THESIS

HEDONIC ANALYSIS OF YEARLING BULL PRICES FOR A LAND GRANT UNIVERSITY: DETERMINING THE VALUE OF A PULMONARY ARTERIAL PRESSURE (PAP) SCORE

Submitted by

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ABSTRACT

HEDONIC ANALYSIS OF YEARLING BULL PRICES FOR A LAND GRANT UNIVERSITY: DETERMINING THE VALUE OF A PULMONARY ARTERIAL PRESSURE (PAP) SCORE

Producers look for various traits in seedstock bulls to enhance their herds and will often pay a premium for those traits. One particular physical trait which is of interest to producers in the mountainous western United States is for cattle that can thrive at a high altitude. Cattle in this environment can be prone to developing High Altitude Disease (HAD) which has been shown to cause weakness, lethargy, and death. Pulmonary Arterial Pressure (PAP) is a test used to detect the likelihood of an animal of developing HAD. The test provides a score from 30 to 130 with scores over 45 indicating an animal is more likely to develop the disease.

Colorado State University specializes in cattle genetics; and in particular, manages a herd that has low PAP scores, strong early growth, fertility, and maternal ability. The center holds an annual auction to sell their yearling bulls each spring. Data was collected from three years of sales (2011, 2012, and 2013), and hedonic models were estimated using ordinary least squares (OLS) to determine the value of simple performance measurements (SPM), expected progeny differences (EPD), and marketing factors of the yearling bulls sold at these auctions.

In one model, a continuous variable for PAP score was found to be significant and have a negative relationship with sale price. In a second model, a dummy variable for a PAP score under 46 was shown to be significant and have a positive relationship with sale price. In a third model using standardized continuous variables, PAP score was shown to have the most influence on sales price, followed by EPD for yearling weight, frame score, and EPD for stayability. The results suggest that producers are willing to pay a premium for a low PAP score.

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DEDICATION

This is dedicated to my sister, Anita, who was always there with love and support. I miss you.

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Chapter 1 - Introduction

Background on the Beef Industry

Cattle were first introduced to the Western Hemisphere in 1493 when Christopher Columbus unloaded a small herd in Hispaniola. About 30 years later, offspring of that herd were transported to Mexico by Hernando Cortez. Over several decades, many of those cattle wandered from Mexico up to Texas and California. In addition, each new batch of settlers brought small numbers of cattle with them from Spain, Portugal and England (Ball, 1998). This was the beginning of what is now the multibillion dollar beef cattle industry in the United States.

Beef production is a key industry in the United States with 2012 production levels at 25.9 billion pounds (commercial carcass weight) which translates to $62.9 billion in total cash receipts (USDA NASS, 2013). In addition, 2011 exports of beef and veal totaled 2.5 billion pounds valued at $5.4 billion with Colorado contributing $263.7 million. This ranks fourth among all states in exporting fresh and frozen beef. The USDA NASS Colorado Field Office reported that 2012 cash receipts for cattle and calves totaled $3.7 billion in Colorado which accounted for more than 50% of total agricultural commodity cash receipts in the state. The percentage is even greater in Wyoming, where 69.3% of all agricultural cash receipts are attributed to cattle and calves (USDA NASS, 2013). These numbers suggest that the beef cattle industry is a vital part of the agricultural industry in Colorado and Wyoming.

Contrary to the term "beef cattle industry," it is not one large industry with one set of management practices but is instead comprised of several segments, each with its own set of problems and concerns (Field, 2007). The supply chain consists of the seedstock breeders, cow-calf operators, yearling-stockers, feedlots, packers, purveyors/distributors, and retailers; all must be profitable with the ultimate goal of providing palatable beef to please the final segment of the supply chain: consumers. The role of the seedstock breeder is to provide bulls to produce offspring and change genetics to increase profitability. The cow-calf operators are responsible for the health and maintenance of cows and their calves from birth until weaning with the proceeds from the sale of the calves providing the primary income to the operators. The yearling-stockers' job is to add weight to the calves not large enough to go directly to the feedlot. Feedlots use specialized finishing rations to add weight to the cattle and improve palatability just prior to harvesting (Field, 2007). The packers harvest the cattle and pack the beef for distribution to purveyors/distributors where it is sent to the food service industry or to retailers and then to the consumers. To end up with high quality beef while maintaining low production costs, one must start at the beginning of the supply chain with the cow-calf operators and seedstock breeders.

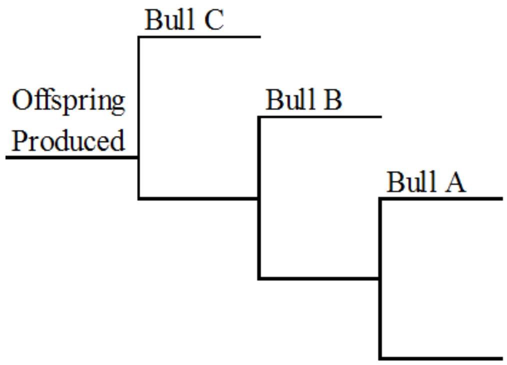
Profitability and Sustainability

Cow-calf operations have benefitted from the many technological advances that have been introduced over the years. The introduction of antibiotics greatly improved the health of the herd by decreasing the number of contagious disease outbreaks. Artificial insemination has made breeding more efficient because many females can be artificially inseminated in one day rather than requiring several days to breed the same number of females using standard practices. These advances, along with others, have lowered the cost of running the operation and increased profitability through multiple avenues including improved genetics, older and heavier calves, etc.

Even with the technological advances adopted over the past 150 years and the increase in the size of the ranch, the number of acres for grazing required per animal and the number of labor hours required per animal have not greatly changed (Wailes, 2013). Although many labor hours are required to tag each individual calf and record statistics such as birth weight, weaning weight, average daily gain; these are necessary steps as each individual animal is extremely important to the rancher and can potentially contributed to the genetics of the next generation and ultimately determine price received. The larger the number of quality offspring available for sale as yearlings, the greater the profit for the producer. Since the goal of the operation is to be profitable, it must also be sustainable which means having funds available to hire and retain good people, improve genetics, and purchase and maintain equipment (Wailes, 2013). This paper will focus on the improvement to the genetics of the herd and, specifically, sire selection. To positively impact the genetics of the herd, producers rely on sire selection (Dyer and Silcox, 2012).

Genetics and Sire Selection

The genetics of a bull is extremely important in herd management to maintain the quality desired by consumers and profitability for the producers (Dhuyvetter et al., 1996). Due to the number of females that must be retained and the relative number of offspring produced in a lifetime, the amount of genetic selection from cows is low when compared to bulls. For producers who purchase bulls and retain replacement heifers from the herd, up to 87.5% of the genetics of a calf can be attributed to just three bulls (Field, 2007). As illustrated in Figure 1.1, the calf's sire contributes 50%, the dam's sire contributes 25% (one half of the dam's contribution), with the remaining 12.5% from the sire of the mother's dam. Therefore, bull selection builds the foundation of the herd (Dyer and Silcox, 2012).



