

Hedonic modeling of estimated progeny differences in angus bull sale auctions

by

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Abstract

Seedstock consumers each value estimated progeny difference values in their own unique way, emphasizing certain traits they believe estimate the best possible genetic makeup over others. Some producers still do not believe they hold much, if any, merit, due to the recency of these standardized measurements. These measurements were created to compare animals within the same breed, and now across different breeds, to each other for desirable traits to cow-calf producers.

This analysis utilizes data from the Kansas State University Department of Animal Sciences and Industry's annual Legacy Bull Sale and Vollmer Angus Ranch in North Dakota to estimate the economic effects certain EPDs have on the price a bull sells for at each sale. Data was gathered for the Legacy Sale from the years 2016-2023, yielding 128 observations and 22 independent variables, and Vollmer Angus Ranch from 2019-2023, yielding 556 observations and 13 independent variables. The datasets were analyzed for each sale for their given years, a combined time-series dataset of the two sales from 2019-2023, and then combined annually to assess certain variables that were only calculated for a certain year. A hedonic model was used to investigate statistically significant variables and a correlation matrix was assessed to reduce or eliminate correlated independent variables.

The results show that producers value different EPDs across the Legacy and Vollmer Angus Ranch sales, as well as different emphasis on certain variables across years. Although this model demonstrates producers are willing to pay more for certain traits, a larger sample size including more university sales or private auctions could give a more accurate representation of the overall seedstock industry's targeted traits and how they affect price. Including other industry

data, gathered either through the American Angus Association, auction sites, or the hosts themselves, can better estimate the comparison between the two separate types of bull sales.

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the 'Cats, and everything in between. You have made this last year at K-State worth every minute.

Dedication

This thesis is dedicated to my family, especially my mother Barbara, father Robert, brother Antonio, and grandmother Helen. Without their continued love and support throughout my college career, none of this would have been possible. They have embraced and mirrored my love for Kansas State University, Agricultural Economics, and the livestock industry. They have supported me through some of life's most difficult lessons and encouraged me to continue pursuing my passion in life. Thank you for always being there for me and always pushing me to reach for the stars.

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Chapter 1 - Introduction

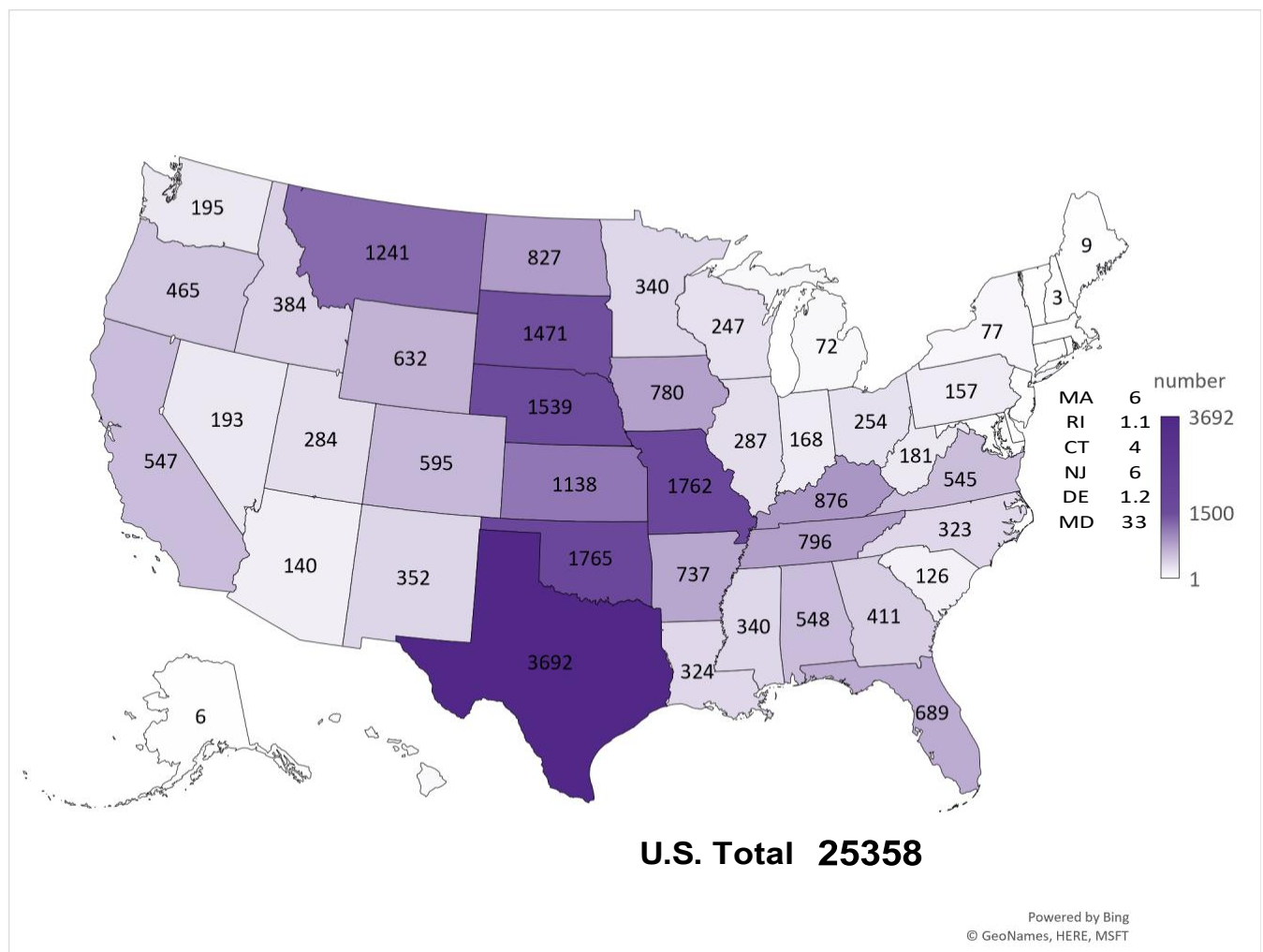
Beef cattle production in the United States consists of four distinct phases: seedstock, the cow-calf producers, backgrounder/stocker ranches, and feedlot operations. Seedstock producers focus on selecting certain cattle to create better genetics for the beef industry. Cow-calf operations prioritize breeding heifers and cows, using high-quality genetic pedigrees and maximizing calves on the ground. Backgrounders, or stockers, purchase weaned calves from the cow-calf producers to put them on pasture, or feed hay, and build up the health of the herds and add size to the animal before shipping to the feedlot. Finally, feedlots are where cattle are finished, being fed rations to increase size and meat quality, maximizing the profit return a feedlot company will see from carcass grading and beef yield at the meatpacking plant.

A seedstock producers' operational goal is to develop high-quality reproduction cattle to sell retain for their own herd, sell at auction to bidders at auction, or provide genetics by collect semen samples from the bulls for the purpose of artificial insemination. The supply of quality bulls for the cow-calf sector is a direct result of the seedstock producer. These bulls, or their genetics, can be utilized by a commercial or purebred cattle operation. Seedstock producers must listen to the desires of the bidders and buyers of bulls, focusing on traits that are desired most from their customers.

Cow-calf producers have the challenge of generating pregnancies, maintaining a constant supply of weaned calves to sustain the annual crop. The acquisition of bulls to be used in the breeding season generally comes from either a private sale, privately-sponsored auction, or by breeding their own herd and retaining their own bulls. For this study, private sales are considered agreements between operators or business owners on certain bulls, also called lots, to be removed from an auction sale at a later date and sold to the buyer for a determined price. This

purchasing method could be beneficial to the buyer due to the agreed price, which eliminates possible market competition that may increase the price necessary to acquire that lot. The seller may also benefit, receiving a guaranteed price for the animal(s) they are selling rather than risking a lower price at auction. However, this could also be a negative to the purchaser, as the price paid could be higher than what would have been the winning bid at auction, leading to overpayment by the buyer. Conversely, the seller may also lose money if the price paid for the lot is lower than the necessary winning bid at auction.

Figure 1.1. Calculated 2023 U.S. Beef Calf Crop by state (in thousand head)



Source: (Livestock Marketing Information Center, 2024)

Many producers choose to buy their bulls from a privately-sponsored livestock auction sale. These sales can be organized by a privately owned cattle business, land grant universities, or occur at large livestock shows like the National Western Stock Show, Houston Livestock Show and Rodeo, or Cattlemen's Congress. To measure desirable genetic traits in the bulls against each other, cattle buyers may use estimated progeny differences (EPD) to determine which bull they want to spend their money on. EPDs are a calculation using the bull's physiological samples comparing each individual trait to the rest of the breed association's registered livestock. The number listed for each category is a standard deviation from the overall breed average, unless noted as the true weight of the animal or an index value. Each breed's association lists and estimates average EPDs for producers to compare the data collected from each bull's offspring performance in the sale catalog. EPDs were developed nearly four decades ago and are still in use today as a way of comparing bulls and predicting desirable paternal and maternal genetic traits (Felix & Freitas, 2023). As more data becomes available, either through genetic testing from the observed bull, the pedigree lineage, or as the bull ages, EPDs become more accurate. EPDs utilize multiple sources of information to measure an animals' genetic potential, including full pedigree, an animal's own record, full and half siblings, genomic data, ultrasound measurements, and especially progeny information (Bullock et. al., 2015). Breed associations are constantly using new data and recalculating EPDs, meaning that the industry average and individual animal EPDs change as genetic information is updated.

Table 1.1. Commonly Used Estimated Progeny Differences

EPD	EPD Abbr.	Unit of Measurement	Usefulness of EPD
Calving Ease Direct	CED	Difference in percentage of unassisted births when bred to first calf	A higher CED value indicates greater calving ease when bred to first-calf heifers.
Birth Weight	BW	Pounds	Indicates a sire's ability to transmit birth weight to his progeny, a lower value indicates calves that will be lighter at birth.
Weaning Weight	WW	Pounds	Indicates a sire's ability to transmit weaning growth to his progeny, a higher value indicates calves that will be heavier at weaning.
Milk	Milk	Pounds	Indicates the additional pounds of calf weaned by a bull's daughters due to milk production. As milk increases, so does a cow's nutritional requirements
Yearling Weight	YW	Pounds	Indicates a sire's ability to transmit yearling weight to his progeny. As yearling weight increases so does mature cow weight.
Ribeye	REA	Square inches	Predicts the difference in ribeye size of a sire's progeny compared to progeny of other sires.
Marbling	Marb	Fraction of the difference in USDA marbling score	Indicates a sire's ability to transmit marbling ability to his progeny. A greater value indicates greater marbling potential in offspring.
Scrotal	SC	Centimeters	Predicts the difference in transmitting scrotal size compared to other sires. A larger scrotal size is positively correlated with the fertility of the bull's offspring.

Source: (Lewis, 2020)

The goal of this thesis is to analyze the annual sale prices of Angus bulls sold in the Kansas State University Purebred Unit and Vollmer Angus Ranch's annual sales, discovering how the listed EPD variables affect the price paid by the consumer. This research will also help producers understand the industry's economic emphasis on certain traits as they purchase purebred breeding stock. The EPD index and calculations are relatively new to the livestock industry, having been introduced, calculated, and recorded by breed associations in 1993 and the use of genetic selection indices proposed by Dr. L. N. Hazel at Iowa State College in 1943 (Kriese-Anderson & Dolezal, 1999; Hazel, 1943).

Some producers are still reluctant to rely on EPDs when they select sires, presumably due to a lack of understanding how EPDs are calculated and their interpretation (Bullock, et al.,

2015). Using statistical knowledge to determine economic impacts and benefits to the sale or purchase price of bulls and how producers value certain traits over others could enhance reliability and understanding of how EPDs have been used, and could be used, to make future purchasing decisions. This research adds to previously published papers on seedstock production, but with proprietary data, only obtained through Kansas State University and the annual Legacy Sale. Economic models have been used before to identify the effect certain EPDs have on the price of Angus bulls (MacNeil and Herring, 2005; Kessler, Pendell, and Enns, 2017), but this would be the first analysis to the author's knowledge of multi-trait EPD differences using university bull sale data. To the author's knowledge, there has also not been a comparison between a university sale and a privately-sponsored auction.

1.1 Kansas State Legacy Sale

Kansas State University's purebred unit can be traced back to 1872, when the legislature provided a large barn on campus to teach students, "how to care for, breed, and market animals," (Kansas State University Department of Animal Sciences and Industry, 2023). The herd was originally established in 1882 with an Aberdeen-Angus heifer from the Ontario Agricultural College and a Hereford pair from Maple Hill, Kansas. The original herd was disposed of nine years later, but the college rebuilt the purebred unit in 1901 from seven breeds and three different purposes. Today, the unit runs roughly 300 purebred Angus, Hereford, and Simmental cows with a goal of providing students practical cattle operation experience. Students will use the cattle from the purebred unit for livestock judging practice, applied classroom teaching, the on-campus Little American Royal livestock show competition, and eventually sold in the student-led Livestock Sales Management course, which is responsible for organizing the Legacy Sale.

Originally called the “Special K Sale,” Kansas State University hosts the annual Legacy Sale, featuring the university’s purebred beef unit Angus, Hereford, and Simmental bulls, open females, and bred females (Kansas State University Department of Animal Sciences and Industry, 2022). This annual on-campus event, held in conjunction with the KSU Stockman’s Dinner and Cattlemen’s Day the first weekend of March, brings seedstock producers, corporations, university sponsors, and cow-calf ranchers to the auction block in Manhattan, Kansas, for the sale and purchase of the purebred unit’s bulls the first weekend of March. K-State’s sale has been traditionally known for high-selling Hereford bulls, with the record for the Special “K” Sale being a 1981 Hereford bull selling for \$12,500 and the current Legacy Sale’s record being set in 2023 by KSU Land Grant 153 ET leaving the auction block for \$43,000 (Kansas State University Department of Animal Sciences and Industry, 2022; Kansas State University Department of Animal Sciences and Industry, 2024). This shows that the Kansas State bull sale reputation has been built upon the Hereford breed rather than the Angus breed; however, Gardiner Angus Ranch has provided genetics and animals to Kansas State University to increase the value of the herd.

The purpose of this sale is to offset the university purebred unit’s operating cost, raise money for student scholarship funds, and provide students the opportunity to experience managing a bull sale. We would also expect a different set of buyers at these events due to geographic location. There are few, if any, common buyers between these two events, being separated by over 750 miles. This event also gives seedstock consumers the chance to improve the genetics of their herds, or new ranchers the opportunity to start and develop their herd. Genetics companies may also purchase interest in a bull or the bull entirely specifically to collect semen from, and sell straws of semen to, producers who artificially inseminate their heifers and

cows. Other universities are known to host an annual bull sale each year, such as Colorado State University's Generations of Progress sale in February, Oklahoma State's Cowboy Classic on the first weekend of April, or the University of Nebraska-Lincoln's Bulls Worth Waiting For sale in mid-April.

Throughout the sale catalog, the Legacy Sale will list certain bulls' EPDs with percentages next to them, informing a buyer of that EPDs percentile rank within the Angus Association. This may be an important metric for producers looking to improve their herd in a certain area or buyers looking to stretch the limits of their cattle, reaching for the top end of the breed in different genetic traits. The Department of Animal Sciences and Industry also guarantees excellent health of the cattle and meets the Kansas state health regulations and guidelines using breeding soundness exams from the Kansas State College of Veterinary Medicine.

1.2 Vollmer Angus Ranch

Vollmer Angus Ranch (VAR) was started in 1952 by the Vollmer family in Wing, North Dakota. The ranch sells just over 100 registered purebred Black Angus yearling bulls each year, as well as some two-year-old registered purebred Black Angus bulls, registered purebred Black Angus heifers, and commercial heifers. The company's website states they "strive to offer bulls that are efficient, deep bodied, wide based, thick, and structurally correct with excellent disposition and carcass traits," (Vollmer Angus, 2024). Vollmer Angus Ranch runs approximately 600 cows and focus on "disposition, mothering ability, performance, and reproductive excellence." The operation utilizes purchased bulls from large seedstock producers to breed VAR-owned dams each year, and then sells the yearling bulls as Vollmer Angus Ranch

offspring. The sale takes place at Vollmer Angus Ranch headquarters and is staffed by the Vollmer family.

Some years, Vollmer Angus Ranch listed a full percentile rank for each EPD of every lot sold in the back of the sale catalog. This could be extremely beneficial to producers using EPDs and percentile rankings as the organizers of the bull sale are not deciding which percentages to list but giving you more available information. For example, a producer may have their mind set on purchasing a bull that could be in the tenth percentile of calving ease direct (CED EPD), but that may not be listed in the sale catalog if the sellers only listed the rankings of EPDs in the fifth percentile or above in the catalog.

1.3 Comparison of the Sales

The two sales are comparable in genetic traits, as they both use pedigrees from Gardiner Angus Ranch, Sitz Angus, Baldrige Performance Angus, and Schaff's Angus Valley, which are all listed in BEEF Magazine's Seedstock 100, a list of the top 100 seedstock ranches and sales each year (BEEF Magazine, 2022). The K-State Legacy Sale and Vollmer Angus Ranch also both started selling purebred registered Black Angus bulls in 1977, giving the same period to continue to improve their herds up to, and during, this analysis. Both sales also predominantly or exclusively use their own heifers or cows, showing a strong, developed maternal bloodline with the opportunity to selectively breed, attempting to maximize the offspring's genetic pedigree. Both sales also broadcast their auction online with the Legacy Sale using CCI.live and Vollmer Angus Ranch using DVAuction.com.

