INFLUENCE OF PERFORMANCE AND GENETIC DATA ON THE SALE PRICE OF SEEDSTOCK BULLS

by

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Abstract

Genetic and phenotypic data are often provided to bull buyers at time of sale to aid producers in establishing economic value (pricing) of candidates for selection. This study evaluates the association between the information provided to bull buyers at time of sale and prices paid for bulls sold by two large seedstock operations located in Kansas (KS Ranch) and Colorado (CO Ranch). Data were gathered from 15 sale catalogs that documented bulls sold at auctions taking place from 2009 to 2013. In total, there were 39 potential predictor variables recorded for 2,601 Angus bulls for the KS Ranch; while 14 plausible predictor variables were recorded for 504 purebred and 1,399 Stabilizer bulls at the CO Ranch. Due to extensive multicollinearity between predictors, principal component (PC) analyses were conducted on the standardized predictors to reduce dimensionality within each ranch and genetic group. Eleven PC were considered to provide important meaningful information in summarizing the 39 predictors originally available to buyers at the KS Ranch. For both the purebred and Stabilizer bulls from each set of breed type data in the CO ranch, 6 principal components had eigenvalues greater than 1.0. Similar to the findings for the KS Ranch, these PCs also explained approximately 75% of the cumulative variability of the predictors. Sale prices were then regressed on the corresponding PC using a stepwise selection to identify the PC subset that most significantly explained the behavior of bull sale prices ($P < 0.05$). The final models explained approximately 63%, 37% and 58% of the variation in sale prices received for Angus, purebred and Stabilizer bulls, respectively. Interpretation of the eigenvectors for the PC having the greatest eigenvalues led to the conclusion that buyers put the most weight on growth traits followed by carcass characteristics and economic selection indices. However, no distinction of a specific variable's numerical impact on price was determined.

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Chapter 1 - Introduction

To maintain the current level of beef production in the U.S. with one of the smallest cattle inventories since 1950, beef producers must use technologies or adopt management strategies to improve productivity and efficiency (Hersom et al., 2011). With most beef bulls sold at auction, seedstock producers provide their customers with sale catalogs containing information such as pedigree, phenotypic data, Expected Progeny Differences (EPD), and indices. This information can aid buyers in establishing the value of bulls in the offering relative to the current genetic merit of their herd so as to enable their reaching of breeding goals and objectives (Spangler, 2009). However, determining the actual price of a bull offered for sale by a seedstock breeder remains a complex process (Ishmael, 2005). The animal's physical appearance, phenotypic attributes, and estimates of genetic merit may all contribute to the buyer's appraisal of a bull. Physical characteristics considered may include conformation and structural soundness, frame size, and other observable qualities such as hide color. Data that is commonly provided by the seller to the buyer include pedigree, performance measures or phenotypes – e. g., actual and adjusted birth, weaning, and yearling weights, scrotal circumference and ultrasound scan data – and EPD. With the advancement of production technologies such as selection indices and DNA testing, even more data is available to producers. Buyers are routinely left to their own devices to integrate this information in determining the actual value of each seedstock bull for sale in the context of their respective herds, and thus the corresponding price to pay at auction.

This study evaluates the association between the information provided to bull buyers at time of sale and prices paid for bulls sold by two large seedstock operations located in Kansas (KS Ranch) and Colorado (CO Ranch).

Chapter 2 - Literature Review

Investment in a herd bull is an important management decision for cow-calf producers. Bulls offer the largest contribution to the genetic improvement in cattle herds (Benyshek and Bertrand, 1990), and thus there are many factors to consider when purchasing a bull. Determining the relative emphasis buyers put on various performance measures available to them at the time of purchase could prove valuable for seedstock producers. In turn, awareness of buyer preferences can allow sellers to better meet the product profile demanded by their customers.

Traditional Genetic Evaluation

Throughout the last 50+ years, establishing value of livestock has expanded from visual appraisal to include quantitative evaluations of merit. Before the first national sire summary was published in 1971, the only comparisons that could be made were within contemporary groups (Evans and Buchanan, 2014). The history of genetic evaluation and the concepts that go into calculation of EPD are foundational to this research. The following sections will review the use of EPD and how they are computed. The amount of information used in their computation provides motivation for utilizing EPD as a primary selection tool in purchasing bulls.

To accurately compare animals from different contemporary groups, an analysis that simultaneously evaluates genetic and environmental factors is required. In the mid 20th century, Henderson (1949) first discussed the inability of genetic evaluation at the time to account for differences in environment and management between herds. This limitation motivated Henderson's proposal, which has since come to be known as the best linear unbiased prediction (BLUP; Henderson, 1973), which includes incorporation of fixed and random effects into the statistical model used to predict genetic merit. Such capabilities allow BLUP to incorporate data from multiple contemporary groups of differing average genetic merit, making it the desired method for the genetic evaluation of large populations, entire breeds, or even groups of breeds (Pollak and Quaas, 2005). Through the use of BLUP, prediction error for EPD or for Estimated Breeding Value (EBV; equal to 2*EPD) is minimized while the correlation between the true genetic merit and the EBV is maximized (Henderson, 1973).

However, due to the complexity of calculations, it wasn't until the early 1980s, with the advancement of computer technology, that BLUP become a practical tool to predict BV on a larger scale (Quaas and Pollak, 1980). Until recently, the "animal model" has been considered the most advanced and widely used form of BLUP because of it making comparisons among an entire population of animals (Bourdon, 2000). The animal model takes into account performance of the animal, the animal's pedigree, and performance of the animal's relatives in calculating its EPD, while adjusting for environmental factors. Currently, genomic BLUP (GBLUP) is utilized in cattle evaluations. Through the use of GBLUP, phenotypes and genotypes are weighted based on information from genotyped sires and dams (Lourenco et al., 2015). Although the animal model served as the foundation for this genomic evaluation, GBLUP avoids the "double counting" of genetic contributions due to relationships and submitted records, as well as accounts for preselection bias of genomically selections sires and dams without phenotypes (Lourenco et al., 2015).

The solutions to the BLUP and GBLUP equations are predictions of an animal's genetic merit for the traits in the model. These solutions are called estimated breeding values or EBV. The beef industry has chosen to publish a function of the EBV called the expected progeny difference (EPD) (Beef Improvement Federation, 2010). Expected progeny differences predict differences between offspring of sires or dams, and are one half of the EBV since an animal only receives one-half of its genes from any one parent. For a particular sire or dam, an EPD predicts how much above or below the breed average, its future progeny should perform (Stewart, 2011). Many breed associations complete their own genetic evaluations, so only EPD from the same evaluation can be accurately compared (Evans and Buchanan, 2014).

Prediction accuracy of an EPD can be calculated from its prediction error variance (Beef Improvement Federation, 2010). Prediction accuracy is defined as the correlation between an animal's unknown actual or true BV and the EBV for a given trait (Beef Improvement Federation, 2010). Expressed as a value from 0 to 1, the closer the accuracy value is to 1, the more likely it is that the EPD is close to the true genetic merit. As more data is added to the animal's record, the accuracy of the EPD increases and less change in it is expected over subsequent evaluations. A high accuracy, usually considered greater than 0.7, indicates a higher degree of confidence can be placed on the EPD. A low accuracy, often less than 0.4, could result in greater change in an EPD as more data is collected (Evans and Buchanan, 2014). Genetic evaluations by breed associations may be performed at different frequencies, ranging from weekly to yearly. Therefore, an animal's EPD are recalculated throughout its lifetime and can change as more data from its relatives, itself, and its eventual progeny are recorded and incorporated into the data. With an increase in data reported on an individual and its relatives, the accuracy of an individual's EPD is improved (Bourdon, 2000). Other factors that impact accuracy are heritability of the trait being evaluated and relationships with other evaluated animals (Bourdon, 2000). Given otherwise similar information, prediction accuracy is greater for traits with higher heritability than it is for traits with lower heritability (Bourdon, 2000). In addition, the more closely related the source of data is to the animal receiving predictions, the higher the resulting prediction accuracy can be expected to be (Bourdon, 2000).

DNA Testing

By the late 1980's and early 1990's, technology capable of providing information about the genetic code of living organisms was in its early stages of development (Womack, 2005). The study of genomics allows for improved understanding of an animal's genetics and the biology associated with economically important traits (Herring et al., 2013). Since its inception, genomics have come to be used in the beef industry as a selection tool (Bullock et al., 2012). Further, genomic technologies provide breeders with methods for parentage verification and identification of qualitative traits (e.g., genetic defects), in addition to genetic evaluation of quantitative traits of economic interest (Bullock et al., 2012).

One of the earliest applications of DNA technology in the beef industry was parentage verification (Glowatzki-Mullis et al., 1995). In the commercial cow-calf sector, multi-sire pastures are common. Therefore, DNA identification is needed to identify which progeny belongs to individual sires. Misidentification of parentage results in biased estimates of genetic parameters, thereby impairing genetic gains from selection (Van Vleck, 1970; Senneke et al., 2004). Further, incorrect relationships decrease estimates of heritability and produce bias estimates of EPD. Parentage identification can reduce these errors (Dodds et al., 2005).

Genomics have also proven useful in identifying simple recessive traits such as coat color, horned or polled status, and a range of genetic defects (Eenennaam, 2015). In fact, genomics has saved numerous dollars with the identification of animals carry recessive alleles that cause genetic defects, such as Arthrogryposis Multiplex, Neuropathic Hydrophalus, and Congenital Contractural Arachnodactyly (Bullock et al., 2012; Eenennaam, 2015). Instead of culling entire lines of cattle, genomics allows for tailored culling of only those animals carrying the undesired allele.

Lastly, genomics can be used as a selection tool to establish breeding values for a variety of traits based on realized relationship, as obtained from genotypes, as opposed to expected relationships. By combining genomics with phenotypic information, genomically enhanced EPD can be produced and used in animal evaluation and selection (Bullock et al., 2012). In beef cattle production, these genomically enhanced EPD are currently the most accurate prediction of genetic merit available (Swan et al., 2012).

