Factors affecting the sale price of bred heifers, bred cows, and beef bulls marketed and sold throughout the United States

by

Maggie Jean Smith

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Approved by:

Co-Major Professor
Dr. Karol E. Fike

Approved by:

Co-Major Professor
Dr. Kenneth G. Odde

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Abstract

Within cow-calf production, the selection of a herd bull and females are important decisions for producers. Across marketing venues, potential buyers of bred females and beef bulls are often provided with various informational at the time of sale. Information often includes physical descriptors, genetic factors, and management and marketing traits. The value of bred females and beef bulls may vary depending on the priorities and goals of the specific buyer. Continued research to better clarify the factors affecting sale price across breeding cattle classes may be of value to the beef cattle industry. Throughout the first chapter, a review of literature surrounding the factors affecting the sale price of bred females and beef bulls is provided. Subsequently, two studies were conducted that investigated potential factors affecting sale price. Within the second chapter, effects of various lot characteristics, physical attributes, and management traits are examined to determine their influence on the sale price of bred heifers sold from 2010 through 2018 and bred cows sold from 2011 through 2018 through video auctions. Findings suggest that multiple elements influence the sale price of bred heifers and bred cows, including auction year or time of sale, breed description, and various physical attributes. The third chapter summarizes research investigating the effect of selection indices and EPDs on the sale price of Red Angus bulls marketed and sold across the United States from 2017 through 2019. Results suggest a relationship between sale price and genetic information but indicate that other factors not captured within the data – such as physical attributes, marketing strategies, and the value of breeder reputation – may be further affecting the sale price of beef bulls. These studies further support the idea that producers consider a combination of marketing factors, physical attributes, genetic traits, and management characteristics when making selection decisions.

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Chapter 1 - Literature Review

Introduction

The United States beef cattle industry is a system encompassing various production sectors. The structure of cattle operations within the United States continues to undergo changes, with a higher percentage of cattle being produced, raised, and managed by a smaller percentage of ranchers (USDA, NASS, 2016). United States production of beef is highly specialized, spanning from grazing grasslands to finishing within feedlots. Cow-calf production is not centralized, with operations present throughout the entire U.S., in every region and state (McBride and Matthews, 2011). This dispersal of cow-calf production is unique when compared to other sectors of beef production. Cow-calf producers possess an opportunity to capitalize on land not valued or utilizable for production of grain or crops (McBride and Matthews, 2011).

The United States Department of Agriculture began counting all cattle classes in 1867, with a recorded low of 28.6 million head across all industry sectors for that year. Cattle inventory grew to new heights in 1975 with a recorded 132 million head (USDA, NASS, 2016). Since that period, the cattle inventory in the United States generally decreased. More specifically, the smallest beef cow inventory was in 1939 with 10 million head. The largest beef cow inventory in the United States was recorded in 1975 with 45.7 million head, following a decreasing trend from that point forward (USDA, NASS, 2016). Drought conditions in 1996 stimulated contraction of the cowherd. Seven years later in 2003, grazing conditions improved, prices increased, and the industry witnessed the end of liquidation, by increasing heifer retention and building numbers. This expansion state persisted until 2007, followed by a seven-year liquidation period due to increased costs associated with feed (USDA, NASS, 2016). Over the past 5 years, the U.S. beef industry

increased inventory by 6.23 million head. This ongoing phase of expansion is reflected by a 2.68 million head increase in beef cow inventory since 2014 (Peel, 2019). As of 2020, the current United States inventory of cattle and calves is at 94.41 million head, with the beef cow herd representing 31.32 million head (USDA, NASS, 2020). Cattle inventories in the United States are subject to cyclic trends, including alterations in herd size as a response to supply and demand from the market, otherwise known as the cattle cycle.

Recently, the size of the U.S. beef cow herd has been decreasing. Possible reasons for this decline are increased production and feed efficiency of slaughter cattle, as cattle producers are generating more pounds per animal (Tonsor and Mitchell, 2017). Observed increases in slaughter weights may be representative of the current decrease in demand for beef cows across the country (Tonsor and Mitchell, 2017). It is imperative for producers selling and purchasing cattle to consider variability within the cattle cycle, as decreases in beef cow demand may result in industry hurdles. Past trends in beef cow retention, expansion, and inventories suggest that the movement, marketing, and sale of breeding stock largely influences the economic state of various other sectors within the U.S. beef industry.

The selection of a herd sire and females are both important decisions for producers. Bred females are production inputs within the cow-calf industry. They contribute present value, and offer future value in the potentially profitable form of calves (Mitchell et al., 2018). Bred females are marketed in various forms, from traditional routes including both sale barn and private treaty to more innovative methods such as within lots through satellite video auction. Across these marketing avenues, potential buyers are provided with various information from sellers. Information ranges from physical descriptors, management traits, and lot characteristics. Limited literature exists on factors affecting the marketing and selling of breeding cattle, making future

research important. Continued evaluation of these factors is useful, as the industry is in a constant state of change regarding the stage of the cattle cycle, utilization of selection tools, and consumer priorities.

The purchase of a beef bull is a principal decision within the cow-calf sector of beef production. The investment is one of extreme value, as a herd sire contributes significant genetic influence within the herd. Physical attributes, performance parameters, and genetic information in the form of EPDs and selection indices are all forms of assessment utilizable to potential buyers when appraising the value of a bull. The relative value of a bull may vary depending on the priorities held by the specific buyer, making defining this worth a complex and potentially unclear process (Ishmael, 2005).

Advancements in marketing strategies, expanded industry knowledge, and innovations in technology have maximized the distribution of available information to producers. With this surplus of information, continued research concerning the quantification of these various forms of data available to producers could prove valuable to buyers and sellers. Understanding current factors that influence the sale price of breeding stock across the United States will provide benefits from production and economic viewpoints.

Price Determinants of Breeding Females

Beef producers possess a variety of avenues to market and sell females. Specific marketing venues have varied benefits, advantages and opportunities. It is evident that buyers prioritize value based off similar traits when making purchasing decisions, including marketing strategies, management factors and physical descriptors (Bailey et al., 1991). Examples of this may include promotional tactics, vaccination and management history, and physical attributes such as weight,

breed description, and flesh. While buyers across various marketing channels may emphasize similar qualities, sellers may receive different prices based upon the specific marketing channel. Obstacles closely associated with sale barns include encountering local, market and climate factors, whereas video auctions provide marketing access to large groups of buyers across the nation, eliminating localized or regional challenges while increasing competition by opening marketing channels to a national level (Bailey et al., 1991; Superior Livestock Auction, 2019).

There is limited literature regarding factors that influence the sale price of bred females. Further research on the value of various traits, and their influence on the sale price of breeding females could prove valuable to potential cattle industry buyers and sellers. Furthermore, developing a clear understanding of these various factors may aid in helping producers make more informed decisions regarding breeding, management, and purchasing (Mitchell et al., 2018).

There are several factors that have the potential to play a role in affecting the sale price of breeding females. A number of these factors reside outside of the realm of control of the cattle producer, for example variability of the cattle market and differences in various regional weather patterns. In addition to more refractory factors associated with the management and marketing of bred females, there are a multitude of elements which cattle producers can influence. Examples of factors associated with increased control include frame size, weight, condition, time of year marketed, breed description, and decisions regarding time of breeding, gestation, and calving of females in possession.

When examining the existing body of literature concerning bred female sale price, various traits have been examined. Throughout this review of literature, potential price determinants that have been investigated will be discussed in sections. Previous research assessing market factors and technology utilization will be summarized. Past studies looking at the effect of descriptors

including age, frame score, and weight and body condition will be reviewed, and major findings will be discussed. Additionally, few studies have attempted to determine the effect of pregnancy status on the value of bred females. Regional differences, seasonality, lot size, and management factors such as health and breed will also be discussed. With the larger research framework established within the beef calf sector, summarizing past studies by factor will allow for comparisons in findings across the cattle classes of bred females and calves. Additionally, the level of research conducted within each area will be better assessed.

Market Variability

As in other market sectors, the size and scope of the beef cow herd in the United States is acclimated to a cyclic trend. This trend includes both increases and decreases in herd size, as a response to supply and demand from the specific market. Cow-calf producers expand inventories in response to profits, while they consolidate in response to losses (Anderson et al., 1996). An individual beef cattle cycle typically lasts between 8 to 12 years, the longest of all meat animals (USDA, ERS, 2018). Periods of high prices are typically associated with expansion, as higher prices encourage producers to increase heifer retainment and decrease culling rate. Periods of lower prices are linked to consolidation, when producers reduce herd size through increased culling and decreased retention (Griffith et al., 2017).

The cattle cycle is susceptible to a variety of factors, including seasonality and weather, industry structure changes, supply and demand, and input prices, such as grain (Norton, 2005). Recent innovations in technology, as well as changes in industry operations have impacted the cattle cycle (Norton, 2005). Market alterations including land, cattle, and feed costs are all factors that lead to producers increasing or decreasing herd size within the industry. Fluctuations in supply

and demand, as well as import and export markets play substantial roles in encouraging expansion or contraction, and therefore tremendously influence the state of the cattle cycle, and current breeding cattle price trends.

Bred females can be viewed as beef production inputs, both from the standpoint of present cow value and future value of the calf (Mitchell et al., 2018). According to Norton (2005) and Blank et al. (2006), numerous circumstances influence the price a producer will offer a seller. Economic factors including cost of inputs, supply, demand and current stage of the cattle cycle are all factors that may directly affect the sale price of females. For example, increased price in feed inputs may result in an unfavorable adjustment concerning the price of bred females (Mitchell et al., 2018). While bred female prices reveal current conditions of supply and demand on a national level, they are easily influenced by local conditions (Mintert et al., 1990). The cattle cycle is especially susceptible to patterns in weather. An instance of drought may cause liquidation to prolong, decreasing availability of utilizable land (Norton, 2005; Crespi et al., 2010). If the drought is contained within a certain region, other areas may continue to flourish and begin to enter an expansion or retainment phase. The market communicates value and relevancy on certain characteristics by associating premiums in price with different factors at a given time (Mintert et al., 1990).

Seasonality

Closely related to market variability, seasonality is a characteristic that is demonstrated across various classes of cattle, including bred females (Spreen et al., 1992). Seasonality addresses alterations in price throughout the year and across seasons. The idea is representative of supply, demand, and the current stage of the cattle cycle. Seasonality can be reflective of times when the

industry is in a retainment phase, as well as when undergoing a period of consolidation. Additional factors that affect seasonality include level of forage production and costs of various of inputs. Patterns in seasonal price are one of the most powerful tendencies influencing trends within the market (Peel, 2019).

To demonstrate this concept, Spreen et al. (1992) examined prices for cull cows in Florida over a 20 year time frame, discovering a seasonal price pattern for the movement and sale of cows. These research findings indicated that peak prices were associated with the spring season and revealed that lower prices reflected the fall season. Mitchell et al. (2018) also examined the effect of seasonality on the sale price of bred cows across Oklahoma. This study implied that buyers emphasize purchasing in late winter and early spring, as February and March were associated with higher prices. Lowest price trends were witnessed in the summer and fall months. Findings from both studies further support the idea that input availability, as well as supply and demand aids in driving this pattern of seasonality, as months associated with higher prices may indicate female retainment in preparation for increased forage and available summer pasture (Mitchell et al., 2018). It is important for cattle producers to understand the pattern of price seasonality and associated risks regarding selling and purchasing decisions, as marketing and management tactics continue to increase in significance (Spreen et al., 1992; Mitchell et al., 2018).

Reproductive Management Options

Hesitancy associated with the incorporation of technology among producers is an obstacle currently facing the beef industry. Information collected through the Show-Me-Select replacement heifer program suggests that several of these opportunities contribute value to females (Patterson, 2017). This educational heifer development program has been operating for over 20 years with the

goal of improving management strategies while increasing marketing opportunities for producers in the state of Missouri. Through this recognized program, incorporation of reproductive technologies including artificial insemination and ultrasound pregnancy detection, as well as genomic prediction tools have proven to add value to females (Patterson, 2017).

Reproductive tools including estrus synchronization, artificial insemination, embryo transfer, and ultrasound utilization are strategies that may enhance profitability for producers. When effectively executed, methods of synchronization and insemination allow producers to incorporate desired genetics into their herd throughout an intended time frame. (Rodning et al., 2012). The utilization of embryo transfer offers several benefits, including selection of superior genetics and desired recipients. The use of ultrasound offers incentives such as early pregnancy diagnosis and fetal sex determination, which could deliver value to producers from a reproductive efficiency standpoint (Lamb and Fricke, 2005).

While there is limited literature regarding the economic value of these technologies, when considering the effect of incorporation from reproductive and genetic viewpoints, there are evident advantages associated with these strategies. Accompanying increased efficiency is the acquisition of data from respective herds. Information regarding genetic and reproductive management may be of value to certain producers, potentially increasing the price they may be willing to offer for a female.

Age

The age of a female at the time of marketing is a factor that has the potential to influence the price at which she is sold. The optimal age of a female in terms of economic value may vary based upon several market factors (Stockton et al., 2016), and the specific value of a female at a

certain age may be dependent on the management and marketing goals of the individual producer. Parcell et al. (1995) examined the interaction of several factors on the price of cow-calf pairs through seven monthly auctions in Kansas. Concerning age, Parcell et al. (1995) hypothesized that cows three to four years old would hold increased economic value when compared to those of two years or less, following suit with milk production. The study uncovered that decreases in price were associated with older cows, concluding that this discount may be indicative of decreased breeding opportunity with increased age.

Mitchell et al. (2018) studied the value of bred heifers and cows across seven Oklahoma auction markets using a hedonic price model. Results conveyed that age did play a significant role in influencing price. Bred heifers were associated with the greatest price premium within the study. Mitchell et al. (2018) discovered that 2 and 3 year old females would hold higher premiums when compared to older cows, as increased age is associated with decreased dystocia. Observations of premiums linked to younger females continue to demonstrate their evident value in terms of longer breeding life.

Frame Score

The frame score of bred females has reportedly been discovered to affect sale price. The frame score indicates the skeletal size of cattle. When examining various factors that influence the price of cow-calf pairs, Parcell et al. (1995) found that a premium was associated with larger framed cows, when compared to small framed cows. Supporting earlier findings, Russell et al. (2014) analyzed data collected from a female sale in Texas, discovering that the management factor of frame also had an impact on the sale price of bred females. The study uncovered that

smaller framed cattle were discounted, and buyers placed greater value and emphasis on cattle of medium to large frames.

Aligning with what is known about the value of frame score for bred females. studies regarding factors influencing the value of beef calves have shown frame score to be an attribute affecting sale price, as frame score typically reveals patterns in growth and feed efficiency. Across various studies, it has been shown that larger framed calves sold for greater prices when compared to smaller framed calves (Bailey et al., 1991; Bulut and Lawrence, 2007; Schulz et al., 2010; Seeger et al., 2011).

Weight and Body Condition

Increased selection pressure on growth and performance traits within the beef industry has resulted in a dramatic increase in cow weights across the United States (Schmid, 2013; Smith, 2014). While these genetic improvements may prove valuable within a feedlot setting, the same may not be said for bred and replacement females being utilized within the cowherd (Bir et al., 2018). Past research has revealed that decreases in reproductive efficiency may be correlated with increases in mature cow weight (Russell and Feuz, 2015). Extensive literature implies that moderate to smaller framed cows may function more efficiently from reproductive, management, and nutritional standpoints within various production settings.

Mintert et al. (1990) analyzed auction data from cattle markets within the state of Kansas to examine the influence of a variety of factors on bred cow sale price. It was discovered that once females reached a certain weight discounts were associated with increases in weight, suggesting that managing and marketing cows at a lighter weight may be a profitable strategy. Stockton et al. (2016) examined 4 years of cow-calf production data originating from the University of Nebraska-

Lincoln. Through various economic regression analyses, it was discovered that the value of cow size may be dependent on the specific production system. Heavier cows may producer animals better suited for slaughter, while lighter cows may contribute more value when calves are sold as yearlings. Mitchell et al. (2018) uncovered greater premiums for cows of heavier weights.

Bir et al. (2018) examined data concerning cow weight and forage type originating from research stations in Oklahoma and Arkansas. Findings revealed that cows at weights of 950 pounds proved to be more efficient from a feeding and nutritional standpoint among various production situations. These observations further support the conviction that while increased emphasis on growth and performance have proven beneficial within the feedlot, these advancements may be detrimental concerning efficiency and production within the cow-calf sector of the industry. Additional research regarding the matter has further supported the idea that the relationship concerning weight and economic profitability of cows is not fully understood (Stockton et al., 2016). With limited research in the area, discussion regarding the value of cow weight and size will likely continue, attempting to close this research gap.

The flesh score of a female, commonly known as condition, is a factor that can be altered by various management strategies. A level of condition on a breeding female is important for various reasons, including reproductive success, maintenance, and efficiency (Hall, 2016). Previous research has established that accumulating an optimum degree of flesh on females at both breeding and calving largely contributes to high reproductive performance (Spitzer et al., 1995). Parcell et al. (1995) found that thin cows received large discounts when compared to those of average condition. When considering current input costs, findings indicated an economic benefit to increasing the condition of cows to at least an average level. Past studies examining the value

of weight for beef calves have concluded that calves described as fairly even in weight tend to sell for greater prices than those described as uneven in weight (King et al., 2006; Seeger et al., 2011).

While weight and body condition may be related, they certainly offer differences when considering the interaction of other factors, such as frame size. When accounting for these multiple traits, variation in price may occur dependent on the specific buyer. A larger framed cow may weigh more while holding less condition, whereas a smaller cow may be at a similar weight while carrying an increased level of flesh on her frame. Furthermore, females of similar frame size at varying levels of condition may demonstrate price variation contingent on the goals of the producer. Acknowledging that the intentions and priorities of the buyer are unknown, the level of weight and condition on a certain frame may be difficult to value between a variety of producers.

Pregnancy Status

The pregnancy status of a female is a factor of importance when making decisions regarding the purchasing of bred females. This characteristic may be extremely variable, as goals of the buyer are unknown and may vary across regions of the United States and between individual producers. For example, gestation status may be of varying importance to producers dependent upon the current stage of the cattle cycle. This factor is likely very important to buyers in expansion or retainment, as this information would be valuable when investing in females. (Russell et al., 2014).

Findings of Mintert et al. (1990) showed premiums associated with cows that were pregnant in comparison to cows that were open, suggesting that buyers of cows at that time were seeking to build herds. Falconer et al. (2009) found that large discounts were associated with open cows. Further and more recent research on price differentials concerning bred cows demonstrated

that greater premiums were associated with cows in later phases of gestation, as compared to early stages. Mitchell et al. (2018) uncovered that buyers are willing to pay higher premiums as number of months bred increases, as later stages of pregnancy may be associated with increased calf survival and decreased risk. These similar discoveries validate that profitability and economic value may increase when prolonging retainment, and marketing females throughout later stages of gestation (Mintert et al., 1990; Mitchell et al., 2018).

Region of Origin in the United States

The area or region in which females are raised or managed throughout the United States has the potential to greatly influence the price a buyer will pay for cattle. Numerous factors play into the environment and location that cattle are raised in, including both predominant breed influences and differences in management styles between specific regions. For example, the influence of Brahman is small, and may reflect discounts in areas of the U.S. such as the North Central, whereas in the South and Southeast, the Brahman breed is respected, widely utilized, and may be associated with increasing value within breeding herds (Russell et al., 2014).

When examining various factors that affect the value of bred cows, Mitchell et al. (2018) concluded that premiums and discounts related to location and transportation from major auction markets to rural delivery areas. According to Mitchell et al. (2018), when retaining breeding stock and investing in females, buyers are more likely to utilize convenient market channels that are near their individual farm or ranch. This evidence suggests that movement of bred females may remain predominantly within respective regions of origin, limiting the actual movement of these cattle across more distant regions of the United States. When considering various beef industry segments, movement of cattle is variable. For example, calves originating from all regions of the United

States may eventually be transported to the plains, or areas that possess more concentrated cattle feeding. Research across the calf sector has widely demonstrated that region of origin influences the price buyers are willing or able to pay, suggesting that transportation distance and trucking costs play a role in investment decisions (Blank et al., 2006; King et al., 2006; Seeger et al., 2011).