These bull sale auctions differentiate themselves in multiple ways. First, Vollmer Angus Ranch guarantees bulls to be injury free through the first breeding season, offering a comparable replacement bull or credit to the following sale (Vollmer Angus Ranch, 2023). The Legacy Sale

guarantees breeders for an unmentioned period with the exceptions of “injury or disease occurring after the purchase and/or gross negligence or willful misconduct by the purchaser,” (Kansas State University Department of Animal Sciences and Industry, 2023). Kansas State retains a full salvage value and 75 percent semen interest on all bulls while Vollmer Angus Ranch reserves a one-third revenue share of semen interest in bulls sold. Both sales offer a discount for taking purchased animals’ home the day of the sale, with the Legacy Sale offering \$50 off the purchase price and Vollmer Angus offering \$100 during the first week after the sale. Vollmer Angus Ranch also offers free delivery of the animal up to 500 miles at no additional charge to the customer. The objectives of this study are to estimate EPD effects on the prices of bulls sold at the Legacy Sale and Vollmer Angus Ranch. We will also assess whether a premium exists between the Legacy Sale at Kansas State and the Vollmer Angus Ranch.

Chapter 2 - Literature Review

2.1 Estimated Progeny Differences

Hazel (1943) first proposed a multi-trait selection index for livestock in his 1943 paper titled “The Genetic Basis for Constructing Selection Indexes.” In his research, Dr. Hazel claimed that multiple traits influence an animal’s value. “The information regarding different traits may vary widely, some coming from an animal’s relatives and some from the animal’s own performance (Hazel, 1943, p. 1).” This is the same general formulation the American Angus Association currently uses for their EPD calculation, utilizing the performance of dams, sires, siblings, and offspring of the animal. The paper also claims that a standard method of selecting breeding animals needed to be adopted by the livestock industry. Until the adoption of EPD calculation in 1993, and even after the implementation of this practice, producers had to understand the “art form” of selecting breeding stock from physicality, visual traits, and matching those with the traits desired when selecting bulls to pair with open heifers or cows.

A 1994 survey of producers from the Kansas Agricultural Experiment Station asked 312 commercial producers which EPDs they emphasize during purchasing decisions (Simms, Geske, and Bolze, 1994). The survey found that producers rank calving ease, frame score, birth weight, and visual appraisal as their top four selection criteria, respectively. For visual criteria, they desire structural soundness, disposition, length, and frame score. When ranking performance characteristics, birth, weaning, and yearling weight statistics, in combination with calving ease EPDs, were most important. The results indicate there was a low emphasis on estimated progeny differences (formerly expected progeny differences during this study), meaning producers were not using the most accurate and up-to-date information at their disposal when buying bulls.

2.2 Hedonic modeling of bull sales

Jones et al. (2008) used production weights, EPDs, and ultrasound data for purebred Angus bulls sold at auction to estimate a hedonic model. These data were gathered nationally over a four-month period from purebred Angus producers across various regions of the United States. This analysis gathered 8,285 bulls from 60 sales in 11 different states. Production EPDs used in the analysis were birth, weaning, milk, and yearling weights; carcass EPDs, ultrasound data, and marketing factors recorded from the sales. Due to differences in magnitude and distribution of the EPDs, comparing the marginal effects of the variables and estimated elasticities is difficult and interpretation should be done with caveats in mind. Jones et al., (2008) found that bulls with a retained semen interest brought a premium at auction, stating that may be perceived by buyers as the bull having a high value or high genetic potential. They also found that animals sold in the spring brought a discount compared to those purchased in the fall.

In 2014 and 2015, four public Mississippi auction sales were attended, and data were collected on cattle run through the sale ring (Parish et al., 2017). Researchers collecting data on the animals were given “a standard key and data-recording format for each trait and its defined levels to ensure consistent data recording (Parish et al., 2017, p. 1)” This study analyzed physical traits when determining changes in price, using visible variables like body condition score (BCS), brand presence, black hair coat color, frame, hair length, gut fill, and locomotion. Data were collected on 21,128 lots and represented a total of 21,879 calves sold. Some variables used do not fully explain the buyer’s thought process, as the study used hair color as a variable, but producers are more likely to buy based on breed rather than hair color (Parish et al., 2017). The study also reported larger lots are preferred by producers when buying calves, with a peak premium occurring for a lot of 77 calves. Physiologically, certain variables returned a premium

to a certain point, like body condition score, while other traits brought a continual price increase or decrease.

The most closely related paper was published by Kessler, Pendell, and Enns (2017) at Colorado State in 2016. This research analyzed the use of lower pulmonary arterial pressure (PAP) testing in Colorado State University's purebred yearling bulls. PAP testing is directly correlated to a bull's ability to withstand higher altitudes, a trait desired by livestock producers in Colorado, Wyoming, Utah, and New Mexico (Kessler, Pendell, and Enns, 2017). Using hedonic modeling, they sought to understand the economic effect this trait had on the sale price of yearling bulls at Colorado State's annual purebred unit sale. They found that producers did emphasize the heritable trait of low pulmonary arterial pressure scores, due to high altitude diseases being a leading cause of morbidity and mortality in herds raised in those states.

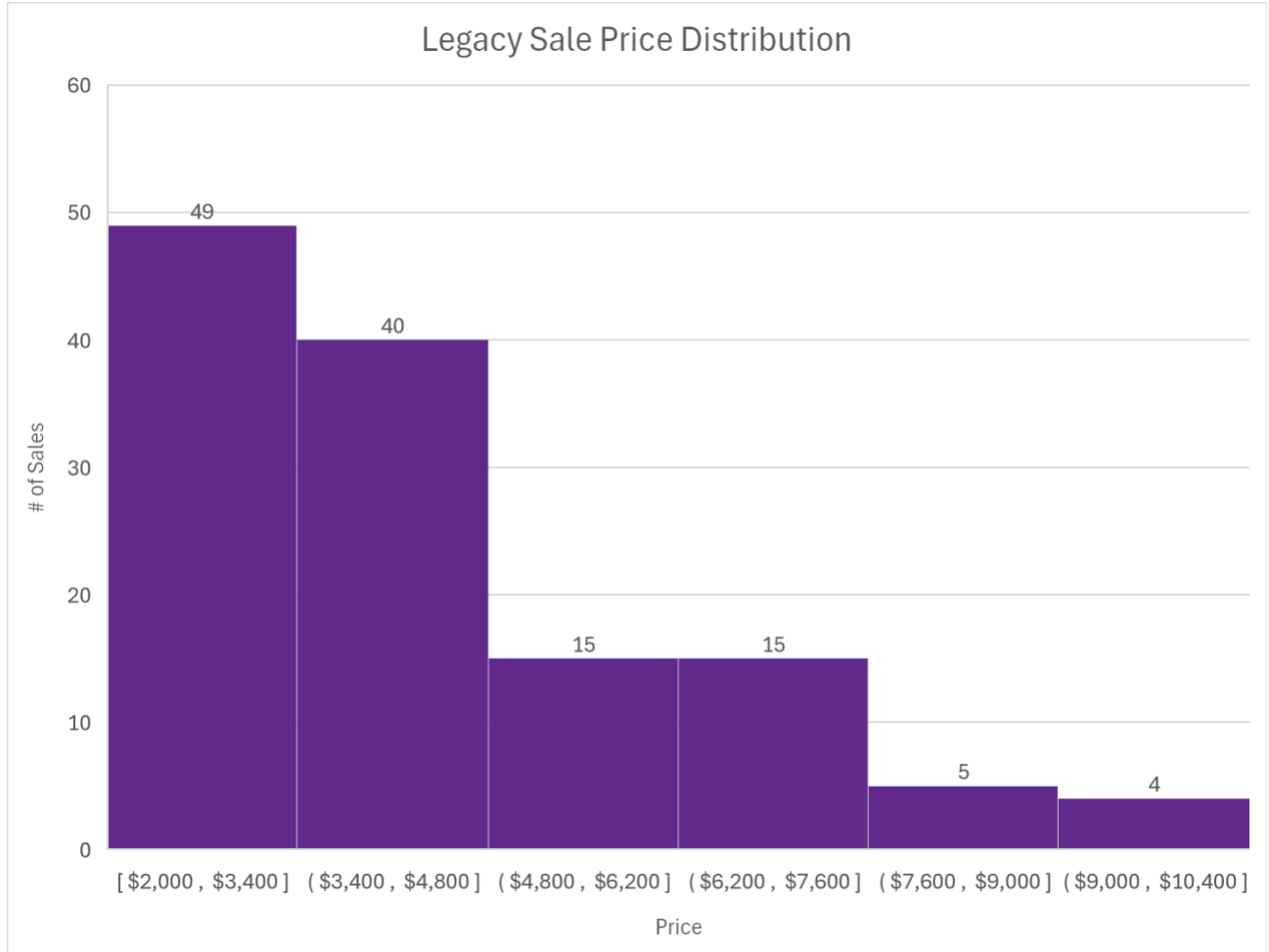
Chapter 3 - Procedure and Data

The analysis in this paper uses a linear hedonic model, which was also used by Jones et. al. (2008) Kessler, Pendell, and Enns (2017). The same issue with hedonic modeling mentioned in Kessler, Pendell, and Enns (2017), multicollinearity, has been accounted for and discussed in the analysis and results sections of this paper. The analysis of these bull sale auctions assumes a perfectly competitive market and the rational buyer is attempting to maximize utility and profit through the purchase of a bull at these sales similar to other studies (Jones et al., 2008).

3.1 Legacy Sale Data

Data was gathered from the Kansas State University Department of Animal Sciences and Industry for the Legacy Sales held from 2016-2023. These bulls are calved in the spring of the previous year, between January and April, weaned, and fed at the KSU Purebred Unit while all ultrasounds and genetic testing are done through the Kansas State University College of Veterinary Medicine. Progeny data are collected at birth, and includes birth, weaning, and yearling weights, which is adjusted by age and to each breed's association, and the final EPD data are collected from the American Angus Association in late January or early February, prior to the bull sale. The bulls are raised just past a year of age and prepared to enter the sale ring for the Legacy Sale. Each bull is given a lot number and a tag number, used to correspond their sale price to the EPDs. Once the bulls are sold, sale prices are recorded, along with the buyer information, and combined into a dataset. Because the KSU Legacy Sale each year contains Angus, Simmental, and Hereford bulls, the animals were then separated into their different breeds, leaving the Angus bulls for analysis.

Figure 3.1. Legacy Sale price distribution



Given 128 observations and 22 independent variables, a hedonic model was used to estimate the most significant variables to the prices of the bulls sold. The correlation matrix and summary statistics were used for analysis of multicollinearity, or correlation, between variables and built a model with all variables. A second model was created, attempting to explain more variation in price with the given dataset. Once the best fitting model was determined, the R-squared, correlation matrix, variance inflation factors (VIF), and root mean square error (RMSE) values were used to see if the model truly represented the dataset and could accurately answer which EPDs influenced the price paid by the seedstock consumer. The model used the price of

the bulls sold as the dependent variable to determine the implicit value producers place on the different EPDs listed and determine their effect on the final sale price of the bull.

The linear equation for the Legacy Sale is as follows:

$$(3.1) \quad Price_{ij} = \beta_0 + \beta_n X_n + \varepsilon_{ij}$$

where β_0 represents the equation intercept, β_n represents the calculated coefficient the n th EPD, X_n represents the EPD of the bull, i represents the lot number of the bull, j represents the Legacy Sale year, and ε_{ij} represents the error term for the model.

3.1.1 Legacy Sale Variables

The model utilized 22 independent variables, starting with the sale year of the observed Angus bull, due to differences in the bull market year-to-year. The bull market would follow a lagged trend to cattle market prices. When prices for cattle are high, ranchers desire to expand herds to increase their profit margins. If prices drop, they will maintain or shrink their herds because of a smaller margin. The expectation would be to see an increase in the price of bulls of the sale over time due to improved genetic makeup of the bulls sold at the Legacy Sale and natural inflation of the U.S. dollar.

The second independent variable included was a dummy variable representing whether there is a picture associated with the bull in the sale catalog. All lots sold are listed with the maternal and paternal pedigrees, along with registration number, date of birth, tattoo number, and the breed association's EPDs. Lots may also have a short description of the bull. If a producer can see a picture of the bull before the sale, they may have a stronger desire to purchase that animal; however, most pictures have the bull posed in a certain position, giving them the most desirable look for both the seller and buyer. Oftentimes, producers would be more willing to visit the animal in-person to determine what their value is, but online bidders either do not

have that option or must contact the seedstock producer or a hired cattle buyer for their opinion. The picture used in the catalog associated with their lot number, or any videos provided of the animal walking around a pen, are all that a bidder may have to base their opinion on the bull. Sellers may also use pictures of only their best bulls to give the appearance that all the lots sold that day may have a similar appearance and genetic traits. Because of this, the estimation is that a picture of a bull in the sale catalog will have a positive correlation with the price paid for the bull.

Calving ease direct EPD (CED EPD) was used as the third independent variable in the model, due to the emphasis producers have recently started applying to this genetic trait. This is a measurement of the likelihood a producer will need to assist with the calving process (Kansas State University Department of Animal Sciences and Industry, 2023). As with other industries, trends have changed over the course of time in the cattle industry. Producers used to emphasize the size of a bull, how much weight the frame was able to hold and the yield ability of the carcass. While these are still EPDs producers focus on, the ease of calving for a heifer or cow has become more important to producers in the last 20 years. Ranchers want to avoid dystocia (an abnormal or difficult birth) in cows, preferring a natural birth, due to physiological stress, decreased calf performance, and costs involved with labor or veterinary assistance. This leads to the desire to seek bulls with a higher EPD for calving ease. Economically, it is expected that calving ease and the price of a bull would have a direct correlation.

Birth weight EPD (BW EPD), was listed as the fourth independent variable, giving a strong indication of the size of the calf when birthed and whether a producer will need to assist during the calving season (Kansas State University Department of Animal Sciences and Industry, 2023). CED EPD is similar to birth weight as it is an indicator of dystocia. This EPD is expected

to show an inverse relationship due to larger calves at birth being less desirable by cow-calf producers.

Weaning weight EPD (WW EPD) and yearling weight EPD (YW EPD) were selected as the fifth and sixth independent variables. Birth, weaning, and yearling weights are important to producers because they can be used as a benchmark measurement to determine the stage of life an animal is in. Weights that are too low also create an added cost to the producer when wanting to reach a certain size to sell weaned calves to a backgrounder/stocker or a feedlot. A higher value is more desirable for producers who are selling calves at weaning, and may be of more importance for a producer who is going to raise the calf from birth to slaughter.

The seventh variable used was calving ease maternal EPD (CEM EPD). This is a genetic indicator of a sire's daughter to have unassisted calves (Kansas State University Department of Animal Sciences and Industry, 2023). This would be a trait considered by commercial producers with a high dam turnover rate, or purebred producers who consistently cull cows and work to improve their herd. Any buyer hoping to purchase a bull and utilize the heifer offspring in their operation would use the CEM EPD to reduce their need to pull calves. We would expect to see a correlation between CED EPD and CEM EPD. Producers would want a higher CEM EPD value, as this shows that the female offspring are more likely to pass calves on their own.

Maternal milk EPD (Milk EPD) was included in the dataset. It is a prediction of the genetic capabilities of sires' daughters regarding milk production and mothering ability (Kansas State University Department of Animal Sciences and Industry, 2023). As milk production increases, so do the energy requirements the heifer or cow needs for lactation. This causes a producer to provide more energy in her diet, increasing feed costs and could potentially result in heavier weaning weights for her calves, due to more milk availability. This variable is expected

to have an indirect relationship with the sale price of a bull, due to the increase in feed costs, and causing the price of the bull to decrease.

Ribeye EPD (RE EPD) and marbling EPD (Marb EPD) were included as the ninth and tenth independent variables, which are strong terminally desired traits and genetic traits producers emphasize with the creation of market differentiating programs and incentives (Kansas State University Department of Animal Sciences and Industry, 2023). Certain marketing programs, like Certified Angus Beef, require a carcass to follow certain specifications, one being a certain level of marbling and another being a certain ribeye size (Certified Angus Beef, 2024). Because this model is looking specifically at Angus bulls, marbling for this program, and the USDA carcass grades, would be a key factor when looking at positive genetic traits to include in breeding. Producers can make large premiums from these programs because of the strict requirements, so if a producer is able to guarantee at a higher rate than others that their calves will grade USDA Choice or USDA Prime, or qualify for the Certified Angus Beef program, they are also guaranteeing at a higher rate that their return on investment will be higher. Another factor to consider is the consumer demand for greater marbling, which can most evidently be seen in the increase in demand for Wagyu beef. End consumers of beef enjoy a better blend of muscle and fat content. Due to these factors, Marb EPD and RE EPD is expected to have a direct relationship with the price of bulls sold.

Weaned calf value (\$W) is a calculated index value and takes revenue and expense into account to determine the estimated average difference in future performance (Kansas State University Department of Animal Sciences and Industry, 2023). These costs are adjusted for differences in birth weights, weaning weights, maternal milk, and cow size. \$W is expected to

have a direct correlation with the sale price of the bull. This would show that better future performance indicates a producer is willing to spend more on the bull.

Feedlot value (\$F) is also an index value, calculating the dollar estimate of a bull's offspring and is the expected performance after weaning compared to the average progeny of the breed (Kansas State University Department of Animal Sciences and Industry, 2023). This would be an EPD that could be used by smaller producers who may raise cattle from birth to processing. \$F is expected to have positive coefficient in the model as this shows an increase in return postweaning and calves are worth more to the backgrounder or stocker, possibly returning more money to the cow-calf producer.

Grid value (\$G) is an index value measurement of the expected performance for carcass grade compared to other sire's offspring (Kansas State University Department of Animal Sciences and Industry, 2023). This calculation, listed in dollars per head, could be beneficial to producers who contractually agree with feedlots to receive part of the premium a carcass may bring when graded at the processor. Producers who are focusing on quality and yield may use this measurement when selecting bulls. This EPD is expected to show a positive relationship with the price of bulls sold.