Bull	% genes contributed to offspring produced
A	12½
B	25
C	50
Total	87½ %

Source: Beef Production and Management Decisions, Field 2007

Figure 1.1 – Genetic Contribution of Three Bulls

When looking to purchase bulls from the seedstock breeder, many producers use simple performance measurements (SPM) to assist with decision making. One highly heritable SPM desired by producers is low birth weight because it is related to calving ease. A high rate of unassisted births translates to lower labor costs and higher overall calf survival. Higher weaning and yearling weights are also desirable because these indicate a faster rate of growth. However, birth weight is positively related to weaning weight and yearling weight, so a careful balance must be maintained when selecting bulls to achieve the desired calving ease without sacrificing higher growth rate (Schalles and Zoellner, 1993). Other SPMs that most breeders look for are maternal milk production, frame size, structural soundness (no deformities or irregularities), good disposition, and fertility (Dyer and Silcox, 2012).

In certain areas of the United States especially in states to the west of the Great Plains, cattle often must graze where the terrain is rough, the winters are harsh, and the vegetation is sparse. Some additional traits that may be desirable to breeders in these regions include cattle with the agility to negotiate rocky hills, efficiency to successfully forage in austere conditions, and adaptability to thrive at high altitudes. For example, management at Y-Cross Ranch in Wyoming found that introducing Herefords to their herd of Black Angus produced nimbler animals which enabled them to successfully overcome harsh conditions while continuing to provide a product that the meat packers desired which improved profitability (Waggener, 2005). Breeders with cattle grazing in mountainous regions in Colorado, Wyoming, Utah and New Mexico have found that some cattle develop High Altitude Disease (HAD) which is one of the top causes of illness and death in cattle raised at altitudes above 5,000 feet (Holt and Callen, 2007). To reduce the risk of developing the disease, breeders look for bulls that are less susceptible to the disease where susceptibility can be detected by a Pulmonary Artery Pressure (PAP) score with lower scores more favorable in those environments..

In addition to SPM's, producers look at Expected Progeny Differences (EPD) when selecting bulls to improve the herd. EPDs are statistics that use SPMs and other measurements from the bull, its offspring, and relatives to predict how the bull's progeny will perform when compared to their contemporaries, with contemporaries defined as "same sex and breed (or similar breeding) that have been raised under similar conditions" (Field, 2007; p 678). These statistics are only used as an estimate to compare animals within the same breed and to predict the genetic merit of individuals—half of this being transmitted to offspring and, in turn, influencing their performance. Breed associations throughout the United States have computed and made available many EPDs for many traits. Some of those are birth weight, weaning weight, total maternal (performance of cattle from the sire's daughter), and yearling weight.

Objective

The main objective of this study is to determine if bull buyers are willing to pay a premium for low PAP scores in yearling bulls sold at auction in a high altitude environment. Specifically, a hedonic model will be used to estimate the intrinsic value of simple performance measures (SPM) and expected progeny differences (EPD). The data used for this study are provided by Colorado State University's John E. Rouse Beef Improvement Center (BIC). Because it is located at an elevation of 6,900 feet, BIC uses PAP scores for herd management to reduce the loss of livestock due to HAD (Colorado State University, 2013). In addition to a low PAP score, other traits such as low birth weight, strong early growth, and maternal ability are goals set forth by the BIC; therefore, variables providing a measurement for these traits will be included in the model.

Organization of Thesis

The organization of the thesis will be as follows: Chapter 2 will provide a review of relevant literature. Chapter 3 discusses the modeling framework, while Chapter 4 describes the data collection used in the study. Chapter 5 reports the results of the study. Finally, Chapter 6 discusses the summary, conclusion, and areas for future study.

Chapter 2 – Literature Review

This chapter consists of five sections. The first section describes the traits that producers often look for when purchasing bulls. The second section provides information on High Altitude Disease (HAD) and the Pulmonary Arterial Pressure (PAP) test that is used to detect susceptibility to HAD. The third section discusses the use of the hedonic model for estimating prices for traits in agricultural commodities. The fourth section reviews prior research in estimating prices for traits of yearling bulls sold through auctions. The chapter is concluded with the contributions of this research to existing literature.

Desired Traits

When purchasing bulls, producers use simple performance measurements (SPMs) to assist with their decision making. Some SPMs desired by producers are related to the likelihood of an unassisted birth; the most common is birth weight. Age of dam is also related to calving ease. Two year olds are more likely to require assistance during calving than three year olds, and three year olds have more difficulty than four year olds (Herring, 1996). For herd improvement or herd consistency, producers might look at the bull's frame score based on the yearling height which is determined by the recommended policies published by the Beef Improvement Federation (Beef Improvement Federation, 2010). One would assume that yearling bulls sold at auction are roughly the same age; however, the difference in age between two yearling bulls sold at the same auction can vary by several weeks to months with older calves being more desirable. Another trait of interest to producers is the scrotal circumference, which is not only an indicator of breeding soundness, but also an indicator of the age of the sire's daughter at puberty; larger size tends to indicate earlier puberty (Vargas et al., 1998). Strong early growth can be found in bulls with a large average daily gain, as well as weaning weight and yearling weight (Dyer and Silcox, 2012).

In addition to SPMs, producers are interested in the expected progeny differences (EPD) associated with the bull's genetic traits. EPDs show the difference between the expected measurements of the bull's offspring versus those of all other bulls in the herd if bred to the same mate. It has been reported that a bull's EPD for weight is a better measurement of his genetic worth than his actual weight, as it takes into account the measurements for the bull itself, its relatives and herd differences (Dyer and Silcox, 2012). Some more common EPDs include those for birth weight, weaning weight and yearling weight. If one compares a bull with an EPD for weaning weight of +3 versus another bull with +1, this suggests that the bull with +3 will have offspring on average two pounds heavier at weaning than the bull with a +1 EPD (Dyer and Silcox, 2012). There is also an EPD for milk which shows how well the daughter's calves utilize milk intake by the number of pounds gained from birth through weaning (Schalles and Zoellner, 1993). This measurement is different than that for a weaning weight EPD. Other EPDs measure the probability of a particular event. For example, an EPD for calving ease direct is the probability of an unassisted birth by the sire's offspring; calving ease maternal is the probability of the sire's daughters to give birth without assistance; and the EPD for stayability is the probability that the sire's daughters will produce calves each year and stay with the herd to at least six years (Colorado State University, 2013).

High Altitude Disease and Pulmonary Arterial Pressure

High Altitude Disease (HAD), also known as Brisket Disease, Dropsy of High Altitudes, and High Mountain Disease affects cattle living at altitudes of 5,000 feet or more and is commonly found in herds in Colorado, New Mexico, Utah, and Wyoming. HAD is one of the top causes of illness and death in cattle raised at high altitude and also accounts for significant loss in growth and reproductive performance. Holt and Callen (2007) estimated that among the 1.5 million cattle raised at high elevation, HAD accounted for a 5% annual death loss in those herds. In 2011 the disease was reported to have a 0.5% to 5% occurrence rate in cattle native to high elevations but jumped to 30% to 40% in cattle transported from low to high elevations or in the offspring of untested sires. This results in an estimated annual financial loss of $60 million (McCormick, 2011).