Lot Size

The size of lot sold is another important factor to consider when examining characteristics that influence the sale price of bred females. Within literature regarding calf price determinants, it has been widely discovered that premiums are associated with lots containing more cattle, indicating an increased instance of home-raised calves with decreased health concerns, as the level of management and vaccination history is likely to increase with home-raise cattle sold in a single lot (Leupp et al., 2009; Zimmerman et al., 2012). Concerning bred females, research on the effect of lot size on sale price is scarce compared to calves, but the fundamental ideas remain comparable. As with studies from the calf sector, bred female research shows that lots with more cattle are likely to be associated with a premium, when compared to smaller lots that accompany discounts (Mintert et al., 1990; Russell et al., 2014). This could be associated with trucking and transportation costs, as seen in other beef industry segments. Mintert et al. (1990) examined data from Kansas cow auctions, ranging in lot size from 1 to 20 head, discovering that this market discounted lots under 5 head, while lots of 11 to 15 head captured the highest premiums. Through the evaluation of data from a special Texas female sale, Russel et al. (2014) found that larger lots held premiums over smaller lots. In this smaller scale setting, with lot size ranging from 1 to 6 head, premiums over $80 could be expected for each additional head sold within a lot. These findings suggest that the value of lot size may be dependent on the factor of auction venue. Bailey et al. (1991) indicated

that while buyers using more traditional auction channels may be able to purchase a multitude of smaller sized lots to be compiled and transported, the likelihood of this method decreases for buyers utilizing more modern routes, including video auction.

Health Management

A factor that remains within the sector of control of the cattle producer is health status. Concerning the cow-calf sector of the industry, some producers take great efforts in intensively managing their calves prior to weaning through various health protocols. Intensive health management strategies, commonly known as preconditioning, began as a way for the industry to differentiate calves with known vaccination and management history, while greatly reducing the risk of respiratory disease (King et al., 2006; Zimmerman et al., 2010). It has been extensively shown that preconditioning adds value to calves, and buyers are likely to contribute a premium if the health status of the calves is guaranteed prior to purchase. When relating the fundamentals of thorough health management from calves to breeding females, preferences of buyers and advantages in economic profitability remain similar.

Various studies relating to price determinants of cows support the idea that improved health management is associated with premiums from buyers across multiple classes of cattle. When examining factors that influence the price of cows, Mintert et al. (1990) found that buyers took note of cattle exhibiting signs of poor health, and discounts were associated with those cattle that were not considered to be in optimal health. Five years later, Parcell et al. (1995) uncovered similar findings in that cows that demonstrated signs of less intensive management and decreased health sold for lower prices, when compared to those cows that were considered in good health. Both studies are indicative of the idea that obtaining possession of a female in poor health may lead to

a financial burden and result in more severe issues within the herd. While data on the value of health and management within the calf sector is predominantly focused on preconditioning and vaccination program records, the primary method of indicating health status for bred females has been by route of visual appraisal.

Breed Description and Hide Color

Various breeds or breed-influences have the potential to affect the sale price of bred females based upon multiple factors. Within the cow-calf sector of the industry, buyers are willing to pay a premium for certain breeds based upon how those breed influences are expected to enable the calf to perform within a feedlot setting (Hersom and Thrift, 2012; Lacy et al., 2017). Bos *taurus* breeds of cattle, including Hereford, Angus, Red Angus, and Simmental, possess performance characteristics that allow them to reach an optimum end-point faster within the feedlot, as compared to Bos *indicus* breeds of cattle, including that of Brahman influenced cattle (Hawkes et al., 2008). Bos *indicus* breeds of cattle are well-known for their ability to tolerate hot climates, but as a criticism are unlikely to hold carcass merit (Hawkes et al., 2008). Falconer et al. (2009) found evidence supporting the idea by uncovering that Brahman females in south Texas brought premiums when compared to other breeds, representative of the value of the breed in hot climates.

Parcell et al. (1995) evaluated cow-calf data from a Kansas auction company, finding significant premiums evident for Angus cow-calf pairs, when compared to cattle of other breeds, including other English breeds such as Hereford, as well as various Continental breeds. This premium in Angus cattle may be associated with the utilization of the Angus breed to produce quality carcasses, with a high degree of marbling. Various studies related to the marketing and sale

of calves support the idea of captured premiums associated with Angus-influenced cattle (Seeger et al., 2011).

Hide color has the potential to influence the sale price of cattle. Extensive research has proven that buyers often utilize the physical characteristic of color of hide to differentiate between various breeds of cattle (Bulut and Lawrence, 2007). Many studies within the calf sector of the industry have detected significant premiums associated with black-hided calves, relative to other hide colors (Bulut and Lawrence, 2007). Regarding bred cows, Mitchell et al. (2018) uncovered that black-hided cows received a premium when compared to cows of other colors. When examining price attributes of replacement heifers, Falconer et al. (2009) found increases in price associated with black-hided cattle. When examining data from a female sale in Texas, Russell et al. (2014) discovered that a large percentage of lots were black-hided, further supporting the idea of a shift towards black-hided animals within the U.S. cowherd. The large proportion of black-hided cattle within the United States has been partially driven by development of branded beef programs (Speer, 2013). Interested cattle sellers, buyers, and producers alike aim meet the standards of the intended program to qualify for associated premiums.

While there is limited research on factors that have the potential to influence the sale price of bred females, similarities across the prior research framework related to the calf sector, combined with the scope of research that is available regarding females makes it evident that further research would prove highly valuable to the beef cattle industry. Management and marketing strategies are continuing to change, and during a time of such industry development, it is paramount for both cattle buyers and sellers to understand what drives variation in the sale price of bred females.

Price Determinants of Beef Bulls

Selection and investment of beef bulls to utilize within the herd is a critical decision for cow-calf producers. A herd bull provides a vast proportion of physical and genetic characteristics and merit within the herd, making it of importance to understand the numerous factors that are necessary to contemplate prior to the investment. Establishing the relative value of various traits that cattle producers and bull buyers place on certain information, both genetic and physical, is sure to prove valuable to commercial, as well as seedstock producers within the industry.

In an industry state of rapid change in terms of producer priorities and buyer preferences, the incorporation of various management strategies, selection tools, and methods of technology have been paramount in ensuring a continued level of economic productivity (Hersom et al., 2011). Numerous categories of information are provided to potential buyers regarding the marketing and sale of beef bulls through various auction channels. Factors of interest range from values concerning expected progeny differences (EPD), selection indices, and phenotypic data. The level of information provided during the time of sale has the potential to alter the perceived value of a bull depending on the priorities of the buyer.

EPDs provide a genetic overview of a herd bull and may prove valuable to cattle producers in terms of investigating the relative value a bull may contribute to the improvement of genetic merit within the herd (Greiner, 2009; Barham, 2011). Indices serve as methods of simplification for genetic selection. A selection index is a combination of EPDs, weighted or distributed by relative value (Weaber, 2014). Upon early incorporation, the utilization of this method of selection allowed multiple trait evaluation of various genetic factors concomitantly (Hazel, 1943). EPDs and selection indices are two genetic improvement tools utilizable by producers when making ongoing selection and herd management decisions. In addition to the value of genetic information

provided, there is substantial emphasis on investment decisions concerning various physical factors. Physical traits, such as frame size, weight, structure, and breed are potential pieces of information attributable to the price a buyer may be willing to offer for a herd bull.

Various studies have investigated the effect of different factors on the sale price of bulls through the utilization of hedonic pricing models. A hedonic pricing model serves as an economic tool that identifies the extent to which certain factors are valued (Papatheodorou et al., 2012). The utilization of hedonic analyses allows for the evaluation of preferences of a population of interest and includes both significant and non-significant factors. In the case of beef bull price determinants, that population would be buyers. Marketing methods, genetic tools, and physical factors have been examined to determine their relative contribution to the overall worth of a herd sire. Through similar methods of analysis, past research has evaluated the contribution of numerous factors on sale price. The vast amount of research in this area demonstrates the way in which the beef industry undergoes changes in a relatively constant manner. Within this review of the literature, summarizing and discussing studies chronologically allows for an overview of how the priorities of buyers of beef bulls have shifted over the past several decades of research.

1988 – 2000

Greer and Urick (1988) examined the relationship regarding the sale price of purebred bulls and various economic elements. Information originated from the Montana Agricultural Experiment Station. Data were available on the sale of purebred Hereford bulls from 1966 through 1984. Utilizing a geometric distributed lag model, it was hypothesized that prices and inventories of feeder calves, heifers, and cows would serve as drivers of the dependent variable, bull price. Results showed that the sale price of bulls during that specified time were deemed reflective of inventory of the cowherd and prices of calves (Greer and Urick, 1988).

A 1993 survey of 312 commercial cattle producers who purchased bulls through sales held in Beloit and Potwin, Kansas was conducted by Simms et al. (1994). The objective was to characterize the relative value bull buyers placed on numerous factors concerning bull selection. Responses were recorded from a commercial population of cattle producers, and various breeds were represented, including but not limited to Angus, Red Angus, Simmental, Charolais, and Hereford. Within selection criteria included, 25% of cattle producers indicated that calving ease score was of utmost importance when making decisions, and 49% of the survey responses included the factor in their top 3 criteria of importance. Frame score remained an important variable for 12% of producers, while 39% of responses included frame in their top 3 selection. Birth weight and visual conformation were ranked a top priority by respondents at 11% for each. When reaching a consensus on value in terms of visual appraisal, 21% of buyers indicated structural soundness as a top physical characteristic, with 43% of buyers including the factor in their top 3. Length, muscling, and frame were additional visual characteristics often included within traits of greater emphasis. Performance parameters of highest value to producers included birth weight and birth weight EPDs, at 35% and 15% of respondents respectively. Only 9% of producers surveyed indicated that EPDs ranked as their initial priority in making selection decisions, and only 23% of buyers included it within their top 3. Simms et al. (1994) states that the lower value placed on EPDs suggests producers were not utilizing the most current, timely, and correct information regarding selection.

Two years later, Dhuyvetter et al. (1996) challenged the relative value EPDs hold in influencing the sale price of beef bulls. Marketing tactics, EPDs, and physical attributes such as muscling score, conformation score, and structural correctness were examined to determine their relationship with sale price. Data encompassed 1,650 bulls originating from 26 separate purebred

bull sales across the state of Kansas in 1993. Seven breeds were accounted for, including Angus, Gelbvieh, Charolais, Hereford, Red Angus, Simmental, and Limousin. Numerous hedonic price models were constructed to evaluate the impact of EPDs on bull value. Angus bulls sold for a significantly greater sale price compared to all other breeds, which sold for similar, but not significantly different prices. Concerning Gelbvieh bulls, birth weight and milk EPDs significantly affected sale price, but weaning weight did not. Across remaining breeds, zero or only one of the EPDs was discovered to influence sale price. These differences in significance suggests variation in the use of EPDs throughout various breeds. For example, producers may utilize different selection tools dependent upon the breed of cattle they raise. When evaluating marketing strategies on the sale price of beef bulls, it was uncovered that sale order, promotional tactics, and retainment rights were all factors associated with a greater premium. (Dhuyvetter et al., 1996).

2000 – 2010

Chvosta et al. (2001) created a hedonic regression price model to measure and determine the influence of various factors, ranging from phenotypic to genotypic, on the sale price of beef bulls. Information originated from two separate data sets to evaluate the relative value of different measures on the sale price of bulls. The first portion of data consisted of performance measures, including production weights and EPDs, and prices on 1,144 breeding bulls marketed and sold from 1982 through 1997. Bulls within this data set were sold by a reputable Angus breeder in Montana. The second set of data contained information resembling the first, but with 6,685 Angus bulls representing eleven breeders throughout Nebraska and South Dakota from 1986 through 1996. All data were collected from sale catalogs that were provided to potential buyers by breeders. Through multiple price models, characteristics found to have an impact on sale price were age, 205-day weight, 365-day weight, birth weight EPD, and yearling weight EPD. Evidence suggested

that EPDs, age, and production weights largely affected sale price. Chvosta et al. (2001) noted that this research is applicable of the idea that buyers incorporate numerous factors into their selection decisions within and across herds, suggesting an increase in utilization of various EPDs at this time.

Walburger (2002) evaluated multiple beef bulls characteristics to determine the influence of each on sale price in Alberta, Canada from 1989 through 2000. Data were available on 797 bulls representing various breeds. Utilizing a hedonic price model, the objective was to examine the potential change in selection priorities of cow-calf producers in the area, in hopes to characterize an increasing emphasis on carcass quality. Quantifiable factors included birth weight, sale weight, average daily gain, and scrotal circumference. Additional characteristics obtained via ultrasound included measurements of backfat, ribeye area, and lean meat yield. Within the model, periods of industry change were identified, suggesting that data could not be combined from all periods. These periods were from 1989 through 1993, from 1996 through 1997, and from 1998 through 2000. Within all specified periods, the values of birth weight, sale weight, and scrotal circumference impacted the sale price of bulls. Birth weight was negatively associated with price, while sale weight and scrotal size held a positive relationship with bull sale price. Average daily gain was positively associated with sale price, only within the last period of the analysis. Walburger (2002) suggested that results indicated breeder prioritization of value-adding traits and represented an increased emphasis on the utilization of carcass parameters by bull byers.

Supporting methodology relevant to Dhuyvetter et al. (1996) and Walburger (2002), Turner (2004) analyzed data on 8,285 purebred Angus bulls from breeders throughout the northern United States. The objective was to examine the value buyers placed on EPDs and various production parameters when purchasing breeding bulls, while also examining the effect of various marketing,

management, and promotional strategies on the sale price of purebred beef bulls. Physical factors available spanned from age, birth weight, adjusted weaning weight, adjusted yearling weight, to ultrasound measures including ribeye area, intramuscular fat, and fat thickness. Utilized EPDs included birth weight, weaning weight, yearling weight, and milk, along with various ultrasound EPDs. Sale order, season, photo inclusion, retention rights, and other methods of technology incorporation were analyzable marketing characteristics. Turner (2004) quantified the influence of these various factors on sale price using a series of hedonic price models. Results demonstrated that while breeders place greater value on most actual weights in comparison to EPDs, emphasis was focused on the birth weight EPD of a bull over the actual birth weight. Ultrasound characteristics were positively associated with sale price, revealing that buyers place importance on carcass quality traits when making potential investments and selection choices. Across various marketing factors, it was determined that promotional tactics including photo utilization, sale order and retention rights highly affected price, along breeder reputation. This information suggests that emphasizing carcass data while taking a more intensive approach to marketing breeding stock may prove profitable and valuable to producers within the industry.

Smith (2007) analyzed data originating from the biannual Indiana Beef Evaluation Program. Data consisted of 1,145 bulls sold at auction from 1998 through 2005, encompassing a variety of breeds including but not limited to Angus, Charolais, Simmental, Hereford, Red Angus, Shorthorn, and crossbred Angus bulls. Through a hedonic regression analysis, various characteristics including birth weight, 365-day weight, average daily gain, ribeye area, rib fat, and intramuscular fat were examined to determine their relative influence on beef bull sale price. Smith (2007) discovered that sale price was positively associated with ribeye area, rib fat, and intramuscular fat. It was found that birth weight was negatively associated with sale price, while

365-day weight and average daily gain positively influenced price. Additionally, the analysis suggested that premiums were evident for bulls possessing Angus genetics.

Irsik et al. (2008) quantified numerous factors to investigate underlying traits of prioritization to potential buyers of breeding bulls. Utilizable data was available on 1,809 bulls marketed through graded bull sales from 1995 through 2007. A team of experienced evaluators assigned numerical grades to bulls based off various parameters including conformation, weight, frame, and scrotal size. Additional characteristics specific to individual bull observations included sale year, age, breed, birth, weaning, yearling, and sale weight, EPDs for various weights, and price. A regression analysis quantified the influence of the multitude of above characteristics on the sale price of bulls. Irsik et al. (2008) uncovered that multiple factors impacted price including grade, breed description, birth weight, and age. These findings suggest that buyers place trust in expert evaluation abilities. When examining the effect of provided EPDs, an association with price was not observed, demonstrating that buyers in this scenario did not highly utilize the provided tools when making decisions, and instead prioritized the physical characteristics available. Additionally, it was discovered that year impacted the sale price of bulls throughout certain periods, supporting the idea that market forces may highly influence buying patterns within the breeding cattle sector of the industry, placing increasing importance on understanding economic factors.

2010 - Present

Brimlow and Doyle (2014) studied how numerous evaluation and selection criteria impact bull buyer behavior through analyzing data from a Nevada bull test station. Available information represented 426 bulls of various breeds in 2007, 2008, 2009, and 2012. Seller-provided visual appraisal scores, genetic information, physical attributes, carcass traits, and values for feed

efficiency were all factors included within the hedonic regression analysis. Through this investigation, Brimlow and Doyle (2014) discovered the value of low birth weights, high growth traits, and measures of carcass quality relative to bull sale price. Regarding the value of feed efficiency, it was found that premiums were associated with those bulls considered to possess positive values for feed efficiency. Differences in breed and age were observed, and premiums were evident with older bulls, as well as bulls of Angus and Hereford breed description, indicating the selection pressure for certain breed characteristics throughout different regions. Visual appraisal scores provided by breeders did not affect price, suggesting that potential buyers place less credibility on seller-provided scores. Supporting previous research, findings revealed continued buyer value on both genotypic and phenotypic measures concerning investments of herd sires.

Grimes (2016) analyzed data originating from two seedstock operations in Kansas and Colorado to evaluate the influence of various performance and genetic parameters on the sale price of beef bulls. Potential phenotypic predictors of sale price included birth, weaning, and yearling weight, frame size, height, average daily gain, and carcass characteristics including ribeye area, as well as intramuscular, rib, and rump fat measures assessed via ultrasound. Genetic information in the form of EPDs were available for calving ease, various weights, scrotal circumference, and multiple carcass characteristics. In addition to EPDs and physical descriptors, the emphasis of economic selection indices was also examined. Influential predictors of price were identified and characterized through multiple quantitative principal component analyses. It was discovered that similar parameters affected price on both ranches. Principal components for selection indices, growth measures, and carcass traits were among the most prominent, suggesting that buyers valued this information when investing in a herd sire.

Bacon et al. (2017) explored the effect of various phenotypic characteristics, carcass traits, and EPDs on the auction price of 424 bulls marketed through the annual Western Illinois University Performance Tested Bull Sale from 2006 through 2015. Through a regression analysis, it was discovered that buyers place emphasis on low birth weights, high weaning weights, and indicators of superior carcass values, which were obtained through ultrasound. Age, frame score, and scrotal size all positively impacted sale price, while breed was not significant within results. Findings indicate similar results as those conducted in past years, in terms of buyers placing importance on a combination of genetic traits and physical attributes, with increasing value of carcass characteristics.

Boyer et al. (2019) analyzed data on 1,070 bulls sold through a Tennessee auction from 2006 through 2016. Using a hedonic pricing model, the influence of physical and genetic parameters on the value of beef bulls was examined. EPDs concerning growth, calving ease, and milk were evaluated along with physical traits of weight, frame score, and average daily gain. Genetic information regarding growth and calving ease were found to positively influence sale price. The performance and physical characteristics of average daily gain, weight, and frame score were also positively associated with the dependent variable of price. Overall, calving ease EPD, sale weight, and frame score significantly increased price in all 11 years of the study. Findings of Boyer et al. (2019) suggest that buyers across Tennessee value larger sized bulls with greater genetic merit in calving ease. While the analysis evaluates bulls within Tennessee, it is important to consider that the worth of high growth bulls with superior calving ease traits may be constant across numerous other regions in the United States.

When considering research concerning the evaluation of price determinants of beef bulls, evident similarities were discovered across the factors of marketing, genetic information, and

physical traits. Producers valued genetic information emphasizing low birth weight predictions, and an emphasis on carcass driven traits was witnessed as literature continued to develop in this area of research. Regarding the various marketing strategies investigated, retention rights, catalogs containing clear information and visuals, and order of sale impacted price of various bulls marketed and sold. Understanding the different facets of information that influence the auction price of beef bulls will prove valuable in guiding buyers through investment decisions, while helping the seller better meet the potential demands of the buyer at hand.

Summary

Various components of information are provided to potential buyers prior to and at the time of sale across multiple classes of cattle. Whether the investment concerns calves, females, or bulls, the decision is of importance for an operation's future success. The beef cattle industry is one of rapid change, with improving methods of technologies, advanced selection tools, and adapting priorities. Understanding these various factors will allow cattle producers to make well-informed decisions from both an economic and production standpoint. As characteristics of the beef industry continue to evolve, ongoing research will be pivotal in sustaining comprehension in this area of study.

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Chapter 2 - Factors affecting the sale price of bred heifers and bred cows sold through video auctions

Abstract

Objective: The objective of this study was to evaluate potential factors influencing the sale price of bred heifers and bred cows sold through video auction while adjusting for all other factors that significantly influenced price.

Materials and Methods: Data were available on 1,870 lots of bred heifers sold through video auction from 2010 through 2018 and 1,237 lots of bred cows sold from 2011 through 2018. Two multiple regression models using backward selection procedures were developed to determine the factors influencing sale price for bred heifers and for bred cows. A value of $P < 0.05$ was required to maintain a factor within each final model.