Beef value (\$B) is the final index value considered and is a combination of \$F (post-weaning value) and \$G (carcass value), attempting to give a buyer a good estimate of the return they may see at each level of the beef supply chain after leaving the cow-calf operation (Kansas State University Department of Animal Sciences and Industry, 2023). This measurement is calculated in dollars per head and is expected to show a positive coefficient and would be correlated with the price of a bull. We would expect to see a correlation between \$B, \$F, and \$G, due to its use of these other index numbers in its calculation.

Embryo transfer (ET) was used as a dummy variable in the Legacy Sale analysis because embryo transfer bulls did not have a birth weight listed. An embryo transferred offspring is generally due to a dam with strong genetic traits coming to the end of their calving years. A producer will insert a hormone to produce multiple eggs, artificially inseminating the cow with semen from a bull with high-quality genetic traits (Karisch and Parish, 2022). After a week, a veterinarian flushes the fertilized eggs from the cow and either transfers them to another cow or freezes them to be used later. This may show a premium to producers because cost of the process itself would be high. This would only be worth the cost if the genetics were high-quality, sending a market signal that those bulls are better than others that were naturally bred or artificially inseminated without a transfer. We would expect to see a positive coefficient associated with an ET dummy variable.

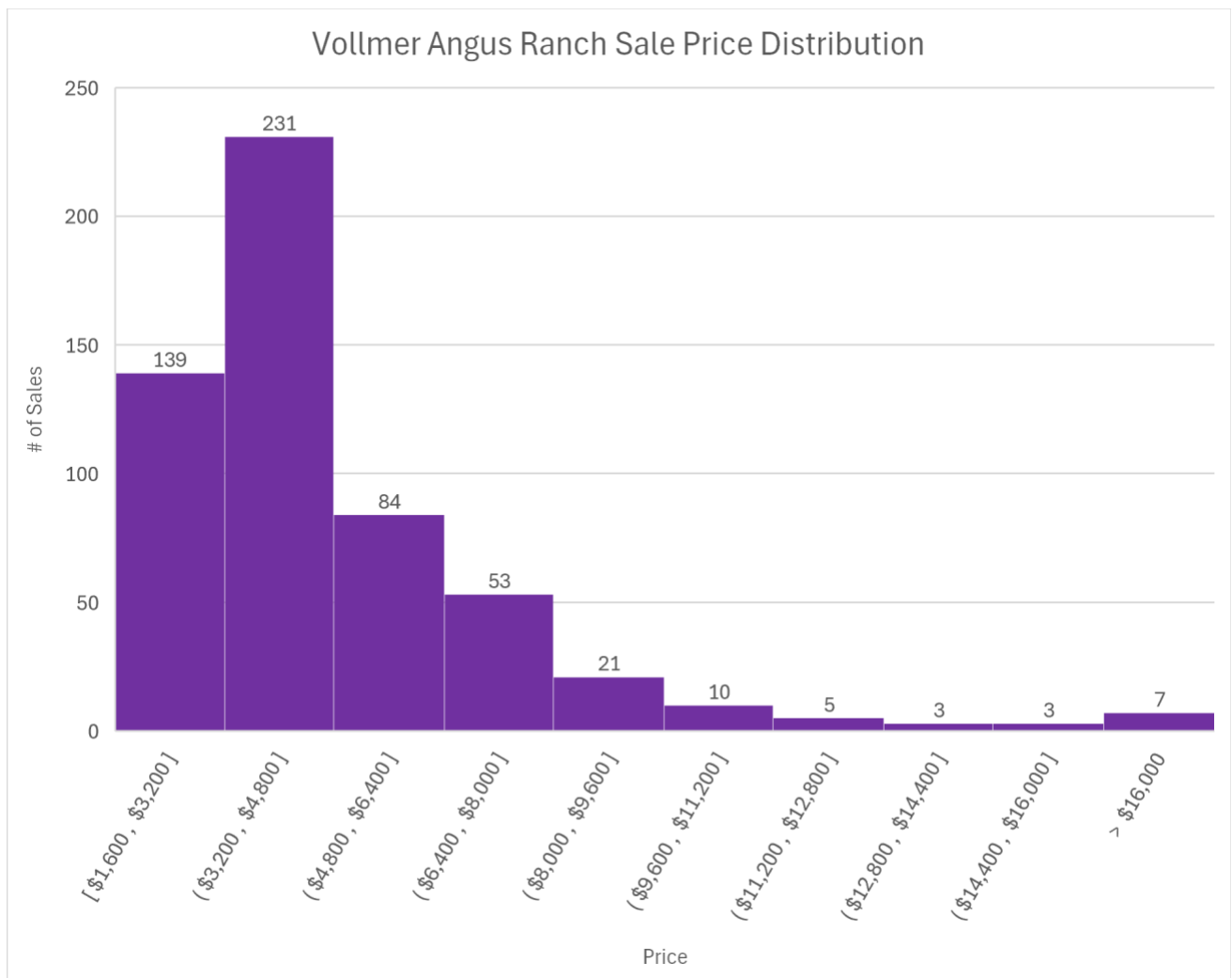
Adjusted weaning weight (Adj WW) is measured in pounds and is a calculation that considers weaning weight, birth weight, weaning age, and age of dam (Gould, 2015). This measurement can be used by producers to compare size at weaning and will further help determine the weight a calf may put on when grazing pasture between weaning weight and yearling weight. We would expect this measurement to have a direct correlation with the price of a bull sold and a positive coefficient within the estimated model.

3.2 Vollmer Angus Sale Data

Data are collected from the Vollmer Angus Ranch in Wing, North Dakota, for the years 2019-2023. Much like the Legacy Sale, Vollmer Angus also follows a spring calving season for their yearling bulls, raising and feeding the animals from birth to sale at their ranch. Progeny data are collected by the operators of the ranch who are registered members of the American Angus Association and follow the American Angus Association guidelines (Angus Genetics Inc., 2024).

The data are collected at the same intervals as the Legacy Sale, which includes birth, weaning, and yearling weights. They also collect their final EPD data from the American Angus Association's database before their bull sale. All lots observed in this dataset are yearling bulls, eliminating the few lots of two-year-old bulls, crossbred bulls, and Simmental bulls Vollmer Angus sold in conjunction with another operation over this timeframe. Pricing data are collected from Vollmer Angus and DVAuction while EPD data are gathered from the sale catalogs.

Figure 3.2. Vollmer Angus Ranch sale price distribution



This resulted in 556 observations with 13 independent variables. A hedonic model is used to analyze the effect each EPD had on the price and understand how EPDs may explain pricing variation. Multiple models are used to determine which EPDs may be most significant when attempting to explain changes in price across lots and over time. It is determined through evaluation of the R-squared, variable p-values, VIF, and RMSE values which model are most statistically significant and could accurately answer which EPDs influenced prices paid by seedstock consumers. This model uses the price as the dependent variable with all 13 independent variables being used in the model. With this model, we can determine implicit value producers place on different EPDs listed in the sale catalog and estimate their effect on the final sale price of the bull.

The linear equation for the Vollmer Angus Ranch sale is as follows:

$$(3.2) \quad Price_{ij} = \beta_0 + \beta_n X_n + \varepsilon_{ij},$$

where β_0 represents the equation intercept, β_n represents the calculated coefficient the n th EPD, X_n represents the EPD of the bull, i represents the lot number of the bull, j represents the Vollmer Angus Ranch sale year, and ε_{ij} represents the error term for the model.

3.2.1 Vollmer Angus Ranch Variables

Most variables listed in the Vollmer Angus Ranch sale catalog were cross listed in the Legacy Sale, as the Legacy Sale listed more calculated EPDs than Vollmer Angus each year. This includes an annual dummy variable, CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, Marb EPD, RE EPD, and Adj WW. The only independent variable included in the Vollmer Angus Ranch analysis that was not available for the Legacy Sale was birth weight. This was due to the Legacy Sale not listing a birth weight for any embryo transfer animals, creating a dummy variable that was used in that analysis for whether a bull was an ET or not.

True birth weight listed in the sale catalog could be important to producers to determine the actual size of the calf when they are born rather than a comparison to the breed average. Some producers may seek a 65-lb. birth weight and nothing higher and do not know what the breed average is, especially since the American Angus Association is constantly recalculating these when they receive more genetic trait data. Birth weight (BW) is expected to have an inverse relationship within the model. Like BW EPD, this is due to the cow-calf industry trend of birthing lighter calves so there are not as many pregnancy issues with first calf heifers.

3.3 Comparison of the Sales

When the datasets are combined, a dummy variable is added to distinguish between the Legacy Sale and Vollmer Angus Ranch lots. This variable helped determine whether one sale had a premium compared to another. The annual dummy variables are also included in the analysis to account for year-to-year price fluctuations for the combined sale data.

The linear equation for the sale comparison is as follows:

$$(3.3) \quad Price_{ijk} = \beta_0 + \beta_n X_n + \varepsilon_{ij},$$

where β_0 represents the equation intercept, β_n represents the calculated coefficient the n th EPD, X_n represents the EPD of the bull, i represents the lot number of the bull, j represents the sale year, k represents the sale the observation is from, and ε_{ij} represents the error term for the model.

The EPDs that are calculated into the analysis were CED, BW, weaning weight, yearling weight, maternal milk, ribeye, and marbling EPDs. These are the common variables between each sale for the 2019-2023 sale years. Some EPDs were available for certain years, such as scrotal circumference EPD. Scrotal circumference EPD is included in both the Legacy and Vollmer Angus Ranch sale catalogs for the years 2019 and 2021. A higher scrotal circumference EPD would directly correlate to more semen produced and indicate an earlier age of puberty with

that bull. This could also imply that the bull could impregnate more heifers or cows over the course of a producer's breeding season. Investing in one bull that could impregnate an entire small herd, or more efficiently impregnate a larger group of unbred females would show a direct correlation between the scrotal circumference EPD and the price paid for the bull.

Figure 3.3. Combined sale price distribution



The linear equation for the annual model is as follows:

$$(3.4) \quad Price_{ij} = \beta_0 + \beta_n X_n + \varepsilon_{ij},$$

where β_0 represents the equation intercept, β_n represents the calculated coefficient the n th EPD, X_n represents the EPD of the bull, i represents the lot number of the bull, j represents the sale year the observation was from, and ε_{ij} represents the error term for the model.

Adjusted yearling weight is calculated and listed in both sale catalogs in 2020 and 2023. Much like Adj WW, this calculation includes the yearling weight, birth weight, weaning weight, and the number of days between weaning and yearling weight (Bormann, 2010). This tells a buyer how much yearling growth is predicted to be passed on to the offspring of the bull. The reasoning for not including yearling weights in many sale catalogs is that once an animal reaches a feedlot, yearling weights are not often reported (Beef Improvement Federation, 2021). We would expect to see a positive correlation with the price a bull sells for and an adjusted yearling weight. As yearling weights get higher, cattle are getting larger quicker. This is desired by feedlots, to a certain point, and cow-calf producers may receive a premium for larger cattle coming to the feedyard.

Maternal weaned calf value (\$M) is another index value and was listed in 2022 and 2023. This EPD “predicts profitability differences from conception to weaning with the underlying breeding objective assuming that individuals retain their own replacement females within their herd,” (Kansas State University Department of Animal Sciences and Industry, 2023). This variable assumes that commercial producers will be replacing 25 percent of females after their first generation and 20 percent in the generations following. We expect to see a direct relationship as this estimates profitability of the maternal offspring of the bull.

From 2021-2023, combined value (\$C) was included as a dollar calculation for each animal in the sale books. This includes the \$M and Beef Value (\$B) and would be beneficial to

commercial producers who are replacing an estimated 20 percent of their breeding females each year (Kansas State University Department of Animal Sciences and Industry, 2023). We would expect to see a positive relationship between the price of a lot and the combined value variable.

Scrotal circumference measurement (SC), not a calculated EPD compared to the breed association average, but a true measurement, and docility EPD (DOC EPD) are listed in the sale catalogs for only the 2023 year. Like the scrotal circumference EPD, the actual scrotal circumference measurement can be used to identify more fertile bulls compared to others. Producers may desire to see the true measurement compared to an EPD calculation because the EPD is a comparison or ranking to the average measurement of rest of the Angus Association's bulls. We expect that scrotal circumference will have a positive coefficient sign because more fertile bulls are desired by producers. More docile cattle are desired as they are more adaptable to newer environments across the same operation and down the supply beef supply chain. We expect this variable to have a positive relationship with the sale price of a bull.

Table 3.1. Expected Coefficient Signs for Variables in Regression Models

EPDs/Index Values		Expected Signs							
Name	Common Abbreviation	Legacy Sale	VAR Sale	Combined	2019	2020	2021	2022	2023
Birth Weight EPD	BW EPD	-	-	-	-	-	-	-	-
Calving ease direct EPD	CED EPD	+	+	+	+	+	+	+	+
Calving ease maternal EPD	CEM EPD	+							
Docility EPD	DOC EPD				+				
Marbling EPD	Marb EPD	+	+	+	+	+	+	+	+
Maternal Milk EPD	Milk EPD	+	+	+	+	+	+	+	+
Ribeye EPD	RE EPD	+	+	+	+	+	+	+	+
Scrotal circumference EPD	SC EPD				+		+		
Weaning weight EPD	WW/WN EPD	+	+	+	+	+	+	+	+
Yearling weight EPD	YW EPD	+	+	+	+	+	+	+	+
Birth Weight	Birth Wt		-						
Adjusted Weaning Weight	Adj WW/ WN Adj WT	+	+		+	+	+	+	
Adjusted Yearling Weight	Adj YW/YR Adj WT					+			+
Scrotal circumference	SC								+
Beef value	\$B	+			+	+	+	+	
Combined value	\$C						+	+	+
Feedlot value	\$F	+							
Grid value	\$G	+							
Maternal weaned calf value	\$M							+	+
Weaned calf value	\$W	+			+			+	
Legacy Sale Dummy				-	-	-	-	-	-
Picture in Catalog		+							
2016 Dummy		-							
2017 Dummy		-							
2018 Dummy		-							
2019 Dummy		-	-	-					
2020 Dummy		-	-	-					
2021 Dummy		-	-	-					
2022 Dummy		-	-	-					
Embryo Transfer	ET	+							

Chapter 4 - Results

4.1 Legacy Sale Results

The Legacy Sale analysis began with a full regression utilizing all independent variables from the years 2016-2023. Nearly half of the EPDs listed in the Legacy Sale were not listed in the Vollmer Angus Ranch sale catalog, giving the opportunity for a more representative model of price changes in the bull sale auction market. A correlation matrix was analyzed and the VIF was considered. The p-values for the first model showed that 10 of the 22 independent variables were statistically significant at the 0.1 confidence level. The correlation matrix showed some multicollinearity among independent variables and the VIF was the highest of any model measured in this analysis, causing some concern of correlation within the model with a value of 4.03. Ideally, we would like to see a VIF number of less than 4 to show little correlation among independent variables. After assessing p-values, a correlation matrix, and the VIF number, ten variables were included in the second model.

Table 4.1. Results of Hedonic Model with Legacy Sale Prices and EPDs (2016-2023)

Regression Statistics	
Multiple R	0.7949
Adjusted R Square	0.7519
Variance Inflation Factor	4.03
Standard Error	979.50
Observations	128

ANOVA					
	df	SS	MS	F	Significance F
Regression	22	390396876	17745312.55	12.59	<0.001
Residual	105	100746230	959488		
Total	127	491143106			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-2,960.65*	1,524.62	-1.94	0.055
Picture in Catalog	787.67***	243.60	3.23	0.002
2022 Dummy	178.20	449.26	0.40	0.692
2021 Dummy	-2,478.89***	525.44	-4.72	<0.001
2020 Dummy	-2,427.57***	605.58	-4.01	<0.001
2019 Dummy	-2,684.14***	599.91	-4.47	<0.001
2018 Dummy	-1,473.24**	619.26	-2.38	0.019
2017 Dummy	-2,319.13***	710.93	-3.26	0.001
2016 Dummy	-1,378.02**	630.07	-2.19	0.031
CED EPD	180.56***	55.51	3.25	0.002
BW EPD	-6.03	146.27	-0.04	0.967
WW EPD	32.25	48.86	0.66	0.511
YW EPD	23.26	22.90	1.02	0.312
CEM EPD	-42.08	46.00	-0.92	0.362
Milk EPD	42.37	35.86	1.18	0.240
RE EPD	1,003.55	661.42	1.52	0.132
Marb EPD	2,316.12**	1095.81	2.11	0.037
\$W	361.92	243.10	1.49	0.362
\$F	4.45	1.79	2.49	0.884
\$G	-26.43	28.85	-0.92	0.220
\$B	-1.83	12.53	-0.15	0.780
ET	31.46	25.50	-1.23	0.140
Adj WW	-2.62**	9.33	-0.28	0.014

The second model utilized the following independent variables: picture in catalog, annual dummy variables, CED EPD, Marb EPD, ET, and Adj WW. These variables were included because they are traits shown to be desired at the Legacy Sale. After running the first model, it was shown that producer buying decisions at this specific sale emphasize general growth of the animal, wanting to see traits from birth to carcass grade. The second model showed that the R-squared value slightly decreased, but the statistical significance of the variables was much greater. Only one variable was not significant at the 0.05 level, being the 2022 dummy variable with a p-value of 0.855. However, it would be incorrect to include annual dummy variables for all other years being statistically significant and not include 2022. The VIF calculation resulted in a 3.87, which is still higher than other models, but still within the acceptable range for model fit.