Research on HAD was first published by the Colorado Agricultural Experiment Station (Glover and Newsom, 1915). The authors found that a disease had been detected in cattle which exhibited lethargy, weakness, diarrhea, bulging eyes, and swelling of the brisket resulting in poor performance and eventual death. The disease had been seen in Colorado as early as 1889 at altitudes above 7,000 feet, but based on reports from veterinarians and stockmen, the authors believed cases had existed prior to 1889, were more widespread, and were found at even lower altitudes. After conducting research and observing herds, they reported that HAD is non-transmissible and not infectious. They also discovered that the only known prevention is through the restriction of susceptible livestock to lower altitudes. In addition, they found that once an animal develops the disease, the only known treatment is to move it to a lower elevation.

A test has been developed to show susceptibility of cattle to HAD. Pulmonary Arterial Pressure (PAP) provides a score that is an indicator trait of an animal’s genetic ability to tolerate high altitudes. To perform a PAP test, the animal is restrained and a catheter inserted into the jugular vein, through the right ventricle and into the pulmonary artery (Holt and Callen, 2007). An animal’s PAP score is the average of diastolic and systolic blood pressures and is a reliable predictor when performed at high altitudes. The scores range from mid-30’s to 130 with scores over 45 indicating a greater risk of developing HAD (Gjermundson, 2000; Ahola et al., 2006). In addition, the PAP score has been shown to be heritable in cattle (Schimmel et al., 1981; Enns et al., 1992; Shirley et al., 2008). This suggests that PAP may be reduced in future generations of herds through retaining bulls with lower (more desirable scores) and culling those with higher scores.

Hedonic Modeling

One of the most common ways to estimate the value of attributes of agricultural products is through the use of hedonic modeling. The hedonic model shows the relationship between the price of a product and its various attributes (Studenmund, 2006). By using partial derivatives, it isolates each attribute to determine the influence on the price (Oczkowski, 2001).

One of the earliest studies illustrating the usefulness of a hedonic model was by Waugh (1928), when he was able to show that long, slender cucumbers brought in an average of $2.00 to $3.00 per bushel more than short, stocky cucumbers. Other recent studies involving agricultural products utilizing a hedonic model include: expert quality ratings and production altitudes with coffee bean prices (Donnet et al., 2007); grape origins, species and quality ratings with wine prices (Oczkowski, 2001); size, fat content and material handling with tuna prices (McConnell and Strand, 2000); marketing conditions including the closure of horse slaughtering plants with horse prices (Taylor and Sieverkropp, 2013); and physical traits with the price of cow-calf pairs (Parcell et al., 2005). As long as the product is heterogeneous, the model has been shown to be robust (Studenmund, 2006).

Bull Prices at Auction

There have been several studies conducted that have placed a value on the attributes of yearling bulls purchased at auctions. Dhuyvetter et al. (1996) performed an early study of market values associated with EPDs, SPMs, and marketing characteristics in determining bull prices at auction. The data was collected from 26 purebred bull sales across Kansas during the spring of 1993. Two separate hedonic models are tested: one with EPDs and one without. In the first model, which did not include EPDs, results showed that yearling bulls that were polled, visually appealing and had a lower birth weight but a higher adjusted weaning weight were drawing a premium. The second model, which included EPDs, showed similar results for physical characteristics. Although still significant, the parameter estimates for birth weight and adjusted weaning weight were lower than in the model that did not include EPDs. EPDs for birth weight, weaning weight and milk were all significant, but the authors found that birth weight and EPD for birth weight might be providing buyers the same information. Marketing factors such as sales order, picture in a pre-sale catalog, and percent of bulls in sale with semen retention rights were significant in both models. After analysis of both models, the authors concluded that EPDs were somewhat important in explaining variation in sale price.

Chvosta et al. (2001) examined the market for breeding bulls, with a primary focus on comparing the influence of SPMs with EPDs on bull auction prices. Data was collected from sales held at Montana ranches between 1982 and 1997, and from Nebraska and South Dakota breeders for bulls sold between1986 and 1996. The SPMs tested were weight at birth, weaning and yearling and a dummy variable for sires. EPD measures for birth, weaning, and yearling weights were also included. Unlike Dhuyvetter et al. (1996), neither physical characteristics nor marketing factors were used in the model. Multiple models were estimated, leading the authors to conclude that buyers of Angus bulls find both SPMs and EPDs to be useful measurements for comparing bulls at auction.

Jones et al. (2008) examined the economic values of actual production measures, EPDs for production, and marketing factors of Angus bulls sold at auction. The data was collected over a four-month period from 60 bull sales spanning 11 states across the western United States; however, the year of data collection was not specified. In addition to the characteristics tested in the prior studies, the authors included EPDs for carcass and ultrasound. Multiple models were estimated, and significant results were found for age, age squared, birth weight, adjusted weaning weight, adjusted yearling weight and EPDs for birth weight, milk, and yearling weight. Some marketing factors and carcass EPDs were also found to be significant. Elasticities were calculated, and those for actual weights were higher than EPDs in most cases. The exception to this was for birth weight, where the elasticity for the EPD was greater than for the actual birth weight.

Vanek et al. (2008) studied the implicit value of EPDs to see if genetic progress was rewarded with a higher sale price. Data was collected from four U.S. Angus producers for auctions held during 2005 and 2006. The authors found that EPDs for birth weight, weaning weight and yearling weight were collinear so a variable for EPD birth-to-yearling gain was substituted. There was also an indicator variable created to account for the difference in the year of the sale. Multiple models were run with non-standardized data and again with weighted least squares parameter estimates. White’s correction for heteroskedasticity was used in both models. Many variables were found to be significant leading the authors to suggest that producers were willing to pay a premium for genetic information found in EPDs.

In contrast to prior research, McDonald et al. (2010) omitted a variable for sale order in the model because it was found to generate multicollinearity problems. It is routine practice for sellers to place bulls with the potential of obtaining the highest sale prices at the front of the sale order, and specific to this sale, the sale order was determined using an index derived from traits that are already included in the statistical model. In addition, following in the footsteps of Vanek et al. (2008), the authors created a variable for birth-to-yearling gain to eliminate correlation between the two variables: birth weight and yearling weight. Ordinary least squares (OLS) was used for the estimation with a correction due to heteroskedastic errors. The authors also standardized the independent variables to estimate the relative importance of each variable. The data for this study was collected during 2008 and 2009 from sales held at the Midland Bull Test Company in Montana.