Selection Indices

Economic productivity and profitability are foundational to efficiency of any system. In production agriculture, goals of selection indexes are to simplify genetic selection and allow producers put appropriate emphasis on traits that have significant economic importance in a particular production system. An economic index is a collection of EPD weighted by their economic value. Traits with larger impacts on production goals have a larger economic weight associated with them (Spangler and Schiermiester, 2013). Phenotypic and genetic variances and covariances are needed to create an economic selection index, along with the economic value of each trait (Hazel, 1943).

Developed in the 1930s and 1940s, selection indices were used to evaluate livestock for several traits simultaneously, and maximize genetic potential for a given multi-trait breeding objective (Hazel, 1943). As a forerunner to BLUP, selection indices were first implemented for making linear predictions of breeding value by combining information on the animal and its relatives. This information included the animal’s own performance records and a limited set of the animal’s relatives. Properties of a selection index include: 1) minimizing the average square prediction error; 2) maximizing the correlation between the true breeding value and the index;

and 3) maximizing probabilities of correctly ranking pairs of animals on their breeding values (Mrode, 2013).

Selection index methods were also used to combine multiple traits with their relative economic values to predict an animal's aggregate breeding value in terms of economic merit (Henderson, 1963). In other words, a selection index can produce a single genetic prediction for each animal that estimates its economic value. With appropriate economic weights, selection index is a superior tool to achieve a breeding objective compared to single-trait selection or multi-trait selection with either tandem selection or independent culling levels (Hazel and Lush, 1943). Although phenotypic indices allow for multi-trait selection for within herd evaluation, such measures are inappropriate for National Cattle Evaluations (NCE) because they do not facilitate comparisons among animals is different contemporary groups (Henderson, 1975). By combining index theory with EBV from NCE, animals in different contemporary groups can be compared on the basis of their economic merit (Henderson, 1963; MacNeil, 1997).

Since its inception, many industries have adopted selection indexes to improve the genetic merit of their respective populations. For instance, in 1971, the United States Department of Agriculture created the first economic selection index, Net Merit, for the dairy industry (VanRaden, 2005). Acceptance of selection indices within the beef industry was not fully achieved until 1997 when a partnership between University of Missouri, Circle A Ranch, American Breeders Service and USDA Agricultural Research Service rolled out a "Total Profit Index" (MacNeil and Herring, 2005). Since then, the American Angus Association, American Hereford Association, American Simmental Association, Red Angus Association of American, American Gelbvieh Association, and others have adopted the concept. By providing customers with financial information that influences an operation's bottom line, a decision support system was created (Newman et al., 2000). This in turn allowed producers to effectively evaluate implications of using alternative sires based on traits that are economically relevant to their production goals. While it might seem use of selection indices would address the weight buyers should give to the individual pieces of performance information, few buyers have formal selection indices and sellers often provide pieces of information that are collinear and therefore confusing. The key to successful use of selection indices is to align the market endpoint of the index with the operation's market endpoint (Weaber, 2014). Thus, buyers may misplace emphasis on traits that aren't necessarily desirable to achieve a specific production goal (Weaber, 2014).

Determination of Prices Paid for Goods Based on Their Characteristics

The study of consumer theory dates back to the 1870's during the neoclassical revolution (Hands, 2009). A dominant assumption that encompasses a majority of consumer theories is the behavior of a rational consumer. Economists define rational behavior as behavior in accordance with a systematic set of preferences (Green, 1978). These preferences are a function of total income, social welfare, and maximization of utility or pleasure (Hall, 1990). In the context of beef production, determining how various pieces of information impact sale price of seedstock bulls can be expected to provide a better understanding of purchasers' preferences relative to the data that is available to them.

In the past, primarily hedonic (i.e., pleasure-based) pricing models were used to determine the value of breeding bulls. These models estimate a marginal value of a product based on its input characteristics. Rosen (1974) is often credited with developing one of the first theoretical frameworks for the hedonic pricing model. The model developed by Rosen to describe the price of a good, $p(z)$, is as follows:

$$p(z) = p(z_1, z_2, . . . , z_n)$$

where z_i represent characteristic of the i^{th} good. Through the utility maximization theory, the marginal bid price for a given product is equal to the sum of the marginal implicit prices for the product's characteristics (Ladd and Martin, 1976).

Hedonic pricing models have also been used to establish the value of numerous commodities based on their characteristics. Examples include establishing worth of: farm and industrial land (Palmquist and Danielson, 1989; Kowalski and Paraskevopoulos, 1991; Xu et al., 1993; Nickerson and Lynch, 2001), irrigation water (Faux and Perry, 1999), automobiles (Triplett, 1969; Griliches, 1971), and household and capital goods (Phyrmes, 1967). Hedonic pricing models also have been used to determine value for agricultural goods such as alfalfa (Klemme et al., 1988; Hopper et al., 2004), cotton (Ethridge and Davis, 1982; Brown et al., 1995), apples (Carew, 2000), honey (Unnevehr and Gouzou, 1998), wheat (Espinosa and Goodwin, 1991; Ahmadi-Esfahani and Stanmore, 1992; Wilson, 1989), and tractors (Fettig, 1963).

Richards and Jeffrey (1995) found the hedonic pricing model to be a simple and powerful method for establishing the value of each component of a bull's genetic proof based on the price of his semen. They used an index depicting the contribution of a genetic profile to herd profitability. This framework has also been used to predict value of various genetic and phenotypic profiles of dairy cattle (St-Onge et al., 2001; Richard and Jeffrey, 1996; Gibson et al., 1992; Schroeder et al., 1992; Kareemulla and Srinivasan, 1992; Trimberger and Etgen, 1983), swine breeding stock (Walburger and Foster, 1994), milk components (Lenz et al., 1994; Gillmeister et al., 1996), and thoroughbred and quarter horses, and broodmares (Lansdord et al., 1998; Neibergs, 2001; Robbins and Kennedy, 2001; Taylor et al., 2004). Further, use of hedonic models has allowed price evaluation of cow-calf pairs (Parcell et al., 1995), cull cows (Minert et al., 1990), preconditioning programs (Ward and Lalman, 2003), feeder and fed cattle (Sullivan and Linton, 1989; Schroeder et al., 1988; Turner et al., 1991; Jones et al., 1992; Dhuyvetter and Schroeder, 2000), the use of ultrasound in marketing techniques (Lusk et al., 2003; Rimal et al., 2003), and beef cut prices (Unnevehr and Bard, 1993).

Price Determination of Purebred Bulls

Greer and Urick (1988) studied relationships between economic variables and sale average price of purebred bulls. Data was collected from the Montana Agricultural Experiment Station's sale of Line 1 Hereford bulls between 1966 and 1984. The hypothesized model was:

$$\text{Bull Price} = f(\text{CP, CI, HI, D78, D79})$$

where: f represented a geometric distributed lag model, CP was the average fourth quarter price of a medium frame, number 1 feeder steer, CI was the cow inventory and HI was the heifer inventory as of January 1 of each year. The dependent variable was the average price of the bulls sold in the sale. To account for the change in reputation of the livestock sold in the Line 1 sale during the sampling period, D78 and D79 were dummy variables used to represent the years 1978 and 1979. Because the model (f) was nonlinear, a modified Marquardt nonlinear least-squares algorithm was used to estimate the effects. The model accurately explained the inter-annual variation in the Line 1 bull sale ($R^2 = 0.98$). In that study, bull sale prices were found to be positively correlated with and proportional to feeder calf prices and cowherd inventory (Greer and Urick, 1988).

Simms et al. (1994) surveyed 312 Kansas commercial cattle producers who purchased a performance-tested bull in sales that were sponsored by Kansas State University and the Kansas Livestock Association and held at Beloit and Potwin in 1993. Their objective was to determine the relative importance of various traits when selecting breeding bulls. Breeds represented were Angus, Simmental, Charolais, Gelbvieh, Red Angus, Salers, Limousin, and Horned Hereford. Among recorded phenotypic characteristics, calving ease score was deemed most important by 25% of producers surveyed and it was ranked in the top 3 selection criteria by 49% of survey participants. Frame score was the most important selection criterion for an additional 12% of breeders surveyed, followed by birth weight and visual appraisal at 11% each. Because calving ease scores were not consistently reported across all breeds and birth weight is perceived as strongly and negatively correlated with calving ease (Patterson, 2005; Greiner, 2004), the survey results could be interpreted to suggest concerns about calving ease were an important consideration for a majority of producers. The authors (Simms et al., 1994) were of the opinion that “the relatively low level of emphasis on EPDs indicated that producers were not using the most accurate selection criteria available”, though no objective criteria was offered to support this statement.

Dhuyvetter et al. (1996) evaluated the impact EPD have on the value of bulls. Relationships of sale price with physical characteristics, genetic information, phenotypic measures, and marketing strategies were examined using data from 1,700 bulls sold in 26 purebred beef bull sales in Kansas. Dhuyvetter et al. (1996) created multiple hedonic models that included and excluded birth, weaning, and milk EPD. When EPDs were omitted from the models, bulls that were black and/or polled had greater sale prices. Angus bulls commanded greatest prices ($P < 0.05$) relative to the other breeds, which were similar. However, when EPD were included in the model, breed effects were not significant and adjusted weaning weight, birth weight EPD, and direct and maternal weaning weight EPD were all associated with prices paid for bulls ($P < 0.05$). All three EPD were related to sale price of Angus and Simmental bulls (P <

0.05). However, for Gelbvieh bulls, only birth weight EPD and milk EPD were associated with prices paid ($P < 0.05$). For Hereford and Limousin bulls, only the weaning weight EPD was related to price ($P < 0.05$). The milk EPD was the only EPD associated with price of Red Angus bulls ($P < 0.05$). These results are interpreted to suggest that use of EPD in informing bull sale price varies considerably across breeds.

In a similar study, Turner (2004) also compared the value of phenotypes, including ultrasound, and EPD for bulls on prices paid at auction. The birth weight EPD was valued more than actual weight, but this did not hold true for the remaining performance EPD. Carcass and ultrasound EPD were closely related to price, suggesting that buyers were increasing emphasis on carcass quality traits. Turner also observed that ultrasound EPD and phenotypes were more valued than over EPD based on carcass data.