Table 4.2. Results of Hedonic Model with Legacy Sale Prices and Selected EPDs (2016-2023)

Regression Statistics	
Multiple R	0.8611
R Square	0.7415
Adjusted R Square	0.7145
Variance Inflation Factor	3.87
Standard Error	1050.72
Observations	128

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	12	364181679.8	30348473.32	27.49	<0.001
Residual	115	126961425.7	1104012.40		
Total	127	491143105.5			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-1,132.73	1,146.71	-0.99	0.325
Picture in Catalog	799.54***	253.59	3.15	0.002
2022 Dummy	-66.83	365.29	-0.18	0.855
2021 Dummy	-2,922.72***	447.46	-6.53	<0.001
2020 Dummy	-2,455.38***	483.75	-5.08	<0.001
2019 Dummy	-2,481.47***	410.14	-6.05	<0.001
2018 Dummy	-1,311.52***	490.06	-2.68	0.009
2017 Dummy	-1,962.27***	377.95	-5.19	<0.001
2016 Dummy	-1,473.49***	394.89	-3.73	<0.001
CED EPD	120.91***	25.82	4.68	<0.001
Marb EPD	1,320.68***	284.24	4.65	<0.001
ET	606.33**	239.74	2.53	0.013
Adj WW	7.01***	1.66	4.22	<0.001

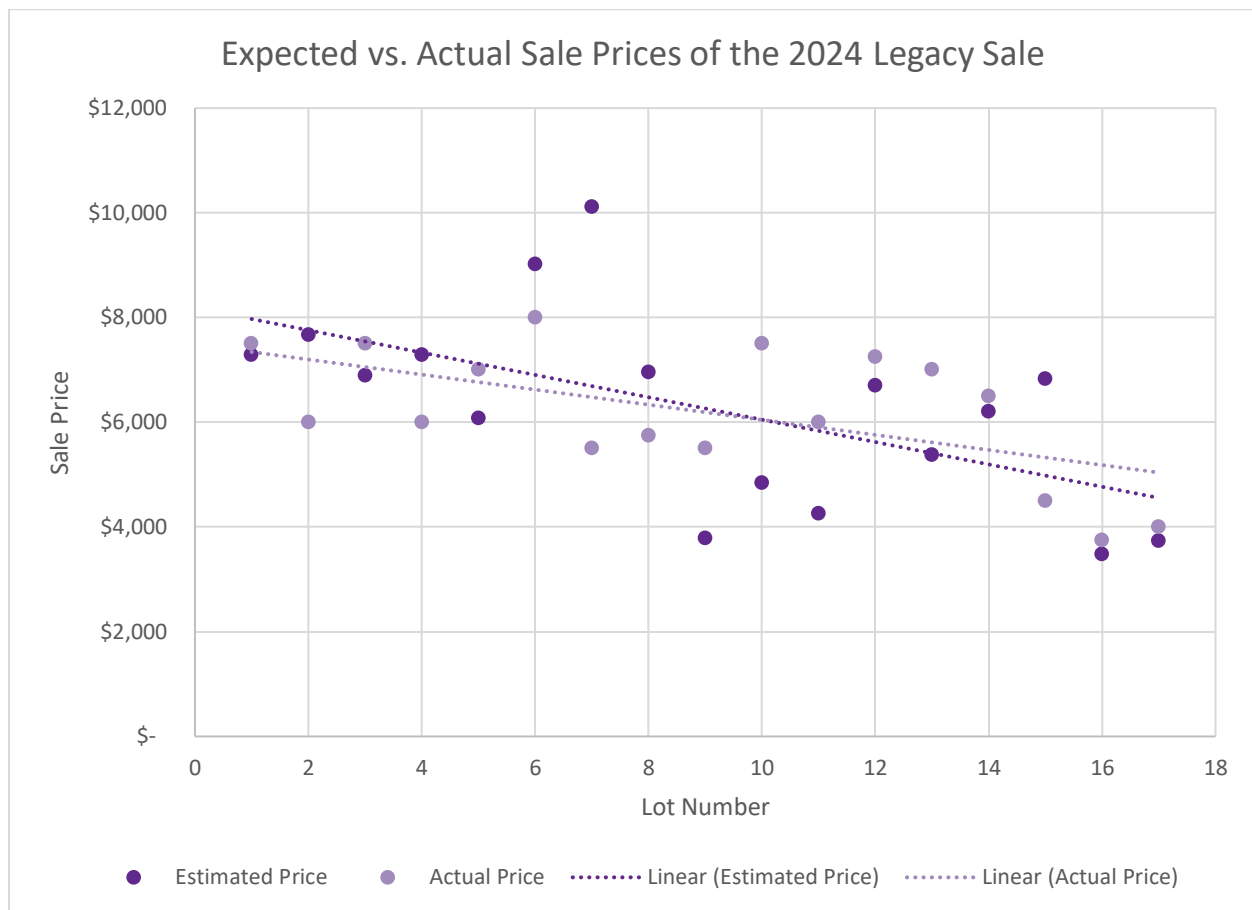
The signs for the coefficients of the independent variables included are what were expected. Using 2023 as the base year, the annual dummy variables follow the current production and price cycle from 2016-2022, seeing prices most negative from 2019-2021 during the COVID-19 pandemic and the bottleneck in the beef supply chain. However, all annual coefficients are negative, which would be expected having not adjusted prices for inflation. CED EPD, Marb EPD, ET, and Adj WW measurement all returned positive coefficients.

4.1.1 2024 Legacy Sale Predictability

It should be noted that it is just as important that this model can predict future prices as well as accurately represent the dataset. The final regression model using selected EPDs from the use of the Legacy Sale data was applied to the data for the 2024 K-State Legacy Sale to estimate how accurate predictions for the sale using the model would be. The 47th annual K-State Legacy Sale took place on March 1, 2024, giving us not only a dataset to predict, but also pricing results from the bull sale. The model was extremely inaccurate, resulting in estimates that varied from the actual prices paid by as much as \$21,692.16 and as low as \$337.68. This shows that while the model may include statistically significant independent variables and good at explaining the prices paid using the given data, there are many factors outside of the dataset that explain a price a producer is willing to pay for a bull.

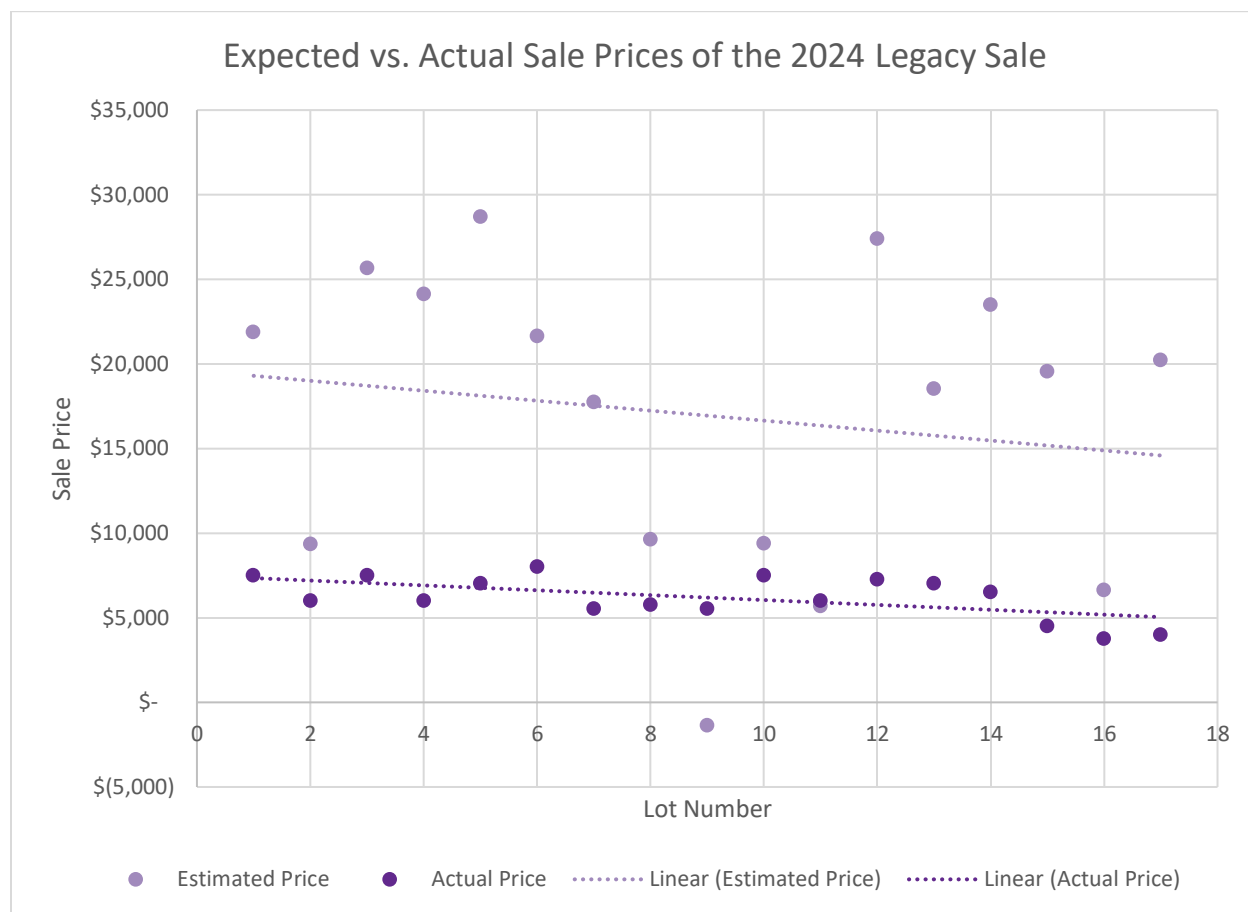
The first model including all variables was also calculated and used to estimate the prices of the 2024 Legacy Sale bulls. The annual dummy variables were excluded because we are using the entire dataset to explain future prices rather than account for pricing differences from year-to-year. The result was a \$72.21 premium when comparing estimated prices to the actual sale price, with the average price paid being \$6,191.18 compared to the estimated average price being \$6,263.38. There was much less volatility in the predictions, with the largest difference being \$4,616.98 between the predicted price and actual price while the smallest difference between the two came in at \$266.91. These estimates show that while the model may not be the most accurate when calculating individual lot results, it can be a good predictor of overall auction results.

Table 4.3. 2024 Predicted Results Using Hedonic Model with EPDs from the Legacy Sale
(2016-2023)



The bidding for each lot started at \$3,500, which the model predicted one price below that threshold; however, the price was \$3,483.09. Being that prices for the same were made in \$250, \$500, or \$1,000 increments and lots can drop below that \$3,500 minimum if there is not a producer bidding on the lot and the auctioneer decides to decrease the price in order to get a bid, this prediction is not impossible. This scenario occurred on the following lot from this prediction, when there was no bid at \$3,500. The prediction came for lot 16, which was the smallest calculated difference between the estimated price and paid price at the sale.

Table 4.4. 2024 Predicted Results Using Hedonic Model with Selected EPDs from the Legacy Sale (2016-2023)



4.2 Vollmer Angus Sale Results

When analyzing the variables for the Vollmer Angus Ranch dataset, all variables were included, using a dummy variable for the year of the sale, CED EPD, birth weight, BW EPD, Adj WW, WW EPD, YW EPD, Milk EPD, Marb EPD, and RE EPD. The regression found five of the 13 variables were statistically significant at the 0.1 level, those being the 2022 dummy variable, 2021 dummy variable, 2019 dummy variable, Adj WW, and RE EPD. The correlation matrix showed high correlation among the birth, weaning, and YW EPDs as well as marbling

and RE EPDs. Based on these results, dummy variables were included, even with 2020 not returning a significant value, BW EPD, adjusted WW EPD, YW EPD, Marb EPD, and RE EPD. Even with BW EPD, YW EPD, and Marb EPD not having statistically significant values, they were marginally insignificant and may reveal information about buyer preferences.

Table 4.5. Results of Hedonic Model with Vollmer Angus Ranch Sale Prices and EPDs (2019-2023)

<i>Regression Statistics</i>	
Multiple R	0.4857
R Square	0.2359
Adjusted R Square	0.2176
Variance Inflation Factor	1.31
Standard Error	3110.08
Observations	556

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	13	1618358750	124489134.6	12.87	<0.001
Residual	542	5242558242	9672616.682		
Total	555	6860916992			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-15,098.92***	3298.66	-4.58	<0.001
2022 Dummy	-988.68**	421.30	-2.35	0.019
2021 Dummy	-1,652.80***	457.56	-3.61	<0.001
2020 Dummy	-501.80	486.25	-1.03	0.303
2019 Dummy	-950.35*	525.62	-1.81	0.071
CED EPD	31.46	54.87	0.57	0.567
Birth Wt	-11.28	31.68	-0.36	0.722
BW EPD	-265.85	183.35	-1.45	0.148
Adj WW	17.60***	3.02	5.84	<0.001
WN EPD	23.10	42.03	0.55	0.583
YW EPD	29.71	23.71	1.25	0.211
Milk EPD	27.98	23.46	1.19	0.233
Marb EPD	762.69	553.00	1.38	0.168
RE EPD	1,641.20**	690.69	2.38	0.018

The second regression model was run with the previously listed variables, calculating seven independent variables to be significant to the change in price. The two that were not

significant were the 2020 dummy variable and Marb EPD. Being that you cannot exclude one year's dummy variable from a regression model while including the rest, the statistical significance of all other years calls for the 2020 dummy variable to be included in the model. Marbling and RE EPDs have shown that including one would inherently include the preferences of producers who use one or both of these variables when determining the price they are willing to pay because they are both carcass trait EPDs. The R-squared for the second model compared to the first model was nearly identical, decreasing slightly from 0.2359 to 0.2331. The VIF measure decreased as well, showing that multicollinearity within the model was decreased with the exclusion of some variables, which was expected after eliminating some variables using the correlation matrix. The VIF of 1.3039 is low and shows a well-fitting model.

Table 4.6. Results of Hedonic Model with Vollmer Angus Ranch Sale Prices and Selected EPDs (2019-2023)

<i>Regression Statistics</i>	
Multiple R	0.4828
R Square	0.2331
Adjusted R Square	0.2204
Variance Inflation Factor	1.30
Standard Error	3104.34
Observations	556

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	9	1599170278	177685586.4	18.43804642	<0.001
Residual	546	5261746714	9636898.744		
Total	555	6860916992			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-15,304.78***	2,286.34	-6.69	<0.001
2022 Dummy	-990.13**	409.98	-2.42	0.016
2021 Dummy	-1,727.57***	433.34	-3.99	<0.001
2020 Dummy	-463.80	472.62	-0.98	0.327
2019 Dummy	-919.60*	498.06	-1.85	0.065
BW EPD	-365.63***	101.54	-3.60	<0.001
Adj WW	17.94***	2.89	6.20	<0.001
YW EPD	42.65***	10.63	4.01	<0.001
Marb EPD	875.60	540.47	1.62	0.106
RE EPD	1,732.57**	683.82	2.53	0.012

The signs for the variables are as expected, with the annual dummy variables all returning negative values. BW EPD was also an inverse relationship, showing larger calves are less desired by producers at birth. Adj WW had a direct relationship, which can be attributed to producers marketing yearling calves by the hundredweight. Higher weighted calves at this time will result in more revenue for the cow-calf producer. YW EPD also showed a positive coefficient, which is also expected. Finally, the carcass traits, Marb EPD and RE EPD, both showed positive

coefficients, which follows the trends of current cattle marketing trends and the producer desire to be included in premiums and marketing programs.

4.3 Combined Sale Results

The combined results were analyzed using the entire dataset available, using the following independent variables: dummy variables for each year represented, holding 2023 as the base year in the hedonic model, a dummy variable for which sale the lot came from (1 is Legacy Sale, 0 otherwise), CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, and Marb EPD. This regression found that all but three variables, the dummy variable for sale, CED EPD and YW EPD, were significant at the 0.1 confidence level interval. After analyzing a correlation matrix, it was determined that CED EPD and BW EPD showed a strong correlation. YW EPD also showed a strong correlation with BW EPD and WW EPD. This would make sense, as birth weight and calving ease are two measurements producers use to determine whether they will need to pull a calf. Marb EPD may not be emphasized by producers in the industry, due to using one variable eliminated the correlation and accounted for this buying decision for bull purchasers. YW EPD's correlation with birth weight and WW EPD's would also make sense because we would expect a constant growth rate throughout the life of an animal, meaning that the positive or negative weight EPD they show at birth would also be reflected throughout the rest of their life.

Table 4.7. Results of Hedonic Model with Combined Sale Prices and EPDs (2019-2023)

Regression Statistics	
Multiple R	0.4420
R Square	0.1953
Adjusted R Square	0.1796
Variance Inflation Factor	1.24
Standard Error	3069.57
Observations	628

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	Significance <i>F</i>
Regression	12	1406624043	117218670.2	12.44	<0.001
Residual	615	5794676005	9422237.407		
Total	627	7201300048			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-3,948.26***	1,308.56	-3.02	0.003
Legacy Sale Dummy	-462.82	820.64	-0.56	0.573
2022 Dummy	-838.70**	392.21	-2.14	0.033
2021 Dummy	-1,371.04***	426.87	-3.21	0.001
2020 Dummy	-1,536.07***	435.06	-3.53	<0.001
2019 Dummy	-719.09	458.78	-1.57	0.118
CED EPD	38.53	51.19	0.75	0.452
BW EPD	-273.18*	162.24	-1.68	0.093
WW EPD	62.36*	37.08	1.68	0.093
YW EPD	26.00	21.81	1.19	0.234
Milk EPD	39.59*	21.75	1.82	0.069
RE EPD	1,103.61*	629.07	1.75	0.080
Marb EPD	681.19	451.57	1.51	0.132

After a first analysis and testing for multicollinearity using a correlation matrix and VIF, a second regression model was run, showing all independent variables were statistically significant at the 90% confidence interval level and the dummy variable for 2019 being the only variable not statistically significant at the 95% confidence interval level. The R-squared value for

this model was calculated at 0.1881, a slight decrease from the first model's value of 0.1953. We would expect the R-squared value to decrease when removing variables because independent variables may be correlated but each EPD explains some variation in price. This shows that the variables included and used in this analysis do not account for much variation in the data. These results are consistent with previous literature in hedonic modeling and surveying of producers of bull sale EPDs and their purchasing decisions (Jones et al., 2008; Simms, Geske, and Bolze, 1994). A VIF was also calculated for the dataset with a result of 1.23. This shows little correlation between the variables included in the regression analysis.