Bekkerman et al. (2013) used quantile regression estimates to determine the differences in values of traits for bulls sold at auctions after evaluation at a large test center. The data was collected at the Midland Bull Test Company from sales held during 2008 and 2009. The authors stated that the quality perceptions for this heterogeneous group of bulls may not be adequately measured through a traditional OLS model which shows the average marginal effects. For instance, their semiparametric regression approach captured the wide fluctuations in the estimates of the effect of intramuscular fat (IMF) on lower quality versus higher quality bulls. The OLS estimate showed a 5.5% increase in price for every 1% increase in IMF. Using Bekkerman's approach, at the 50% quantile the estimate was 3.6% compared to12.2% at the 90% quantile. The authors also reported that for sales made through homogenous auctions (i.e., one producer) the standard OLS model would be relatively accurate.

Contribution to Literature

There have been several studies showing the marginal effect on sale price by the traits of bulls sold through auctions. These studies have utilized data for simple performance measurements, expected progeny differences, and marketing data from test centers and private sales throughout the United States.

This study will contribute to existing literature by analyzing sale data for a herd owned and managed by a land grant university (Colorado State University) and sold through a public auction held exclusively for selling bulls from this herd. Additionally, this study is the first to estimate the marginal effect of a PAP score on the sale price for seedstock bulls sold at auction. Finally, the data used is more recent than prior studies, as it was collected from sales held in the spring of 2011, 2012, and 2013.

Chapter 3 - Methods

This chapter will focus on the model used for this research. The theoretical model is explained first, followed by the empirical model. Finally, common issues with hedonic models are addressed.

A hedonic model is being used to estimate the premium paid for PAP score and other bull characteristics for yearling bulls sold at auction. A hedonic model has been used to quantify attributes of various agricultural commodities (Parcell et al., 2005; Donnet et al., 2007) and specifically for yearling bulls (Chvosta et al., 2001; Vanek et al., 2008). The model used in this study follows the theoretical model used by Dhuyvetter et al. (1996) and Jones et al. (2008):

1) Bull Price = *f(*Simple Performance Measurements, Expected Progeny Differences, Marketing Factors)

where the bull price is a function of the simple performance measurements (SPMs), expected progeny differences (EPDs), and marketing factors for the individual bull. SPMs refer to the bull's own traits while EPDs refer to expected performance of offspring. The marketing factors in this study are for the year of the sale. Yearling bull prices can be specified in the following empirical model:

2) $SALE\_PRICE = \beta_0 + \beta_1*PAP + \beta_2*BW + \beta_3*WW + \beta_4*SALE\_AGE + \beta_5*SALE\_AGE^2 + \beta_6*DAM\_AGE + \beta_7*FRAME + \beta_8*ADG + \beta_9*SC + \beta_{10}*EPD\_BW + \beta_{11}*EPD\_WW + \beta_{12}*EPD\_YW + \beta_{13}*EPD\_MILK + \beta_{14}*EPD\_CED + \beta_{15}*EPD\_CETM + \beta_{16}*EPD\_STAY + \beta_{17}*YR2012 + \beta_{18}*YR2013$

The coefficients (β's) are the partial derivatives of the sale price with respect to the characteristic and measure the marginal implicit price of the characteristic. For example, β_1 is the partial derivative of the sale price with respect to the PAP score which shows the marginal change in the sale price for each one unit increase in PAP score.

The SPMs included are pulmonary arterial pressure (PAP) score, birth weight (BW), weaning weight (WW), age of bull at the time of sale (SALE_AGE), sale age squared (SALE_AGE^2), age of dam (DAM_AGE), frame score (FRAME), average daily gain (ADG) and scrotal circumference (SC). The EPDs in the model are for birth weight (EPD_BW), weaning weight (EPD_WW), yearling weight (EPD_YW), daughter's milk producing ability (EPD_MILK), calving ease direct (EPD_CED), calving ease total maternal (EPD_CETM), and stayability (EPD_STAY). Two dummy variables are included to account for the sales in 2012 and 2013, with 2011 being the base year.

Common Problems with Hedonic Models

Two common problems that arise with hedonic modeling are multicollinearity and heteroskedasticity. Although the estimated coefficients are BUE (Best Unbiased Estimator), the effect of multicollinearity is a high R^2, but few or no statistically significant coefficients which results in the increased likelihood of making a Type II error (Gujarati, 2003). There is no formal statistical test for detecting multicollinearity, but the general rule of thumb is that a variance inflation factor (VIF) over 10 is problematic (Koontz, 2008; Ott and Longnecker, 2001). This corresponds to an R^2 greater than 0.9 when each independent variable is regressed on the remaining ones. In several prior studies, EPDs for birth weight, weaning weight and yearling weight were found to be collinear (Vanek et al., 2008; McDonald et al., 2010). That was not found to be the case in this study, so all three variables are retained. However, a VIF of 11.0 was found for the EPD for calving ease direct.

The models used to calculate calving ease direct and calving ease total maternal both use birth weight and a calving ease score from the BIF Guidelines. Because the input received to calculate calving ease direct is retained within the birth weight and calving ease total maternal variables, it is determined that the EPD for calving ease direct could be omitted from the final model without compromising accuracy.

Heteroskedasticity is another issue that has been detected in prior studies (Holt et al., 2004; and Jones et al., 2008). The consequences of heteroskedasticity include estimates that are not BUE because the variances are no longer the minimum and no longer efficient which can lead to incorrect hypothesis testing and erroneous conclusions (Gujarati, 2003). There are several tests that can be performed to detect heteroskedasticity such as Goldfeld-Quandt, Bruesch-Pagan-Godfrey and White. However, White's test does not require putting the observations in order of suspected heteroskedasticity, nor is it sensitive to the assumption of normality. Therefore, White's test is utilized in this study, and no evidence of unequal variances is found.

Chapter 4 - Data

This chapter focuses on the collection of the data and the description of the variables used in this study. The approval of the Institutional Animal Care and Use Committee was not requested as all data are obtained through pre-existing databases created and maintained by Colorado State University (CSU) faculty and staff.

Data were collected at the John E. Rouse—Colorado State University Beef Improvement Center in Saratoga, Wyoming, from their March 2011, March 2012, and April 2013 bull sales. The test data were distributed to potential buyers through pre-sale catalogs and actual purchase prices were obtained directly from CSU personnel after each sale. There were 39, 41, and 43 bulls listed at the 2011, 2012 and 2013 sales, respectively. Bulls scratched prior to the sale and those that did not sell at the reserve price are eliminated from this study leaving a total of 91 bulls sold through the three auctions. The auction type used is an English auction which begins with a reserve price and uses open cry of ascending bids until the highest final bid is received.

Description of Variables

Sale Price (SALE_PRICE) is the dependent variable and is determined by the final bid received at auction. The independent variables are either simple performance measures (SPM) or expected progeny differences (EPD). There are also two dummy variables included in the model, year of sale (YR2012 and YR2013). A list of all the variables with their descriptive statistics and expected signs are shown in Table 4.1.

Simple Performance Measures

Pulmonary Arterial Pressure (PAP) score is one of the independent variables for (SPM) and is the actual score as determined by veterinarian Dr. Timothy Holt and CSU research personnel.