Chvosta et al. (2001) used a hedonic model to compare values of EPD and phenotypes on sale price of bulls. Two data sets were used to determine if alternative measures of future performance caused differences in prices paid for bulls. The first data set included data on 1,144 bulls sold from 1982 to 1997, by an Angus breeder in Montana. The second data set was comprised of 6,685 bulls sold from 1986 to 1996, by 11 Angus breeders in Nebraska and South Dakota. Bull price was modeled as a function of beef price, feed price, age, and performance measures. Predictors found to be significantly were age, age squared, 205-day weight, 365-day weight, birth weight EPD, and yearling weight EPD. When the model included both EPD and phenotypes, R^2 was 0.40. However, R^2 decreased to 0.25 when the model only contained EPD, but increased to 0.37 when it only contained phenotypes. Therefore, it was concluded that both EPD data and phenotypes were strongly associated with sale price. However, similar to Simms et al. (1994), buyers seemed to give phenotypic information greater credence than EPD, despite the EPD being the more accurate predictor of performance by future progeny.

Walburger (2002) investigated underlying determinants of prices of approximately 800 bulls sold in Alberta, Canada from 1989 to 2000. Attributes examined were birth weight, sale weight, predicted lean meat yield, average daily gain, scrotal circumference, and ribeye area and fat depth measured using ultrasound. They used a hedonic Tobit regression model that revealed 3 structurally different time periods. These time periods were 1989 and 1993, 1996 to 1997, and 1998 to 2000. During all 3 periods, sale weight, birth weight, and scrotal circumference were significant predictors of sale price, while average daily gain and fat depth were only significant during the last time period. Walburger (2002) suggested that the shift in selection criteria during the last time period might be due to producers starting to better understand and therefore use performance data in their selection decisions.

In terms of marketing factors: sale order, pictures and semen retention seemed to be potentially related to price. In general, prices declined at a decreasing rate as bulls were sold later in the sale (Dhuyvetter et al., 1996; Turner, 2004). If a sale contained 120 or more bulls, a discount of 20% was seen just over halfway through the sale. A similar discount was observed after 80% of bulls had been sold in sales that had 60 bulls to offer. Although prices declined for bulls sold later in sales, this could be a function of better bulls being sold earlier in the sale. Bulls pictured in the sale catalog received approximately 27% higher prices compared to bulls that were not pictured (Dhuyvetter et al., 1996). Retention of a semen interest by the breeder resulted in a greater price being paid for the bull (Dhuyvetter et al., 1996; Turner, 2004), with the premium decreasing as the percentage of bulls with retained semen rights increased (Dhuyvetter et al., 1996). Turner (2004) also found that bulls not having “unique” pedigrees and bulls that were sold in the spring were discounted. It was hypothesized that when several bulls of similar ancestry were offered for sale, they may be considered as close substitutes for each other in terms of genetic merit (Turner, 2004). The availability of these substitutes increased the perceived supply of the particular genetic package and thus reduced the price (ceteris paribus).

Taken together, bull prices were associated with performance measures, physical attributes, and expected performance predictors of the bull, but marketing techniques (i.e. sale order, semen retention, pictures, etc) not necessarily related to the quality of the bull also impacted prices paid for bulls at auction.

The concept of establishing value of a good based on its characteristics as found in the hedonic pricing model set the foundation for this research. As discussed above, when used in determining factors affecting prices paid for bulls, these models were most commonly implemented using regression analyses. However, using multiple regression with potentially strong collinearity among the independent variables results in the possibly of elevated levels of Type I and Type II errors (Tu et al., 2005). In addition, collinearity can sometimes lead to serious stability problems in regression analysis (Weisberg, 1985). Multivariate analysis that can account for these relationships may be necessary to determine more accurately what traits have an impact on sale price.

Multivariate Analysis

One problem that confronts the stereotypical buyer of seedstock at a production sale is the plethora of data that are presented for each candidate in the sale catalog. This abundance of data may be justified by the sellers as it allows individual buyers to tailor their decision-making. However, it may also lead confusion on the part of buyers due to "information overload" (Enns, 2013). There is a degree of collinearity among the data that characterizes individual bulls. Tu et al. (2005) presented a concise overview of statistical ramifications relative to prediction in the presence of collinearity.

Multivariate statistical methods can be used to facilitate making sense out of large datasets with many interrelated variables (Johnson and Wichern, 2007). Among other applications, multivariate methods are useful when the objectives of a scientific investigation require: 1) data reduction or structural simplification; 2) sorting and grouping; 3) investigation of variable dependence; 4) prediction; and 5) hypothesis construction and testing (Johnson and Wichern, 2007). As overviewed previously, multiple phenotypic and genotypic factors can impact the price of seedstock bulls. However, none of the previous studies used multivariate statistical methods to address issues that arise from collinearity or simplify the structure of the data.

First developed by Pearson (1901), principal components analysis (PCA) is a statistical method that transforms a set of potentially correlated variables into orthogonal linear functions (Wold, 1987). A principal component (PC) can is as an optimally-weighted linear combination of the observed variables. The terminology "linear combination" refers to a sum of products for each variable multiplied by a constant, while "optimally weighted" refers to the constants being calculated so that the resulting component accounts for the maximum amount of otherwise unexplained variance in the data set. Thus, the first component accounts for the maximum amount of total variance in the observed variables. The second component accounts for the maximum amount that is left unexplained by the first and is orthogonal to the first, and so on with subsequent components. Therefore, each proceeding component will account for smaller and smaller amounts of the total variance, while staying uncorrelated (i.e. orthogonal) to the other components (Cooley and Lohnes, 1971). The end goal of a PC analysis is data reduction and simplification (Johnson and Wichern, 2007). The principle component scores can then be used in further analysis as independent variables in subsequent regression analyses (Hotelling, 1957; Kendall, 1957).

Information produced in a PCA analysis includes the eigenvectors containing the optimal weights or loadings for the variables as described above and the associated eigenvalues. For each individual, the loadings can used to calculate a PC score as the sum of the products of the loadings and variables. Further, the magnitude of the loadings measures the relative contribution of each standardized predictor to the corresponding principal component (Fernandez, 2011). The PC scores are uncorrelated. The corresponding eigenvalues can be used to calculate indicate how much of the variability of predictors in the data can be explained by a particular PC eigenvector or PC (Jolliffe, 2002).

Due to the use of multiple linear regression approaches with potentially strong multicollinearity amongst predictors in the previous studies, there exists the possibly of biased inference, as well as elevated levels of Type I and Type II errors (Tu et al., 2005). Among strategies, recommended by Tu et al. (2005), for addressing problems arising from collinearity was regressing responses of interest on principal component scores that summarize the many interrelated predictors available.

Summary

The seedstock cattle industry has seen significant informational change over the last 30 years. Data recording and genetic evaluation provide bull buyers with many pieces of information on individual seedstock bulls. This information aids buyers in making more informed breeding decisions and allow for greater genetic progress. By understanding how information available to buyers at time of sale is used and its association with sale price of seedstock bulls, sellers could potentially improve their understanding of customer preferences. However, previous studies failed to accurately account for collinearity and redundancy among the many pieces of information available. By implementing multivariate statistical methods, the issues that arise from collinearity are better addressed.

Chapter 3 - Materials and Methods

Description of Data

Data from this study were collected from 2 of the top 5 seedstock operations in the U.S., in terms of numbers of bulls sold annually according to Beef Magazine (http://beefmagazine.com/2016-seedstock-100). The first operation was an Angus seedstock operation from southwest Kansas (KS Ranch); while the second was a purebred and composite seedstock operation from north-central Colorado (CO Ranch). The composite cattle at the latter ranch are referred to by the trade-name "Stabilizer." Bulls included in this study were offered to buyers through production sales that were conducted as auctions. All data that were included in the sale catalogs and prices that were received by the sellers for bulls sold from 2009 to 2013 at these two ranches were included in this study.

There were 3,501 bulls sold in 10 sales held by the KS Ranch. Of the 3,501 bulls that were sold complete data were available for 2,609 of them. Seven of these bulls were identified as being carriers for a genetic defect and were removed from the final analysis. Sale prices ranged from $2,250 to $270,000, with a mean of $5,116 and median of $5000. No bulls were sold for less than $2,250.

Table 3.1 lists the potential predictors considered in this study, consisting of indicators of performance or genetic merit, which were consistently presented to potential buyers across all sales and used to characterize the bulls sold by the KS Ranch. It is noted that, due to differences in reporting across sales, some predictors that could be deemed desirable could not be included in this study. The docility EPD was not considered as a predictor in this study because it was not introduced until 2011 and thus was not available for approximately half of the bulls that were sold. Mature weight and height were also not consistently presented, and were therefore excluded from the analyses.

Figure 3.1 depicts the empirical distribution of age at time of sale for the 2,609 bulls sold at the KS Ranch. The histogram reveals a tri-modal distribution. The distinct peaks indicate different age groups of bulls being offered for sale. The three modes represent yearling bulls, 15-month-old bulls, and 18-month-old bulls. The youngest bull was 355 days of age and the oldest being 774 days of age. Approximately 63% of the bulls were between 523 and 628 days of age at time of sale.

Of the initial 2,691 bulls offered in the sales of the CO Ranch, only 2,080 had a recorded sale price. A lack of sale price indicated that the bull did not reach the minimum bid to be sold. These animals were kept for private treaty and were excluded from this analysis. Prices received for bulls that were sold by the CO Ranch ranged from $1,250 to $76,000, with means (medians) of approximately $3,500 ($3000) and $4,100 ($3500) for purebred and Stabilizer bulls, respectively.

As with the KS Ranch data set, some predictors that might be deemed of interest were not recorded across all sales. Adjusted weights and ultrasound measurements were only presented in 2009 and 2010 catalogs. Adjusted scrotal circumferences and height were reported every year, except 2013, wherein EPD for scrotal and height were presented. Changes in marketing strategy affected information available to buyers. From 2009 to 2013, dollar indexes reflective of weaning profitability and overall profit potential were provided to buyers. In 2013, the weaning index, $Weaning, was renamed to $Ranch, and a profit predictor for the value of feeder calves for terminal scenarios was added. Therefore, only factors consistently reported across all years were included in the data analysis (Table 3.2) and data from 1,913 bulls were used in this study.