Table 4.8. Results of Hedonic Model with Combined Sale Prices and Selected EPDs (2019-2023)

<i>Regression Statistics</i>	
Multiple R	0.4338
R Square	0.1882
Adjusted R Square	0.1777
Variance Inflation Factor	1.23
Standard Error	3073.19
Observations	628

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	8	1355174325	169396790.7	17.94	<0.001
Residual	619	5846125723	9444468.049		
Total	627	7201300048			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-3,520.73***	1,269.83	-2.77	0.006
2022 Dummy	-774.45**	378.05	-2.05	0.041
2021 Dummy	-1,258.93***	411.86	-3.06	0.002
2020 Dummy	-1,531.51***	419.43	-3.65	<0.001
2019 Dummy	-792.05*	435.11	-1.82	0.069
BW EPD	-398.91***	91.11	-4.38	<0.001
VW EPD	108.14***	15.35	7.05	<0.001
Milk EPD	49.78**	21.02	2.37	0.018
RE EPD	1,272.06**	617.23	2.06	0.040

The signs for the variables are consistent with what we would expect to see. A negative term was calculated for all annual dummy variables, which would make sense with an improvement of genetic pedigrees and the use of nominal prices compared to adjusting previous years to real pricing. BW EPD showed a negative coefficient, following previous studies and industry trends of less desire to pull calves during pregnancy. Weaning weight showed a positive coefficient which would increase the price a producer receives for larger calves at weaning from the background/stocker operation. Milk EPD was also positive, showing more maternal milk production was desired by producers. More milk production would limit any necessary bottle feeding and help increase growth among calves while nursing off the mother. Finally, RE EPD showed the highest positive coefficient. As ribeye size gets larger, the price increases; this is expected as carcasses are graded on the ribeye size and marbling.

4.3.1 2019 Results

When estimating the results for 2019, 13 variables were included in the first regression. The independent variables commonly found between the Legacy Sale and Vollmer Angus for the 2019 sales were a dummy variable for the sale the lot originated from (1 for Legacy Sale, 0 otherwise), CED EPD, BW EPD, WW EPD, YW EPD, scrotal circumference EPD, Milk EPD, RE EPD, Marb EPD, docility EPD, \$W, beef value, and Adj WW. The first analysis showed six of the independent variables to be statistically significant at the 0.1 confidence interval level. The variables that were not significant, CED EPD, BW EPD, scrotal circumference EPD, RE EPD, Marb EPD, and beef value, were analyzed using the correlation matrix to determine any multicollinearity. YW EPD was highly positively correlated with beef value and CED EPD and BW EPD had a strong negative correlation. Marb EPD can also be strongly associated with RE

EPD and RE EPD was marginally insignificant, so this variable was included and Marb EPD was removed. Because purchasers of these bulls are primarily cow-calf producers, CED EPD was included in the second analysis, eliminating BW EPD. Beef value was excluded as well because of their correlation with YW EPD. Scrotal circumference EPD was a variable that was not included in the combined analysis. This was included in the second model to see how producers valued this variable, having not been analyzed previously.

Table 4.9. Results of Hedonic Model with Combined Prices and EPDs (2019)

<i>Regression Statistics</i>	
Multiple R	0.6102
R Square	0.3723
Adjusted R Square	0.2931
Variance Inflation Factor	1.59
Standard Error	1445.21
Observations	117

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	13	127594016.6	9814924.354	4.70	<0.001
Residual	103	215128205.6	2088623.355		
Total	116	342722222.2			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-8935.29***	2954.28	-3.02	0.003
Legacy Sale Dummy	2105.50**	893.01	2.36	0.020
CED EPD	-4.92	56.97	-0.09	0.931
BW EPD	177.24	225.71	0.79	0.434
WW EPD	-276.65***	84.98	-3.26	0.002
YW EPD	104.21***	30.98	3.36	0.001
SC EPD	18.05	228.65	0.08	0.937
Milk EPD	-129.89**	54.63	-2.38	0.019
RE EPD	1312.85	815.16	1.61	0.110
Marb EPD	704.38	659.99	1.07	0.288
DOC EPD	53.60***	19.92	2.69	0.008
\$W	118.35**	45.64	2.59	0.011
\$B	-1.03	10.44	-0.10	0.922
Adj WW	15.59***	3.42	4.55	<0.001

After creating a second model, seven variables were statistically significant at the 0.01 confidence level. CED EPD, scrotal circumference EPD, and RE EPD were still insignificant. CED EPD being insignificant is surprising, since there would be no other direct indicator of calving ease or birth size included in the model if this was removed. Scrotal circumference EPD did not return a significant result and showed a small relative price change and could be reasoning for not having been included in 2020 or 2022 sale catalogs. RE EPD being insignificant was also surprising as producers would not have another EPD listed to determine future carcass quality without either ribeye area or Marb EPD. The R-squared value from the first model was 0.3723 and the second model, like the combined model, showed a decrease in R-squared value with a calculation of 0.2996. The variables explain slightly less variation in the price but could be attributed to other factors not accounted for in the dataset. The VIF was 1.42, showing little correlation among variables in the regression.

Table 4.10. Results of Hedonic Model with Combined Prices and Selected EPDs (2019)

Regression Statistics	
Multiple R	0.6000
R Square	0.3599
Adjusted R Square	0.2996
Variance Inflation Factor	1.43
Standard Error	1438.56
Observations	117

ANOVA					
	df	SS	MS	F	Significance F
Regression	10	123359837.2	12335983.72	5.96	<0.001
Residual	106	219362385	2069456.46		
Total	116	342722222.2			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-8709.82***	2845.65	-3.06	0.003
Legacy Sale Dummy	2174.40**	880.51	2.47	0.015
CED EPD	-22.83	41.92	-0.54	0.587
WW EPD	-236.65***	72.71	-3.25	0.002
YW EPD	96.34***	29.40	3.28	0.001
SC EPD	-13.41	226.47	-0.06	0.953
Milk EPD	-103.80**	46.48	-2.23	0.028
RE EPD	989.78	747.12	1.32	0.188
DOC EPD	58.74***	19.07	3.08	0.003
\$W	97.15***	35.67	2.72	0.008
Adj WW	14.92***	3.31	4.51	<0.001

There were mixed results with expected signs for coefficients and the calculated signs in the model. A premium was calculated for Legacy Sale bulls compared to the Vollmer Angus Ranch bulls. This may be more statistically significant because of a smaller concentration of data from the Legacy Sale to Vollmer Angus Ranch. Kansas also serves more cow-calf operations, geographically, than North Dakota does, creating more demand for bulls for the Legacy Sale. CED EPD and WW EPD saw a negative coefficient, meaning that as these EPDs increase compared to the Angus Association's average, the price paid by a producer decreased. This

would be different than expected as producers do not want to pull calves and would desire a higher CED EPD as well as larger cattle at weaning and yearling weights. A positive coefficient for yearling weight shows what was just discussed: larger cattle at these measurements. A negative scrotal circumference EPD was not expected because a higher scrotal circumference EPD is associated with fertility among bulls. This analysis would say that as bulls are considered more fertile, producers are willing to pay less for the lot. Milk EPD was negative, which is inverse to what producers desire. Ribeye EPD showed a positive coefficient, showing market trends and the premiums offered to producers for larger ribeye areas and larger cattle. Docility EPD showed a positive result, meaning producers desire more flexible and temperamentally sound cattle. This is correlated with the reaction to change, such as transport from cow-calf operations to backgrounders or feedlots and moving locations within the same operation. \$W and Adj WW returned a positive coefficient, which would be expected as a higher \$W returns more revenue for the cow-calf producer when selling to the backgrounder and the Adj WW variable helps explain a negative WW EPD coefficient.

4.3.2 2020 Results

The 2020 data utilized some of the same variables as the 2019 dataset, including a dummy variable for the sale, CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, Marb EPD, beef value, and Adj WW. The independent variable included in this dataset that was not used in the 2019 regression was adjusted yearling weight. Scrotal circumference EPD and docility EPD were not included in the 2020 dataset. This could be an indicator from the market that these EPDs were not considered valuable by producers when making purchasing decisions.

Table 4.11. Results of Hedonic Model with Combined Prices and EPDs (2020)

Regression Statistics	
Multiple R	0.7697
R Square	0.5924
Adjusted R Square	0.5501
Standard Error	1238.53
Variance Inflation Factor	2.45
Observations	118

ANOVA					
	df	SS	MS	F	Significance F
Regression	11	236332989.5	21484817.23	14.01	<0.001
Residual	106	162599404.6	1533956.65		
Total	117	398932394.1			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-26367.75***	2726.59	-9.67	<0.001
Legacy Sale Dummy	2787.44***	641.27	4.35	<0.001
Adj YW	11.97***	2.41	4.96	<0.001
CED EPD	153.65***	52.65	2.92	0.004
BW EPD	-36.06	168.33	-0.21	0.831
WW EPD	0.25	38.49	0.01	0.995
YW EPD	17.28	24.12	0.72	0.475
Milk EPD	-3.63	22.38	-0.16	0.871
RE EPD	-346.59	753.74	-0.46	0.647
Marb EPD	181.33	728.21	0.25	0.804
\$B	1.52	8.66	0.18	0.861
Adj WW	14.91***	3.04	4.91	<0.001

The 2020 dataset, originally estimated with all independent variables, showed the highest R-squared value of any annual model, calculated in this project at 0.5924. Most independent variables came back statistically insignificant, those being BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, Marb EPD, and beef value. A strong correlation between WW EPD and Adj WW helped eliminate WW EPD from a second regression model due to its statistical insignificance and the correlation effect. YW EPD and adjusted yearling weight showed the same effect, also

eliminating YW EPD from a second model. Marbling and RE EPD showed to be insignificant again, so Marb EPD was left out of the second regression to continue to account for carcass quality and having used RE EPD previously, wanted to estimate a possible statistical difference by using the other carcass quality indicator. BW EPD was excluded because of its correlation with CED EPD and the significance of that variable. Milk EPD and beef value were removed from the analysis for a second model due to insignificance and the thought that producers do not see value in the listing of these EPDs.

Table 4.12. Results of Hedonic Model with Combined Prices and Selected EPDs (2020)

Regression Statistics	
Multiple R	0.7609
R Square	0.5790
Adjusted R Square	0.5602
Variance Inflation Factor	2.38
Standard Error	1224.61
Observations	118

ANOVA					
	df	SS	MS	F	Significance F
Regression	5	230970215.3	46194043.07	30.80	<0.001
Residual	112	167962178.7	1499662.31		
Total	117	398932394.1			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-26468.78***	2654.33	-9.97	<0.001
Legacy Sale Dummy	3138.03***	555.98	5.64	<0.001
Adj YW	13.01***	2.22	5.87	<0.001
CED EPD	141.47***	23.95	5.91	<0.001
Marb EPD	544.91	518.98	1.05	0.296
Adj WW	15.56***	2.79	5.58	<0.001

The second model included five independent variables, returning four of them to be statistically significant at the 0.01 confidence interval level. The only insignificant variable still included in the model was Marb EPD, which shows that in future models, if both RE EPD and

Marb EPD return insignificant p-values, there may be no reason to include either of them. This can be interpreted as producers are not as worried about carcass quality and marbling when making buying decisions. This would make sense, as cow-calf producers are not paid the premiums or discounts the feedlot sees for high-grading cattle, but receive their payment at the weaning or yearling level and are paid by hundredweight. Furthermore, that would explain the significance of a weaning weight measurement, yearling weight measurement, and CED EPD. The R-squared calculation for the second model decreased slightly from 0.5924 in the first model to 0.5790 in the second model. The variables do not explain price as much, but eliminates strong multicollinearity. The VIF returned a value of 2.7 but still under 4, showing that the model does not show any concern.

The signs for the coefficients returned the expected values, with all independent variables having a positive result on the price of the lot sold. The Legacy Sale showed a premium again when compared to Vollmer Angus Ranch of \$3,138.03. This would continue the discussion as to whether producers are truly willing to pay more at a university-sponsored bull sale and their reasoning as to why. Adjusted yearling weight was expected to increase the price a producer would pay because they will receive a higher price for the cattle they sell to the feedlot. CED EPD was also expected to return a positive result due to the increase of age in ranchers and their previously mentioned desire to not pull calves during calving season. Marb EPD increased the price producers were willing to pay since many producers' goals are to deliver high-grading carcasses to the packer and receive a premium for their cattle. Finally, Adj WW was expected to be positive because, much like adjusted yearling weight, producers are paid by the hundredweight and receive a higher return from the backgrounder if cattle are larger.

4.3.3 2021 Results

The 2021 combined data showed many of the same variables as previously seen in 2019 and 2020, with a dummy variable for the Legacy Sale, CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, Marb EPD, beef value, and Adj WW all being considered in this model. Other variables that were included are scrotal circumference EPD, which was previously listed in the sale book in 2019 and used in that model, as well as combined value, which is new to the analysis. The combined value calculates the dollar value of traits that make up the \$M and beef value characteristics. This trait is primarily used by commercial producers who are assumed to be replacing larger percentages of breeding females each year. This is the first annual analysis where the Legacy Sale dummy showed not to be statistically significant in the first model. Removing this dummy variable would be interesting to see how results from a second regression model are estimated without classifying the sale the lot came from. CED EPD, BW EPD, Marb EPD, combined value, and Adj WW were all statistically significant at the 0.1 confidence level. These variables all account for producer desires within the cow-calf industry. Scrotal circumference has previously been seen in the 2019 model at roughly the same statistical significance level within the model and should not be included again in the regression analysis. There has not been an annual model yet where both CED EPD and BW EPD were both significant within the first model and analyzed together again in the second model, so those were both included. Marb EPD is finally significant within a model and should be included. Regardless of significance level in the first analysis, combined value was determined to be included to estimate the producer emphasis on this new variable. Adj WW was also included to give another measurement of stage of life and size at these stages besides birth stage EPDs.

Table 4.13. Results of Hedonic Model with Combined Prices and EPDs (2021)

Regression Statistics	
Multiple R	0.4747
R Square	0.2253
Adjusted R Square	0.1368
Variance Inflation Factor	1.29
Standard Error	3683.15
Observations	118

ANOVA					
	df	SS	MS	F	Significance F
Regression	12	414353829.3	34529485.77	2.55	0.005
Residual	105	1424388226	13565602.15		
Total	117	1838742055			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-21140.93***	6960.59	-3.04	0.003
Legacy Sale Dummy	2075.59	1751.00	1.19	0.239
CED EPD	-255.92*	130.59	-1.96	0.053
BW EPD	-1165.64***	432.65	-2.69	0.008
WW EPD	-8.17	121.58	-0.07	0.947
YW EPD	41.97	80.78	0.52	0.604
SC EPD	99.15	661.64	0.15	0.881
Milk EPD	-56.00	63.62	-0.88	0.381
RE EPD	-538.09	2397.51	-0.22	0.823
Marb EPD	-3951.36*	2337.23	-1.69	0.094
\$B	-50.18	53.43	-0.94	0.350
\$C	79.96**	32.57	2.46	0.016
Adj WW	19.30**	9.09	2.12	0.036

2021's second model included the use of calving ease EPD, BW EPD, Marb EPD, combined value, and Adj WW. All variables included were significant at the 0.1 level and only CED EPD proved to be insignificant at the 0.05 level. This could be expected with the inclusion of BW EPD and the correlation between the two independent variables. This simple model still accounts for the genetic traits cow-calf operations seek: ease of calving, carcass quality, offspring value, and animal growth measurement. The R-squared decreased again, but slightly,

from 0.2253 to 0.1892. The VIF of the model was calculated at 1.2333, showing little correlation and multicollinearity within the model. This is expected, as none of the remaining variables besides CED EPD and BW EPD had obvious correlation when examining the correlation matrix. The fit of the model calculated an F-significance of 0.0002, showing that the overall model was significant.

Table 4.14. Results of Hedonic Model with Combined Prices and Selected EPDs (2021)

Regression Statistics	
Multiple R	0.4350
R Square	0.1892
Adjusted R Square	0.1530
Variance Inflation Factor	1.23
Standard Error	3648.43
Observations	118

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	5	347902289.6	69580457.92	5.23	<0.001
Residual	112	1490839765	13311069.33		
Total	117	1838742055			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-15991.59***	4629.02	-3.45	0.001
CED EPD	-228.03*	125.52	-1.82	0.072
BW EPD	-973.08**	406.65	-2.39	0.018
Marb EPD	-5010.53***	1691.26	-2.96	0.004
\$C	56.66***	16.26	3.49	0.001
Adj WW	15.45***	5.18	2.98	0.004

The immediate coefficient sign that stuck out was Marb EPD returning a negative coefficient of -5010.53. This result contrasts current industry trends, mentioned previously, is a larger ribeye and frame size with more marbling to try and reach marketing programs like Certified Angus Beef and premiums for carcass quality. The negative coefficient would assume that producers are desiring lower marbling within the ribeye area, measuring a lower quality

carcass. CED EPD and BW EPD showed an expected inverse relationship while combined value and Adj WW showed an expected positive relationship. Combined value is expected to be positive because this variable shows the estimated dollars per head a commercial producer will return from the bull's offspring.

4.3.4 2022 Results

The 2022 analysis included previously included variables and saw the introduction of the \$M index value. This resulted in the 2022 independent variables being CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, Marb EPD, \$M, weaned calf value, beef value, combined value and Adj WW all being used in the first model. The first estimated hedonic model showed only the Legacy Sale dummy and Adj WW being significant variables. This is the first model that needs other considerations within industry trends and producer selection to select included EPDs in the second model. CED EPD, and YW EPD were marginally insignificant at the 0.1 significance level.