Table 4.1 – Expected Signs and Descriptive Statistics

				2011 Sale Data - Count = 34				2012 Sale Data - Count = 39				2013 Sale Data - Count = 17			
Variables	Description	Unit of Measure	Expected Sign	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
PAP	Score as determined by test	score	-	46.7	10.9	36.0	87.0	47.0	6.2	37.0	59.0	42.7	3.7	38.0	51.0
BW	Bull's birthweight	pounds	-	80.1	8.5	52.0	91.0	78.7	6.8	60.0	90.0	66.5	9.9	49.0	80.0
WW	Bull's weaning weight	pounds	+	509.1	33.9	439.0	572.0	534.5	42.9	455.0	640.0	529.3	29.9	480.0	582.0
SALE_AGE	Age of bull at sale date	days	+	379.3	16.6	347.0	406.0	361.0	18.8	328.0	406.0	398.6	15.2	372.0	415.0
SALE_AGE^2	Sale age squared	days	-												
DAM_AGE	Age of dam	years	unknown	4.2	2.9	2.0	12.0	5.9	3.5	2.0	14.0	3.5	2.4	2.0	11.0
FRAME	Frame score	score	unknown	4.5	0.8	3.1	7.6	5.7	0.6	4.4	7.1	4.8	0.5	4.1	5.8
ADG	Average daily gain from birth	pounds	+	3.0	0.3	2.4	3.5	3.3	0.3	2.3	3.9	3.3	0.4	2.6	4.0
SC	Scrotal circumference	centimeters	+	35.4	1.4	33.5	39.0	34.5	2.1	31.0	40.5	35.9	2.6	32.0	41.0
EPD_BW	EPD for birth weight	pounds	-	-0.1	2.0	-5.1	3.6	-0.4	1.8	-4.9	3.0	-1.9	1.8	-5.5	1.7
EPD_WW	EPD for weaning weight	pounds	+	9.0	8.4	-6.7	22.0	7.4	11.0	-17.0	35.0	5.5	6.7	-3.0	22.0
EPD_YW	EPD for yearling weight	pounds	+	51.6	17.3	18.4	86.3	56.5	21.2	18.0	102.0	32.1	18.1	6.0	68.0
EPD_MILK	EPD for milk	pounds	+	6.6	3.2	-2.5	10.7	5.4	2.5	0.0	11.0	5.1	2.9	0.0	9.0
EPD_CED	EPD for calving ease direct	percentage	+	2.9	3.4	-3.2	12.1	2.7	4.6	-8.1	11.1	6.0	4.8	-4.8	14.4
EPD_CETM	EPD for calving ease total maternal	percentage	+	2.3	2.9	-3.6	7.6	1.8	4.2	-8.7	10.1	1.4	1.4	-1.5	4.2
EPD_STAY	EPD for stayability	percentage	+	3.0	1.3	0.0	5.8	3.1	1.6	-0.1	7.3	4.5	2.3	1.0	10.2
SALE_PRICE	Actual price paid at auction	US Dollars	n/a	2,304.4	748.8	1,300.0	4,200.0	3,498.7	887.6	2,100.0	5,900.0	1,967.6	585.8	1,600.0	3,700.0

A lower PAP score indicates a lower probability of developing High Altitude Disease. The sign is expected to be negative.

There are two weights included in this study: birth weight (BW) and weaning weight (WW). Birth weight is the weight of the calf within 24 hours of birth and is measured in pounds. A lower birth weight is related to a higher incidence of unassisted birth. The sign is expected to be negative. Weaning weight is measured in pounds and is determined at 205 days of age. It is one measure of early growth and also is an indicator of milking ability of the dam. Thus, a higher weight is desired, and the sign is expected to be positive. Most prior studies included an adjusted weaning weight, but that number was not provided in the presale catalog for all three years so is not included in this study.

The age of the bull at time of the sale (SALE_AGE) is measured in days and represents the number of days between birth and sale. Previous research has found that a more mature bull is desired, so the expected sign is positive. However, the increase in the premium for a bull's age at the time of sale diminishes as the bull gets older. To correctly model this non-linear relationship, prior researchers have included a variable for age squared (SALE_AGE^2) in the model (Jones et al., 2008; Chvosta et al., 2001). The coefficient is expected to be negative. The age of the dam at the time of calving (DAM_AGE) is measured in years. Some buyers look for the age of the dam around four years old due to calving ease and larger weaning weight. However, some buyers look for older dams because it indicates a long, reproduction period. Due to this contradiction, the expected sign is unknown.

Frame score (FRAME) uses a hip height measurement and the age that the measurement was taken to create a score to describe the skeletal size of cattle (Beef Improvement Federation, 2010). Most animals maintain the same score throughout their lives so this is a good indicator of fatness level and body size. Because some buyers may be looking to increase the size of the individual animals in the herd while others may be looking to maintain or decrease, the expected sign for FRAME is unknown. The average daily gain (ADG) is measured in pounds. It is the difference between birth weight and yearling weight divided by the number of days between when these two measurements were taken. It is a good measure of strong early growth and should have a positive sign. Scrotal circumference (SC) is measured in centimeters and is taken at 365 days old (Field, 2007). The size of the bull's scrotum is positively related to his age at puberty and to the puberty age of his daughters. It is also an indicator as to whether or not he can produce sperm (Beef Improvement Federation, 2010). A positive sign for SC is expected.

Expected Progeny Differences

Several variables for EPD are included in the model. EPDs show the difference between the expected measurements of the bull's offspring versus those of all other bulls in the herd if bred to the same mate. EPDs for birth weight, wean weight and yearling weight are represented by EPD_BW, EPD_WW, and EPD_YW, respectively. Similar to the signs for the simple performance measures, EPD_BW is expected to be negative due to its negative relationship with calving ease, while EPD_WW and EPD_YW should be positive because they show potential for early growth.

The EPD for milk (EPD_MILK) is measured in pounds. This measurement shows an estimate of the amount of the weaning weight that is due to the milk production of the bull's daughter. Because increased milk production requires additional nutrition requirements, this variable may be positive or negative depending on the feed and/or forage availability of the buyers' operations.

EPDs for calving ease total maternal (EPD_CETM) and stayability (EPD_STAY) are measurements of probability of occurrence. Calving ease total maternal is the probability of the sire's daughter's to give birth without assistance for first-calf heifers, and the EPD for stayability is the probability that the sire's daughter will stay with a herd through age six while consistently producing a healthy calf each year (Colorado State University, 2013). The expected sign for both is positive.

Dummy Variables

In addition to the SPMs and EPDs, there are two indicator (dummy) variables included in the model (YR2012 and YR2013) which are used to isolate the effect that the year of the sale has on the sale price. The year 2011 is used as the base year. The dummy variable used to delineate bulls sold in 2012 is expected to have a positive sign while the dummy variable used for the 2013 sale is expected to be negative. The reason for the expected drop in price for the 2013 sale is due to extreme drought conditions across the major beef and feed producing states resulting in high prices of feed and a subsequent fall sell-off of cattle. The USDA's National Agricultural Statistics Service reported a 2% drop in cattle and calf inventory from 2012 to 2013, which resulted in the lowest inventory since 1952 (USDA NASS, 2013). This is also reflected in the steer and heifer prices which dropped from $132 to $128 per cwt from March 2012 to March 2013, and in culled cow prices which dropped from $84.20 to $82.90 per cwt during the same time period.