Histograms depicting bimodal distributions of bull age at time of sale are shown in Figures 3.2 and 3.3 for purebred and Stabilizer bulls, respectively. The bimodal distribution for the purebred bulls shows offerings of 12- and 18-month old bulls with a few older bulls also being sold. Virtually all of the Stabilizer bulls sold were less than 15 months old. Overall, approximately 92% of the bulls offered for sale were between the ages of 337 to 462 days. Other continuous variables describing the bulls sold had approximately normal distributions.

Data Analyses

Data from the Angus bulls offered for sale by the KS ranch and purebred and Stabilizer bulls offered by the CO ranch were analyzed in three separate analyses using similar quantitative approaches. Briefly, 1) principal component (PC) analyses were conducted on predictors that characterized the bulls; 2) prices paid for the bulls were regressed on PCs that were important (as judged by the Kaiser (1960) criterion of eigenvalues ≥ 1.0) and breed and defect carrier status when appropriate; 3) outliers from the distribution of prices were identified and these observations were removed from the data; 4) step 1 was repeated using the edited data; and 5) prices paid for bulls were regressed on all PCs using a stepwise model selection approach.

As recommended by Johnson and Wichern (2007), predictors were standardized prior to PC analyses in order to minimize effects of scale of measurement. Standardization was conducted within each ranch and breed. For standardization, each observation on a given predictor was expressed as a deviation from its corresponding mean and divided by its SD from the corresponding ranch and breed type. Analyses for PC decomposition were conducted using the PRINCOMP procedure in SAS v9.2 (SAS Institute Inc., Cary, NC).

To identify potential extreme observations on price, preliminary regression analyses of price on breed (CO ranch purebred data only), defect carrier status, and PCs that were important as judged by the Kaiser (1960) criterion to obtain the residuals which were externally transformed to t-statistics and then compared with a Bonferroni-adjusted critical value from a Student's t-distribution with degrees of freedom given by the number of observations in each analysis minus 1 (Kutner et al., 2005). Specific critical values were 4.28 for the KS ranch data, 3.93 for the CO ranch purebred data, and 4.15 for the CO ranch Stabilizer data. This being an extremely conservative approach, any observations with studentized residuals more extreme than the critical value were considered not representative of the population under study and were removed from further analyses. A total of 8 bulls from the KS ranch were identified using this approach, their sale prices ranging from $42,000 to $270,000. At the CO ranch, data from 4 purebred and 6 Stabilizer bulls were similarly excluded from further analyses. Their sale prices ranged from $15,500 to $76,000.

After removing the data which were outliers from the distribution of prices, a total of 39 principal components were again produced from the KS Ranch data and from the purebred and Stabilizer data from the CO Ranch. A scree plot was constructed in a further attempt to determine the number of meaningful components. For each dataset, PC scores were calculated as the sum of products of the loadings and corresponding observations in the standardized scale.

Following the final PC analyses, bull sale prices for each breed type and ranch were regressed on their corresponding principal components scores. For the purpose of numerical stability in computations, bull sale prices were divided by 1,000 and re-expressed as multiples of 1,000 (e.g. a bull price of $5,000 was re-expressed as $5 *1000). Further, responses were subjected to log transformation to ensure that model assumptions were reasonably met. These principal components regression analyses were implemented using the GLIMMIX procedure SAS (SAS Institute Inc., Cary, NC). In all three of these analyses, the dependent variable was price, defect status and year were independent fixed classification variables, and the principal component scores were continuous fixed linear independent variables. In addition, because the purebred data from the CO ranch included multiple breeds, breed was added to that model as an additional independent random classification variable. Following Jolliffe (1982), all of the principal components were considered as potential independent variables in the regression models. For each dataset, forward stepwise model selection was implemented to identify the predictors (in the PC scale) that best explained the behavior of bull sale prices, expressed in the log scale. The criterion used for selection was Bayesian Information Criterion. Final models were selected as those whereby addition or removal of any PC predictor failed to reduce the BIC by 2.0. Additionally, for the purpose of comparison, similar regression analyses were conducted using only those PC that satisfied the Kaiser (1960) criterion as independent variables. Differences between these regression models were summarized using the residual variance, coefficient of determination, Bayes information criterion, and Mallows (1973) Cp.

Table 3.1. Performance and genetic data descriptions for Angus bulls sold through auction at KS Ranch.

Variable	Abbreviation	Definition
Age	age	Age (d) at time of sale.
Defect Status	defect	Indicates a carrier of a genetic defect.
		Phenotypes
Birth Weight	BWT	Weight at birth (lb).
Weaning Weight	WWT	Weaning weight (lb) adjusted to an age of 205 d.
Yearling Weight	YWT	Yearling weight (lb) adjusted to an age of 365 d.
Average Daily Gain	ADG	Growth rate (lb/d) between recorded weaning and yearling weights.
Yearling Frame	FSC	Yearling frame score based on Beef Improvement Federation (2010) guidelines.
Yearling Height	YHT	Yearling hip height (in) adjusted to an age of 365 d.
Scrotal Circumference	SCR	Scrotal circumference (cm) adjusted to an age of 365 d
Intramuscular Fat	IMF	Age-constant fat within the ribeye, as measured by ultrasound.
Ribeye Area	REA	Age-constant area of ribeye (in^2), as measured by ultrasound.
Rib Fat	RBF	Age-constant depth of fat cover over the 12th rib (in), as measured by ultrasound.
Rump Fat	RPF	Age-constant fat depth over rump (in), as measured by ultrasound.
		Performance Ratios
Birth Weight	BWR	Birth weight of individual relative to average of its contemporaries.
Weaning Weight	WWR	205-d weight of individual relative to average of its contemporaries.
Yearling Weight	YWR	365-d weight of individual relative to average of its contemporaries.
Average Daily Gain	DGR	Postweaning growth rate of individual relative to average of its contemporaries.
Intramuscular Fat	IMFR	Intramuscular fat of individual relative to average of its contemporaries.
Ribeye Area	REAR	Ribeye area of individual relative to average of its contemporaries.
Rib Fat	RBFR	Rib fat of individual relative to average of its contemporaries.
Rump Fat	RPFR	Rump fat of individual relative to average of its contemporaries.
		Expected Progeny Differences (EPD)
Calving Ease Direct	CE_d	EPD for calving ease (%) for calves out of 2-yr-old heifers. Greater values indicate fewer assisted births.
Birth Weight	BW	EPD for birth weight (lb).
Direct Weaning Weight	WW	EPD for direct 205-d weight (lb).
Yearling Weight	YW	EPD for 365-d weight (lb).
Yearling Height	YH	EPD for hip height at 365-d of age (in).

Table 3.1. (Continued) Performance and genetic data descriptions for Angus bulls sold through auction at KS Ranch.

Variable	Abbreviation	Definition
		Expected Progeny Differences (EPD) – continued
Scrotal Circumference	SC	EPD for scrotal circumference at 365-d of age (cm).
Calving Ease	CE_m	EPD for calving ease (%) for calves born to 2-yr-old heifers.
Maternal Weaning Weight	MM	EPD for maternal weaning weight (lb), commonly referred to as “milk”.
Carcass Weight	CWT	EPD for hot carcass weight (lb).
Marbling	MB	EPD for USDA marbling score.
Ribeye Area	RE	EPD for ribeye area (in^2).
Fat Thickness	FT	EPD for fat depth (in) combining and rump fat measures.
		Economic Indices
Cow Energy Value	$EN	Cost savings per cow per year ($), resulting from differences in energy requirements.
Weaned Calf Value	$W	Returns to weaning ($) as a function of BW, WW, MM, and mature cow size.
Feedlot Value	$F	Returns from feeding ($) as a function of WW, YW, and feed intake.
Quality Grade	$QG	Transformation of MB into economic terms ($).
Yield Grade	$YG	Multi-trait index ($) of CWT, RE, and FT indicating value of red-meat yield.
Grid Value	$G	Combines components of $QG and $YG to predict carcass merit ($).
Beef Value	$B	Combines components of $F and $G to facilitate multi-trait genetic selection for feedlot and carcass merit ($).

Figure 3.1. Distribution of days in age for bulls at time of sale at KS Ranch (N = 2609).