Results and Discussion: Significant determinants of sale price of bred heifers and bred cows included sale year, breed description, weight, frame score, and flesh score. Bred heifers sold for the greatest ($P < 0.0001$) price in 2014 ($2,455/head) compared to all other years. In 2014 and 2015, bred cows sold for similar ($P = 1.0$) prices ($2,392 and $2,402/head, respectively), but at prices greater ($P < 0.0001$) than all other years. For both bred heifers and bred cows, Red Angus-sired lots sold for the greatest ($P < 0.0001$) sale price ($1,721 and $1,935/head, respectively) compared to heifers and cows of all other breed groups. Sale year, breed, weight, and various other elements influenced the sale price of bred females, suggesting that buyers utilize several components of information at the time of sale.

Implications and Applications: Understanding the various factors influencing the sale price of bred heifers and bred cows will allow producers to make more informed investment decisions.

Key words: bred cows, bred heifers, breeding females, sale price, video auction,

Introduction

Literature reporting factors that influence the sale price of bred heifers and bred cows is typically limited to analyses within a defined region or breed composition (Mintert et al., 1990; Falconer et al., 2009; Russell et al., 2014; Mitchell et al., 2018). Few studies have examined the influence of various breeds across many regions. Descriptive information about bred females is often provided to buyers across numerous marketing venues. From physical descriptors, management factors, and lot characteristics, comprehending how different information has the potential to cause variation in sale price is imperative to make sound and informed purchasing decisions. Continued research and increased understanding of the value placed on bred female characteristics may prove advantageous to beef cattle producers throughout the United States.

Information regarding the pricing structure of feeder calves (Bailey et al., 1991; Hawkes et al., 2008; Schulz et al., 2010; Seeger et al., 2011) and beef bulls (Dhuyvetter et al., 1996; Irsik et al., 2008; Boyer et al., 2019) is widely available. While these studies have allowed the industry to gain an understanding of the factors affecting these particular classes of cattle, factors influencing the value of bred females are not well understood. Bred heifers and bred cows serve a different purpose within beef production. They are unique in their total worth, as they offer value from both a current female and future calf standpoint (Mitchell et al., 2018).

Research has shown that factors associated with weaning and health management, nutrition, and reproductive strategies should be considered when developing females (Anderson et al., 2002; Engelken, 2008; Houghton, 2009; Patterson, 2017). While this suggests that various

components contribute to producing females, there is limited information regarding which traits are emphasized in determining value to potential buyers of bred heifers and cows.

Mintert et al. (1990) evaluated the effect of numerous physical and market characteristics on cow sale price across Kansas auctions. Weight, breed, time of sale, and location were found to impact the price a producer is willing to pay for a female. Mitchell et al. (2018) investigated the value of various factors throughout auction markets in Oklahoma and concluded that the sale price of bred females followed a cyclic trend. Traits such as hide color, physical quality, location, and weight influenced price. Physical parameters such as weight, frame, and body condition have been found significant (Mintert et al., 1990; Mitchell et al., 2018). Previous findings indicate market forces, such as time of year and location marketed, acting within the pricing framework of bred females.

Most of these studies described previously have examined price determinants of bred females within a given location or auction market, but none have evaluated the relative value of females across regions. Video auctions allow sellers to market cattle to buyers nationwide. The use of video auction data allows us to examine bred female price determinants across several regions within the United States.

Thus, the objective of this study was to evaluate factors influencing the sale price of bred heifers and bred cows sold through video auction while adjusting for all other factors that significantly influenced price.

Materials and Methods

Data Collection

Information describing lots of bred heifers and bred cows marketed and sold nationwide through a livestock video auction service were obtained from Superior Livestock Auction (Fort Worth, TX) for all lots of bred heifers offered for sale from 2010 through 2018 and for all lots of bred cows offered for sale from 2011 through 2018.

The quantifiable factors available for all lots of bred heifers and bred cows were auction year, weight, region of origin, breed description, variation in weight within the lot, origin (home-raised or purchased), frame score, flesh score, and number of females within the lot.

The livestock video auction service defines five regions from which a lot of bred heifers or bred cows marketed may originate. The five regions are as follows: West Coast (AK, CA, HI, ID, NV, OR, UT, and WA), Rocky Mountain/North Central (CO, IA, IL, IN, MI, MN, MT, ND, NE, SD, WI, and WY), South Central (AZ, KS, MO, NM, OK, and TX), Northeast (CT, DE, MA, MD, ME, NH, NJ, NY, OH, PA, RI, VT, and WV), and Southeast (AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, and VA). Lots from the Northeast region were excluded from the bred heifer analysis and lots from the Northeast and Southeast regions were excluded from the bred cow analysis due to the limited number of lots originating from those regions.

Sellers worked collaboratively with their sales representatives to describe the breed composition of each lot. The breed description of each bred heifer or bred cow lot was then provided by the livestock auction service. Lots were then classified into one of five groups: 1) English and English-crossed with no Brahman influence, 2) English-Continental crossed with no

Brahman influence, 3) Black Angus-sired out of dams with no Brahman influence, 4) Red Angus-sired out of dams with no Brahman influence, and 5) Brahman-influenced.

Statistical Analysis

Two separate multiple regression models were developed using backward selection procedures. At each phase of the backwards selection procedure, the independent variable with the largest *P*-value was removed from the model until all factors were significant. For a factor to remain in the model, a value of $P < 0.05$ was necessary. For both analyses, the MIXED procedure within SAS (version 9.3, SAS Institute Inc., Cary, NC) was utilized. Auction year, weight (linear and quadratic), region of origin, breed description, variation in weight within the lot, origin (home-raised or purchased), frame score, flesh score, and number of females within the lot (linear and quadratic) were included within both original models as fixed effects. Factors with linear and quadratic terms (base weight and number of females within the lot) were centered at zero by subtracting the overall mean of the factor from the value of that factor for each lot in order to avoid the occurrence of multicollinearity (King et al., 2006).

Results and Discussion

Non-adjusted means, standard deviations, medians, and ranges of the continuous factors describing the lots of bred heifers and bred cows sold are shown in Table 2.1. Data available for analysis were collected from 1,870 lots of bred heifers over a nine year period (2010-2018) and 1,237 lots of bred cows over an eight-year period (2011-2018).

Of the 11 quantifiable factors included within the initial bred heifer analysis, 7 remained significant, revealing an influence on sale price. Those factors were 1) auction year ($P < 0.0001$),

2) base weight of the lot (linear terms; $P < 0.0001$), 3) region of the United States where the lot originated ($P < 0.0001$), 4) breed description of the lot ($P < 0.0001$), 5) origin ($P = 0.0008$), 6) frame score of the lot ($P = 0.0016$), and 7) flesh score of the lot ($P = 0.02$) (Table 2.2).

Within the bred cow analysis, the 8 independent factors that remained significant were 1) auction year ($P < 0.0001$), 2) base weight of the lot (linear terms; $P < 0.0001$), 3) base weight of the lot (quadratic terms; $P < 0.0001$), 4) number of cows in the lot ($P = 0.03$), 5) breed description of the lot ($P < 0.0001$), 6) variation in weight within the lot ($P < 0.0001$), 7) frame score of the lot ($P = 0.04$) and 8) flesh score of the lot ($P < 0.0001$) (Table 2.3).

Variation in weight within the lot ($P = 0.75$), number of heifers in the lot (linear terms; $P = 0.35$), number of heifers in the lot (quadratic terms; $P = 0.63$), and base weight of the lot (quadratic terms; $P = 0.07$) did not affect the sale price of bred heifers. For bred cows, the number of cows in the lot (quadratic terms; $P = 0.71$), origin ($P = 0.48$), and region of the United States where the lot originated ($P = 0.08$) did not impact sale price.

Auction Year

Auction year was a significant factor influencing price within both the bred heifer and bred cow analyses. Bred heifers sold for the greatest ($P < 0.0001$) price in 2014 ($2,455/head) (Figure 2.1). In 2014 and 2015, bred cows sold for similar ($P = 1.0$) prices, but at prices greater ($P < 0.0001$) than all other years ($2,392 and $2,402/head, respectively) (Figure 2.1).

Mintert et al. (1990) implied that although bred female prices reveal information concerning markets on a national level, they may be dependent on local or regional market conditions. Mitchell et al. (2018) discovered that bred cow prices were associated with costs of inputs and feeder calves, further implying that bred female prices are sensitive to alterations in

industry structure, following a cyclic pattern through periods of consolidation and expansion. Findings from our study are consistent with previous research suggesting that year and time of sale continue to heavily influence the sale price of bred females, as in other classes of cattle. The sale price of bred females was highest in 2014 and 2015, then experienced a period of rapid decrease throughout the remainder of the study period, aligning with the idea that the sale price of bred females follows a cyclic trend, similar to other classes of cattle. Driving forces of price differences across these years could likely be explained by cowherd liquidation as a result of drought, followed by a period of rapid expansion as a result of improved weather conditions (Burdine and Halich, 2016).

Base Weight

Base weight influenced ($P < 0.0001$) the sale price of bred heifers. Base weight of the lots for the nine years of the study ranged from 650 to 1,450 lb. From 2010 through 2018, the mean base weight was 1,000 lb. (Table 2.1). Our findings suggest a positive and strong relationship between weight and price. As average weight of the lot increased by 100 pounds per head, sale price increased by $90.00 per head (Table 2.2). The relationship between base weight and sale price of bred heifers can be seen in Figure 2.2. Heavier heifers closer to calving may have a decreased risk of dystocia, increased calf survival, and a greater likelihood of getting rebred earlier post-calving, thus potentially explaining greater value of heavier heifers.

Within the bred cow analysis, base weight of the lots for the eight years of the study ranged from 825 to 1,600 lb. From 2011 through 2018, the mean base weight was 1,150 lb. (Table 2.1). Our results indicate a quadratic effect ($P < 0.0001$) of weight on sale price. The relationship between base weight and sale price of bred cows can be seen in Figure 2.2. Weight appears to

positively influence bred cow sale price until bred cows reached approximately 1,150 lb., with a decreasing trend associated with weights beyond 1,200 lb. Previous research has revealed that decreases in reproductive efficiency may be correlated with increases in mature cow weight (Russell and Fuez, 2015). Extensive literature has implied that smaller cows may function at a more favorable level within production settings in terms of decreased maintenance requirements and increased reproductive efficiency (Mintert et al., 1990; Schmid, 2013; Bir et al., 2018). Cow age may be an additional factor affecting the relationship between weight and price, suggesting that older, heavier cows may not be as valued. Findings indicate that the industry does not prefer to pay beyond a buyer optimum when purchasing bred cows, consistent with past research suggesting that moderate cows are valued by buyers. Our data shows bred cows weighing between approximately 1,100 lb. and 1,200 lb. to be the most valued.

Lot Size

Our results indicate a linear effect (P = 0.03) of lot size on the sale price of bred cows, however, having only a small effect on price. The number of cows within a lot ranged from 2 to 315 head, with a mean lot size of 43. head. With an average base weight of 1,150 lb. per head, the average total weight would be slightly over 50,000 lb. (typical truckload weight limit) for a single lot. As the size of a lot of bred cows increased by 10 head, the sale price decreased by $8.00 (Table 2.3).

Region of Origin

Region of the United States from where a lot originated significantly affected bred heifer sale price (Figure 2.3). Those lots originating from the Rocky Mountain/North Central region of

the United States sold for the greatest ($P < 0.001$) price ($1,681/head). Bred heifers originating from the South Central region sold for prices similar ($P = 0.17$) to those lots in the Southeast region, but at prices greater ($P = .0036$) than the West Coast region ($1,622; $1,559; and $1,563/head; respectively). Sale price of bred heifers was similar ($P = 1.0$) for lots originating from the Southeast and West Coast regions of the United States ($1,559 and $1,563/head, respectively).

Numerous studies have investigated price determinants of bred females within respective states or regions (Mintert et al., 1990; Russell et al., 2014; Mitchell et al., 2018), but none have examined the pricing structure of females on a national level. Mintert et al. (1990) discovered differences in auction markets across Kansas, finding that day or time of sale impacted prices captured at certain sale locations. Mitchell et al. (2018) analyzed cow data originating from Oklahoma and speculated that buyers are more likely to utilize convenient market channels near their respective ranches. When considering literature on the price differentials of calves, the idea that region of origin influences calf value is further supported, and may be explained by trucking costs, management practices, and different breed influences (Blank et al., 2006; Hawkes et al., 2008; Seeger et al., 2011).

Breed Description

Breed description significantly impacted the sale price of bred heifers and bred cows (Figure 2.4). Within the bred heifer analysis, lots categorized as Red Angus-sired sold for the greatest ($P < 0.0001$) price ($1,721/head). Bred cow lots categorized as Red Angus-sired also sold for the greatest ($P < 0.0001$) price ($1,935/head). Black Angus-sired bred cow lots sold for prices similar ($P = 0.14$) to those lots categorized as English-Continental crosses, but at prices greater (P

= 0.003) than cows classified as English-English crosses ($1,719; $1,638; and $1,637/head; respectively). Similar (P = 1.0) sale prices were observed for English-Continental cross lots and English-English cross lots ($1,638 and $1,637/head, respectively). Lots of Brahman-influenced bred cows sold for prices lower (P < 0.001) than all other breed categories ($1,435/head).

Analyses examining price differences among breeds are typically restricted to distinct regions within the United States. Various studies have examined the effect of hide color, discovering that black-hided females sold for greater prices (Falconer et al., 2009; Mitchell et al., 2018). Previous research has indicated that certain breeds may bring premiums dependent on the region of interest. Falconer et al. (2009) examined data from replacement female sales in Texas, discovering that Brahman cross females were valued greater than any other breed types offered for sale. Russell et al. (2014) analyzed South Texas female sale data and found that as degree of Brahman influence in females increased, premiums increased as well. These studies suggest greater demand for Brahman influence females in southern states or regions, as they are known for their adaptability to hotter climate conditions. Various calf studies have also found breed description to be a significant determinant of price (Schulz et al., 2010; Seeger et al., 2011), suggesting that different breeds are often utilized because of the way they may perform within different production settings. By quantifying the effect of breed description nationwide, insight regarding the perceived value of breed across multiple regions of the United States may be gained.

Origin

Origin (purchased versus home-raised) significantly influenced the sale price of bred heifers (Figure 2.5). Bred heifer lots of home-raised origin sold for prices greater (P = 0.0008) than lots of bred heifers that were purchased and then re-sold ($1,628 and $1,584/head,

respectively). We speculate that this could be due to increased confidence of buyers in the management history or health status of home-raised bred heifers. When considering past research regarding price determinants of beef calves, it is evident that information providing insight about how calves were managed prior to delivery is highly valued by buyers (King et al., 2006; Seeger et al., 2011).

Weight Variation

Variation in weight within the lot was a significant price determinant for bred cows (Figure 2.6). Lots with less variation in weight sold for prices greater ($P < 0.0001$) than those lots with greater variation in weight ($1,747 and $1,598/head, respectively). While research is limited regarding bred females, this finding is consistent with past research by King et al. (2006) and Seeger et al. (2011), who found that beef calves described as fairly even in weight often sold for prices greater than calves described as uneven in weight. Findings indicate that buyers are seeking females that are more uniform in weight across lots.

Frame Score

The frame score of bred heifers and bred cows significantly impacted sale price (Figure 2.7). Bred heifer lots categorized as medium-medium large frame and medium-large to large frame sold for similar ($P = 1.0$) prices ($1,618 and $1,621/head, respectively), but at prices greater ($P < 0.05$) than those lots considered to be of small to medium frame ($1,579/head). Within the bred cow analysis, lots considered to be of small to medium frame, medium-medium large frame, and medium large to large frame all sold for similar ($P > 0.05$) prices ($1,637; $1,690; and $1,692/head; respectively). Parcell et al. (1995) and Russel et al. (2014) both found that medium

to larger framed cows sold for greater prices than smaller framed cows, which is consistent with our results.

Flesh Score

Flesh score of the lot was a significant determinant of price for both bred heifers and bred cows (Figure 2.8). Within the bred heifer model, lots categorized as medium flesh and medium-medium heavy to heavy flesh sold for similar ($P = 0.51$) prices ($1,615 and $1,639/head, respectively), but at prices greater ($P < 0.05$) than those lots of bred heifers considered to be of light to light medium-medium flesh ($1,565/head). Bred cows lots of medium-medium heavy to heavy flesh sold for the greatest ($P < 0.05$) price ($1,796/head), compared to all other levels of flesh score. Lots categorized as medium flesh sold for prices greater ($P < 0.0001$) than those lots of bred cows with a level of light to light medium-medium flesh ($1,705 and $1,517/head, respectively).

The level of flesh or condition on a breeding female is important for several reasons, including reproductive success, maintenance, and efficiency (Hall, 2016). Previous research has established that accumulating an optimum degree of flesh on females at both breeding and calving contributes to improved reproductive performance (Spitzer et al., 1995). Parcell et al. (1995) found that thin cows received large discounts when compared to those of average condition. Significance across models for weight variation, frame score and flesh score suggest that buyers rely heavily on visual appraisal when making investment decisions regarding bred females. Extensive literature regarding the value of beef calves further supports the idea that buyers utilize these physical attributes when purchasing cattle across various classes.

In addition to the traits previously discussed, information on other management characteristics was provided within the data but not thoroughly and consistently described enough to analyze. These factors include stage of gestation, health and management history, and various reproductive management strategies. Existing literature suggests that these management factors contribute value within herds when utilized by progressive cattle producers. Although we are not able to accurately quantify the effects, these informational components are likely influencing bred female sale price.

Applications

The results of our study indicate that multiple factors influence the sale price of bred heifers including auction year, weight, region of origin, breed description, origin, frame score, and flesh score. Auction year, weight, lot size, breed description, weight variation, frame score, and flesh score all significantly impacted bred cow sale price. Greater understanding of the characteristics that influence the sale price of breeding cattle across the United States may provide benefits and insight from both an economic and production standpoint.

Acknowledgments

Superior Livestock Auction (Fort Worth, TX) provided the data to Kansas State University, Department of Animal Sciences & Industry, for this project. The Red Angus Association of America (Commerce City, CO) provided funding to Kansas State University, Department of Animal Sciences & Industry, for this project.

Tables and Figures

Table 2.1 - Non-adjusted means, medians, and ranges for factors describing the lots of bred heifers sold from 2010 through 2018 and bred cows sold from 2011 through 2018 through Superior Livestock video auctions

Factor	Mean ± SD	Median	Range
Bred heifers			
Number of heifers in the lot	47.5 ± 17.6	48	1 to 306
Base weight of the lot (lb)	1,000.7 ± 67.1	1,000	650 to 1,450
Price per head ($)	1,859.1 ± 517.4	1,735	800 to 3,250
Bred cows			
Number of cows in the lot	43.6 ± 23.8	41	2 to 315
Base weight of the lot (lb)	1,182.8 ± 103.9	1,150	825 to 1,600
Price per head ($)	1,675 ± 581.2	1,525	650 to 3,750

Table 2.2 - Factors affecting the sale price of bred heifers sold through Superior Livestock video auctions from 2010 through 2018

Factor	Number of lots	Least squares mean of sale price ($/head)	Price difference	P value of factor
Auction year				<.0001
2010	44	1,086[a]	-340	
2011	146	1,294[b]	-132	
2012	228	1,394[c]	-32	
2013	260	1,688[d]	262	
2014	405	2,455[e]	1,029	
2015	372	2,201[f]	775	
2016	178	1,449[c]	23	
2017	146	1,463[c]	37	
2018	91	1,426[c]	0	
Base weight of the lot	1,870		.90	<.0001
Region of the United States where the lot originated[g]				<.0001
West Coast	233	1,563[a]	4	
Rocky Mountain/North Central	988	1,681[b]	122	
South Central	591	1,622[c]	63	
South East	58	1,559[ac]	0	
Breed description of the lot				<.0001
English, English crosses	438	1,584[a]	62	
English-Continental crosses	149	1,622[a]	100	
Black Angus sired[h]	768	1,582[a]	60	
Red Angus sired[i]	391	1,721[b]	199	
Brahman influenced	124	1,522[a]	0	
Origin				.0008
Home-raised	390	1,628[a]	44	
Purchased	1,480	1,584[b]	0	
Frame score of the lot				.0016
Small to Medium	582	1,579[a]	-42	
Medium-Medium Large	875	1,618[b]	-3	
Medium Large to Large	413	1,621[b]	0	
Flesh score of the lot				.02
Light to Light Medium-Medium	123	1,565[a]	-74	
Medium	1,622	1,615[b]	-24	
Medium-Medium Heavy to Heavy	125	1,639[b]	0	

[a,b,c,d,e,f]Values within a factor without a common superscript differ ($P < 0.05$).
[g]States in the region of origin were: West Coast—California, Idaho, Nevada, Oregon, Utah, and Washington; Rocky Mountain/North Central—Colorado, Iowa, Illinois, Indiana, Michigan, Minnesota, Montana, North Dakota, Nebraska, South Dakota, Wisconsin, and Wyoming; South Central—Arizona, Kansas, Missouri, New Mexico, Oklahoma, and Texas; South East—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia.
[h]Lots of bred heifers in this breed group were sired by Black Angus bulls and out of dams with no Brahman influence.
[i]Lots of bred heifers in this breed group were sired by Red Angus bulls and out of dams with no Brahman influence.