Table 4.15. Results of Hedonic Model with Combined Prices and EPDs (2022)

<i>Regression Statistics</i>	
Multiple R	0.6056
R Square	0.3667
Adjusted R Square	0.3024
Variance Inflation Factor	1.58
Standard Error	2481.25
Observations	142

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	13	456342175.4	35103244.26	5.70	<0.001
Residual	128	788044021.8	6156593.92		
Total	141	1244386197			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-14633.13***	4141.51	-3.53	0.001
Legacy Sale Dummy	3694.11***	941.03	3.93	<0.001
CED EPD	133.59	94.51	1.41	0.160
BW EPD	269.16	392.74	0.69	0.494
WW EPD	-172.92	194.15	-0.89	0.375
YW EPD	83.21	60.44	1.38	0.171
Milk EPD	-17.59	152.35	-0.12	0.908
RE EPD	655.67	1585.19	0.41	0.680
Marb EPD	1338.64	1327.03	1.01	0.315
\$M	401.51	731.09	0.55	0.584
\$W	101.66	130.56	0.78	0.438
\$B	508.44	943.45	0.54	0.591
\$C	-393.40	728.00	-0.54	0.590
Adj WW	14.03***	3.74	3.75	<0.001

Based on previous analyses and industry desires, the included variables for a second analysis were the sale dummy variable, CED EPD, YW EPD, Marb EPD, and adjusted yearling weight. This accounts for the three stages of life that are evaluated in the sale catalog, the price difference between the Legacy and Vollmer Angus Ranch cattle, and the carcass measurement. The revised model for the 2022 dataset found four of the five independent variables included to

be statistically significant at the 0.01 confidence level and the last EPD measurement, CED EPD, to be marginally insignificant at this level with a p-value of 0.0199. The R-squared and VIF calculations both decreased, the VIF showing less correlation and the R-squared value showing less explanation using these variables in changes to price change.

Table 4.16. Results of Hedonic Model with Combined Prices and Selected EPDs (2022)

Regression Statistics					
Multiple R	0.5592				
R Square	0.3127				
Adjusted R Square	0.2874				
Variance Inflation Factor	1.45				
Standard Error	2507.79				
Observations	142				

ANOVA					
	df	SS	MS	F	Significance F
Regression	5	389082095.7	77816419.14	12.37	<0.001
Residual	136	855304101.5	6289000.746		
Total	141	1244386197			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-13610.24***	2930.43	-4.64	<0.001
Legacy Sale Dummy	3464.83***	892.84	3.88	<0.001
CED EPD	137.59***	58.38	2.36	<0.001
YW EPD	40.46***	13.99	2.89	<0.001
Marb EPD	1937.00***	675.88	2.87	<0.001
Adj WW	13.77***	3.57	3.86	<0.001

The immediate coefficient sign that stuck out was Marb EPD returning a negative coefficient of -5,010.53. This result contrasts current industry trends, mentioned previously, is a larger ribeye and frame size with more marbling to try and reach marketing programs like Certified Angus Beef and premiums for carcass quality. The negative coefficient would assume that producers are desiring lower marbling within the ribeye area, measuring a lower quality carcass. CED EPD and BW EPD showed an expected inverse relationship while combined value

and Adj WW showed an expected positive relationship. Combined value is expected to be positive because this variable shows the estimated dollars per head a commercial producer will return from the bull's offspring.

4.3.5 2023 Results

Finally, the 2023 year was analyzed with the same common variables as previously used, introducing scrotal circumference measurement and docility EPD as a common variable between the sales. This year also saw adjusted yearling weight included again, which had not been in the sale catalog since 2020. Other variables listed were the sale dummy variable, CED EPD, BW EPD, WW EPD, YW EPD, Milk EPD, RE EPD, Marb EPD, \$M, combined value, and adjusted yearling weight. The first estimated hedonic model showed only the Legacy Sale dummy and Adj WW being significant variables. This is the first model that needs other considerations within industry trends and producer selection to select included EPDs in the second model. CED EPD, and YW EPD were marginally insignificant at the 0.1 significance level. This model, including all variables, showed an R-squared value of 0.4627. Only two variables were statistically significant at the 0.1 level, with three other variables being marginally insignificant at this level.

Table 4.17. Results of Hedonic Model with Combined Prices and EPDs (2023)

Regression Statistics	
Multiple R	0.6803
R Square	0.4627
Adjusted R Square	0.4036
Variance Inflation Factor	1.86
Standard Error	3554.64
Observations	132

ANOVA					
	df	SS	MS	F	Significance F
Regression	13	1284202716	98784824.33	7.82	<0.001
Residual	118	1490982890	12635448.22		
Total	131	2775185606			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-28683.04***	5791.60	-4.95	<0.001
Legacy Sale Dummy	3407.06***	1273.10	2.68	0.009
YR Adj WT	14.32***	2.75	5.20	<0.001
SC	179.93	182.77	0.98	0.327
CED EPD	112.00	150.44	0.74	0.458
BW EPD	-286.87	468.07	-0.61	0.541
WW EPD	-27.77	107.58	-0.26	0.797
YW EPD	99.33	71.36	1.39	0.167
Milk EPD	59.00	57.18	1.03	0.304
RE EPD	2108.33	1648.32	1.28	0.203
Marb EPD	2986.08	2023.22	1.48	0.143
DOC EPD	-8.72	49.70	-0.18	0.861
\$M	19.46	36.96	0.53	0.600
\$C	-34.56	26.12	-1.32	0.188

For the second model, the dummy variable for the sale was included, as well as adjusted yearling weight, CED EPD, Marb EPD, and combined value. One significant variable, YW EPD, was excluded, due to the multicollinearity with adjusted yearling weight, which was selected to be included based on significance and its reintroduction of being listed in both sale catalogs. Docility EPD and scrotal circumference were also included to see what the inclusion of these

variables for the first time does to price in a second model. The adjusted model showed an R-squared value decrease from 0.4036 to 0.3725 and the VIF was still showing little multicollinearity within the entire model, calculated at 1.68. The p-values of the coefficients were split, with three of the seven being significant at the 0.05 level and the other four being insignificant. Scrotal circumference and docility EPD were still not considered significant in the price paid for a bull at the sale. Adjusted yearling weight was the most significant of any variable in the model, explaining why it was listed in the sale catalog again.

Table 4.18. Results of Hedonic Model with Combined Prices and Selected EPDs (2023)

Regression Statistics	
Multiple R	0.6372
R Square	0.4060
Adjusted R Square	0.3725
Variance Inflation Factor	1.68
Standard Error	3645.97
Observations	132

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	7	1126845027	160977861	12.11	<0.001
Residual	124	1648340579	13293069.19		
Total	131	2775185606			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-23905.35***	5490.36	-4.35	<0.001
Legacy Sale Dummy	3639.83***	1275.44	2.85	0.005
CED EPD	176.33**	80.12	2.20	0.030
Marb EPD	528.14	1558.16	0.34	0.735
\$C	15.67	15.26	1.03	0.307
DOC EPD	-1.63	47.72	-0.03	0.973
YR Adj WT	15.32***	2.78	5.51	<0.001
SC	97.95	185.56	0.53	0.599

The signs of the coefficients for the reduced model were largely as expected. The Legacy Sale dummy variable showed a premium compared to Vollmer Angus bulls, CED EPD, Marb

EPD, combined value, adjusted yearling weight, and scrotal circumference all showed positive relationships with the price of the lots sold. All of those EPDs and listed values measure a genetic trait producers desire when making purchasing decisions, representing ease of calving, carcass grade and yield, supply chain value, high selling weight from the cow-calf producer, and fertility measurement, respectively. The only sign that did not make sense, and the variable was not significant, was docility EPD. This shows the adaptability of the animal and its submissive behavior, which would be desired by producers, but shows an inverse relationship with price.

The findings of these models were generally consistent with the results from Simms, Geske, and Bolze, (1994), seeing cattle producers focus their buying decisions on birth weight, weaning weight, yearling weight, and calving ease. Kessler, Pendell, and Enns (2017) found the same indirect relationships as most models in this paper with BW EPD and direct relationship with YW EPD in their first model using order of least squares. SC was used in the 2023 regression, showing a positive coefficient in the model, while Kessler, Pendell, and Enns (2017) had a negative coefficient through all four models used in their paper.

Chapter 5 - Summary, Implications, and Conclusions

5.1 Legacy Sale

Data from the annual Kansas State University Legacy Bull Sale was used to determine the effect EPDs have on the sale price of the Angus bulls the university's purebred unit auctions off each year. Seven years of sale data (2016-2023), were gathered for this research, yielding 128 observations with 22 independent variables. Using all the EPDs given, a hedonic regression was used to observe the statistical significance of certain variables and the model as a whole. A correlation matrix was used to visualize any correlating independent variables and attempt to eliminate any multicollinearity within the model. The desire to retain some variables due to their perceived importance to producers, or a perceived relationship to current industry trends or carcass premiums when purchasing a bull, were strongly considered.

The final calculated hedonic regression returned a model that included the following independent variables: annual dummy variables for years 2016-2022, CED EPD, Marb EPD, ET, and Adj WW. The economic effect these variables have on the final sale price of a bull sold at the Legacy Sale can be estimated from the coefficients calculated and their inherited importance to producers can be determined from the value they add to the sale price. When used to predict the prices bulls would sell for at the 2024 Legacy Sale, the model calculated a \$72.21 premium compared to the actual selling price of the bulls, a less than 5 percent error. The VIF also shows that there is little correlation among the independent variables used in the model. Using this model to estimate future prices should be cautioned, though, as the R-squared value determines that there are other factors outside the dataset that should be observed to more accurately account for variation across lot pricing. This could be combated by increasing the sample size and other physical, visual, and physiological characteristics of the bulls sold at the Legacy Sale.

5.2 Vollmer Angus Ranch

Data was gathered from the operators of Vollmer Angus Ranch and was used to measure how the EPDs listed in their annual catalog changed the price producers were willing to pay for a lot sold at their sales. Five years of data (2019-2023) were used for the analysis, resulting in 556 observations and 13 independent variables. The first model created for the sale used all given variables to determine statistical significance to the price, given all other information. Some variables were eliminated based on multicollinearity and their strong correlation with another variable within the model. Some variables were kept to include industry trends or analyze desired traits from producers.

The second model that was calculated utilized nine variables from the dataset, those being the annual dummy variables (2019-2023), BW EPD, Adj WW, YW EPD, Marb EPD, and RE EPD. The resulting variables showed to all be statistically significant to the price a producer was willing to pay. However, the R-squared of the model is low and shows that other factors outside of this dataset account for a large majority of the variation of the prices lots sell for. The VIF calculation shows little correlation in the model.

5.3 Combined Datasets and Annual Estimates

The previously mentioned bull sales were combined into a larger time-series dataset and a hedonic model was calculated. The larger dataset combining both sales was limited, as nearly half the variables listed in the Legacy Sale catalog were not listed in the Vollmer Angus Ranch catalog. With the Legacy Sale having roughly 20 percent of the observed sold lots over the same period of time, limiting the reduction of data from the Legacy Sale and reducing data from Vollmer Angus was preferred. Once the dataset was complete, a first analysis was run to see which variables may be significant to all lots sold. From there, p-values, a correlation matrix, and

VIF values were used to determine significance and the variables used in a second estimated model.

The second hedonic model included eight independent variables from the previous full set of 12. Most interestingly, the Legacy Sale was not found to see a statistically different price compared to a private auction. The included variables were dummy variables for the year of the sale, BW EPD, WW EPD, Milk EPD, and RE EPD. All variables were statistically significant to the model with a good overall model fit from VIF measure.

Annual models were also run from 2019-2023 to determine which EPDs were significant or insignificant to the price. The resulting calculations showed that EPDs that did not return a significant p-value were often removed from the catalogs for the following years, sometimes returning in later years or being reintroduced in the form of another calculation (i.e., scrotal circumference EPD and scrotal circumference). The results of the annual models show that while a majority of common variables between the sales were significant, there are changes year-to-year of the dollar effect each EPD has on the sale price of a bull.

This research can conclude that each EPD listed is not only valued by livestock producers and seedstock consumers in a different way, but also changes the economic value of a bull based on certain traits. No two producers think the same when buying bulls or using EPDs to measure genetic performance characteristics, which can largely be contributed to a maternal genetic pedigree that must be combined with the bull's genetic traits. EPDs also become more accurate over time, as more data is collected, meaning young bulls who have not sired many offspring only have genetic tests and ultrasound data, whereas older bulls will have offspring EPDs that are calculated and included in their estimations. A second conclusion from the results shows that there is a large range of profit potential from different genetic differences within the Angus

breed. The estimated coefficients of the different variables range from -659.42 to 2,407.57, showing that the change of certain genetic traits greatly impacts the price a bull sells for. Knowing each coefficient, certain traits can be targeted when breeding a herd, emphasizing these high value-added traits, and attempting to maximize their profit potential for each bull. Single trait breeding is strongly discouraged, and a holistic approach should be considered when breeding cattle.

The low R-squared values for all the models could be contributed to the question of whether producers see value in, or trust, EPDs. Much of the variation in the price may not be explained by the listed EPDs and their effect on price because producers are not using those to make their purchasing decisions (Simms, Geske, and Bolze, 1994). This conforms with previous literature on the topic, other factors such as structure, appearance, and temperament (Jones et al., 2008; Parish et al., 2017). The combined analysis attempted to find a price difference paid by the bidders between Legacy Sale bulls and Vollmer Angus Ranch bulls. While the first regression did find a \$462.82 discount for bulls sold at the Legacy Sale, this did not result in a statistically significant coefficient and was not used in the second model. Due to the statistical insignificance, interpretation of this number is cautioned for the overall dataset.

Chapter 6 - Limitations

A major limitation of the research produced is the small sample size of Angus bulls sold for the years collected in the Legacy Sale. Having 128 observations and 22 independent variables in the Legacy Sale data can greatly influence which independent variables are relevant and statistically significant to the overall dataset. Of the observations that were collected, some values were missing for certain EPDs that may have been statistically significant to the sale price of the bull, notably ribeye area EPD. Marketing programs place importance on certain ribeye sizes, meaning that bulls with a ribeye area too small or too large for those programs must yield high carcass grades to increase their value. Another ultrasound measurement that was not included because of a lack of data was the intramuscular fat ratio (IMF ratio). Carcasses are graded from the U.S. Department of Agriculture's Food Safety and Inspection Service between the twelfth and thirteenth rib on the ribeye. Producers may use this ultrasound measurement to determine the premium or discount a producer will receive when sending that animal and future offspring to the beef processor. EPDs listed in sale catalogs have also changed over the course of the dataset available in both the Legacy Sale and in Vollmer Angus Ranch's sale. This leads to some variables being eliminated simply because one variable in 2016 may not have been calculated or listed in 2019 or other years following that catalog. Creating a more consistent EPD listing and available data from ultrasound and genetic testing could reveal more statistically significant variables from what is currently being used in this analysis.

Another limitation to the analysis is the Legacy Sale auctioning a small number of animals off each year, which contributes to the small sample size. The Legacy Sale auctions off roughly 40 bulls each year across three different breeds and holds just one sale each year. Trends in what seedstock producers focus on, what the seedstock consumer wants, and the type of beef

end consumers desire to purchase changes over time, changing the effect certain EPDs have on the sale price of a bull. Using prices from the first Legacy Sale would be little to no help when determining what producers of the 2024 Legacy Sale would consider when purchasing their next bull. Second, narrowing the scope of the research to a specific breed, even Angus, which represents approximately half of the bulls sold each year, reduces the number of observations research can use to determine how EPDs change the price of the bull. EPDs can be adjusted across breeds to estimate how a crossbred animal may perform. Using observations from Hereford and Simmental bulls during the Legacy Sale could be included, converting the EPDs from their breed associations to the Angus index, but this would be difficult to compare purebred bulls of Hereford and Simmental to a private sale of only Angus bulls. Producers see benefits to each breed in their own way. As priorities change over time, collecting relevant data from this specific sale that would yield statistically significant results and accurately predict possible future purchase values becomes more difficult.

The primary goal of this research was to estimate the effect EPDs have on the price seedstock consumers are willing to pay for a bull at auction. The results suggest the EPDs available and used in the regression analysis show little explanation of variation in prices of lots sold. External variables may be included in future studies to determine if they have an impact on prices. Those variables may include land values, cattle market prices, or a dummy variable to determine if the calf crop is in expansion or contraction. These could all justifiably influence the price producers are willing to pay for a bull at auction. A contraction of the national herd may lead producers to use the bulls they already own or start reducing the size of their own herd, putting more bulls on the market, increasing supply, and decreasing prices received for bulls from a low buying power and surplus of quality bulls. Low cattle market prices would show a

lower willingness to pay because they are not in a financial situation to expand. High land values do not allow a producer to expand their operation as easily, requiring more capital to expand the operation and a lower likelihood of buying more bulls for a producer's operation.

Using data from bull sales with more common EPDs may also change the hedonic model estimates. Vollmer Angus Ranch utilized nearly the same EPDs in their catalog for the years data was gathered, whereas the Legacy Sale changed listed EPDs more often. This could be due to the Legacy Sale being the product of Kansas State's Livestock Sales Management class and wanting to focus on a more detailed and strict reporting of EPDs and marketing of cattle. Vollmer Angus Ranch also does not publicly report ultrasound data like the Legacy Sale does, immediately eliminating those variables from the overall regression.

Chapter 7 - Further Research

Further research that could be done on this paper and the dataset gathered would be to survey producers, asking them to rank the EPDs they utilize when deciding which bulls to bid on at a livestock auction and how they determine their maximum bid price for that bull. This survey could show more stated preferences from producers rather than revealed preferences through econometrics and data analysis. Transitioning the survey from a best/worst scaling of EPDs listed in the sale catalog into a choice experiment using the selected EPDs in the previous questions would also show each producer's emphasis on certain EPDs. Having producers explain which EPDs they consider when buying a bull could help increase the predictive accuracy of the model. As with the dataset used, a larger survey sample would help create an even more specific and well-fitted model to the industry, giving more observations for each EPD listed and more variation among the EPD importance. Since the Simms, Geske, and Bolze (1994) survey, index values have been introduced to many sale catalogs, giving producers an estimate of the return value they may see. An emphasis on these values, as well as a higher priority on carcass traits, would be expected when surveying producers.