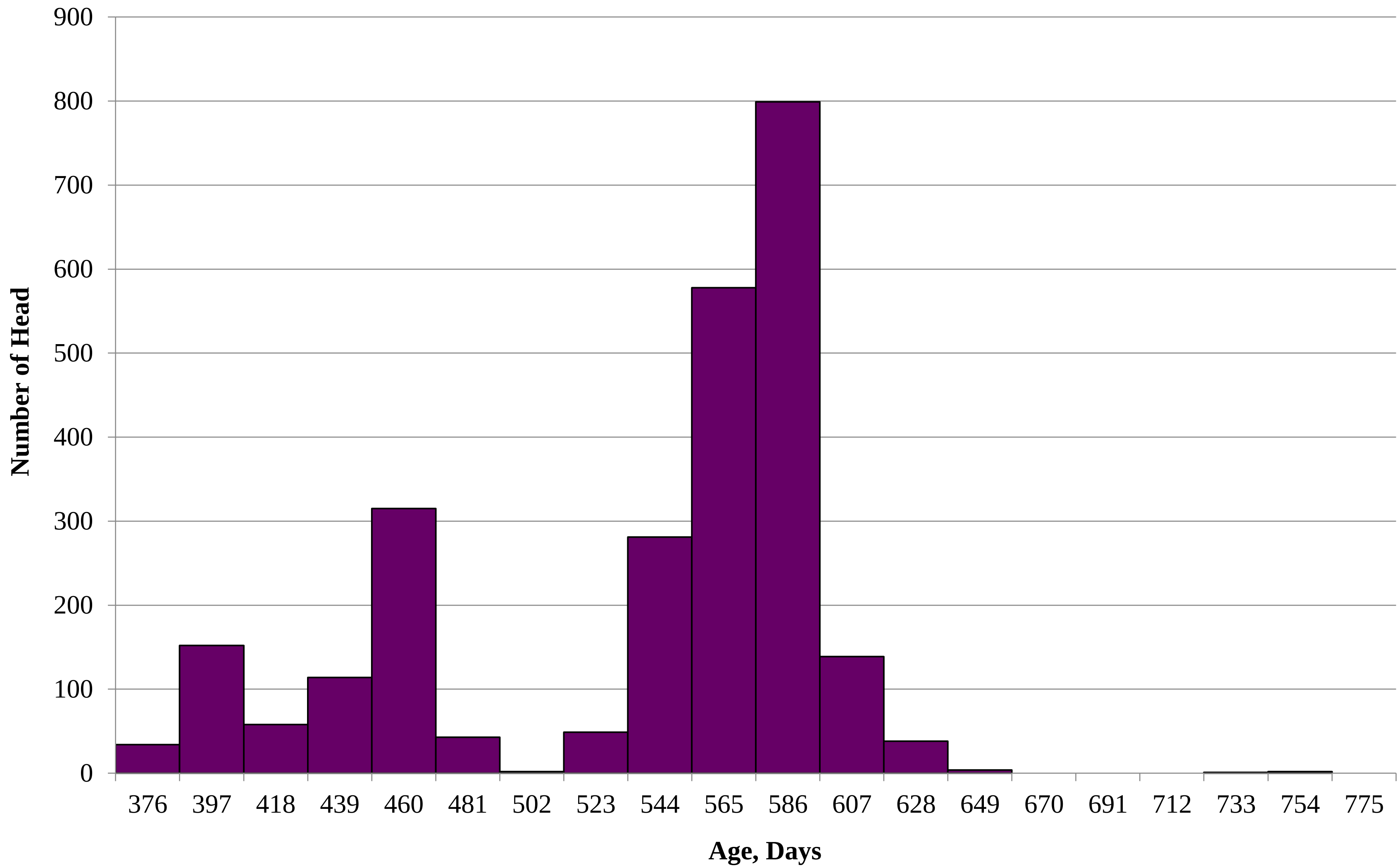


Table 3.2. Performance and genetic data descriptions for purebred and Stabilizer bulls sold by the CO Ranch.

Variable	Abbreviation	Definition
Age	age	Age (d) at time of sale.
Defect Status	defect	Indicates a carrier of a genetic defect.
		Phenotypes
Birth Weight	BWT	Weight of animal at birth.
		Scores[1]
Calving Ease	CES	Predicted calving ease for bull used on heifers.
Disposition	DSP	Individual's temperament: 5 = very calm, 3 = average, 2 = nervous.
		Expected Progeny Differences (EPD)[2]
Birth Weight	BW	EPD for birth weight (lb).
Weaning Weight	WW	EPD for direct 205-d weight (lb).
Maternal Milk	MM	EPD for maternal 205-d weight (lb) commonly referred to as "milk".
Yearling Weight	YW	EPD for 365-d weight.
Feed to Gain	FG	Predicts feedlot efficiency. A negative indicates increased efficiency.
Mature Weight	MW	EPD for weight at 5-years of age.
Marbling	MB	EPD for USDA marbling score.
Ribeye Area	RE	EPD for ribeye area (in2).
		Economic Indices
$Ranch	$R	Economic index for weaning endpoint ($) based on CES, WW, MM, cow cost, and fertility, assuming slide on calf prices of $10/cwt.
$Profit	$P	Economic index for life-cycle production ($) that gives each trait a weight according to its impact on profit, assuming production of 100 progeny.

[1] In-house evaluation developed over time by CO Ranch.
[2] Two sets of EPD are used by the CO Ranch to present genetic values for their cattle. The first is an across-breed EPD as defined in the Beef Improvement Federation (2010) Guidelines and is used for the purebred cattle. The second is an in-house developed evaluation system used to compare the genetic merit of Stabilizer cattle and used for purebred cattle when an EPD is not available from the breed association. Herein, the latter set of EPD is designated by a prime following the abbreviation (e.g., BW').

Figure 3.2. Distribution of days of days in age, at time of sale by the CO Ranch, for purebred (N = 508).

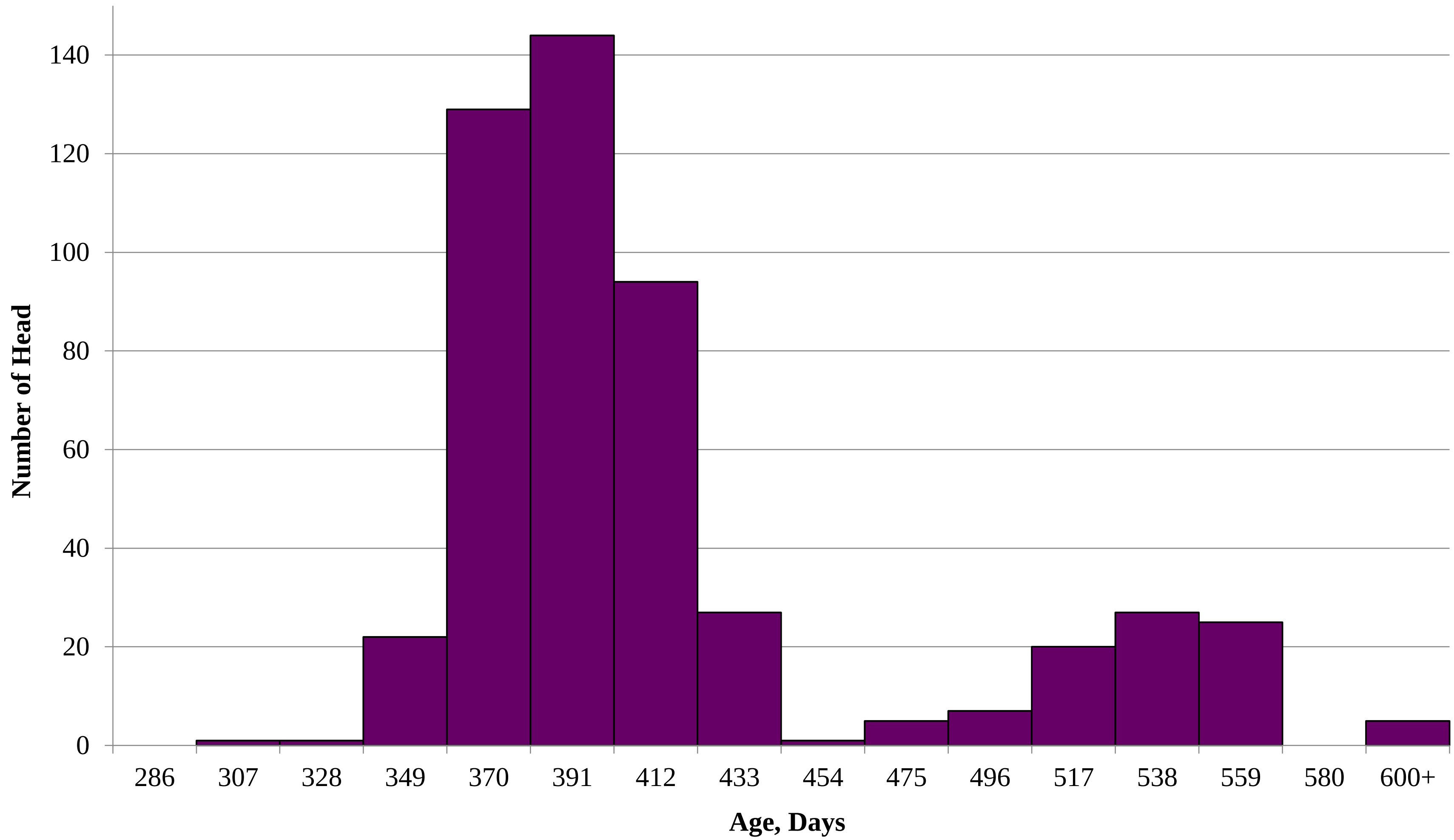
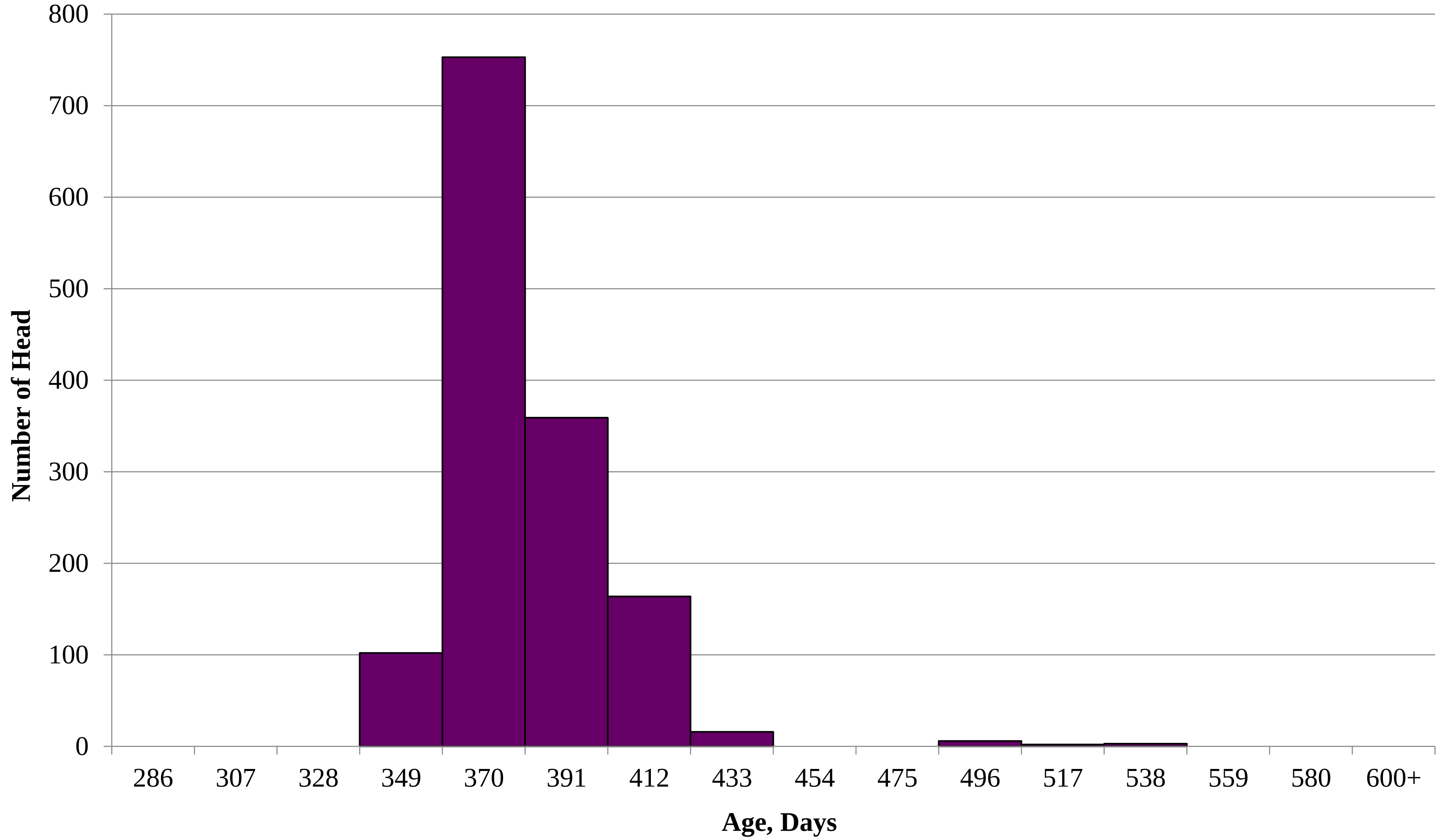