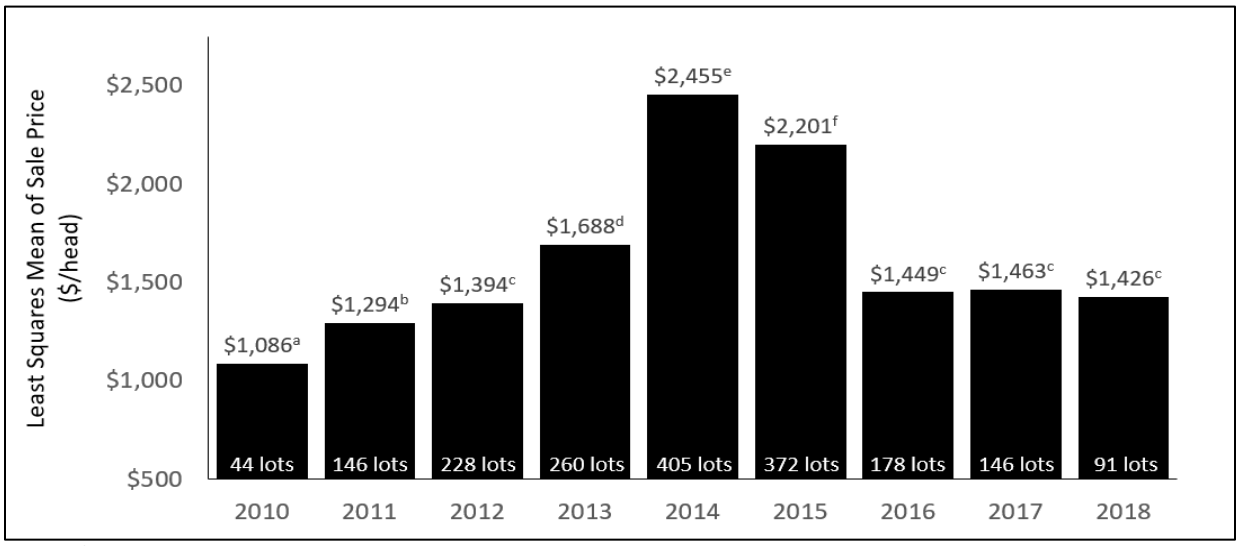
Table 2.3 - Factors affecting the sale price of bred cows sold through Superior Livestock video auctions from 2011 through 2018

Factor	Number of lots	Least squares mean of sale price ($/head)	Price difference	P value of factor
Auction year				<.0001
2011	232	1,295[a]	-5	
2012	140	1,381[ad]	81	
2013	132	1,590[b]	290	
2014	159	2,392[c]	1,092	
2015	197	2,402[c]	1,102	
2016	184	1,604[b]	304	
2017	120	1,420[d]	120	
2018	73	1,300[ad]	0	
Base weight of the lot	1,237		-0.65	<.0001
Base weight of the lot (quadratic)[e]	1,237		-0.0025	<.0001
Number of cows in the lot	1,237		-0.82	.03
Breed description of the lot				<.0001
English, English crosses	515	1,637[a]	202	
English-Continental crosses	121	1,638[ab]	203	
Black Angus sired[f]	362	1,719[b]	284	
Red Angus sired[g]	168	1,935[c]	500	
Brahman influenced	71	1,435[d]	0	
Variation in weight within the lot				<.0001
Fairly even	109	1,747[a]	149	
Uneven	1128	1,598[b]	0	
Frame score of the lot				.04
Small to Medium	354	1,637[a]	-55	
Medium-Medium large	482	1,690[a]	-2	
Medium Large to Large	401	1,692[a]	0	
Flesh score of the lot				<.0001
Light to Light Medium-Medium	221	1,517[a]	-279	
Medium	926	1,705[b]	-91	
Medium-Medium Heavy to Heavy	90	1,796[c]	0	

[a,b,c,d]Values within a factor without a common superscript differ ($P < 0.05$).
[e]In order to prevent multicollinearity between the linear and quadratic base weight terms, the base weight of each lot was centered at zero by subtracting the mean base weight of all the lots (1,182.8 lb) from the base weight of each lot.
[f]Lots of bred cows in this breed group were sired by Black Angus bulls and out of dams with no Brahman influence.
[g]Lots of bred cows in this breed group were sired by Red Angus bulls and out of dams with no Brahman influence.

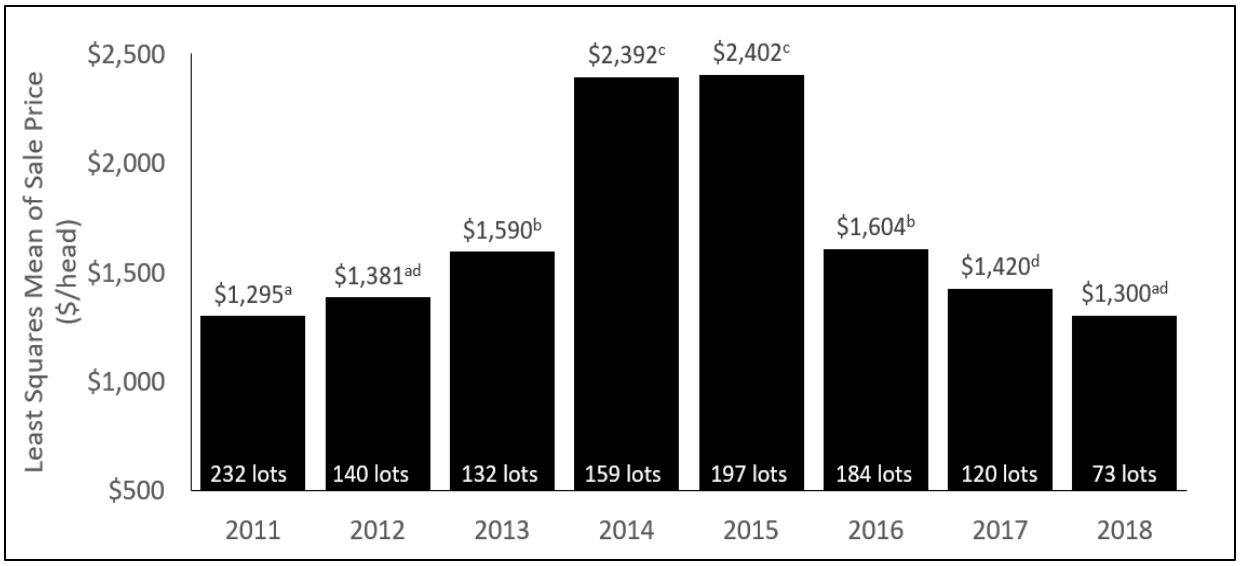
Figure 2.1 – Effect of auction year on the sale price of bred heifers and bred cows

Bred heifers



[a,b,c,d,e,f]Values in a factor without a common superscript differ ($P < 0.05$).

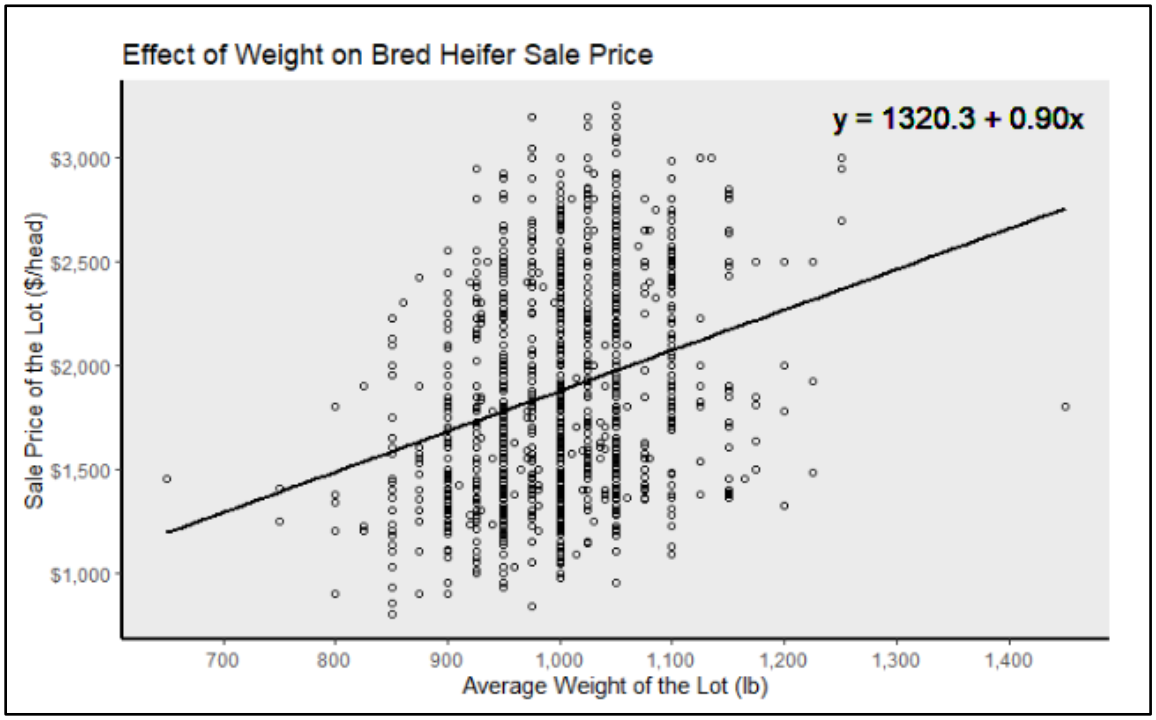
Bred cows



[a,b,c,d]Values in a factor without a common superscript differ ($P < 0.05$).

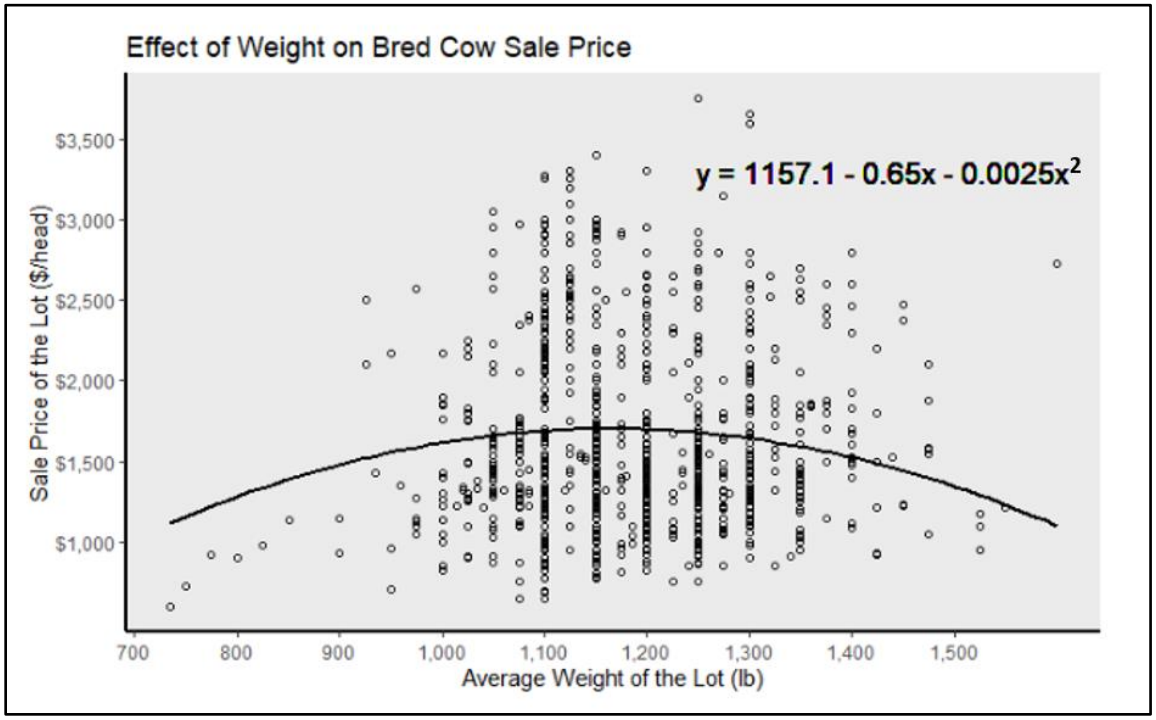
Figure 2.2 - Effect of base weight on the sale price of bred heifers and bred cows

Bred heifers



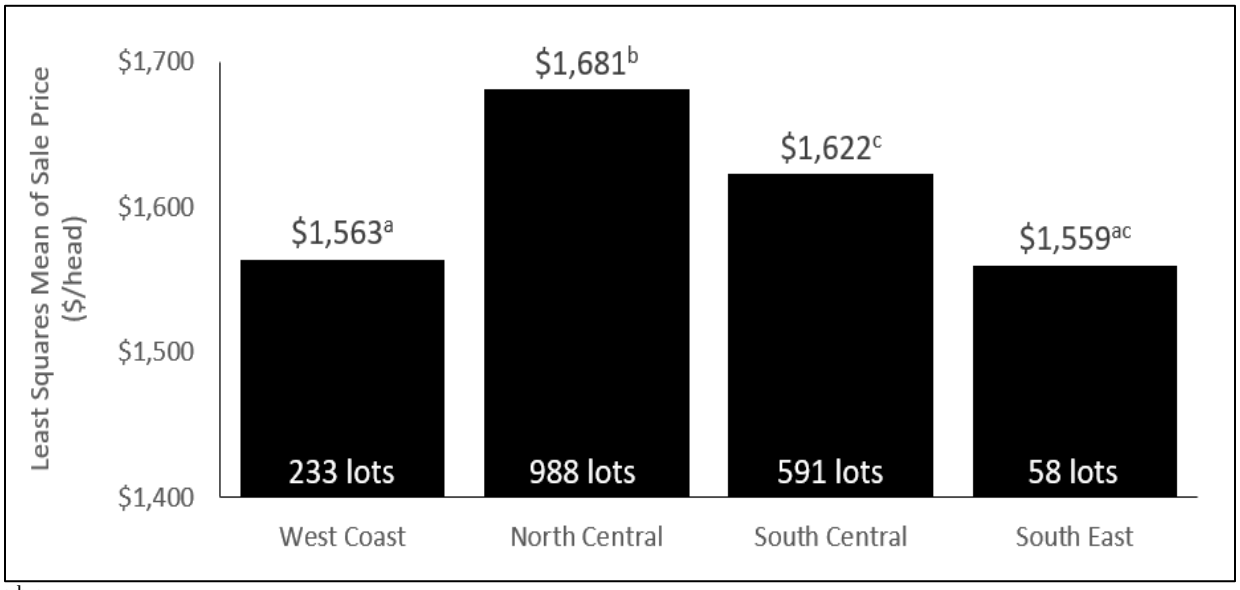
n = 1,870 lots of bred heifers

Bred cows



n = 1,237 lots of bred cows

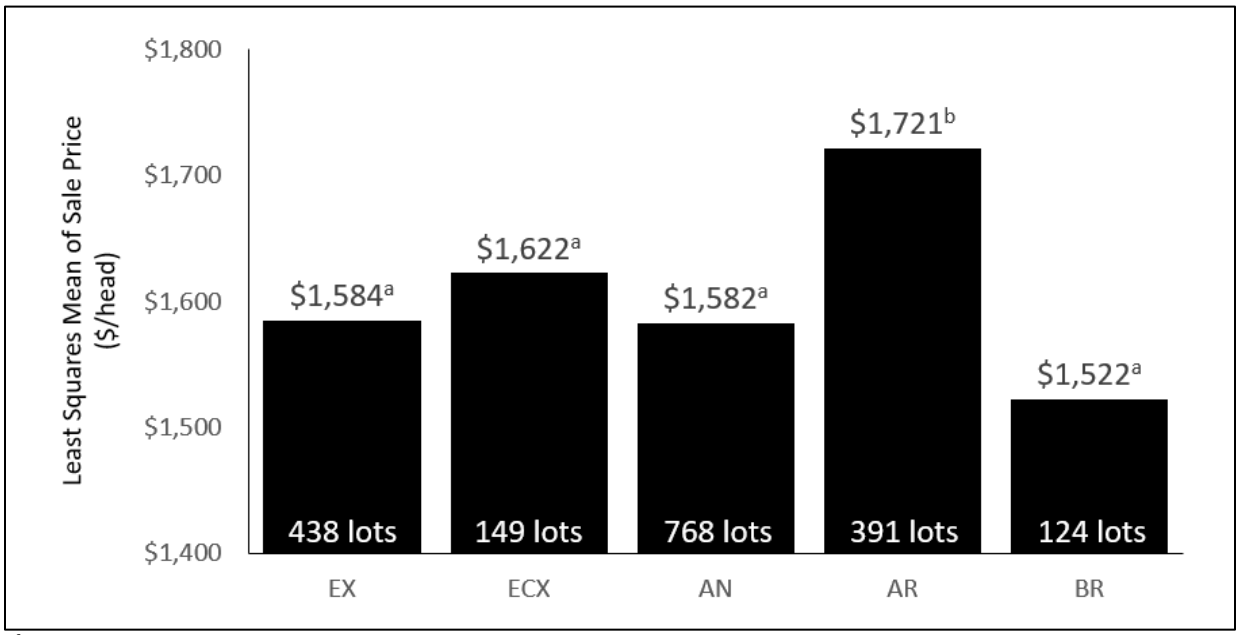
Figure 2.3 - Effect of region on the sale price of bred heifers



[a,b,c]Values in a factor without a common superscript differ ($P < 0.05$).
States in the region of origin were: West Coast—California, Idaho, Nevada, Oregon, Utah, and Washington; Rocky Mountain/North Central—Colorado, Iowa, Illinois, Indiana, Michigan, Minnesota, Montana, North Dakota, Nebraska, South Dakota, Wisconsin, and Wyoming; South Central—Arizona, Kansas, Missouri, New Mexico, Oklahoma, and Texas; South East—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia.

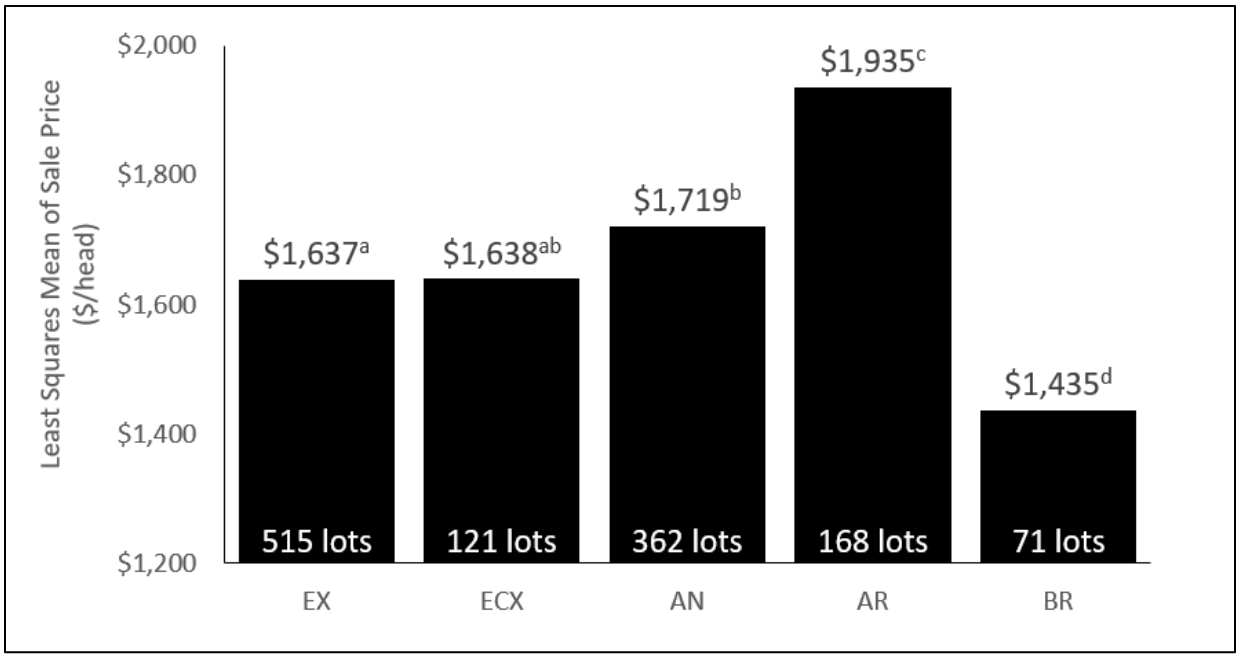
Figure 2.4 - Effect of breed description on the sale price of bred heifers and bred cows

Bred heifers



[a,b]Values in a factor without a common superscript differ (P < 0.05).

