2nd ed. Upper Saddie River (NJ): Prentice Hall.

Briggs EA, Enns RM, Thomas MG, Holt TN, Speidel SE. 2020. Evaluation of the gentic relationship between high elevation pulmonary arterial pressure with moderate elevation with feedlot and carcass performance. *American Society of Animal Science*, S98-S102.

Cockrum RR, Speidel SE, Crawford NF, Zeng X, Blackburn HD, Holt T, Thomas MG. 2019. Genotypes identified by genome-wide association analyses influence yearling pulmonary arterial pressure and growth traits in Angus heifers from a high-altitude beef production system. *Livestock Science, 224*, 75-86.

Crawford NF, Thomas MG, Holt TN, Speidel SE, Enns RM. 2016. Heritabilities and genetic correlations of pulmonary arterial pressure and performance traits in Angus cattle at high altitude. *Journal of Animal Science, 94*(11), 4483-4490.

Freetly HC, Kuehn LA, Thallman RM, Snelling WM. 2020. Heritability and genetic correlations of feed intake, body weight gain, residual gain, and residual feed intake of beef cattle as heifers and cows. *Journal of Animal Science, 98*(1), 1-6.

Jamrozik J, Miller SP. 2014. Genetic evaluation of calving ease in Canadian Simmentals using birth weight and gestation length as correlated traits. *Livestock Science, 162*, 42-49.

Kukor I. 2022. *FEEDLOT HEART DISEASE: UNDERSTANDING HEART SCORE AND ITS RELATIONSHIPS TO ECONOMICALLY RELEVANT TRAITS.* Fort Collins (CO).

Mader CJ, Montanholi YR, Wang YJ, Miller SP, Mandell IB, McBride BW, Swanson KC. 2009. Relationships among measures of growth performance and efficiency with carcass traits, visceral organ mass, and pancreatic digestive enzymes in feedlot cattle. *Journal of Animal Science*, 1548-1557.

Martín N, Coleman L, López-Villalobos N, Schreurs N, Morris S, Blair H, Hickson R. 2021. Estimated Breeding Values of Beef Sires Can Predict Performance of Beef-Cross-Dairy Progeny. *Frontiers in Genetics, 12*.

Neary JM, Gould DH, Garry FB, Knight AP, Dargatz DA, Holt TN. 2013. An investigation into beef calf mortality on five high-altitude ranches that selected sires with low pulmonary arterial pressures for over 20 years. *Journal of Veterinary Diagnostic Investigation, 25*(2), 210-218.

Negreiros MP, Amorim ST, Lôbo RB, Brunes LC, Magnabosco CU, Bergmann JA, Baldi F. 2023. Genetic correlation estimates between calving ease in primiparous cows and economically important traits in Nellore cattle. *Journal of Animal Breeding and Genetics*, 1-12.

Newman CA, Morris RL, Baker, Nicoll GB. 1992. Genetic improvement of beef cattle in New Zealand: breeding objectives. *Livestock Production Science*, 32, 111-130.

Okut H, Wu XL, Rosa GJ, Bauck S, Woodward BW, Schnabel RD, Gianola D. 2013. Predicting expected progeny difference for marbling score in Angus cattle using artificial neural networks and Bayesian regression models. *Genetics Selection Evolution*.

Saad HM, Thomas MG, Speidel SE, Peel RK, Frasier WM, Enns RM. 2020. Differential response from selection for high calving ease vs. low birth weight in American Simmental beef cattle. *Journal of Animal Science, 98*(7).

Tedeshi LO, Fox DG, Fonseca MA, Cavalcanti LF. 2015. Models of protein and amino acid requirements for cattle. *Revista Brasileira de Zootecnia*, 109-132.

Uskenov R, Yengsebek T, Kurzhykaev Z, Bostanova S, Akkair B. 2024. The relationship between dry matter intake and the average daily gain. *BIO Web of Conferences, 85*.

Vleck LD. 1993. *Selection Index and Introduction to Mixed Model Methods.* CRC Press Inc.

Zeng X. 2013. Beef Cattle Maternal and Terminal Economic Selection Indices. Fort Collins, Colorado: Colorado State University.

Zuin RG, Borquis ME, Caires SL, Venturini GC, Gondo DG, Gregorio DA, Munari DP. 2012. Genetic analysis on growth and carcass traits in Nelore cattle. *Meat Science, 91*(3), 352-7.