Figure 3.3. Distribution of days of days in age, at time of sale by the CO Ranch, Stabilizer bulls (N = 1405).



Chapter 4 - Results

Bulls offered for sale at auction by the KS and CO ranches that contributed data to this study were characterized by sets of data that contained 39 and 14 individual traits, respectively. Thus, 39 PCs were produced from the KS ranch data and 14 principal components were produced for the purebred and Stabilizer data from the CO Ranch. Shown in Tables 4.1, 4.2, and 4.3 are univariate statistics summarizing the data for all bulls sold by the KS Ranch, and purebred and Stabilizer bulls sold by the CO Ranch, respectively. Tables 4.4, 4.5, and 4.6 contain correlation matrices describing the respective multivariate distributions of the standardized performance data. Bulls that were known to be heterozygous for an allele which would confer a genetic defect if homozygous were rare (< 2%) in all three datasets and thus defect status will not be discussed further.

Principal Components Analysis

Figure 4.1 shows the scree plot of eigenvalues and cumulative variance explained by principal components for data from the KS Ranch. Using the Kaiser criterion (i.e. meaningful PC with eigenvalues >1), 11 PC were considered to provide meaningful information in summarizing the 39 predictors originally available. In fact, the first 11 PC jointly explained approximately 75% of the cumulative variance. Table 4.7 lists the loadings of the top 11 PCs satisfying the criterion by Kaiser (1960) for the 38 predictors. Loadings corresponding to the remaining PCs are listed in Appendix A.

Similarly, Figures 4.2 and 4.3 illustrate scree plots of eigenvalues and corresponding cumulative variances for purebred bulls and Stabilizer bulls from the CO Ranch, respectively. For consistency, the Kaiser (1960) criterion was again used to select the most meaningful PCs to summarize predictors in each case. For both the purebred and Stabilizer bulls from the CO ranch, 5 principal components had eigenvalues greater than 1.0 and, similar to our findings for the KS Ranch, these PCs explained approximately 75% of the cumulative variability of predictors. Loadings corresponding to PCs with eigenvalues > 1 are shown in Table 4.8 and 4.9, for purebred and Stabilizer bulls, respectively, at the CO ranch. Loadings for the remaining principal components are shown in Appendix B and C.

Principal Component Regression Analysis

For the KS ranch, all 39 PC scores were considered for inclusion as predictors in the regression model fitted to the response sale prices for Angus bulls, expressed in the log scale and as a multiple of 1000, as explained before. The final selected model included the PCs listed in Table 4.10 and was characterized by the following statistics: Residual variance = 0.008, R^2 = 63.1%, BIC = -12263.9, C_p = 24.2. An analysis whereby the PC scores subjected to model selection were constrained to the 11 PC's with corresponding eigenvalues > 1.0 was also conducted. In this case, the final selected model included 9 of the 11 PCs (PC3 and PC4 excluded) and was characterized by the following statistics: Residual variance = 0.016, R^2 = 41.4%, BIC = -11105.7, Cp = 1493.8.

The second, first and fifth PC each explained more that 5% of the variation in transformed sale price at the KS ranch. In the second PC, YWT, WWT, WWR, YWR, FSC, YHT, YH, WW, YW, and $F had loadings greater than 0.2; whereas only $EN had a negative loading of similar magnitude. In the first PC, CEm, $YG, $QG, RE, $B and $G had loadings greater than 0.2. Only ADG and YWT had loadings that were less than -0.2 in the first principal component. In the fifth PC, CWT, RE, REA and REAR had loadings that were greater than 0.2 and WW, YW, $F and IMFR had loadings that were less than -0.2.

For purebred bulls sold at the CO ranch, scores for all 14 PCs were considered for inclusion as predictors in the regression model fitted to $\log_{10}$ (sale price/1000). The final model (Table 4.11) was characterized by the following statistics: Residual variance = 0.018, R^2 = 33.8%, BIC = -2012.6, C_p = 7.5. When the model was reduced to consider only those principal components meeting the Kaiser (1960) condition (i.e., having eigenvalues > 1.0) as potential independent variables then it contained PC1-PC5 and was characterized by the following statistics: Residual variance = 0.022, R^2 = 23.7%, BIC = -1926.7, C_p = 103.3. Breed also had a highly significant effect on prices paid for the bulls (results not shown due to small sample size for some of the breeds).

The first and second PC each explained more that 5% of the variation in transformed sale price received for purebred bulls at the CO ranch. In the first PC, MM, WW, MB, $P, and YW had loadings that were greater than 0.35. No predictor had a negative loading of similar magnitude. The second PC, BW and BWT had loadings that were greater than 0.45 and CES, to which the preceding two variables are negatively correlated, had a negative loading of similar magnitude.

All 14 principal components were potential independent variables to model of $\log_{10}$(sale price/1000) for Stabilizer bulls sold by the CO Ranch. The final model (Table 4.12) was characterized by the following statistics: Residual variance = 0.013, R^2 = 58.2%, BIC = -6108.8, C_p = 11.8. When the model was reduced to consider only those principal components meeting the Kaiser (1960) condition (i.e., having eigenvalues > 1.0) as potential independent variables then it contained PC1-PC5 and was characterized by the following statistics: Residual variance = 0.016, R^2 = 47.9%, BIC = -5811.6, C_p = 285.6.

The second and first PC each explained more than 10% of the variation in transformed sale price received for Stabilizer bulls at the CO ranch, whereas the next most important PC (PC9) only explained approximately 4% of the variation. In the second PC, YW', WW' and $P had loadings that were greater than 0.35, whereas no predictor had a negative loading of similar magnitude. The first PC, BW' and BWT had loadings that were greater than 0.39 and CES, to which the preceding two variables are negatively correlated, along with $R had negative loadings of similar magnitude.

Table 4.1. Mean, standard deviation (SD), minimum (Min), and maximum (Max) of sale prices and of each predictor variable considered for analysis describing Angus bulls from the KS Ranch (N = 2601).

Variable[1]	Mean	SD	Min	Max
Price, $	5159	2139	2250	36000
AGE	547	65.4	378	774
CE_d	8.32	2.9	-3	21
BWT	79.4	9.6	40	118
BWR	100.6	5.2	69	133
BW	1.95	1.2	-3.5	6.3
WWT	630	81.6	319	975
WW	56.4	5.6	37	79
WWR	101.2	5.2	73	137
YWT	1197	121.3	790	1594
YWR	101.3	4.4	81	127
ADG	4.28	0.8	1.14	8.47
DGR	102.5	11.0	51	159
YW	104.2	8.2	72	133
YHT	50.7	1.2	46.9	54.6
FSC	5.83	0.6	3.9	7.8
ASCR	37.1	1.9	28.89	44.36
YH	0.41	0.2	-0.3	1.3
SCR	0.20	0.8	-1.44	35.5
CE_m	9.03	2.0	-1	17
MM	28.8	4.1	14	43
CWT	25.3	8.4	4	65
MB	0.84	0.2	0.34	1.6
RE	0.69	0.3	0.05	1.54
FT	0.01	0.0	-0.05	0.076
IMF	5.72	1.1	2.93	10.81
IMFR	103.5	15.8	53	188
REA	13.5	1.5	9	18.5
REAR	102.3	8.4	73	131
RBF	0.27	0.1	0.07	0.62
RBFR	102.7	24.6	32	205
RPF	0.34	0.7	0.1	34
RPFR	101.7	22.0	0.73	193
$EN	-12.59	7.6	-42.85	5.1
$W	30.61	4.2	16.76	48.35
$F	43.09	7.5	17.4	75.58
$G	42.00	5.7	24.01	58.76
$QG	33.22	4.4	20.21	50.11
$YG	8.78	3.1	-3.23	18.26
$B	76.95	12.2	55.29	115.75

[1]Abbreviations of variable names are defined in Table 3.1.

Table 4.2. Mean, standard deviation (SD), minimum (Min), and maximum (Max) of variables used in analysis of data describing purebred bulls from the CO Ranch (N = 504)[1].