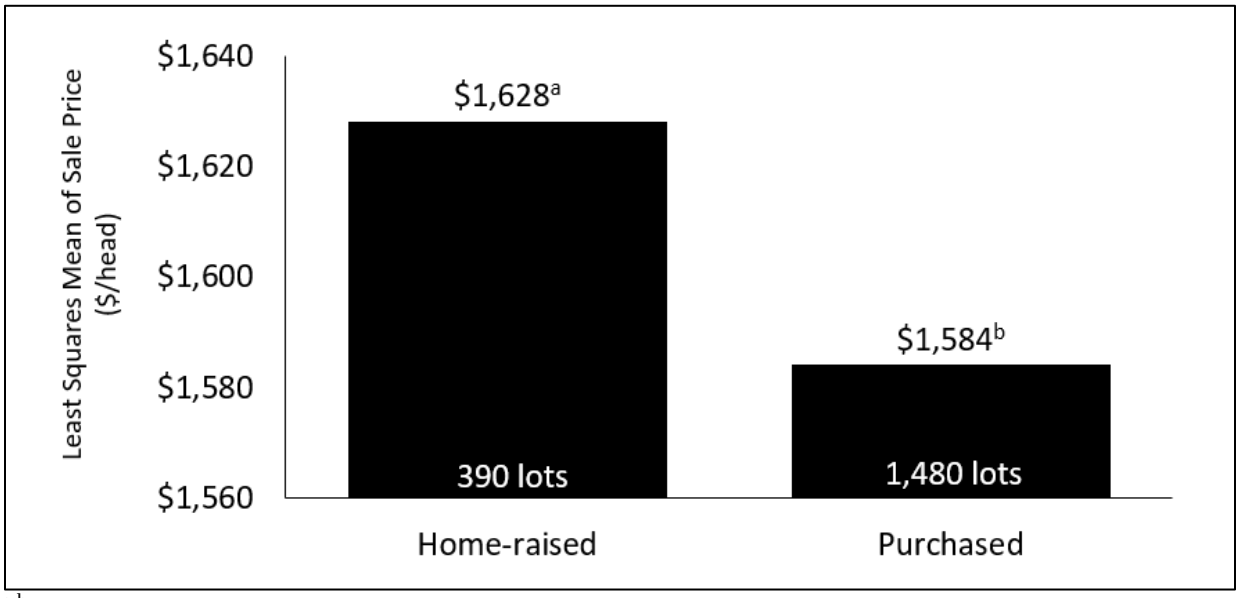
Bred cows



[a,b,c]Values in a factor without a common superscript differ (P < 0.05).

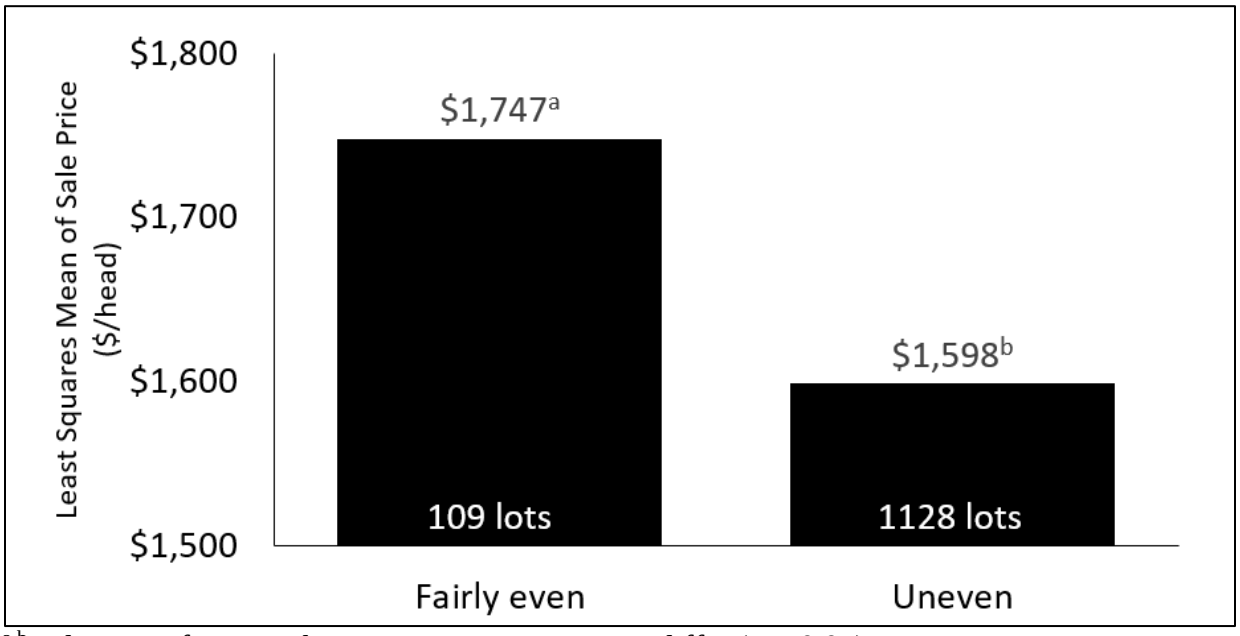
Breed description of a lot of bred cows was categorized into five groups: English, English crosses (EX); English-Continental crosses (ECX); Black Angus sired (AN); Red Angus sired (AR); and Brahman influenced (BR).

Figure 2.5- Effect of origin on the sale price of bred heifers



[a,b]Values in a factor without a common superscript differ (P < 0.05).

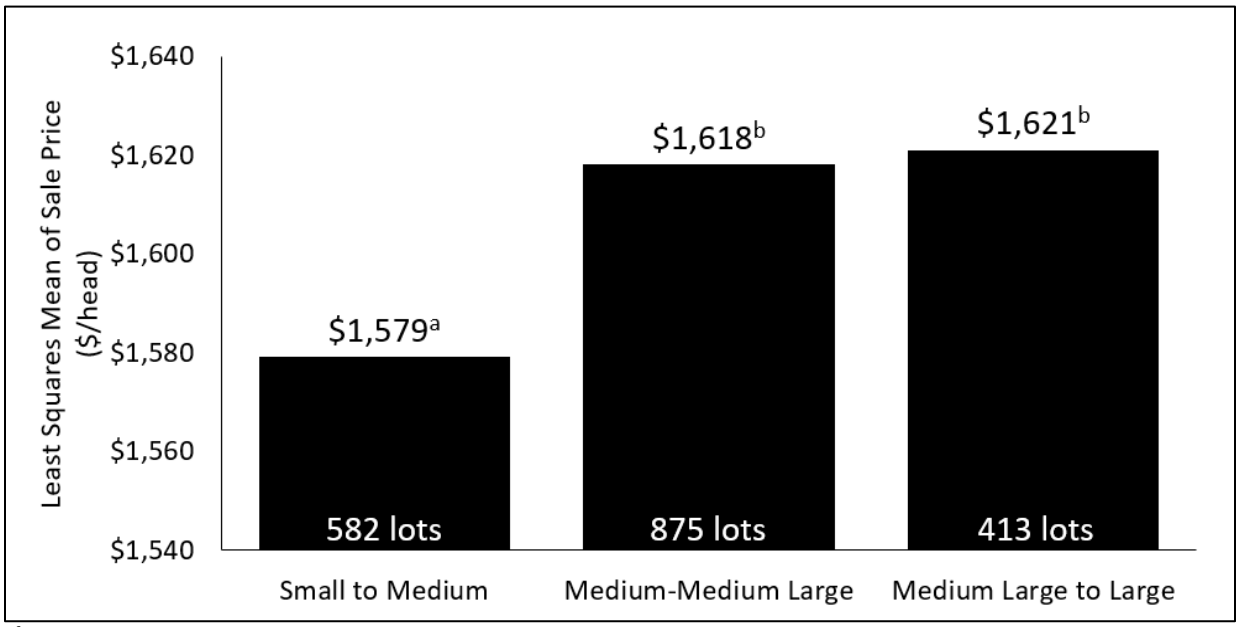
Figure 2.6 - Effect of weight variation on the sale price of bred cows



[a,b]Values in a factor without a common superscript differ (P < 0.05).

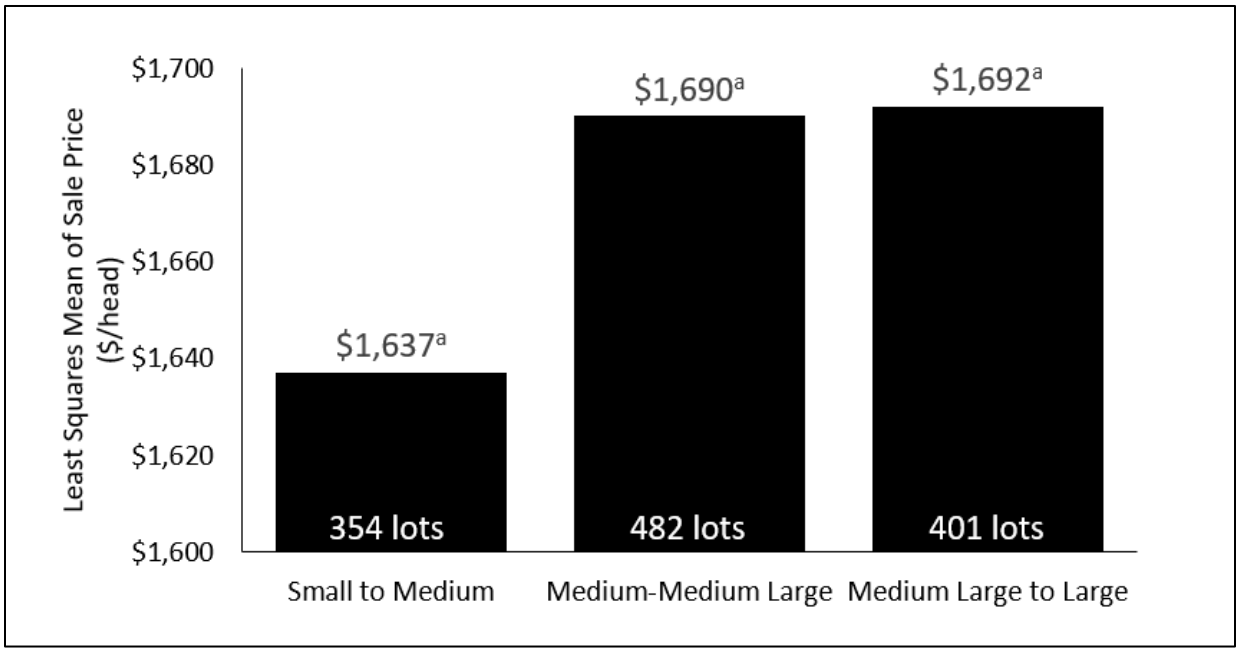
Figure 2.7 - Effect of frame score on the sale price of bred heifers and bred cows

Bred heifers



[a,b]Values in a factor without a common superscript differ (P < 0.05).

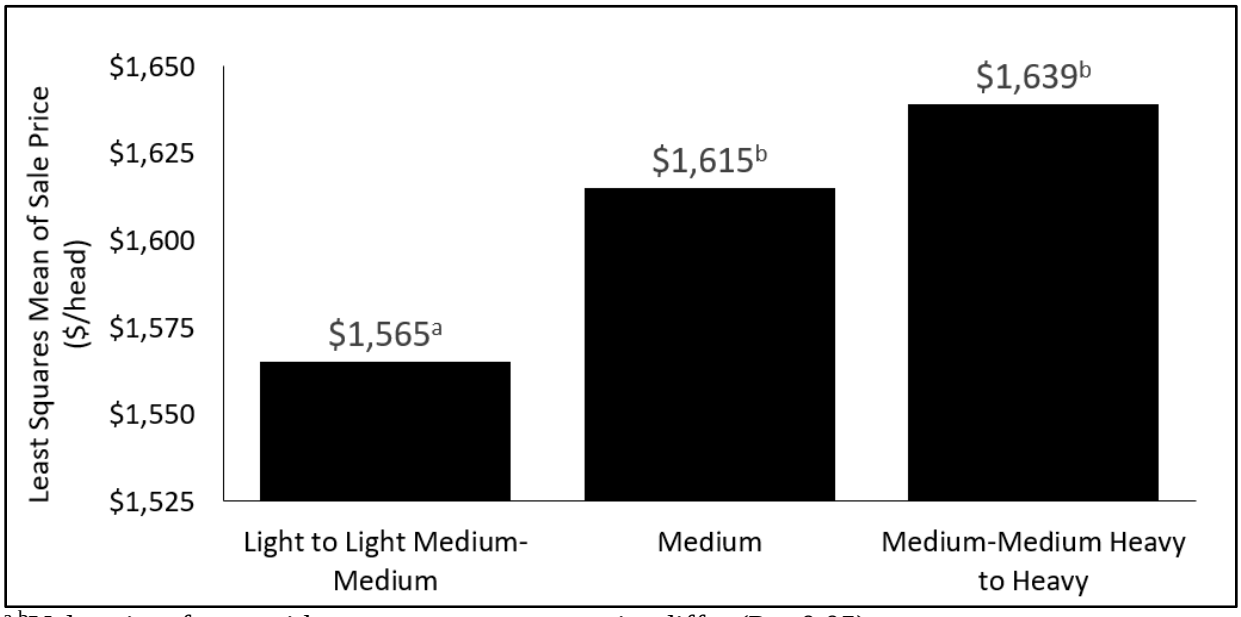
Bred cows



[a]Values in a factor without a common superscript differ (P < 0.05).

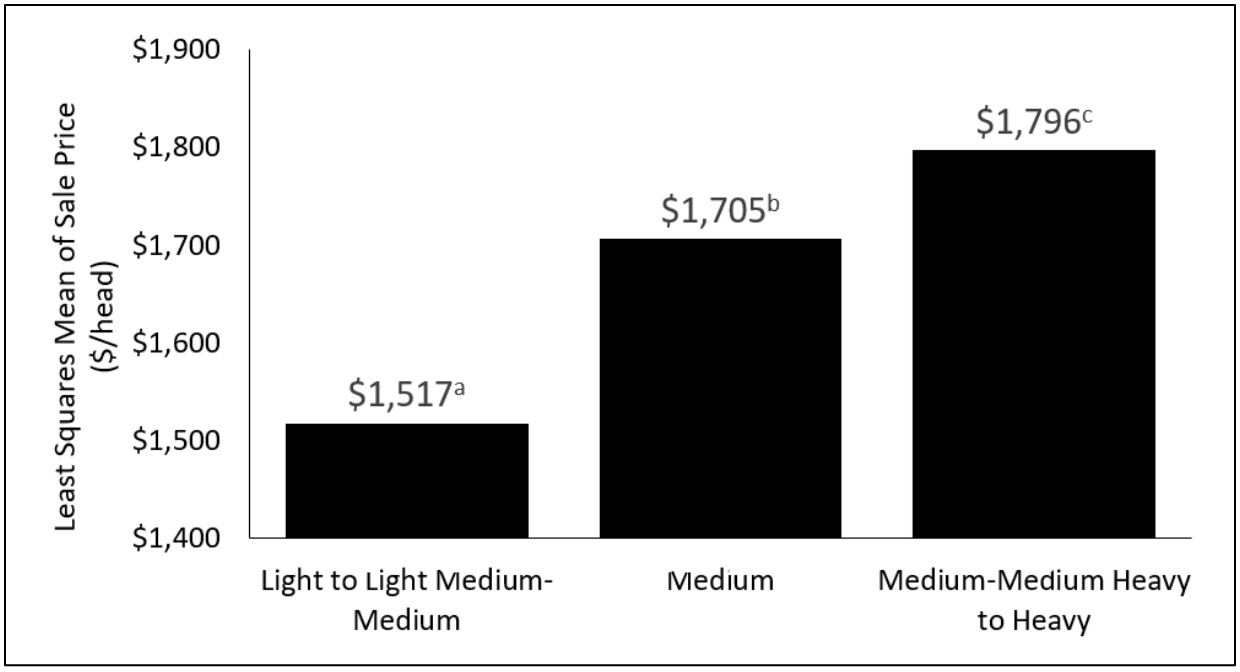
Figure 2.8 - Effect of flesh score on the sale price of bred heifers and bred cows

Bred heifers



[a,b]Values in a factor without a common superscript differ (P < 0.05).

Bred cows



[a,b,c]Values in a factor without a common superscript differ (P < 0.05).

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Chapter 3 - Genetic factors affecting the sale price of Red Angus bulls sold at auction

Abstract

Objective: The objective of this study was to evaluate the influence of selection indices and EPDs on the sale price of Red Angus bulls sold at auction from 2017 through 2019 across the United States.

Materials and Methods: Data were available on 21,362 Red Angus bulls sold at auction over five sale seasons: Spring 2017, Fall 2017, Spring 2018, Fall 2018, and Spring 2019. Two separate multiple regression models were developed using backward selection procedures to evaluate the effect of various selection indices and EPDs on the sale price of Red Angus bulls. In addition, bulls were categorized into groups by respective sale prices to descriptively summarize and determine relationships between auction price and values of selection indices and EPDs.

Results and Discussion: Various selection indices and EPDs were significant factors influencing Red Angus bull sale price. Sale price was found to be positively associated with HerdBuilder Index and GridMaster Index. Results indicated relationships between sale price and various EPD values including Calving Ease Direct EPD, Birth Weight EPD, Milk EPD, Maintenance Energy EPD, Heifer Pregnancy EPD, Calving Ease Maternal EPD, Stayability EPD, Marbling Score EPD, Carcass Weight EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD. However, relatively low R^2 values across both models suggest that these relationships are weak, indicating that producers are utilizing additional information that we are not able to fully characterize when making purchasing decisions, placing little emphasis on selection indices and EPDs.

Implications and Applications: In addition to genetic factors, buyers may be considering other characteristics not captured within this data such as physical attributes, marketing tactics, and breeder reputation. Continued research and understanding of the various factors affecting beef bull sale price may prove valuable to this sector of the beef industry.

Key words: beef bulls, bull price, EPDs, sale price, selection indices

Introduction

The selection of a beef bull is an important choice, as a herd sire provides over 80% of genetic merit and change to a herd (Ishmael, 2017). In an industry with rapid change in producer priorities and preferences, the utilization of various management strategies and selection tools has been crucial in ensuring a continued level of economic productivity (Hersom et al., 2011). Numerous categories of information are provided to potential buyers through various auction channels. Information ranges from values concerning expected progeny differences (EPD), selection indices, and phenotypic data and characteristics. Different information provided to buyers during the time of sale may have the potential to alter the price a buyer may be willing to offer for the bull depending on the goals and priorities of the specific producer (Dhuyvetter et al., 1996; Chvosta et al., 2001).

Several studies have investigated the effect of different informational components on sale or auction price. Marketing strategies, genetic tools, and physical factors have been examined to determine their relative contribution to the overall value of a herd sire. The value of a herd sire may vary dependent on the goals of the buyer, making the process of quantifying which traits are of most importance complex and potentially unclear.

Greer and Urick (1988) conducted one of the earliest studies examining the relationship between sale price and economic elements, discovering that cowherd inventory and calf prices impacted price. The idea that buyers utilize a combination of factors when making purchasing decisions was reinforced by later work (Dhuyvetter et al., 1996; Chvosta et al., 2001; Boyer et al., 2019). Multiple studies have revealed less emphasis on EPDs and more value associated with physical attributes (Simms et al., 1994; Turner, 2004; Irsik et al., 2008). A shift in prioritization towards value-added traits and carcass characteristics has been seen in more contemporary studies (Walburger, 2002; Turner, 2004; Bacon et al., 2017).

The body of literature demonstrates that sale price is positively associated with physical attributes and performance traits such as actual weights (Simms et al., 1994; Dhuyvetter et al., 1996; Irsik et al., 2008; Boyer et al., 2019). Producers value low birth weight predictions and have shifted greater emphasis to carcass and consumption driven traits (Walburger, 2002; Turner, 2004; Bacon et al., 2017). Earlier studies suggested a lower emphasis placed on EPDs in comparison to physical attributes, while more recent research shows that the use of genetic information is becoming more important for purchasing decisions. Marketing strategies and promotional tactics appeared to positively impact the sale price of beef bulls (Dhuyvetter et al., 1996). When considering the variation in priorities and goals of cattle producers, continued research investigating the traits affecting the sale price of beef bulls may prove valuable to commercial and seedstock producers.

The objective of this study was to evaluate the influence of selection indices and EPDs on the sale price of Red Angus bulls sold at auction from 2017 through 2019 across the United States.