Chapter 5 - Results

This chapter will focus on the results of the study. First, a hedonic model using ordinary least squares (OLS) will be analyzed. In this model a continuous variable for Pulmonary Arterial Pressure (PAP) score is used. Second, the results are reported for a model where PAP is represented by a dummy variable (Low_PAP) for a score under 46. Third, a log-linear model will be utilized to calculate and report elasticities. Finally, the variables will be standardized and a new OLS model will be run.

Model 1 - Ordinary Least Squares

OLS is the most-used method for regression (Studenmund, 2006). The primary reason for its popularity is because it is easy to use, much simpler than other techniques such as maximum likelihood, and achieves the same results (Gujarati, 2003). The empirical model using OLS is as follows:

3) $$SALE\_PRICE = \beta_0 + \beta_1{*}PAP + \beta_2{*}BW + \beta_3{*}WW + \beta_4{*}SALE\_AGE + \beta_5{*}SALE\_AGE\text{^}2 + \beta_6{*}DAM\_AGE + \beta_7{*}FRAME + \beta_8{*}ADG + \beta_9{*}SC + \beta_{10}{*}\ EPD\_BW + \beta_{11}{*}EPD\_WW + \beta_{12}{*}EPD\_YW + \beta_{13}{*}EPD\_MILK + \beta_{14}{*}\ EPD\_CETM + \beta_{15}{*}\ EPD\_STAY + \beta_{16}{*}YR2012 + \beta_{17}{*}YR2013$$

White's test was conducted to detect heteroskedasticity. The test results failed to produce evidence to reject the null hypothesis that the variances are equal, thus no adjustments were made.

Table 5.1 reports the regression results. Five of the independent variables and one indicator variable were shown to be statistically significant at the 10% level or less. All of the significant variables possessed the expected sign. The R^2 statistic is 0.67 which is higher than those reported by Jones et al. (2008) and McDonald et al. (2010), 0.63 and 0.16, respectively.

Table 5.1 Regression Results

Variable	Description	Model 1 OLS	Model 2 OLS w/PAP Dummy	Model 3 Log-Linear	Model 4 Standardized Variables
		Coefficient (t-statistic)	Coefficient (t-statistic)	Coefficient (t-statistic)	Coefficient (t-statistic)
C	Intercept	-22432.59	-26798.54	1.27	n/a
		(-0.87)	(-1.10)	(0.13)	
BW	Birth weight	-18.69	-21.58	-0.01	-0.21
		(-1.12)	(-1.36)	(-1.36)	(-1.23)
WW	Weaning Weight	5.45 ***	4.13	<0.01 ***	0.19
		(1.85)	(1.52)	(1.86)	(1.52)
SALE_AGE	Age at Time of Sale	147.36	162.62	0.04	0.37
		(1.06)	(1.24)	(0.79)	(0.11)
SALE_AGE^2	Squared Age at Time of Sale	-0.21	-0.23	<0.01	-0.69
		(-1.16)	(-1.34)	(-0.89)	(-0.21)
DAM_AGE	Age of Dam	-35.92	-26.62	-0.01	-0.16
		(-1.13)	(-0.88)	(-0.89)	(-1.29)
FRAME	Frame Score	-242.40 ***	-154.81	-0.10 ***	-0.21 ***
		(-1.72)	(-1.19)	(-1.90)	(-1.78)
PAP	Pulmonary Arterial Pressure Score	-43.87 *	n/a	-0.02 *	-0.40 *
		(-4.61)	(n/a)	(-4.79)	(-4.02)
LOW_PAP	PAP Score <46	n/a	852.82 *	n/a	n/a
			(5.74)		
SC	Scrotal Circumference	8.33	-15.03	<0.01	0.08
		(0.19)	(-0.37)	(0.29)	(0.77)
ADG	Average Daily Gain	128.11	73.55	0.07	0.06
		(0.54)	(0.33)	(0.82)	(0.59)
EPD_BW	EPD Birth Weight	-54.55	-22.98	-0.02	0.01
		(-0.67)	(-0.30)	(-0.52)	(0.05)
EPD_WW	EPD Weaning Weight	10.47	-1.09	0.00	-0.06
		(0.83)	(-0.09)	(0.53)	(-0.44)
EPD_YW	EPD Yearling Weight	10.22 **	13.32 *	<0.01 ***	0.30 **
		(2.03)	(2.75)	(1.72)	(2.40)
EPD_CETM	EPD Calving Ease Total Maternal	50.04 ***	35.53	0.02 ***	0.14
		(1.74)	(1.30)	(1.67)	(1.11)
EPD_MILK	EPD Milk	-10.38	2.04	0.00	-0.02
		(-0.31)	(0.06)	(-0.13)	(-0.16)
EPD_STAY	EPD Stayability	77.17	127.47 *	0.03 ***	0.21 **
		(1.66)	(2.94)	(1.84)	(2.04)
YR2012	Year of Sale 2012	1137.94 *	1128.29 *	0.41 *	n/a
		(4.05)	(4.26)	(4.00)	
YR2013	Year of Sale 2013	-484.32	-547.30 ***	-0.23 ***	n/a
		(-1.46)	(-1.74)	(-1.89)	
R^2		0.67	0.71	0.68	0.39
Adjusted R^2		0.60	0.64	0.60	0.27
n = 91					

Level of Significance

** = 1%, ** = 5%, *** = 10%*

Birth weight (BW) and the EPD for birth weight (EPD_BW) are associated with calving ease and were expected to have a negative impact on bull price, but neither were found to be significant. However, the EPD for calving ease total maternal (EPD_CETM) is also a measure for calving ease for the daughter of the bull and was found to be significant and positively related to sale price. This means that for every one unit increase in the EPD, the sale price increased by $50.04.

Weaning weight is a measure of early growth and is an indicator of the milking ability of the dam. Data suggests that buyers are willing to pay a premium of $5.44 for each additional pound of weaning weight, which is similar to Chvosta et al. (2001).

The EPD for yearling weight (EPD_YW) measures the expected yearling weight for the offspring of the bull and is an indicator of early growth. The variable was significant implying the sale price increased $10.22 for every one unit increase in the EPD. Chvosta et al. (2001) and Jones et al. (2008) both found the EPD for yearling weight to be positive and significant.

Frame size is a measure representing the skeletal size of the bull. It was not known what sign the parameter estimate would have as it could have been positive or negative. It was significant, implying the sale price decreased by $242.40 for every one unit increase in the frame score (using scoring of 1 to 9 as specified in Beef Improvement Federation Guidelines). This suggests that the buyers were most likely looking to decrease the size of the animals in the herd which is often associated with forage availability due to drought conditions, rough terrain, and calving ease.