Variable[2]	Mean	SD	Min	Max
Price	3456	1444	1250	11000
AGE	426.2	63.4	320	768
BWT	77.9	8.4	40	102
CES	3.07	0.98	1	5
DSP	3.41	0.60	1	5
BW	-0.04	1.8	-7.6	4.6
WW	46.3	10.5	7	89
MM	22.1	5.8	2	35
YW	85.5	15.2	39	132
FG	-0.20	0.22	-0.90	0.61
MW’	1233	19	1172	1306
MB	0.44	0.24	-0.16	1.41
RE	0.34	0.21	-0.15	1.16
$R	30.0	10.1	-0.7	58.3
$P	9049	2267	794	15031

[1] The purebred population consisted of Angus (n=337), Red Angus (n=155), Charolais (n=7), South Devon (n=5)

[2]Abbreviations of variable names are defined in Table 3.2.

Table 4.3. Mean, standard deviation (SD), minimum (Min), and maximum (Max) of variables used in analysis of data describing Stabilizer bulls from the CO Ranch (N = 1399).

Variable[1]	Mean	SD	Min	Max
Price	3997	1810	1250	17500
AGE	390.7	20.3	349	556
BWT	79.1	8.5	50	110
CES	2.66	0.89	1	5
DSP	3.35	0.60	1	5
BW’	0.47	1.77	-7.10	7.10
WW’	45.8	7.1	22.0	74.0
MM’	21.9	4.6	0.04	38.00
YW	82.0	13.6	8.0	130.0
FG	-0.06	0.52	-18.00	1.11
MW’	1226	40	1117	2303
MR’	0.16	0.16	-0.43	0.74
RE’	0.49	0.28	-0.29	1.36
$R	27.9	8.7	-16.0	63.0
$P	9370	1946	1282	16902

[1]Abbreviations of variable names are defined in Table 3.2.

Table 4.4. Correlations among predictor variables used to describe Angus bulls offered for sale by the KS Ranch (N = 2601).

Variable[1]	AGE	CE_d	BWT	BWR	BW	WWT	WW	WWR	YWT	YWR
AGE	1.00									
CE_d	-0.30	1.00								
BWT	0.06	-0.33	1.00							
BWR	0.09	-0.41	0.44	1.00						
BW	0.24	-0.83	0.41	0.52	1.00					
WWT	0.06	-0.02	0.07	0.12	0.02	1.00				
WW	-0.02	0.02	-0.02	0.09	-0.03	0.22	1.00			
WWR	0.09	-0.07	0.06	0.29	0.06	0.36	0.46	1.00		
YWT	0.20	-0.01	0.17	0.13	0.05	0.58	0.19	0.27	1.00	
YWR	0.09	-0.06	0.09	0.29	0.06	0.30	0.36	0.71	0.41	1.00
ADG	0.20	-0.03	0.05	0.07	0.10	-0.01	-0.02	0.09	0.38	0.24
DGR	0.05	-0.02	0.10	0.10	0.03	0.03	0.08	0.09	0.38	0.36
YW	-0.02	0.07	-0.02	0.12	-0.09	0.20	0.92	0.40	0.25	0.46
YHT	0.05	-0.01	0.20	0.14	0.01	0.35	0.25	0.19	0.42	0.25
FSC	0.05	-0.01	0.20	0.14	0.01	0.34	0.25	0.19	0.41	0.25
ASCR	0.05	-0.06	0.12	0.08	0.07	0.33	0.06	0.14	0.35	0.21
YH	-0.17	0.02	0.10	0.06	-0.10	0.16	0.35	0.08	0.08	0.10
SCR	-0.02	-0.06	0.03	0.03	0.04	0.07	0.04	0.07	0.02	0.09
CE_m	-0.38	0.67	-0.23	-0.40	-0.62	-0.07	-0.11	-0.18	-0.23	-0.20
MM	-0.09	0.08	-0.08	-0.01	-0.13	0.12	0.03	0.10	-0.06	0.03
CWT	-0.17	-0.25	0.14	0.04	0.14	0.08	-0.01	-0.02	-0.10	0.00
MB	-0.20	-0.03	0.00	-0.06	0.06	0.02	-0.12	-0.10	-0.22	-0.16
RE	-0.31	0.03	0.00	-0.04	-0.13	0.05	0.04	-0.09	-0.24	-0.11
FT	0.04	-0.08	0.03	0.01	0.15	0.06	-0.29	0.08	0.07	0.05
IMF	-0.06	-0.02	-0.06	-0.05	0.02	0.03	-0.01	-0.07	-0.13	-0.11
IMFR	0.09	-0.03	-0.04	-0.01	0.05	0.00	-0.07	0.00	-0.01	-0.02
REA	0.26	-0.04	0.12	0.08	0.06	0.34	0.00	0.13	0.52	0.18
REAR	0.07	-0.06	0.06	0.05	0.04	0.14	0.01	0.13	0.22	0.20
RBF	0.34	-0.06	0.07	0.05	0.09	0.33	0.07	0.14	0.48	0.17
RBFR	-0.02	0.02	0.00	-0.01	0.02	0.16	0.05	0.13	0.18	0.17
RPF	0.06	-0.02	0.01	0.00	0.02	0.06	0.00	0.02	0.08	0.02
RPFR	-0.02	0.02	-0.02	-0.01	-0.04	0.14	0.08	0.14	0.17	0.17
$EN	0.17	-0.05	0.07	-0.06	0.14	-0.22	-0.41	-0.24	0.07	-0.19
$W	-0.29	0.46	-0.21	-0.33	-0.55	0.06	0.38	0.08	-0.04	-0.07
$F	-0.15	0.10	-0.03	0.10	-0.14	0.21	0.81	0.33	0.14	0.40
$G	-0.34	0.10	-0.06	-0.08	-0.16	0.02	0.05	-0.14	-0.34	-0.20
$QG	-0.29	0.00	-0.02	-0.07	-0.02	0.04	-0.08	-0.10	-0.29	-0.17
$YG	-0.22	0.18	-0.08	-0.06	-0.26	-0.02	0.21	-0.11	-0.21	-0.13
$B	-0.33	-0.05	0.03	-0.01	-0.05	0.09	0.12	-0.05	-0.25	-0.07

[1]Abbreviations of variable names are defined in Table 3.1.

Table 4.4. (Continued) Correlations among variables used to describe Angus bulls offered for sale by the KS Ranch (N=2601).

Variable	ADG	DGR	YW	YHT	FSC	SCR	YH	SCR	CE_m	MM
ADG	1.00									
DGR	0.62	1.00								
YW	0.06	0.19	1.00							
YHT	0.18	0.22	0.29	1.00						
FSC	0.17	0.22	0.28	1.00	1.00					
ASCR	0.05	0.14	0.08	0.21	0.21	1.00				
YH	-0.02	0.15	0.37	0.67	0.67	0.12	1.00			
SCR	0.00	0.07	0.03	0.05	0.05	0.31	0.10	1.00		
CE_m	-0.29	-0.10	-0.11	-0.07	-0.07	-0.03	0.15	0.01	1.00	
MM	-0.10	-0.06	0.01	-0.10	-0.10	0.04	-0.09	0.08	0.00	1.00
CWT	-0.20	0.08	0.01	0.10	0.10	0.14	0.32	0.12	0.22	0.07
MB	-0.26	-0.16	-0.19	-0.17	-0.17	-0.06	-0.07	0.04	0.21	0.05
RE	-0.40	-0.08	0.05	-0.07	-0.07	0.07	0.24	0.08	0.35	0.34
FT	0.15	-0.01	-0.32	-0.08	-0.08	0.03	-0.30	0.03	-0.12	0.25
IMF	-0.22	-0.07	-0.05	-0.04	-0.04	-0.07	0.03	0.03	0.14	-0.03
IMFR	0.00	-0.06	-0.09	-0.03	-0.02	-0.04	-0.10	0.00	-0.02	-0.06
REA	0.17	0.13	0.04	0.28	0.28	0.21	-0.02	-0.04	-0.16	-0.05
REAR	0.12	0.17	0.03	0.12	0.12	0.12	0.05	0.02	-0.07	0.01
RBF	0.07	0.08	0.07	0.20	0.20	0.21	-0.09	0.02	-0.18	-0.02
RBFR	0.09	0.09	0.05	0.07	0.08	0.11	0.02	0.09	-0.02	0.02
RPF	0.00	-0.03	0.00	0.04	0.04	0.03	-0.02	0.00	-0.02	-0.03
RPFR	0.10	0.08	0.07	0.06	0.06	0.08	0.00	0.06	-0.05	0.07
$EN	0.24	-0.02	-0.42	-0.08	-0.08	-0.11	-0.29	-0.11	-0.11	-0.70
$W	-0.22	-0.11	0.27	-0.07	-0.07	0.00	0.07	0.02	0.41	0.30
$F	-0.06	0.17	0.93	0.25	0.25	0.11	0.45	0.06	0.05	0.09
$G	-0.50	-0.18	0.01	-0.16	-0.15	-0.02	0.19	0.05	0.41	0.19
$QG	-0.39	-0.16	-0.14	-0.15	-0.15	0.00	0.08	0.07	0.34	0.15
$YG	-0.36	-0.11	0.21	-0.07	-0.07	-0.03	0.24	0.00	0.28	0.14
$B	-0.41	-0.04	0.12	0.00	0.00	0.10	0.37	0.12	0.39	0.19

Table 4.4. (Continued) Correlations among variables used to describe Angus bulls offered for sale by the KS Ranch (N = 2601).