Materials and Methods

Data Collection

Information describing various factors about Red Angus bulls marketed and sold nationwide through auctions were obtained from the Red Angus Association of America (Commerce City, CO) in an electronic format. Quantifiable factors available for the population of Red Angus bulls were sale price, auction date, state, HerdBuilder Index, GridMaster Index, Calving Ease Direct EPD, Birth Weight EPD, Weaning Weight EPD, Yearling Weight EPD, Milk EPD, Maintenance Energy EPD, Heifer Pregnancy EPD, Calving Ease Maternal EPD, Stayability EPD, Marbling Score EPD, Yield Grade EPD, Carcass Weight EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD. These data were collected for 21,362 Red Angus bulls offered for sale in auctions during the spring 2017, fall 2017, spring 2018, fall 2018, and spring 2019 seasons. Descriptions of selection indices and EPDs provided by the Red Angus Association of America are shown in Table 3.1 (Red Angus Association of America, 2018).

Six geographical regions were used to analyze distribution of bulls sold throughout the United States, six regions were defined. The six regions are as follows: West Coast (AK, CA, HI, ID, NV, OR, UT, and WA), Great Plains (CO, KS, MT, NE, ND, SD, and WY), Midwest (IA, IL, IN, MI, MN, MO, OH, and WI), South Central (AZ, NM, OK, and TX), Southeast (AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, and VA), and Northeast (CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, and WV).

Statistical Analysis

Two separate multiple regression models were developed using backward selection procedures to examine the effect of various genetic factors in the form of selection indices and EPD on the sale price of Red Angus bulls, respectively. HerdBuilder Index and GridMaster Index were included in the model as fixed effects. Concerning the EPD model, Calving Ease Direct EPD, Birth Weight EPD, Milk EPD, Maintenance Energy EPD, Heifer Pregnancy EPD, Calving Ease Maternal EPD, Stayability EPD, Marbling Score EPD, Carcass Weight EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD were all included in the model as fixed effects. Across both models, at each phase of the backwards selection procedure, the independent variable with the largest *P*-value was removed from the model until all variables were significant. For a factor to remain in the model, a value of $P < 0.05$ was necessary.

In order to minimize the occurrence of multicollinearity between genetic factors, correlations among variables were examined using a correlation matrix. Highly correlated EPD variables included 1) Weaning Weight EPD and Yearling Weight EPD (0.93), 2) Weaning Weight EPD and Carcass Weight EPD (0.80), 3) Yearling Weight EPD and Carcass Weight EPD (0.84), 4) Yield Grade EPD and Rib Eye Area EPD (-0.67), and 5) Yield Grade EPD and 12th Rib Fat Thickness EPD (0.72). The following parameters were excluded from the regression model to minimize the occurrence of multicollinearity: 1) Weaning Weight EPD, 2) Yearling Weight EPD, and 3) Yield Grade EPD. We chose to remove Weaning Weight EPD and Yearling Weight EPD, while including Carcass Weight EPD in the model, however, we recognize that producers may be purchasing based on a combination of one or more of these traits. Yield Grade EPD is highly correlated with and calculated from predictions of Rib Eye Area EPD and 12th Rib Fat Thickness EPD, thus Yield Grade EPD was removed.

Highly correlated variables across both selection indices and EPD included 1) HerdBuilder Index and Stayability EPD (0.94), 2) HerdBuilder Index and Calving Ease Direct EPD (0.75), and 3) GridMaster Index and Marbling Score EPD (0.86). By including selection indices within a separate regression model, we more appropriately separate their effects on sale price while avoiding the occurrence of multicollinearity between selection indices and EPDs. A complete table showing correlation coefficients between all continuous variables is shown in Table 3.2.

Descriptive Data and Summarization

With the limitations of removing highly correlated variables from the regression models, we chose to further examine the relationship between auction price and genetic parameters by evaluating potential trends in selection indices and EPDs across sale price categories. Red Angus bulls were categorized into eight groups by respective auction price. The unadjusted, average values of selection indices and EPDs were then calculated across sale price categories to investigate the trend of these various genetic factors relative to sale price.

Eight groups were defined: bulls sold at auction between $1,000 and $2,000; bulls sold at auction between $2,000 and $4,000; bulls sold at auction between $4,000 and $6,000; bulls sold at auction between $6,000 and $8,000; bulls sold at auction between $8,000 and $10,000; bulls sold at auction between $10,000 and $12,000; bulls sold at auction between $12,000 and $14,000; and bulls sold at auction for greater than $14,000. Various descriptive figures were developed to further demonstrate the relationship between sale price and genetic values in the form of selection indices and EPD.

Results

Sale Season Distribution

Non-adjusted mean sale prices, number of head, and percentages of bulls sold throughout various sale seasons are shown in Table 3.3. Eighty-five percent of bulls were sold during Spring sale seasons (18,290 bulls), compared to Fall sale seasons (3,072 bulls). The largest percentage of bulls were sold in the Spring 2019 sale season (31%, 6,649 bulls). Non-adjusted mean sale prices, number of head, and percentages of bulls sold by months are shown in Table 3.4. The largest percentage of bulls auctioned from 2017 through 2019 was during the month of March (49%, 10,483 bulls), followed by February (18%, 3,812 bulls) and April (16%, 3,461 bulls).

State and Regional Distribution

Of the 21,362 initial bull observations, 17,956 bulls had a producer state listed. When examining the distribution of bulls sold, 80% of these bulls were sold across 8 states. The highest percentage of bulls were sold throughout Montana (21%, 3,787 bulls), followed by Nebraska (13%, 2,345 bulls), South Dakota (11%, 2,009 bulls), Kansas (9%, 1,544 bulls), Iowa (8%, 1,432 bulls), North Dakota (7%, 1,228 bulls), Wyoming (6%, 1,030 bulls), and Texas (5%, 817 bulls). For the remaining states, the percentage of bulls sold was less than 5%. Non-adjusted mean sale prices, number of head, and percentages of bulls sold by state shown in Table 3.5.

When evaluating the distribution of bulls sold by region, six regions were defined: West Coast, Great Plains, Midwest, South Central, Southeast, and Northeast. Two regions represented 83% of bulls, with the greatest percentage of bulls being sold in the Great Plains (69%, 12,322 bulls), followed by the Midwest region (14%, 2,520 bulls). The South Central (7%, 1,343 bulls)

and West Coast (7%, 1,331 bulls) regions accounted for 14% of bulls auctioned, and the Southeast and Northeast represented a combined 3% of bulls sold. Non-adjusted mean sale prices, number of head, and percentages of bulls sold across all regions are provided in Table 3.6.

Genetic Factors Influencing Sale Price

Non-adjusted means, standard deviations, medians, and ranges for sale price, selection indices, and EPDs of Red Angus bulls are shown in Table 3.7. Of the 11 quantifiable factors included within the initial EPD analysis, 10 significantly influenced the sale price of Red Angus bulls. Those factors were 1) Calving Ease Direct EPD ($P < 0.0001$), 2) Birth Weight EPD ($P < 0.0001$), 3) Maintenance Energy EPD ($P < 0.0001$), 4) Heifer Pregnancy EPD ($P < 0.0001$), 5) Calving Ease Maternal EPD ($P < 0.05$), 6) Stayability EPD ($P = 0.02$), 7) Marbling Score EPD ($P < 0.0001$), 8) Carcass Weight EPD ($P < 0.0001$), 9) Rib Eye Area EPD ($P <0.0001$), and 10) 12^{th} Rib Fat Thickness EPD ($P < 0.0001$). Parameter estimates, standard errors, t-values, and p-values for significant factors included in the final model are reported in Table 3.8. Milk EPD ($P = 0.67$) did not significantly affect the sale price of Red Angus bulls and was therefore excluded from the final model.

Positive relationships with price were discovered for the variables of Calving Ease EPD, Heifer Pregnancy EPD, and Stayability EPD. When examining regression coefficients, it can be interpreted that a single unit increase in Calving Ease EPD increased sale price by $57.09. For every single unit increase in Heifer Pregnancy EPD and Stayability EPD, sale price increased by $51.62 and $20.66, respectively. Birth Weight EPD, Maintenance Energy EPD, and Calving Ease Maternal EPD were found to be inversely associated with sale price. For every unit increase in Birth Weight EPD and Maintenance Energy EPD, sale price decreased by $276.40 and $62.53,

respectively. For a single unit increase in Calving Ease Maternal EPD, sale price decreased by $22.79. Various carcass parameters including Marbling Score EPD, Carcass Weight EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD were discovered to be positively associated with the sale price of Red Angus bulls. For every single unit increase in Marbling Score EPD, sale price increased by $567.15. A single unit increase in Carcass Weight EPD resulted in an increase of sale price by $69.47. For a single unit increase in Rib Eye Area EPD and 12th Rib Fat Thickness, sale price increased by $1,125.72 and $3,114.31, respectively. Smaller ranges for the variables of Marbling Score EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD equate to larger adjustments seen within the regression model results. Therefore, a tenth of unit increase in Marbling Score EPD results in an increase of $56.72 in sale price, while a tenth of a unit increase in Rib Eye Area EPD and 12th Rib Fat Thickness EPD increased sale price by $112.57 and $311.43, respectively.

Within the selection index model, both indices remained significant, showing an influence on Red Angus bull sale price. Those selection indices were 1) HerdBuilder Index ($P < 0.0001$) and 2) GridMaster Index ($P < 0.0001$). Parameter estimates, standard errors, t-values, and p-values for significant factors included in the final model are reported in Table 3.9. HerdBuilder Index was discovered to positively impact sale price. Regression coefficients indicate that a single unit increase in HerdBuilder Index increased auction price by $5.08 while a single unit increase in GridMaster resulted in a $331.00 increase in sale price.

While selection indices and EPDs were found to be significant, relatively low R^2 values were found across both analyses. Within the EPD model, a R^2 of 0.07 was found, indicating that only 7% of the variation in auction price of Red Angus bulls can be explained by the associated EPDs included within the model. When examining the R^2 within the model encompassing both

selection indices, a value of 0.05 was found, showing evidence of only 5% variation in auction price being explained by both multi-trait selection tools.

Descriptive Data and Summarization

When summarizing descriptive raw data across the eight Red Angus bull sale price groups, positive relationships with sale price were discovered for HerdBuilder Index (Figure 3.1), GridMaster Index (Figure 3.2), Calving Ease Direct EPD (Figure 3.3), Weaning Weight EPD (Figure 3.4), Yearling Weight EPD (Figure 3.5), Heifer Pregnancy EPD (Figure 3.6), and Stayability EPD (Figure 3.7). An inverse relationship was discovered between sale price and Birth Weight EPD (Figure 3.8). Relatively flat trends were observed for Milk EPD (Figure 3.9), Maintenance Energy EPD (Figure 3.10), Calving Ease Maternal (Figure 3.11), and Yield Grade EPD (Figure 3.12). Sale price was positively associated with Marbling Score EPD (Figure 3.13), Carcass Weight EPD (Figure 3.14), Rib Eye Area EPD (Figure 3.15), and 12th Rib Fat Thickness EPD (Figure 3.16).

Discussion

Results from the regression models indicate relationships consistent with previous research in the field. Positive associations with both selection indices, HerdBuilder Index and GridMaster Index, were observed. This may suggest that producers are using these tools to simplify selection across various traits. EPDs in the form of calving, growth, and maternal traits influenced sale price. These findings further support past research of genetic information in the form of growth and calving ease traits affecting price (Boyer et al., 2019). Inverse relationships with price were discovered for Birth Weight EPD and Maintenance Energy EPD, consistent with previous

literature suggesting value in low birth weight predictions and easy maintenance characteristics (Turner, 2004). Various carcass traits in the form of Marbling Score EPD, Carcass Weight EPD, Rib Eye Area EPD, and 12th Rib Fat Thickness EPD held positive relationships with sale price. Results reported on carcass variables align with the idea of a producer shift in focus toward high growth, carcass driven, and value-adding traits (Walburger, 2002; Turner, 2004; Bacon et al., 2017). Walburger (2002) and Turner (2004) both discovered emphasis on the utilization of carcass parameters through various ultrasound measurements, indicating increased importance placed on carcass quality traits. Bacon et al. (2017) reported consistent results, suggesting that producers are continuing to heavily weigh carcass parameters in selection decisions. When considering the non-significance of Milk EPD within the regression model, a possible explanation may be because Milk EPD is often known as a 2-way trait, creating a neutral effect. Beef producers may prioritize higher or lower milk EPD values. High Milk EPD bulls can produce high milking cows and wean heavier calves but may be accompanied by higher maintenance costs (Rasby, 2012).

While significant variables across both models demonstrate relationships between auction price and genetic parameters, low R^2 values indicating a small amount of explained variation suggest that buyers of bulls are prioritizing other informational components, while placing little to no emphasis on selection indices and EPDs. This finding aligns with previous beef bull research showing less emphasis placed on the utilization of EPDs in comparison to physical attributes and actual weights when making selection decisions (Simms et al., 1994; Turner, 2004; Irsik et al., 2008). Through a survey, Simms et al. (1994) found that producers heavily weigh physical traits such as frame score, visual conformation, and structural soundness, with an overall lower value placed on EPDs in selection decisions. Findings from Turner (2004) demonstrated that buyers place value on most actual weights in comparison to genetic predictions. Irsik et al. (2008) did not

observe an association between sale price and EPDs but uncovered that other factors such as actual weights and physical conformation influenced price.

In addition to genetic factors, various physical attributes, actual weights, management traits, marketing characteristics, and the value of breeder reputation not captured within the data may be serving as potential influences on bull buyers prior to or at the time of auction. This is consistent with past literature suggesting that various factors influence bull buyers at the time of sale (Greer and Urick, 1988; Dhuyvetter et al., 1996; Chvosta et al., 2001; Irsik et al., 2008; Boyer et al., 2019). Dhuyvetter et al. (1996) discovered that in addition to certain EPDs, physical traits such as muscling, structure, and conformation and marketing strategies such as sale order, promotional tactics, and retainment rights positively increased price. While Chvosta et al. (2001) witnessed an increased utilization of EPDs, they reported that other factors such as actual weights and age also affected price. More recently, Bacon et al. (2017) found that buyers place importance on a combination of genetic traits and physical attributes. Boyer et al. (2019) reported results supporting that EPDs related to growth and calving ease influenced price, in addition to performance measures such as average daily gain and physical traits such as weight and frame score.

Relationships between genetic parameters and sale price, while apparent in the present data through descriptive figured developed, industry knowledge suggests buyers are likely prioritizing other factors ahead of EPDs (Glen, 2017), including physical attributes, performance characteristics in the form of actual weights, and breeder reputation. Buyer intentions are unknown, making it difficult to gauge the incorporation of genetic tools in selection. Industry surveys have demonstrated that a large percentage of producers do not fully understand genetic material or utilize it when making decisions, are slow to adopt genetic tools, and tend to rely more

heavily on familiar information (Glen, 2017; Rutherford, 2019) such as physical conformation or actual production weights.

Applications

The results of our study demonstrate weak relationships between sale price and selection indices and EPDs. Relatively low R^2 values suggest that bull buyers are utilizing other informational components not captured within the data when making investment decisions, placing little emphasis on selection indices and EPDs. Knowledge of physical attributes, marketing strategies, and breeder reputation are likely influencing buyers, and may explain additional variation in the sale price of Red Angus bulls. Continued research on factors influencing the sale price of beef bulls across the United States may prove advantageous to commercial and seedstock producers.

Acknowledgments

The Red Angus Association of America (Commerce City, CO) provided the data and funding to Kansas State University, Department of Animal Sciences & Industry, for this project.

Tables and Figures

Table 3.1 – Selection index and EPD descriptions

Selection Index	
HerdBuilder Index (HBI)	- Ideal for utilization by producers selecting bulls to develop profitable replacement females and maximize the value of non-replacement marketing progeny. Significant influence is placed on Stayability, Heifer Pregnancy and Calving Ease.
GridMaster Index (GMI)	- Ideal for utilization by producers with the primary goal of maximizing profitability of feeders in the feedyard and on the rail. Marbling Score, Yield Grade, and growth EPDs are the primary traits of importance.

Expected Progeny Difference	Abbreviation	Description
Calving Ease Direct	CED	- predicts the probability of calves being born unassisted out of 2-year-old heifers
Birth Weight	BW	- predicts the difference, in pounds, for birth weight, and is also used in the calculation of Red Angus' Calving Ease Direct (CED) EPD
Weaning Weight	WW	- predicts the difference, in pounds, for weaning weight (adjusted to age of dam and a standard 205 days of age). This is an indicator of growth from birth to weaning
Yearling Weight	YW	- predicts the expected difference, in pounds, for yearling weight (adjusted to a standard 365 days of age). This is an indicator of growth from birth to yearling
Milk	MILK	- predicts the difference in maternal production of an individual animal's daughters as expressed by the weaning weight of their calves
Maintenance Energy	ME	- predicts differences in daughters' maintenance energy requirements and is expressed in Mcal/Month
Heifer Pregnancy	HPG	- predicts the probability of heifers conceiving to calve at two years of age.
Calving Ease Maternal	CEM	- predicts the probability of a given animal's daughters calving unassisted at two years of age.
Stayability	STAY	- predicts the probability of a bull's daughters remaining productive until at least six years of age.
Marbling Score	MARB	- predicts differences for carcass marbling score as expressed in marbling score units
Yield Grade	YG	- predicts differences in USDA Yield Grade score and is expressed in USDA Yield Grade units.
Carcass Weight	CW	- predicts differences in hot carcass weight and is expressed in pounds.
Rib Eye Area	REA	- predicts differences of carcass Rib Eye Area between the 12th and 13th rib.
12^{th} Rib Fat Thickness	FAT	- predicts differences for carcass fat depth over the 12th rib, as expressed in inches

Descriptions for selection indices and expected progeny differences were provided by the Red Angus Association of America – The Ranchers' Guide to EPDs

Table 3.2 – Correlation coefficients among continuous variables describing the Red Angus bulls sold at auction from 2017 through 2019

	PRICE	HBI	GMI	CED	BW	WW	YW	MILK	ME	HPG	CEM	STAY	MARB	YG	CW	REA	FAT
PRICE	1.00	0.10	0.22	0.08	-0.11	0.13	0.17	0.00	-0.01	0.09	0.01	0.03	0.13	0.00	0.13	0.13	0.06
HBI		1.00	0.18	0.75	-0.23	0.02	0.11	0.10	-0.07	0.11	0.48	0.94	0.19	0.30	-0.13	-0.15	0.36
GMI			1.00	0.02	-0.13	0.48	0.61	-0.07	0.18	0.20	-0.08	-0.03	0.68	-0.13	0.46	0.43	-0.02
CED				1.00	-0.57	-0.30	-0.20	0.18	-0.16	0.02	0.51	0.61	0.14	0.21	-0.41	-0.21	0.34
BW					1.00	0.45	0.38	-0.22	0.01	-0.17	-0.17	-0.10	-0.27	0.06	0.44	0.06	-0.15
WW						1.00	0.93	-0.28	0.22	0.03	-0.12	-0.03	0.13	0.09	0.80	0.33	-0.01
YW							1.00	-0.22	0.22	0.03	-0.07	0.02	0.17	0.17	0.84	0.31	0.06
MILK								1.00	0.13	-0.01	0.12	0.14	0.05	0.03	-0.20	-0.06	0.11
ME									1.00	-0.01	-0.02	-0.04	0.14	-0.03	0.23	0.12	-0.06
HPG										1.00	0.02	-0.03	0.24	-0.06	0.03	0.14	0.06
CEM											1.00	0.34	0.01	0.22	-0.16	-0.23	0.18
STAY												1.00	0.04	0.31	-0.18	-0.21	0.34
MARB													1.00	0.05	0.11	0.16	0.18
YG														1.00	0.12	-0.67	0.72
CW															1.00	0.37	-0.05
REA																1.00	-0.16
FAT																	1.00

Table 3.3 – Distribution of Red Angus bulls sold at auction by sale season

Sale Year	Sale Season	# of Observations	Mean Price	% of Observations
2017	Spring	5,895	$4,535	28%
2017	Fall	1,445	$5,218	7%
2018	Spring	5,746	$4,785	27%
2018	Fall	1,627	$4,217	7%
2019	Spring	6,649	$4,378	31%

Table 3.4 – Distribution of Red Angus bulls sold at auction by sale month

Sale Month	# of Observations	Mean Price	% of Observations
January	427	$3,482	2%
February	3,812	$4,422	18%
March	10,483	$4,571	49%
April	3,461	$4,838	16%
May	107	$3,200	1%
September	299	$4,107	1%
October	1,375	$4,914	6%
November	796	$4,089	4%
December	602	$5,254	3%