More data collected from the Legacy Sale would also allow for the other two breeds in the sale to be analyzed. Angus cattle are the most desired breed of cattle in the State of Kansas and the cattle industry, due to their mothering ability and conversion of feed into high-quality meat (Kansas Beef Council, 2024). The Black Angus' marketing in the beef sector and the premiums the carcasses and byproducts can bring have also led to them being the most common breed of registered purebred beef cattle in the United States (AGDAILY Contributors, 2020). These qualities are the reasoning behind the desire to analyze this specific breed. However, some sales are known for having higher quality cattle in one breed or category than the rest, just as

sales with a single breed in all sold lots may be known for having certain high-quality EPDs. With the Special “K” Sale and Legacy Sale’s highest selling bulls both being Herefords, it could be fair to say that high-quality seeking purchasers may not be heading to Manhattan, Kansas, for a prized Angus bull. EPDs are breed-specific calculations that should be evaluated for all major beef breeds in the United States to understand how seedstock consumers within different breeds evaluate and utilize EPDs from their respective associations. Comparisons could also be made from breed to breed by adjusting EPD calculations to one breed, or through crossbreeding, to understand how producers may value certain genetic traits across breeds differently. There are ways to adjust breed specific calculations to a common measurement due to commercial producers crossbreeding in order to use genetic traits one breed is known for, combining with another breed’s genetics, and creating cross-bred offspring. These commercial cattle are not eligible for some of the same marketing programs as purebred counterparts but can still see high-quality premiums and profitable returns from the market.

Kansas either is, or is bordered by, four of the top seven beef calf crop producing states (Oklahoma, Missouri, and Nebraska) in the United States while North Dakota is bordered by two more of the top seven states (South Dakota and Montana). Comparing data from two different states within the same region of the country that supply a large percentage of the nation’s calf crop is comparable. However, comparable industry data in Kansas could also be used to create a model to compare to the Legacy Sale, seeing where producers, possibly some of the same buyers at different sales, might desire certain traits more than the rest of the industry. This could also determine if there is a premium price brought by the bulls sold from the Kansas State University Legacy Bull Sale within the state of Kansas.

Gathering data from other university-sponsored sales could be beneficial in an analysis to further determine if producers nationally see more value in purebred bulls from a university sale compared to a privately-sponsored auction. This premium, if relevant, could be for many reasons. One may assume that producers are willing to pay more because they are an alum of the school, using the bull sale as their way of giving back to the university that helped educate them rather than directly writing a check. Another assumption from this could be the producer's desire to help fund the university's operations and student scholarships, continuing the land-grant mission to educate students in the agricultural sciences and give them the experience of raising and feeding cattle. This possibility should be included in a demographic section of a producer survey.

Chapter 8 - References

- AGDAILY Contributors. (2020, May 2). *Top 10 most popular cattle breeds in the United States*. Retrieved from AGDAILY: <https://www.agdaily.com/livestock/top-10-cattle-breeds-united-states/>
- Angus Genetics Inc. (2024, March 13). *Submitting DNA Samples*. Retrieved from AGI: <https://www.angus.org/AGI/SubmittingSamples>
- Beef Improvement Federation. (2021, April 13). *Yearling Weight*. Retrieved from BIF Guidelines: https://guidelines.beefimprovement.org/index.php/Yearling_Weight#Adjusted_Value
- BEEF Magazine. (2022, May 12). *2022 BEEF Seedstock 100*. Retrieved from <https://www.beefmagazine.com/cattle-market-outlook/2022-beef-seedstock-100>
- Bormann, J. M. (2010). Data Collection and Interpretation. In *Beef Sire Selection Manual* (pp. 21-23).
- Bullock, D., Decker, J., Rolf, M., Spangler, M., Eennaam, A., & Weaber, R. (2015). EPD Basics and Definitions. (3), 1-6. Retrieved March 25, 2023
- Certified Angus Beef. (2024, March 12). *Our 10 Specifications for Quality*. Retrieved from Certified Angus Beef: <https://www.certifiedangusbeef.com/brand/specs.php>
- Felix, T. L., & Freitas, T. B. (2023). Understanding EPDs and Genomic Testing in Beef Cattle. *Penn State Extension*, 1-8. Retrieved April 4, 2023
- Gould, K. (2015, August 31). *Calculating calf-adjusted weaning weights and herd indexes*. Retrieved from Michigan State University Extension: https://www.canr.msu.edu/news/calculating_calf_adjusted_weaning_weights_and_herd_indexes
- Hazel, L. N. (1943, May 27). The Genetic Basis for Constructing Selection Indexes. *Iowa Agricultural Experiment Station*, 476-490.
- Jones, R., Turner, T., Dhuyvetter, K. V., & Marsh, T. L. (2008, April). Estimating the Economic Value of Specific Characteristics Associated with Angus Bulls Sold At Auction. *Journal of Agricultural and Applied Economics*, 40(1), 315-333.
- Kansas Beef Council. (2024, March 3). *Popular Breeds of Cattle*. Retrieved from Kansas Beef: <https://www.kansasbeef.org/popular-breeds-of-cattle/>
- Kansas State University Department of Animal Sciences and Industry. (2022, September 21). *Special "K" Edition History*. Retrieved from <https://www.asi.k-state.edu/about/facilities/purebredbeefunit/history.html>

- Kansas State University Department of Animal Sciences and Industry. (2023, October 13). *Purebred Beef Unit*. Retrieved from <https://www.asi.k-state.edu/about/facilities/purebredbeefunit/>
- Kansas State University Department of Animal Sciences and Industry. (2023). *The 46th Annual Bull & Female Sale*. Manhattan, Kansas.
- Kansas State University Department of Animal Sciences and Industry. (2024, March 1). *The Legacy Sale*. Retrieved from <https://www.asi.k-state.edu/about/services/legacy/>
- Karisch, B., & Parish, J. A. (2022). *Embryo Transfer in the Beef Herd*. Mississippi State University, Animal and Dairy Science. Starkville: Mississippi State University Extension.
- Kessler, B. A., Pendell, D. L., & Enns, R. M. (2017). Hedonic prices of yearling bulls: Estimating the value of a pulmonary arterial pressure score. *American Registry of Professional Animal Scientists*, 113-119.
- Kriese-Anderson, L., & Dolezal, S. (1999, March 1). The ABC's of EPDs. *BEEF Magazine*. Retrieved April 12, 2023, from https://www.beefmagazine.com/mag/beef_abcs_epds
- Lewis, K. (2020). *Bull Selection Using Expected Progeny Differences (EPDs)*. Glacier County: Montana State University Extension.
- Livestock Marketing Information Center. (2024, February 29). *Calculated Beef Calf Crop 2023*. Retrieved from Livestock Marketing Information Center.
- MacNeil, M. D., & Herring, W. O. (2005). Economic Evaluation of Genetic Differences Among Angus Bulls. *Western Section American Society of Animal Science*, 56, 87-90.
- Parish, J. A., Williams, B. R., Coatney, K. T., Best, T. F., & Stewart, C. O. (2017). A hedonic analysis of sale lot traits affecting. *The Professional Animal Scientist*(34), 240-249.
- Simms, D. D., Geske, J. M., & Bolze, J. M. (1994). *Commercial cattle producers: bull selection criteria*. Kansas State University. Manhattan: Kansas Agricultural Experiment Station Research Reports.
- Vanek, J. K., Watts, M. J., & Brester, G. W. (2008). Carcass quality and genetic selection in the beef industry. *Journal of Agriculture and Resource Economics*(3), 349-363.
- Vollmer Angus. (2024). *Vollmer Angus Ranch--About Us*. Retrieved from Vollmer Angus: <http://www.vollmerangus.com/about-us>
- Vollmer Angus Ranch. (2023). *Vollmer Angus Ranch's 46th Production Sale*. Wing, North Dakota: The Cattle Business Weekly.

Appendix A - 2020 Vollmer Angus Ranch EPD Percentile Rankings

Genomic Percentile Ranks

LOT	CED	BW	WW	YW	DMI	YH	SC	DOC	HP	CEM	MILK	MW	MH	CW	MARB	RE	FAT	TEND
1	9	10	5	11	25	32	68	54	50	91	4	55	14	8	28	7	33	95
2	45	45	30	66	73	85	77	20	32	50	50	88	87	50	33	62	69	30
3	17	21	2	2	78	45	1	8	29	12	26	86	82	2	50	8	61	23
4	35	69	2	2	80	48	41	36	97	11	30	20	14	3	16	19	46	77
5	55	40	20	19	82	77	78	40	99	30	93	36	23	39	16	35	16	94
6	76	95	2	4	96	36	17	1	7	60	17	9	11	1	41	19	89	57
7	35	35	4	3	86	25	30	8	20	43	25	74	47	7	52	28	67	11
8	27	38	19	15	17	46	37	2	60	8	17	91	87	11	63	19	86	85
9	35	31	66	69	21	72	73	3	7	8	61	69	29	40	40	50	51	23
10	31	35	26	22	95	34	10	22	76	84	63	26	28	48	53	21	76	68
11	24	27	47	16	78	70	95	27	30	15	67	70	76	54	81	49	84	45
12	36	24	9	16	93	81	80	10	82	85	76	27	24	10	73	28	50	52
13	32	42	14	4	36	42	79	68	50	76	59	5	12	4	52	4	12	63
14	48	66	30	32	27	27	40	17	35	49	41	51	69	39	80	22	48	51
15	82	98	3	32	70	5	15	6	19	54	22	19	5	1	21	29	59	9
16	15	7	73	83	32	79	69	50	40	45	76	35	59	87	36	99	100	33
17	68	65	3	3	51	31	65	8	35	33	41	75	78	3	21	14	36	77
18	23	50	14	20	90	55	23	39	53	69	51	12	9	21	64	41	70	75
19	6	25	22	48	39	89	43	8	91	67	73	45	40	41	62	2	17	98
20	72	83	12	23	41	5	52	55	51	74	28	52	12	5	59	22	28	10
21	23	70	26	26	55	63	76	19	80	82	66	8	24	24	26	11	42	66
22	78	80	1	5	74	20	78	13	91	64	47	24	28	1	40	24	27	98
23	11	4	44	65	54	99	59	45	56	64	26	73	66	61	66	36	25	23
24	36	49	68	51	18	85	54	51	56	60	88	54	51	82	73	29	49	54
25	29	51	36	28	64	48	87	91	97	35	81	8	11	22	53	12	6	47
26	9	21	18	38	10	12	84	69	47	71	33	37	31	18	38	64	85	94
27	46	38	11	15	55	24	86	7	47	65	54	11	16	13	55	16	33	79
28	86	91	8	12	19	12	73	22	69	46	22	14	15	19	64	8	57	63
29	53	75	51	41	37	13	64	4	37	6	27	19	17	50	45	72	48	83
30	100	99	4	6	73	10	43	7	5	7	73	7	6	8	65	48	21	47
31	71	81	8	11	83	9	84	43	67	38	11	71	55	2	69	49	42	67
32	90	76	10	23	39	10	83	49	50	35	6	58	28	1	55	73	96	19
33	76	89	36	6	35	10	22	34	69	33	34	40	20	13	18	18	38	19
34	23	51	5	3	81	3	8	5	45	81	1	42	9	15	18	56	80	36
35	34	65	40	18	75	8	12	23	88	43	22	34	41	58	56	77	84	28
36	37	47	43	4	72	35	5	1	74	87	4	63	28	22	40	62	81	59
37	71	60	54	62	17	3	72	19	57	76	84	16	20	64	80	64	29	44
38	82	79	8	31	3	10	21	37	36	17	68	10	7	18	44	32	56	18
39	51	56	21	38	53	86	87	84	90	95	42	39	73	27	38	36	79	74
40	51	46	20	52	32	50	23	9	64	61	29	51	77	22	55	17	21	99
41	36	62	3	8	37	56	46	30	24	94	99	6	4	7	60	4	5	77
42	51	55	17	11	43	25	27	5	11	31	33	23	13	12	72	30	49	13
43	71	89	26	8	85	50	71	40	83	81	67	22	24	28	92	3	4	35
44	22	64	22	20	61	50	53	46	62	84	37	15	10	17	37	40	87	57
45	24	13	48	75	44	86	53	12	2	85	52	87	96	83	32	96	68	63
46	10	6	66	51	90	86	6	17	13	81	58	11	17	92	32	73	93	32
47	70	69	2	5	76	6	6	2	66	43	76	1	1	2	77	26	38	39
48	74	66	2	3	98	40	43	17	85	81	86	8	32	1	68	23	68	37
49	61	61	67	85	43	74	21	2	27	14	23	70	33	86	45	69	60	85
50	90	90	34	45	73	42	55	31	83	70	49	47	71	3	56	62	91	19
51	66	71	34	36	58	33	67	39	40	51	23	41	53	36	53	40	38	9
52	13	48	31	12	98	51	3	4	36	46	51	41	66	13	40	57	70	93
53	65	73	93	85	40	77	83	28	30	23	88	45	43	98	48	92	35	16
54	91	90	28	6	51	7	18	1	90	81	3	40	21	10	70	16	40	59
55	76	76	51	13	6	70	67	15	19	75	80	53	64	53	33	93	22	27

Bull videos available at vollmerangus.com or DVauction.com.

LOT	CED	BW	WW	YW	DMI	YH	SC	DOC	HP	CEM	MILK	MW	MH	CW	MARB	RE	FAT	TEND
56	16	14	14	5	73	58	1	1	52	21	27	88	81	16	11	37	96	56
57	84	93	14	1	82	16	7	4	91	63	22	17	58	3	22	13	42	67
58	73	71	5	38	65	35	39	38	78	77	48	25	53	22	66	31	44	96
59	82	70	17	9	71	53	40	61	71	81	61	27	39	15	38	16	23	51
60	93	88	2	15	86	44	12	52	85	10	76	36	51	17	27	20	18	85
61	13	26	37	36	70	16	68	16	44	68	64	6	9	20	26	17	63	64
62	18	22	4	9	34	78	45	50	67	9	94	77	48	13	51	61	97	10
63	56	34	34	28	33	92	19	40	45	64	33	55	43	45	78	58	72	23
64	29	28	24	21	66	47	22	62	80	60	33	66	51	14	79	14	43	59
65	20	61	8	2	48	39	4	1	32	67	26	30	21	8	34	18	17	71
66	64	42	21	4	40	11	2	2	64	15	20	8	5	10	75	17	35	39
67	42	40	85	51	82	47	39	28	5	2	32	19	46	62	35	70	46	60
68	86	56	73	74	43	49	88	43	79	71	83	66	50	65	89	43	28	37
69	8	8	33	15	56	74	86	28	41	83	8	38	50	35	19	8	33	93
70	41	47	53	53	50	60	14	74	71	44	19	80	39	46	40	43	87	8
71	23	44	39	34	76	27	6	46	2	50	29	31	31	30	46	61	48	83
72	97	97	21	62	90	66	91	34	87	42	96	85	66	64	95	54	60	60
73	66	85	19	26	90	71	34	23	88	88	49	88	91	12	87	23	26	40
74	83	58	38	65	35	91	45	93	27	48	47	60	47	76	46	43	68	50
75	80	96	12	11	56	11	1	4	60	72	35	21	12	4	55	48	53	92
76	69	47	32	43	80	96	68	33	3	52	20	47	56	33	44	14	48	72
77	70	79	16	20	82	26	44	18	13	68	6	52	38	19	79	11	33	73
78	25	55	32	30	95	96	13	8	80	38	82	85	93	52	89	46	36	37
79	62	71	84	77	44	19	29	49	62	44	60	15	31	69	88	35	30	6
80	56	65	20	5	92	88	16	21	24	34	49	51	77	14	42	61	69	14
81	56	60	15	24	8	61	69	90	18	66	86	36	30	26	67	28	69	83
82	92	97	56	61	51	62	73	89	78	75	65	71	69	85	73	43	5	8
83	98	97	1	18	68	45	8	1	33	6	21	5	9	5	32	20	32	60
84	18	6	45	63	66	95	65	56	87	20	74	65	59	73	23	83	93	50
85	29	12	47	37	80	98	72	19	39	83	65	90	96	47	20	31	55	89
86	51	36	65	59	38	59	27	98	33	51	80	37	58	77	60	37	13	55
87	80	60	5	17	87	29	32	42	39	9	28	9	12	22	48	46	48	61
88	7	7	74	38	89	67	15	15	77	68	17	60	36	68	8	49	89	91
89	59	24	51	53	90	97	63	15	29	78	87	63	76	42	84	34	81	33
90	64	51	47	29	83	100	72	44	90	65	89	19	43	36	68	20	52	60
91	89	84	23	8	47	2	64	5	80	12	38	1	1	31	67	90	35	84
92	43	69	7	4	60	75	57	2	40	82	61	46	30	5	85	23	51	14
93	40	50	13	29	93	29	17	1	29	31	30	71	58	38	5	45	64	33
94	9	5	53	87	90	93	27	3	63	51	88	48	80	91	82	47	66	71
95	76	82	26	43	90	69	42	79	67	56	57	23	72	19	92	85	99	50
96	24	40	6	5	91	82	6	2	47	53	1	63	56	10	24	5	54	8
97	87	64	39	24	90	99	35	76	59	69	60	19	36	27	61	12	30	18
98	60	35	25	23	81	71	94	36	82	38	13	64	71	50	25	30	83	81
99	59	74	14	32	88	86	94	78	50	29	79	38	62	34	37	63	97	6
100	36	32	11	21	53	85	35	51	41	5	56	62	71	25	58	13	21	25
101	39	35	38	77	37	96	68	97	91	17	48	75	65	68	15	62	77	83
102	55	46	11	30	90	98	3	35	70	86	59	56	76	49	70	21	51	38
103	28	61	24	24	89	9	14	3	49	50	69	1	7	24	51	79	52	23
104	17	14	73	71	17	68	93	44	52	83	20	89	80	56	56	55	79	69
105	36	65	56	76	56	94	27	5	28	35	85	36	58	70	94	77	76	22
106	42	25	27	19	45	55	44	74	46	56	52	57	61	16	54	23	63	11
107	24	44	46	31	53	46	2	4	24	69	13	60	71	36	49	19	68	12
108	56	65	56	50	94	59	1	3	57	19	7	51	51	44	42	22	61	32
109	28	21	47	10	73	62	10	14	7	65	38	75	75	48	25	21	44	83
110	9	4	23	34	65	86	20	56	27	18	55	21	39	41	19	88	96	66
111	1	3	72	63	76	97	1	42	58	30	15	97	100	82	50	43	98	18
112	66	56	31	25	74	43	54	40	89	54	29	36	46	8	27	16	17	89
113	70	36	34	48	72	63	63	81	29	68	33	51	48	37	47	40	90	1
114	98	97	59	47	38	54	68	15	77	99	90	56	75	75	100	14	3	61
115	85	74	25	53	70	57	64	59	36	69	30	41	33	26	93	58	73	30
116	78	96	6	5	82	7	3	2	88	84	12	46	19	9	19	78	99	56
117	49	40	61	72	43	61	51	38	45	41	37	88	97	53	86	70	93	65