The indicator variables to account for the effects of the year of the sale were expected to be positive for 2012 and negative for 2013. Although the signs were consistent with our expectations for both 2012 and 2013, 2013 was not statistically significant. Buyers paid $1,137.94

more in 2012 than at the 2011 sale. This is consistent with prices for yearling Angus bulls which rose 24% or $896 per head from 2011 to 2012 (Gilliam, 2012).

Pulmonary arterial pressure (PAP) score is a measure of the probability of developing High Altitude Disease. A lower PAP score is associated with a lower likelihood of developing the disease. PAP was statistically significant at the 1% level with a parameter estimate of -43.87. With each drop of one in the score, buyers are willing to pay an additional $43.87.

Figure 5.1 shows actual sale price ($/head) versus predicted sale price ($/head) with the actual values for PAP score used in the predicted price while all other continuous variables are held at their mean values. The top five bulls with the highest actual sale prices sold for more than their respective predicted price with the highest-price bull selling for $1,671 over the predicted sale price. In addition, there was one bull with a very high PAP score of 87 which sold for more than $1,000 over the predicted price suggesting that the buyer was not looking for a bull that would be spending time at a high altitude.

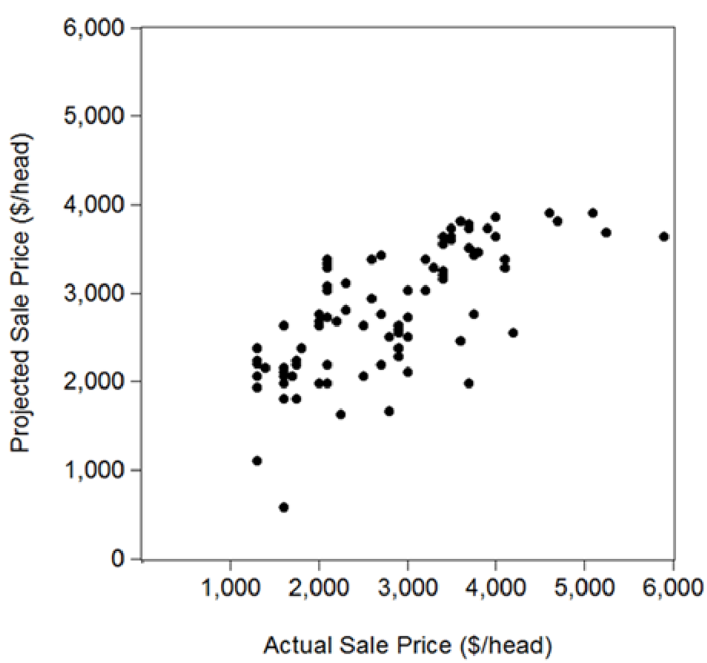


Figure 5.1 Actual vs. Predicted Sale Price ($/head) with Actual Values for PAP

Model 2 – PAP as a Dummy Variable

Prior research has shown that PAP scores range from the mid-30's to 130, and scores over 45 indicate a greater risk of developing HAD (Gjermundson, 2000; Ahola et al., 2006). To test whether a score of 45 or lower was significant to the bull buyers, a second model was created using a dummy value for a PAP score under 46 (LOW_PAP). All other variables were retained in this model and is as follows:

4) $$\text{SALE\_PRICE} = \beta_0 + \beta_1{*}\text{LOW\_PAP} + \beta_2{*}\text{BW} + \beta_3{*}\text{WW} + \beta_4{*}\text{SALE\_AGE} + \beta_5{*}\text{SALE\_AGE}\hat{}2 + \beta_6{*}\text{DAM\_AGE} + \beta_7{*}\text{FRAME} + \beta_8{*}\text{ADG} + \beta_9{*}\text{SC} + \beta_{10}{*}\ \text{EPD\_BW} + \beta_{11}{*}\text{EPD\_WW} + \beta_{12}{*}\text{EPD\_YW} + {}_{13}{*}\text{EPD\_MILK} + \beta_{14}{*}\text{EPD\_CETM} + \beta_{15}{*}\ \text{EPD\_STAY} + \beta_{16}{*}\text{YR2012} + \beta_{17}{*}\text{YR2013}$$

The regression results are provided in Table 5.1. The R^2 for this model is 0.71 and the adjusted R^2 is 0.64 which are both greater than the previous model. LOW_PAP was statistically significant at the 1% level with a parameter estimate of 852.82, indicating bull buyers were willing to pay a premium of $852.82 for bulls with a PAP score of less than 46.

Two variables that were significant in both Model 1 and Model 2 are the EPD for yearling weight (EPD_YW) and 2012 year of sale (YR2012). The EPD for stayability (EPD_STAY) was significant in the second model, but was not in the first one and has a parameter estimate of 127.47, implying a $127.47 increase in sale price for every one unit increase in EPD. This variable measures the probability that the sire's daughter will consistently produce healthy calves each year and will stay with the herd. The 2013 year of sale (YR2013) was also significant in the second model, but was not in the first. This dummy variable shows the effect on sale price for bulls sold at the 2013 auction. Bulls at the 2013 auction sold for

$547.30 less than those in 2011. Three variables, WW, FRAME, and EPD_CETM, were all significant in Model 1, but not in Model 2.

Model 3 – Log-linear

Elasticities are often used by economists to show the sensitivity of the variation of one variable on another by measuring the percentage change of the dependent variable when the independent variable is increased or decreased by 1% (Pindyck and Rubinfeld, 2005). In addition, elasticities can be used to compare the results across the variables because they use a unitless measure. One way to find the elasticity is by regressing the log of the dependent variable on the log of the independent variables. Because several of the independent variables contain negative numbers, this method could not be used. Instead, a similar technique as noted in Jones et al. (2008) was incorporated. Elasticities were estimated using results from a log-linear model as follows:

5) $LnSALE\_PRICE = \beta_0 + \beta_1 * PAP + \beta_2 * BW + \beta_3 * WW + \beta_4 * SALE\_AGE + \beta_5 * SALE\_AGE^2 + \beta_6 * DAM\_AGE + \beta_7 * FRAME + \beta_8 * ADG + \beta_9 * SC + \beta_{10} * EPD\_BW + \beta_{11} * EPD\_WW + \beta_{12} * EPD\_YW + \beta_{13} * EPD\_MILK + \beta_{14} * EPD\_CETM + \beta_{15} * EPD\_STAY + \beta_{16} * YR2012 + \beta_{17} * YR2013$

The parameter estimates are then multiplied by the mean value of the independent variable. This technique works because the definition of elasticity is:

$$\frac{\%\Delta P}{\%\Delta Q} = \frac{\Delta P/P}{\Delta Q/Q} = \frac{Q}{P}\frac{dP}{dQ}$$

and the coefficient for a log-linear model is defined as:

$$\beta_1 = \frac{d(\ln P)}{dQ} = \frac{1}{P}\frac{dP}{dQ}$$

Any value for Q can be used to find the elasticity at that particular point. However, to find the elasticity at the mean, one must multiply the parameter estimate by the mean of the variable. The results of the log-linear regression are reported in Table 5.1 and the elasticities for the continuous variables are listed in Table 5.2.