Table 3.5 – Distribution of Red Angus bulls sold at auction by state

State	# of Observations	Mean Price	% of Observations
Montana	3,787	$4,501	21.1%
Nebraska	2,345	$5,458	13.1%
South Dakota	2,009	$4,460	11.2%
Kansas	1,544	$4,232	8.6%
Iowa	1,432	$4,001	8.0%
North Dakota	1,228	$4,340	6.8%
Wyoming	1,030	$5,504	5.7%
Texas	817	$4,695	4.6%
Oregon	625	$4,364	3.5%
Oklahoma	518	$4,094	2.9%
Minnesota	448	$3,847	2.5%
Idaho	401	$3,632	2.2%
Colorado	379	$4,051	2.1%
Missouri	334	$3,896	1.9%
Illinois	163	$5,115	0.9%
Washington	149	$5,560	0.8%
Wisconsin	111	$4,010	0.6%
California	103	$4,860	0.6%
Tennessee	94	$4,702	0.5%
South Carolina	70	$2,544	0.4%
Alabama	65	$5,100	0.4%
West Virginia	64	$5,230	0.4%
North Carolina	49	$4,002	0.3%
Utah	42	$3,252	0.2%
Ohio	34	$4,604	0.2%
Michigan	25	$4,458	0.1%
Pennsylvania	15	$3,410	0.1%
Maryland	14	$4,796	0.1%
New York	13	$3,281	0.1%
Nevada	11	$5,036	0.1%
Arizona	7	$2,586	0.0%
Indiana	7	$2,879	0.0%
Kentucky	7	$5,464	0.0%
Mississippi	5	$6,000	0.0%
Florida	4	$3,312	0.0%
Arkansas	2	$4,075	0.0%
Georgia	2	$7,250	0.0%
Louisiana	2	$8,500	0.0%
New Mexico	1	$19,500	0.0%
Total	17,956	$4,887	100%

Table 3.6– Distribution of Red Angus bulls sold at auction by region

Region of the United States	# of Observations	Mean Price	% of Observations
Great Plains	12,322	$4,697	69%
Midwest	2,520	$4,033	14%
South Central	1,343	$4,463	7%
West Coast	1,331	$4,286	7%
Southeast	300	$4,230	2%
Northeast	140	$4,659	1%

West Coast – AK, CA, HI, ID, NV, OR, UT, WA; Great Plains – CO, KS, MT, NE, ND, SD, WY; Midwest – IA, IL, IN, MI, MN, MO, OH, WI; South Central – AZ, NM, OK, TX; Southeast – AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA; Northeast – CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, WV

Table 3.7 – Non-adjusted means, standard deviations, medians, and ranges for factors describing the Red Angus bulls sold at auction from 2017 through 2019

Factor	# of Observations	Mean	SD	Median	Range
Sale Price	21,362	$4,576	$3,798	$4,000	$1,000 to $190,000
HerdBuilder Index	21,362	146.80	43.51	149	-3 to 287
GridMaster Index	21,362	50.23	2.44	50	41 to 62
Calving Ease Direct EPD	21,362	9.14	4.78	9	-8 to 24
Birth Weight EPD	21,362	-1.91	2.03	-1.9	-10.7 to 7.5
Weaning Weight EPD	21,362	61.77	9.85	62	16 to 104
Yearling Weight EPD	21,362	97.48	16.46	98	15 to 162
Milk EPD	21,362	21	4.60	21	3 to 40
Maintenance Energy EPD	21,362	-0.46	3.72	0	-14 to 14
Heifer Pregnancy EPD	21,362	11.78	2.69	12	0 to 24
Calving Ease Maternal EPD	21,362	5.38	2.61	5	-7 to 15
Stayability EPD	21,362	13.32	4.02	13	-4 to 28
Marbling Score EPD	21,362	0.52	0.25	0.5	-0.49 to 2.25
Yield Grade EPD	21,362	0.06	0.11	0.07	-0.64 to 0.58
Carcass Weight EPD	21,362	23.12	11.55	23	-35 to 72
Rib Eye Area EPD	21,362	0.13	0.25	0.11	-0.99 to 1.54
12^{th} Rib Fat Thickness EPD	21,362	0.02	0.03	0.02	-0.14 to 0.14

Table 3.8 – Genetic factors in the form of EPD affecting the sale price of Red Angus bulls sold at auction from 2017 through 2019

Factor	Estimate	Standard Error	T-value of factor	P-value of factor
Intercept	627.10	164.24	3.82	<0.01
Calving Ease Direct EPD	57.09	9.91	5.76	<0.0001
Birth Weight EPD	-276.40	18.32	-15.09	<0.0001
Maintenance Energy EPD	-62.53	7.19	-8.70	<0.0001
Heifer Pregnancy EPD	51.62	9.82	5.26	<0.0001
Calving Ease Maternal EPD	-22.79	11.58	-1.97	<0.05
Stayability EPD	20.66	8.75	2.36	0.02
Marbling Score EPD	567.15	114.16	4.97	<0.0001
Carcass Weight EPD	69.47	2.78	24.96	<0.0001
Rib Eye Area EPD	1,125.72	115.62	9.74	<0.0001
12^{th} Rib Fat Thickness EPD	3,114.31	1,016.32	3.06	<0.01
# of observations	21,362			
R^2	0.07			
Adjusted R^2	0.07			

Table 3.9 – Genetic factors in the form of selection indices affecting the sale price of Red Angus bulls sold at auction from 2017 through 2019

Factor	Estimate	Standard Error	T-value of factor	P-value of factor
Intercept	-12,800.00	521.30	-24.55	<0.0001
HerdBuilder Index	5.08	0.60	8.61	<0.0001
GridMaster Index	331.00	10.53	31.44	<0.0001
# of observations	21,362			
R^2	0.05			
Adjusted R^2	0.05			