Source: (Vollmer Angus Ranch, 2020)

Appendix B - Legacy Sale Summary Statistics

Legacy Sale Summary Statistics																		
	Adj	WW	ET	\$B	\$G	\$F	\$W	Marb	RE	Milk	CEM	YW	EPD	WW	BW	CED	Picture in	Price
								EPD	EPD	EPD	EPD	EPD	EPD	EPD	EPD	EPD	Catalog	
Mean	614.34	0.48	136.72	47.84	73.33	64.97	0.75	0.65	26.25	9.48	111.09	63.45	0.71	8.51	0.30		0.30	4255.86
Standard Error	6.22	0.04	2.99	1.87	2.23	1.24	0.04	0.02	0.42	0.32	1.86	1.12	0.14	0.37	0.04		0.04	173.82
Median	615.5	0	132.82	42	69.85	64.965	0.67	0.7	26	10	109	62	0.65	8	0		0	3600
Mode	588	0	171	30	64.89	61.58	0.46	0.7	25	8	109	61	0.6	8	0		0	2250
Std Dev	70.38	0.50	33.86	21.20	25.24	14.04	0.41	0.26	4.77	3.59	21.04	12.66	1.54	4.13	0.46		0.46	1966.54
Sample Variance	4953.52	0.25	1146.28	449.24	637.13	197.22	0.17	0.07	22.72	12.87	442.57	160.22	2.38	17.07	0.21		0.21	3867268.55
Kurtosis	-0.39	-2.02	-0.11	0.41	0.23	-0.58	0.23	-0.63	0.33	-0.26	-0.27	-0.03	-0.16	0.02	-1.28		-1.28	0.24
Skewness	-0.11	0.09	0.40	1.07	0.25	0.05	0.58	-0.20	0.03	-0.18	0.52	0.51	0.15	-0.15	0.86		0.86	1.04
Range	349	1	186.82	93.07	137.79	64.94	2.07	1.26	24	17	90	63	7.1	21	1		1	7500
Minimum	445	0	44.18	11.93	9.21	30.06	-0.21	0.02	14	1	71	32	-2.9	-2	0		0	2000
Maximum	794	1	231	105	147	95	1.86	1.28	38	18	161	95	4.2	19	1		1	9500
Sum	78636	61	17500.1	6123.9	9386.8	8316.3	95.53	82.8	3360	1214	14219	8121	91.4	1089	39		39	544750
Count	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128		128	128

Appendix C - Vollmer Angus Ranch Summary Statistics

Vollmer Angus Ranch Summary Statistics														
Milk EPD	WN EPD	Birth Wt	CED EPD	RE EPD	Marb EPD	YW EPD	Adj WW EPD	BW EPD	2019 Dummy	2020 Dummy	2021 Dummy	2022 Dummy	Purchase Price	
Mean	26.14	71.79	80.49	5.88	0.65	0.61	125.93	812.02	1.60	0.19	0.20	0.19	0.22	4903.15
Standard Error	0.25	0.43	0.22	0.19	0.01	0.01	0.74	2.44	0.06	0.02	0.02	0.02	0.02	149.11
Median	26	72	81	6	0.64	0.6	125	820	1.6	0	0	0	0	4000
Mode	24	72	78	6	0.57	0.67	125	843	0.9	0	0	0	0	4000
Std Dev	6.01	10.13	5.10	4.48	0.21	0.27	17.47	57.54	1.50	0.39	0.40	0.39	0.42	3515.97
Sample Variance	36.11	102.68	26.03	20.05	0.04	0.07	305.14	3310.68	2.24	0.15	0.16	0.15	0.17	12362012.60
Kurtosis	0.42	0.01	0.14	-0.32	0.08	-0.36	0.15	0.28	-0.13	0.64	0.31	0.59	-0.22	56.16
Skewness	0.19	0.07	-0.44	-0.24	0.27	-0.10	0.05	-0.55	0.04	1.62	1.52	1.61	1.33	5.87
Range	42	65	29	26	1.33	1.55	122	358	8.5	1	1	1	1	45400
Minimum	9	43	64	-9	0.11	-0.21	65	596	-2.4	0	0	0	0	1600
Maximum	51	108	93	17	1.44	1.34	187	954	6.1	1	1	1	1	47000
Sum	14532	39913	44754	3272	363.72	336.6	70018	451482	890	103	110	104	124	2726150
Count	556	556	556	556	556	556	556	556	556	556	556	556	556	556

Appendix D - Combined Summary Statistics

Combined Data Summary Statistics													
	Marb	RE	Milk	YW	WW	BW	CED	2019	2020	2021	2022	Legacy	Price
	EPD	EPD	EPD	EPD	EPD	EPD	EPD	Dummy	Dummy	Dummy	Dummy	Dummy	
Mean	0.63	0.66	26.15	125.41	71.56	1.51	6.14	0.19	0.19	0.19	0.23	0.03	4903.98
Standard Error	0.01	0.01	0.24	0.71	0.42	0.06	0.18	0.02	0.02	0.02	0.02	0.01	135.24
Median	0.61	0.64	26	125	71	1.4	6	0	0	0	0	0	4000
Mode	0.57	0.62	24	125	68	0.6	6	0	0	0	0	0	4000
Std Dev	0.31	0.22	5.96	17.91	10.44	1.53	4.51	0.39	0.39	0.39	0.42	0.16	3389
Sample Variance	0.10	0.05	35.49	320.92	108.97	2.35	20.38	0.15	0.15	0.15	0.18	0.03	11485327.03
Kurtosis	0.78	0.04	0.35	0.05	0.03	-0.23	-0.29	0.61	0.57	0.61	-0.33	32.23	57.63
Skewness	0.40	0.15	0.15	0.02	0.03	0.05	-0.23	1.62	1.60	1.62	1.29	5.84	5.82
Range	2.07	1.42	42	122	67	8.5	28	1	1	1	1	1	45400
Minimum	-0.21	0.02	9	65	41	-2.4	-9	0	0	0	0	0	1600
Maximum	1.86	1.44	51	187	108	6.1	19	1	1	1	1	1	47000
Sum	395.8	411.6	16421	78755	44941	948	3854	117	118	117	144	17	3079700
Count	628	628	628	628	628	628	628	628	628	628	628	628	628

Appendix E - 2019 Summary Statistics

2019 Summary Statistics

	<i>Adj WW</i>	<i>\$B</i>	<i>\$W</i>	<i>DOC</i> <i>EPD</i>	<i>Marb</i> <i>EPD</i>	<i>RE</i> <i>EPD</i>	<i>Milk</i> <i>EPD</i>	<i>SC</i> <i>EPD</i>	<i>YW</i> <i>EPD</i>	<i>WW</i> <i>EPD</i>	<i>BW</i> <i>EPD</i>	<i>CED</i> <i>EPD</i>	<i>Legacy</i> <i>Dummy</i>	<i>Price</i>
Mean	803.50	132.28	65.23	18.55	0.46	0.62	25.85	0.91	114.58	65.74	1.61	6.15	0.12	4222.22
Standard Error	8.02	2.28	0.98	0.66	0.03	0.02	0.59	0.06	1.53	0.85	0.15	0.44	0.03	158.91
Median	825	134.43	64.88	18	0.44	0.62	26	0.91	113	66	1.6	6	0	3750
Mode	854	#N/A	#N/A	13	0.53	0.62	24	0.07	112	68	1.9	12	0	2750
Std Dev	86.72	24.65	10.55	7.16	0.31	0.19	6.35	0.61	16.52	9.22	1.57	4.77	0.33	1718.87
Sample Variance	7520.30	607.69	111.34	51.27	0.09	0.04	40.31	0.38	272.94	84.94	2.48	22.71	0.11	2954501.92
Kurtosis	1.95	-0.06	-0.64	0.23	1.56	-0.51	1.07	-0.24	0.23	0.06	-0.47	-0.66	3.70	1.15
Skewness	-1.50	-0.34	-0.06	0.28	0.82	-0.04	0.49	-0.02	0.01	-0.01	0.15	-0.36	2.37	1.25
Range	428	117.73	48.51	39	1.88	0.88	38	3.12	94	45	7.8	21	1	7500
Minimum	526	64.47	40.49	2	-0.16	0.11	13	-0.44	65	43	-2.3	-6	0	2000
Maximum	954	182.2	89	41	1.72	0.99	51	2.68	159	88	5.5	15	1	9500
Sum	94009	15477	7632.1	2170	53.65	72.1	3025	106.97	13406	7691	189	719	14	494000
Count	117	117	117	117	117	117	117	117	117	117	117	117	117	117

Appendix F - 2020 Summary Statistics

2020 Summary Statistics												
	<i>Adj WW</i>	<i>\$B</i>	<i>Marb EPD</i>	<i>RE EPD</i>	<i>Milk EPD</i>	<i>YW EPD</i>	<i>WW EPD</i>	<i>BW EPD</i>	<i>CED EPD</i>	<i>Adj YW</i>	<i>Legacy Dummy</i>	<i>Price</i>
Mean	747.08	146.90	0.56	0.67	26.19	120.89	68.85	1.71	5.84	1335.04	0.07	3871.61
Standard Error	4.93	2.37	0.02	0.02	0.52	1.43	0.83	0.16	0.48	6.98	0.02	169.99
Median	744	147	0.56	0.68	26	120.50	68	1.60	6.5	1342	0	3500
Mode	716	135	0.43	0.68	24	120	68	1.60	9	1414	0	2500
Std Dev	53.60	25.71	0.24	0.20	5.64	15.54	9.04	1.72	5.17	75.85	0.25	1846.53
Sample Variance	2872.69	660.90	0.06	0.04	31.85	241.45	81.79	2.96	26.75	5753.31	0.06	3409678.58
Kurtosis	0.65	-0.52	0.05	0.02	0.24	-0.28	-0.15	-0.40	-0.20	6.23	10.30	5.55
Skewness	-0.30	0.07	0.02	-0.06	0.04	0.01	-0.21	0.00	-0.21	-1.56	3.48	1.95
Range	273	129	1.26	1.06	30	82	48	8.10	28	544	1	10250
Minimum	588	75	-0.06	0.12	12	78	43	-2	-9	934	0	1750
Maximum	861	204	1.20	1.18	42	160	91	6.10	19	1478	1	12000
Sum	88155	17334	66.07	79.5	3090	14265	8124	202	689	157535	8	456850
Count	118	118	118	118	118	118	118	118	118	118	118	118

Appendix G - 2021 Summary Statistics

2021 Summary Statistics

	<i>Adj WW</i>	<i>\$C</i>	<i>\$B</i>	<i>Marb</i> <i>EPD</i>	<i>RE</i> <i>EPD</i>	<i>Milk</i> <i>EPD</i>	<i>SC EPD</i>	<i>YW EPD</i>	<i>WW</i> <i>EPD</i>	<i>BW</i> <i>EPD</i>	<i>CED</i> <i>EPD</i>	<i>Legacy</i> <i>Dummy</i>	<i>Price</i>
Mean	815.74	248.20	144.86	0.66	0.68	24.64	0.98	125.35	70.82	1.47	6.56	0.11	4438.56
Standard Error	6.31	2.86	2.07	0.03	0.02	0.56	0.05	1.52	0.95	0.14	0.43	0.03	364.94
Median	838	251	146.50	0.68	0.69	25	0.94	124.50	70.50	1.30	7	0	3750
Mode	850	254	135	0.45	0.70	24	0.85	123	66	0.80	11	0	3500
Std Dev	68.56	31.12	22.44	0.28	0.21	6.08	0.59	16.48	10.32	1.51	4.70	0.31	3964.31
Sample Variance	4701.15	968.20	503.39	0.08	0.05	37.00	0.35	271.48	106.59	2.27	22.06	0.10	15715744.06
Kurtosis	2.03	-0.56	-0.54	0.12	0.17	-0.05	0.37	1.57	0.88	-0.38	-0.35	4.44	57.31
Skewness	-1.41	-0.23	-0.22	-0.48	0.05	-0.11	0.13	0.01	0.11	0.01	-0.28	2.52	6.86
Range	351	140	108	1.48	1.23	29	3.32	115	64	7.50	24	1	38250
Minimum	559	169	88	-0.21	0.02	9	-0.59	72	41	-2.40	-7	0	1750
Maximum	910	309	196	1.27	1.25	38	2.73	187	105	5.10	17	1	40000
Sum	96257	29288	17093	77.91	80	2908	115.1	14791	8357	173.70	774	13	523750
Count	118	118	118	118	118	118	118	118	118	118	118	118	118

Appendix H - 2022 Summary Statistics

2022 Summary Statistics

	<i>Adj WW</i>	<i>\$C</i>	<i>\$B</i>	<i>\$W</i>	<i>\$M</i>	<i>Marb</i> <i>EPD</i>	<i>RE</i> <i>EPD</i>	<i>Milk</i> <i>EPD</i>	<i>YW</i> <i>EPD</i>	<i>WW</i> <i>EPD</i>	<i>BW</i> <i>EPD</i>	<i>CED</i> <i>EPD</i>	<i>Legacy</i> <i>Dummy</i>	<i>Price</i>
Mean	791.69	257.63	146.77	76.58	67.27	0.67	0.62	26.43	129.13	73.54	1.49	5.89	0.14	5109.86
Standard Error	7.41	3.23	2.17	0.90	1.17	0.03	0.02	0.45	1.41	0.84	0.12	0.33	0.03	249.30
Median	810	257	145	76	67	0.65	0.61	26	129	73.50	1.35	6	0	4750
Mode	856	260	134	80	60	0.52	0.65	27	122	77	1.3	6	0	4750
Std Dev	88.30	38.51	25.84	10.73	13.98	0.34	0.21	5.35	16.86	9.96	1.39	3.90	0.35	2970.76
Sample Variance	7797.59	1483.13	667.78	115.15	195.56	0.11	0.04	28.63	284.19	99.19	1.93	15.22	0.12	8825434.02
Kurtosis	0.07	-0.14	0.40	0.22	-0.52	1.92	0.14	0.07	-0.34	-0.14	-0.04	-0.24	2.39	9.41
Skewness	-0.83	0.23	0.30	-0.07	-0.17	0.96	0.22	0.32	-0.04	-0.08	0.00	-0.18	2.09	2.44
Range	420	194	155	62	65	2.07	1.18	26	85	53	7.40	20	1	20400
Minimum	530	170	76	47	35	-0.21	0.10	15	83	43	-2.10	-6	0	1600
Maximum	950	364	231	109	100	1.86	1.28	41	168	96	5.30	14	1	22000
Sum	112420	36584	20841	10874	9552	94.94	87.8	3753	18337	10442	211.90	837	20	725600
Count	142	142	142	142	142	142	142	142	142	142	142	142	142	142

Appendix I - 2023 Summary Statistics

2023 Summary Statistics

	\$C	\$M	DOC EPD	Marb EPD	RE EPD	Milk EPD	YW EPD	WW EPD	BW EPD	CED EPD	SC	YR Adj WT	Legacy Dummy	Price
Mean	271.92	74.85	19.61	0.77	0.70	27.45	135.07	77.73	1.30	6.24	36.91	1351.51	0.13	6621.21
Standard Error	2.58	1.07	0.64	0.03	0.02	0.53	1.50	0.83	0.13	0.36	0.22	16.86	0.03	400.61
Median	274	76	20	0.755	0.7	27	136.5	78	1.35	6	37	1334	0	5250
Mode	274	76	24	0.73	0.93	25	141	82	0.9	5	37	1378	0	4000
Std Dev	29.62	12.29	7.39	0.30	0.24	6.14	17.27	9.55	1.48	4.12	2.50	193.68	0.34	4602.68
Sample Variance	877.62	151.15	54.61	0.09	0.06	37.73	298.14	91.22	2.18	16.95	6.26	37512.48	0.11	21184622.95
Kurtosis	-0.67	0.10	-0.04	0.05	-0.04	0.17	-0.27	-0.29	0.02	-0.39	0.48	2.94	3.07	45.29
Skewness	0.10	-0.27	-0.29	0.15	0.21	0.04	-0.04	0.02	-0.10	-0.05	0.75	1.18	2.24	5.59
Range	135	63	37	1.52	1.27	32	91	50	7.30	19	12	1213	1	44250
Minimum	212	41	-1	0.03	0.17	11	94	58	-2.30	-3	32	887	0	2750
Maximum	347	104	36	1.55	1.44	43	185	108	5	16	44	2100	1	47000
Sum	35893	9880	2588	102.2	92.1	3624	17829	10260	171.20	824	4872.50	178399	17	874000
Count	132	132	132	132	132	132	132	132	132	132	132	132	132	132