Table 5.2 - Elasticities for Continuous Variables

Variable	Elasticity	
BW	-0.64	
WW	1.06	***
SALE_AGE	15.18	
SALE_AGE^2	-8.52	
DAM_AGE	-0.05	
FRAME	-0.50	***
PAP	-0.77	*
SC	0.16	
ADG	0.22	
EPD_BW	0.01	
EPD_WW	0.02	
EPD_YW	0.16	***
EPD_CETM	0.03	***
EPD_MILK	-0.01	
EPD_STAY	0.10	***

Level of Significance

** = 1%, ** = 5%, *** = 10%*

Weaning weight (WW) was the only significant variable that was also elastic with a measure of 1.06 showing that a 1% increase in weaning weight resulted in a 1.06% increase in sale price. The elasticity for PAP score was -0.77. All other significant variables resulted in smaller elasticities. Jones et al. (2008) reported elasticities for adjusted yearling weight and age of bull at time of sale of 1.59 and 1.44, respectively; all other variables were less elastic.

Model 4 - Standardized Variables

Elasticities do provide a comparison of importance among the independent variables and are easy to interpret; however, they have some shortcomings. The elasticity is only relevant at the estimation point which, in this case, is the mean. In addition, a 1% change in a variable can be a huge change for one variable and miniscule for another (Jones et al., 2008). Vanek et al. (2008), McDonald et al. (2010), and Jones et al. (2008) use standardized independent variables to overcome these obstacles.

The independent variable is standardized by subtracting the mean of each variable from the recorded value and then divided by the standard deviation. After regressing the standardized independent variables on the dependent variable, the coefficient is interpreted as an increase or decrease in standard deviations of the dependent variable given a one standard deviation increase in the independent variable (Pindyck and Rubinfeld, 1997). Following McDonald et al. (2010) the variables were standardized within each year of sale.

The larger the absolute value of the standardized coefficient indicates the greater the influence on the dependent variable. The results are listed in Table 5.1. Of the four continuous variables that were statistically significant, the actual PAP score was shown to have the greatest impact on sales price. An increase of one standard deviation resulted in a 0.40 standard deviation decrease in sales price. The EPD for yearling weight (EPD_YW) had the second greatest impact with a 0.30 standard deviation increase in sales price. Finally, the standardized coefficient for frame score (FRAME) showed a 0.21 decrease in the sale price standard deviations, while the EPD for stayability (EPD_STAY) showed a 0.21 increase. Multiple F tests was performed to see if these coefficients were significantly different from each other. The results showed that the coefficients for PAP and frame score were not significantly different from each other and that the coefficient for EPD stayability was not significantly different from EPD yearling weight. None of these standardized variables were statistically significant in Vanek et al. (2008) or McDonald et al. (2010).

Chapter 6 – Summary and Conclusions

The beef cattle industry brings in almost $63 billion in total cash receipts annually. However, for it to remain sustainable and profitable, each member of the supply chain must be profitable. For the cow/calf operations, this means improving genetics to maintain a healthy, productive herd. One way to accomplish this is by purchasing bulls with the desired traits because almost 90% of the genetics of the herd can be attributed to a few bulls.

Producers look for various traits in seedstock bulls to enhance their herds and will often pay a premium for those traits. Some of these desirable traits are simple performance measurements (SPMs) such as birth weight, yearling weight, age at the time of sale, and scrotal circumference. Other traits of interest are expected progeny differences (EPDs). EPDs show the difference between the expected measurements of the bull's offspring versus those of the other bulls in the herd. Two of the more commonly-used EPDs are for birth weight and weaning weight.

One particular physical trait which is of interest to producers in the mountainous western United States is for cattle that can thrive at a high altitude. Cattle are prone to developing High Altitude Disease (HAD) which has been shown to cause weakness, lethargy, and death. Researchers have developed a test to detect the likelihood of an animal of developing HAD. This test, Pulmonary Arterial Pressure (PAP) provides a score from 30 to 130 with scores over 45 indicating an animal is more likely to develop the disease.

Colorado State University, a land grant university, owns and operates the John E. Rouse—Beef Improvement Center (BIC) which specializes in cattle genetics; and in particular, a herd that has low PAP scores, strong early growth, fertility, and maternal ability. The center holds an annual auction to sell their yearling bulls. Data was collected from three years of sales

(2011, 2012, and 2013), and a hedonic model was created to estimate the value of SPMs, EPDs, and marketing factors of the yearling bulls sold at these auctions.

Four different models were estimated using ordinary least squares. The first model contained a continuous variable for PAP score which was negative and significant. Frame score was also found to be negative and significant. Variables which had positive and significant results included: weaning weight, EPD for yearling weight, EPD for calving ease total maternal, and a 2012 year of sale.

The second model was similar to the first one with the exception of the addition of a dummy variable for a PAP score under 46. Positive, significant results were found for a low PAP score, EPD for yearling weight, EPD for stayability, and a 2012 year of sale. Negative, significant results were found for a 2013 year of sale.

The third model was a log-linear model. PAP score, frame score, and a 2013 year of sale were negative and significant. Positive, significant results were found for weaning weight, EPDs for yearling weight, calving ease total maternal, stayability, and a 2012 year of sale. Elasticities were also calculated using this model with weaning weight being the only significant value that was also elastic.

Lastly, the fourth model used standardized continuous variables for comparison purposes. Of the significant variables, PAP score was shown to have the most influence on sales price, followed by EPD for yearling weight, frame score, and EPD for stayability.

PAP score, an indicator trait of HAD, was shown to be a heritable trait in cattle in 1981; however, this is the first study where a PAP score has been included in a model showing the marginal effect on sale price by the traits of bulls sold through auctions. This research suggests that BIC bull buyers place a high value on low PAP scores, specifically, for scores under 46. In addition, these buyers will also pay a premium for greater weaning weights, smaller frame scores, and higher EPDs for yearling weight, calving ease total maternal, and stayability. Because these results coincide with the BIC's breeding program goals of maternal ability and strong early growth, this suggests that those goals are being successfully communicated to the buyers.

A limitation to this study is that only three years of auction data are used with one year, 2013, providing atypical sales data due to severe drought conditions in the western United States. Data from sales prior to 2011 were recently made available for future studies. This could be useful in detecting trends which may not have shown up in only three years of data.

The BIC has already developed an EPD for PAP which was added to the 2013 pre-sale catalog and could be included in future hedonic models. EPDs for ribeye area and intramuscular fat are good indicators of the quality of the carcass and have been found to be relevant in recent studies (McDonald et al., 2010; Vanek et al., 2008). Both of these measurements are in the database maintained by the BIC, and, perhaps, should be included in future pre-sale catalogs. Finally, it has been proposed to present a survey to the potential buyers at the 2014 spring bull sale to discover which bull traits they look for and to rank the order of importance. It would be interesting to see if the survey corresponds to the results of this research. It also might reveal potential traits to test in future models.

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