Figure 3.1 – HerdBuilder score by sale price category

Figure 3.2 – GridMaster score by sale price category

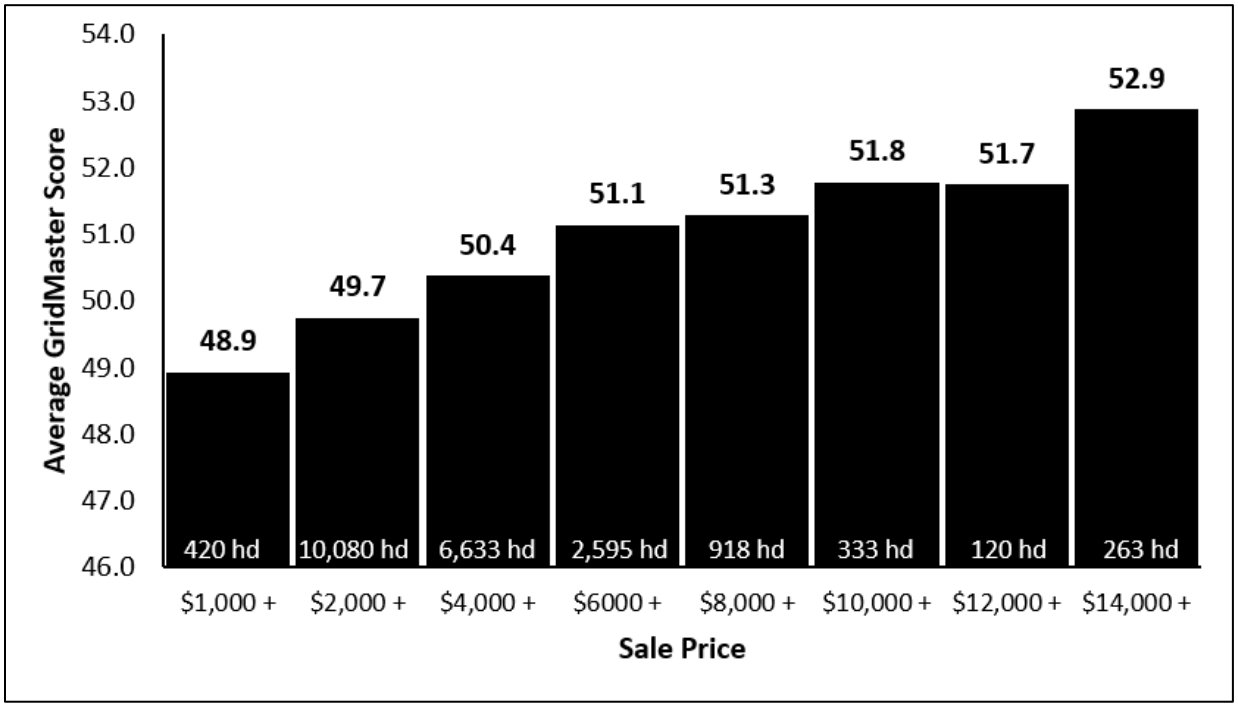


Figure 3.3 – Calving Ease Direct EPD by sale price category

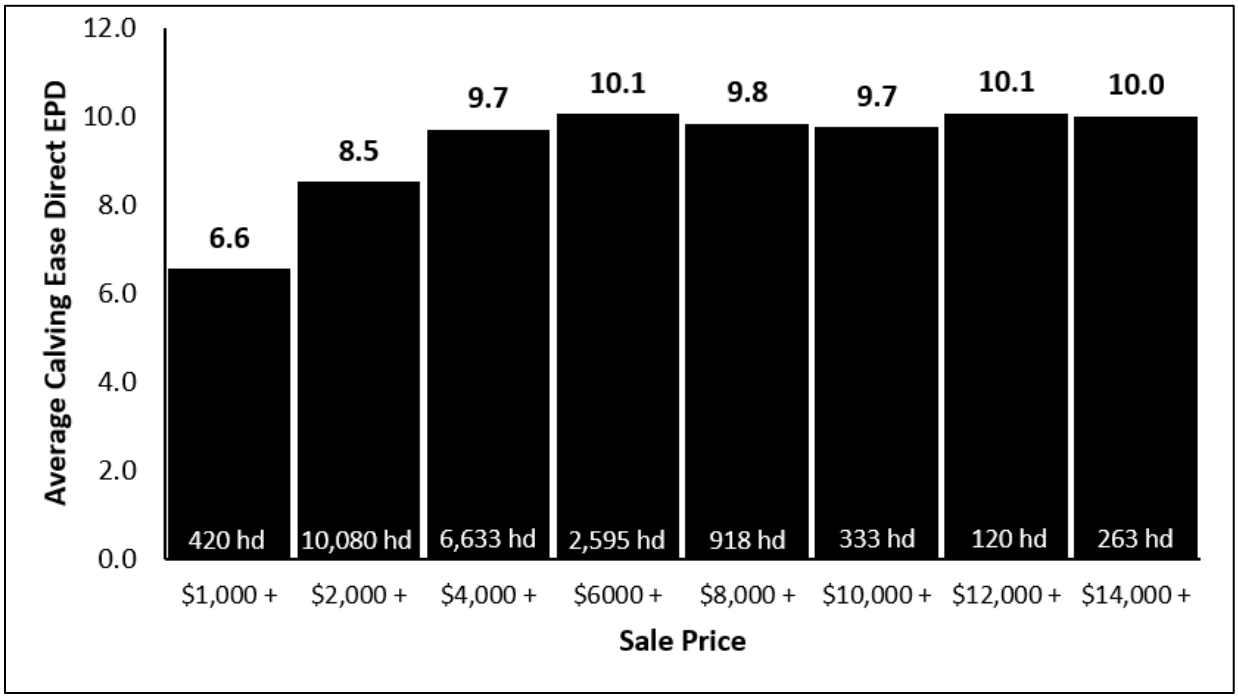


Figure 3.4 – Weaning Weight EPD by sale price category

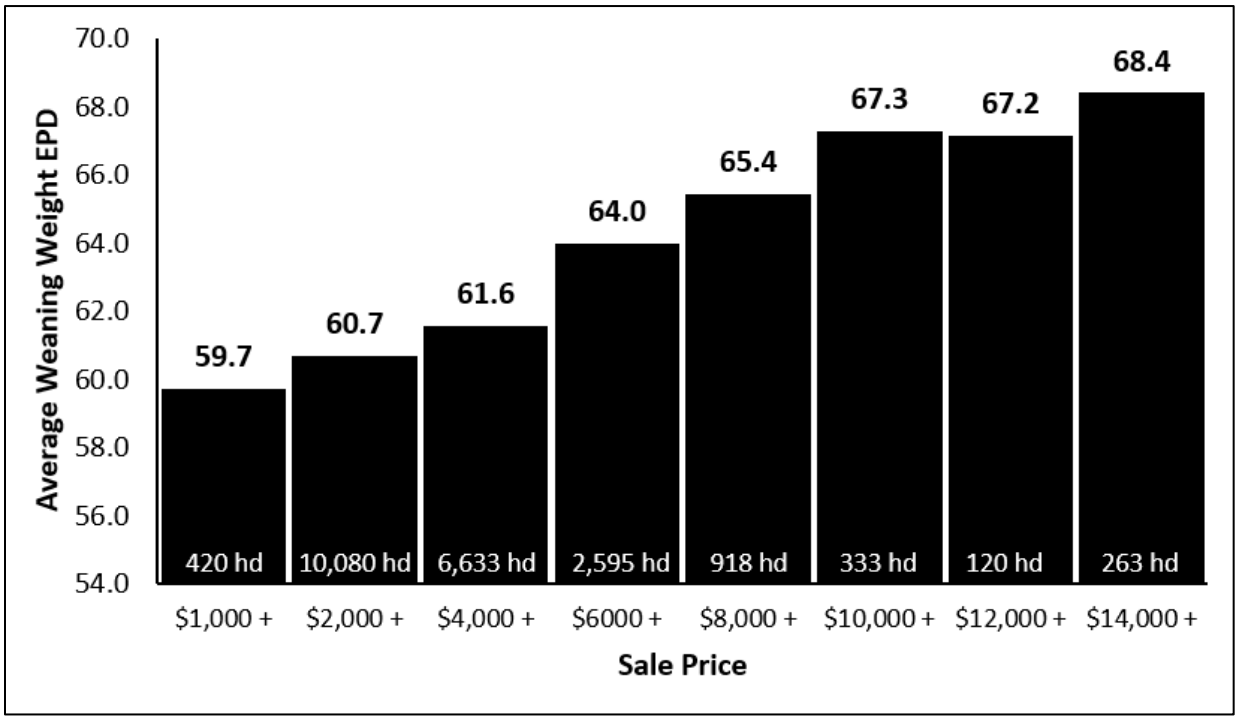


Figure 3.5 - Yearling Weight EPD by sale price category

Figure 3.6 – Heifer Pregnancy EPD by sale price category

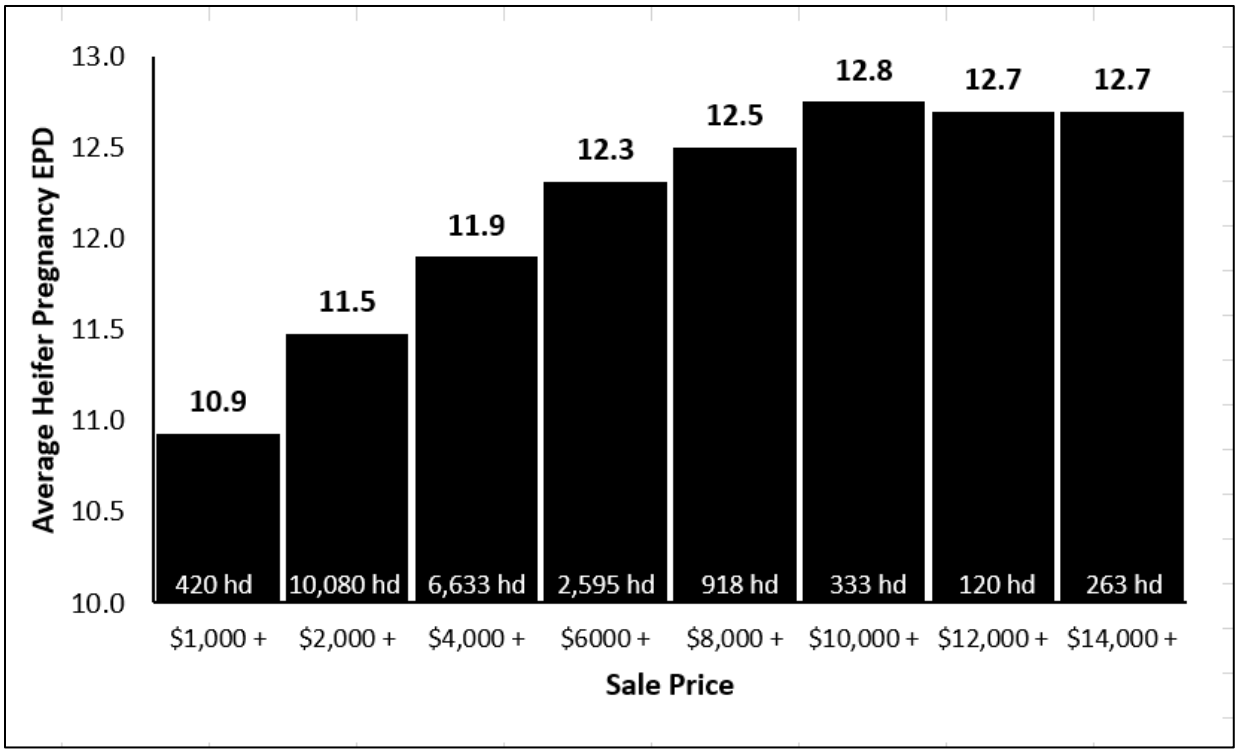


Figure 3.7 – Stayability EPD by sale price category

Figure 3.8 – Birth Weight EPD by sale price category

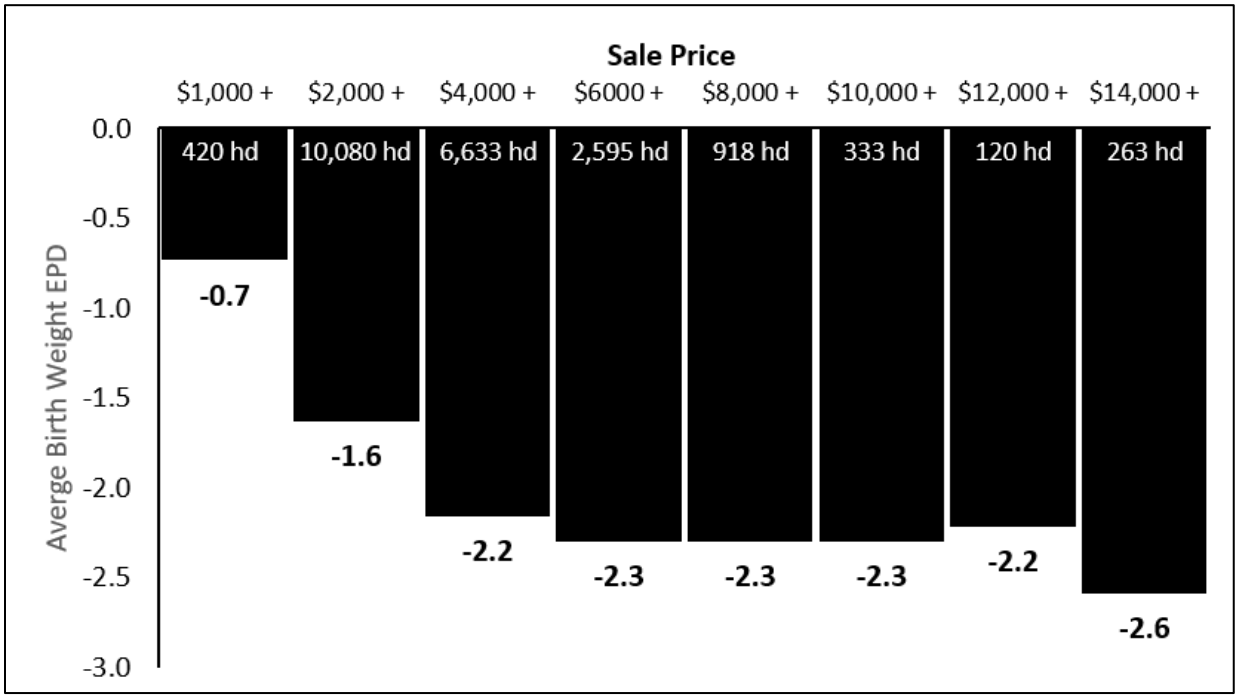


Figure 3.9 – Milk EPD by sale price category

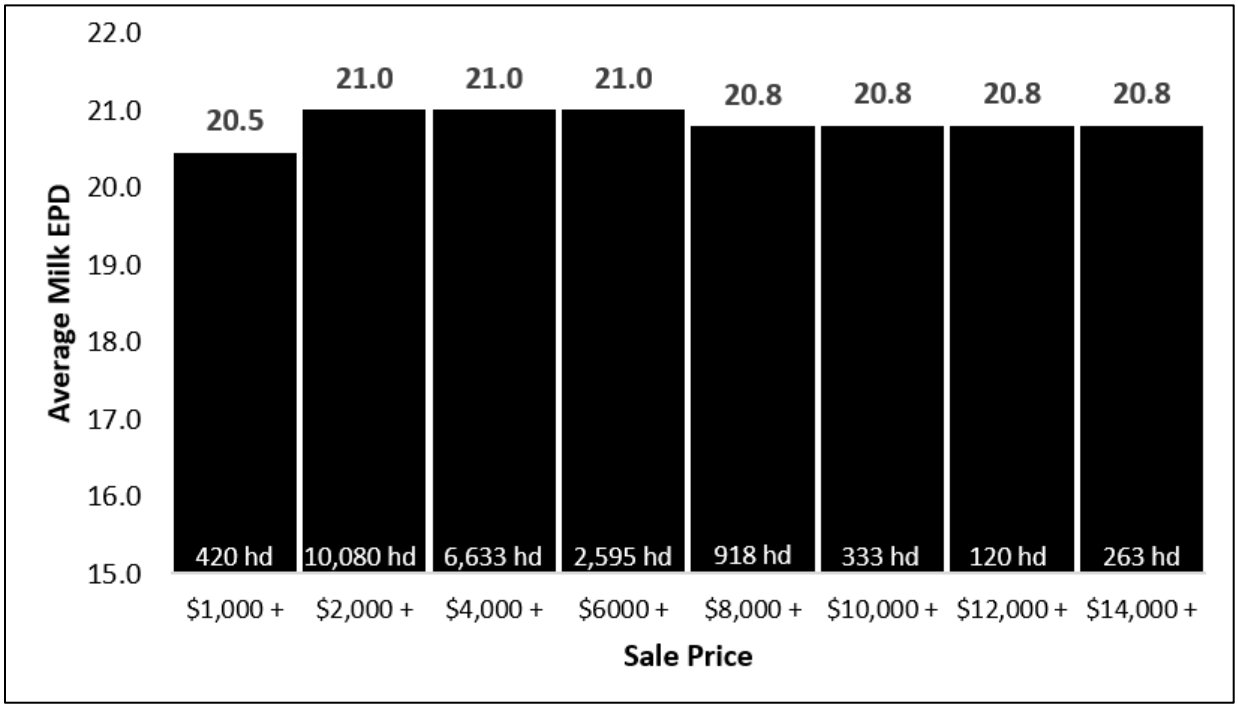


Figure 3.10 – Maintenance Energy EPD by sale price category

Figure 3.11 – Calving Ease Maternal EPD by sale price category

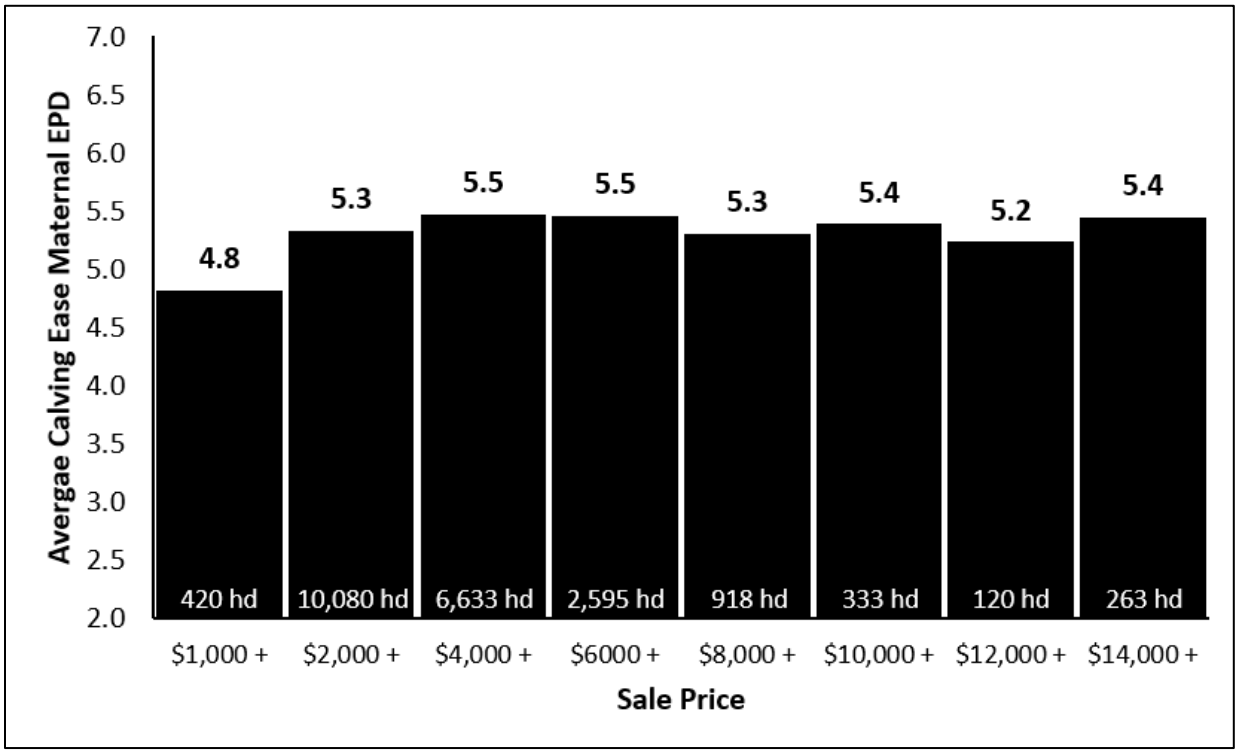


Figure 3.12 – Yield Grade EPD by sale price category

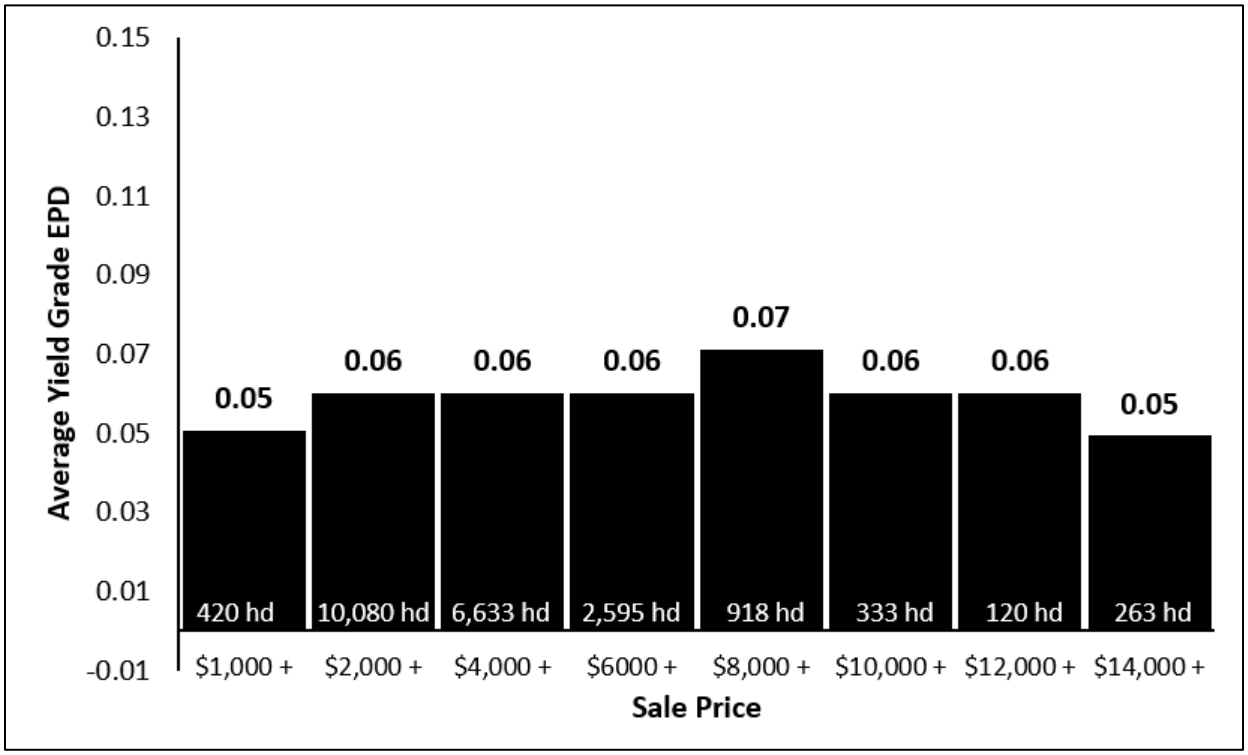


Figure 3.13 – Marbling Score EPD by sale price category

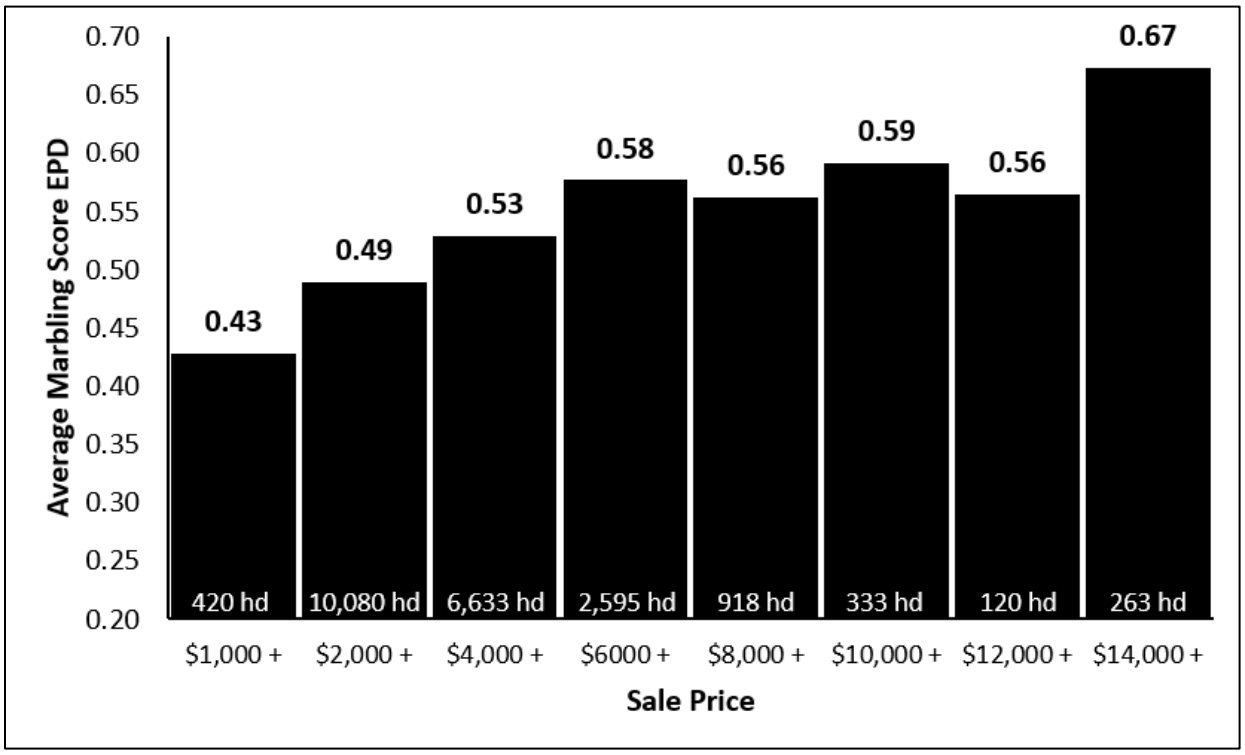


Figure 3.14 – Carcass Weight EPD by sale price category

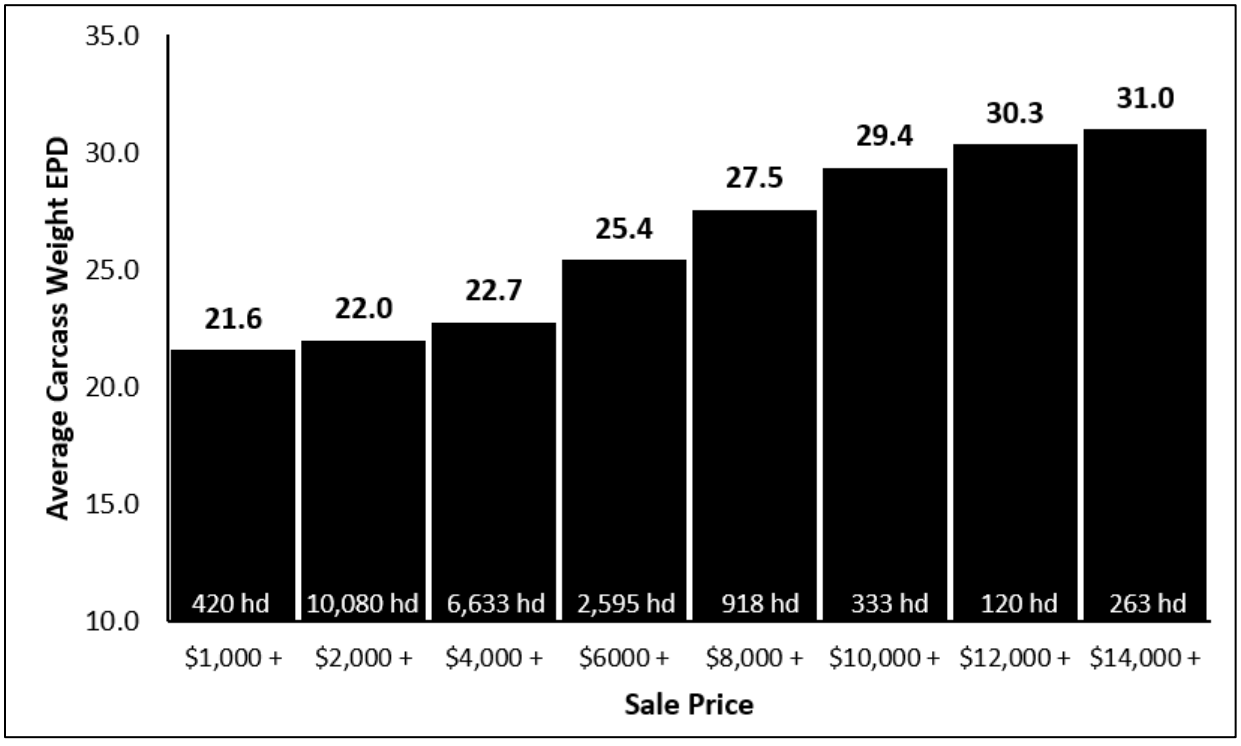


Figure 3.15 – Rib Eye Area EPD by sale price category

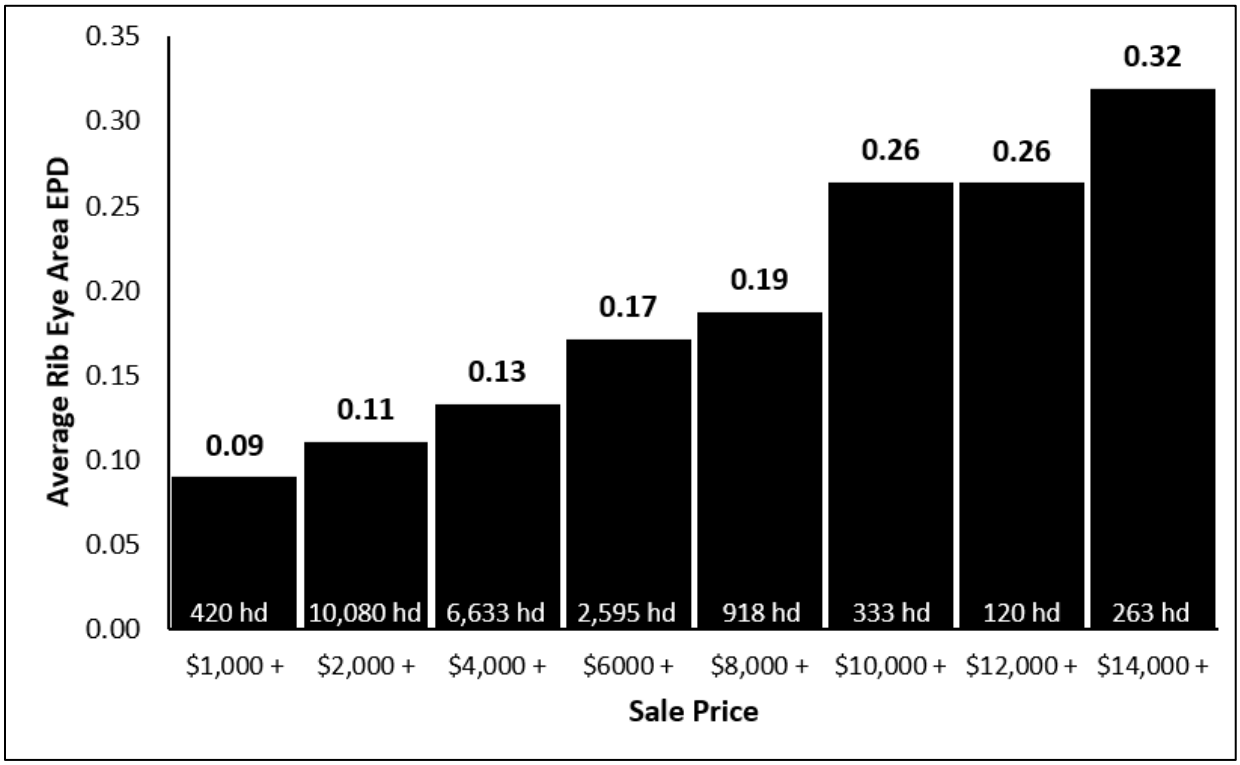
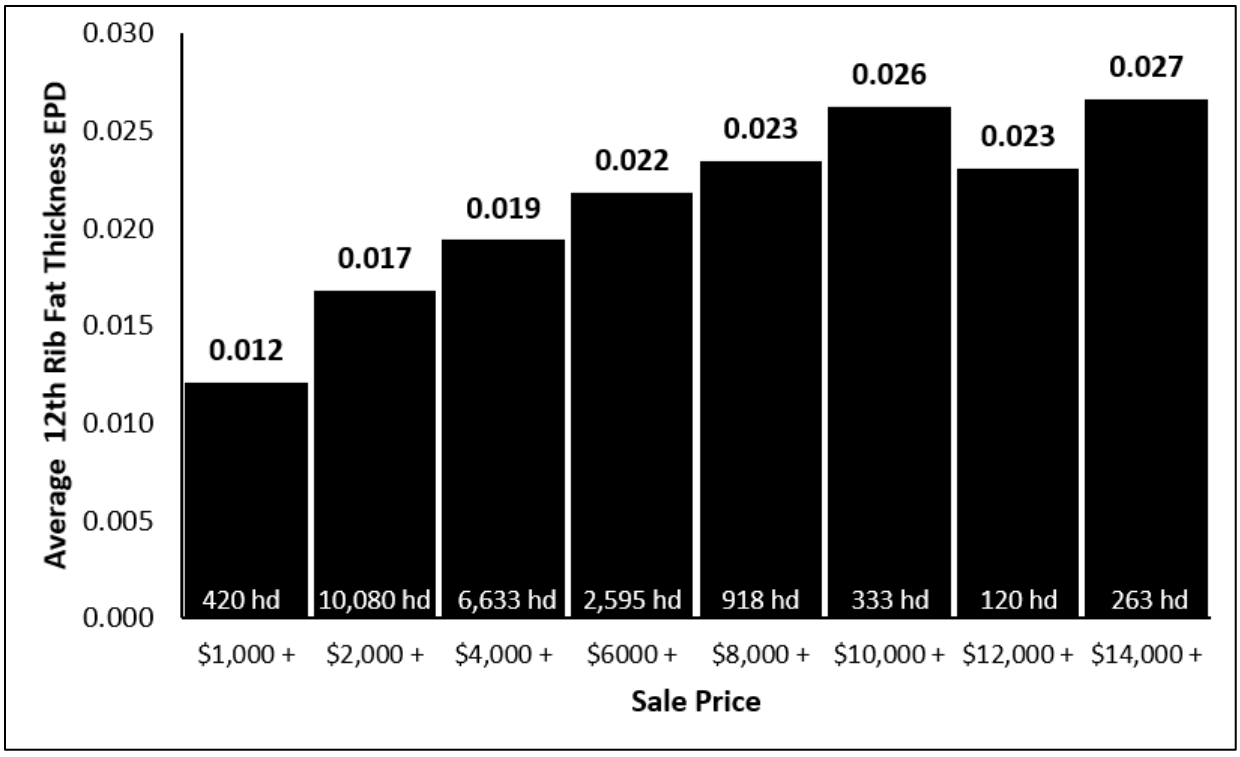


Figure 3.16 – 12th Rib Fat Thickness EPD by sale price category



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