Variable	CWT	MB	RE	FT	IMF	IMFR	REA	REAR	RBF	RBFR
CWT	1.00									
MB	0.16	1.00								
RE	0.59	0.09	1.00							
FT	0.04	0.21	-0.16	1.00						
IMF	0.09	0.64	0.04	0.05	1.00					
IMFR	-0.08	0.55	-0.19	0.19	0.77	1.00				
REA	-0.04	-0.29	0.06	0.08	-0.18	-0.11	1.00			
REAR	0.12	-0.20	0.29	0.08	-0.18	-0.17	0.73	1.00		
RBF	-0.07	-0.02	-0.21	0.40	0.15	0.21	0.39	0.09	1.00	
RBFR	0.07	0.10	-0.06	0.51	0.15	0.23	0.05	0.10	0.70	1.00
RPF	-0.01	-0.01	-0.05	0.05	0.01	0.03	0.06	0.01	0.10	0.03
RPFR	0.01	0.05	-0.05	0.45	0.09	0.16	0.03	0.08	0.38	0.56
$EN	-0.32	-0.04	-0.56	0.06	-0.01	0.11	0.10	0.01	0.07	0.00
$W	0.00	0.11	0.29	-0.11	0.05	-0.04	-0.13	-0.04	-0.10	0.03
$F	0.21	-0.09	0.30	-0.33	-0.02	-0.11	-0.02	0.02	-0.02	0.04
$G	0.31	0.65	0.68	-0.30	0.41	0.18	-0.24	-0.06	-0.29	-0.15
$QG	0.35	0.91	0.37	0.11	0.55	0.40	-0.32	-0.20	-0.10	0.06
$YG	0.08	-0.10	0.72	-0.70	-0.03	-0.24	0.02	0.16	-0.38	-0.37
$B	0.78	0.42	0.80	-0.20	0.24	0.01	-0.18	0.01	-0.23	-0.04

Table 4.4. (Continued) Correlations between variables included in principal component analysis (PCA) for KS Ranch (N = 2601).

Variable	RPF	RPFR	$EN	$W	$F	$G	$QG	$YG
RPF	1.00							
RPFR	0.08	1.00						
$EN	0.04	-0.04	1.00					
$W	-0.04	0.08	-0.20	1.00				
$F	-0.02	0.04	-0.59	0.31	1.00			
$G	-0.05	-0.15	-0.44	0.34	0.25	1.00		
$QG	-0.03	0.02	-0.28	0.21	0.07	0.84	1.00	
$YG	-0.06	-0.30	-0.40	0.32	0.36	0.65	0.12	1.00
$B	-0.05	-0.07	-0.56	0.25	0.41	0.80	0.69	0.49

Table 4.5. Correlations among variables used to describe purebred bulls offered for sale by the CO Ranch (N = 504).

Variable[1]	AGE	BWT	CES	DSP	BW	WW	MM	YW	FG	MW’	MB	REA	$R	$P
AGE	1.00													
BWT	-0.03	1.00												
CES	-0.15	-0.62	1.00											
DSP	-0.14	-0.05	0.03	1.00										
BW	0.16	0.52	-0.60	0.00	1.00									
WW	-0.15	0.18	-0.13	0.10	0.36	1.00								
MM	-0.03	-0.04	0.06	-0.04	0.27	0.39	1.00							
YW	-0.14	-0.04	-0.10	0.09	0.41	0.88	0.49	1.00						
FG	0.03	0.07	-0.09	-0.08	0.03	-0.08	-0.02	-0.20	1.00					
MW’	0.06	0.22	-0.26	0.01	0.22	0.17	-0.06	0.21	-0.03	1.00				
MB	-0.06	-0.04	0.08	-0.05	-0.04	0.47	0.53	0.55	-0.16	0.00	1.00			
RE	-0.17	0.04	0.03	-0.05	0.04	0.24	0.34	0.37	-0.20	-0.25	0.38	1.00		
$R	-0.03	-0.32	0.35	0.00	-0.32	0.27	0.40	0.27	-0.20	-0.38	0.37	0.25	1.00	
$P	-0.12	-0.08	0.10	-0.02	-0.08	0.41	0.44	0.53	-0.35	0.05	0.61	0.47	0.56	1.00

[1]Abbreviations of variable names are defined in Table 3.2.

Table 4.6. Correlations among variables used to describe Stabilizer bulls offered for sale by the CO Ranch (N = 1399).

Variable[1]	AGE	BWT	CES	DSP	BW’	WW’	MM’	YW	FG	MW’	MR’	RE’	$R	$P
AGE	1.00													
BWT	-0.03	1.00												
CES	-0.02	-0.59	1.00											
DSP	0.09	0.04	-0.03	1.00										
BW’	0.03	0.64	-0.85	0.04	1.00									
WW’	-0.13	0.16	-0.32	-0.01	0.35	1.00								
MM’	-0.12	-0.16	0.11	-0.05	-0.18	0.12	1.00							
YW	-0.09	0.13	-0.27	0.02	0.30	0.79	0.09	1.00						
FG	0.03	-0.03	0.06	0.00	-0.06	0.01	0.03	0.01	1.00					
MW’	-0.02	0.07	-0.09	0.03	0.14	0.27	-0.09	0.36	0.03	1.00				
MR’	-0.02	-0.17	0.20	-0.13	-0.19	0.09	0.23	0.05	0.01	-0.09	1.00			
RE’	-0.03	0.09	-0.13	-0.04	0.07	0.25	0.13	0.12	-0.03	0.03	-0.02	1.00		
$R	-0.11	-0.41	0.44	-0.04	-0.55	-0.02	0.31	-0.14	-0.04	-0.29	0.29	0.19	1.00	
$P	-0.11	-0.12	0.10	-0.05	-0.17	0.39	0.34	0.34	-0.07	-0.08	0.44	0.50	0.52	1.00

[1]Abbreviations of variable names are defined in Table 3.2.

Figure 4.1. Eigenvalues and cumulative percent variance explained by principal components computed on predictor variables from Angus bulls offered for sale by the KS Ranch (The black vertical line designates the cut-off for PCs that satisfy the Kaiser (1960) criterion).

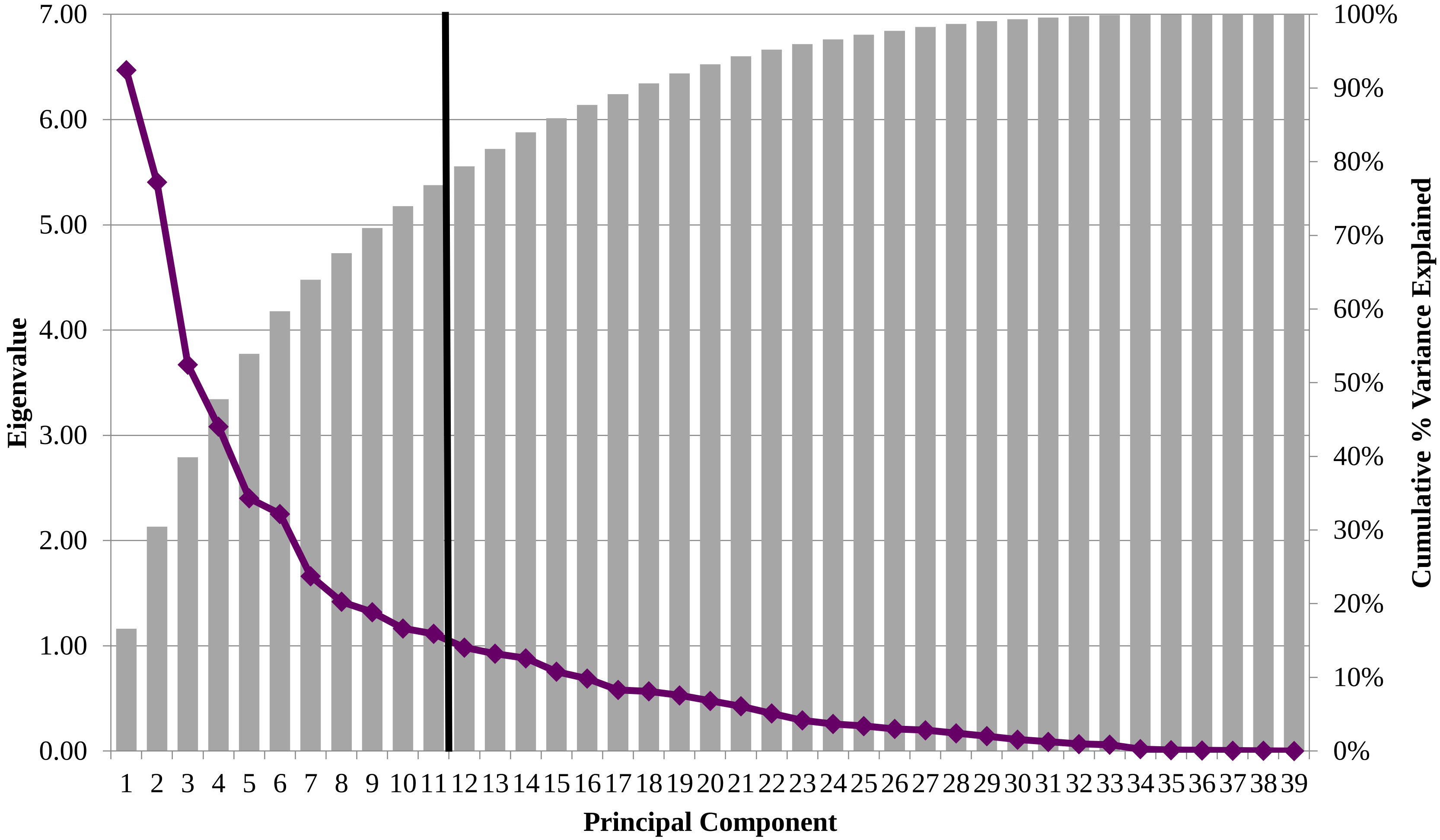


Table 4.7. Loadings corresponding to the first 11 PCs computed from predictor variables provided in catalogs describing Angus bulls offered for sale by the KS Ranch.

Variable	PC1	PC2	PC3	PC4	PC5	PC6
AGE	-0.191	-0.021	0.029	-0.074	-0.038	-0.041
CE_d	0.111	0.007	-0.196	0.415	0.079	0.094
BWT	-0.083	0.057	0.119	-0.268	0.042	0.068
BWR	-0.105	0.095	0.121	-0.303	-0.114	-0.083
BW	-0.144	-0.029	0.209	-0.403	-0.092	-0.071
WWT	-0.056	0.217	0.147	0.071	0.124	-0.012
WWR	-0.089	0.224	0.071	0.049	-0.167	-0.203
WW	0.023	0.311	-0.056	0.065	-0.325	-0.085
YWT	-0.212	0.201	0.063	0.108	0.123	0.064
YWR	-0.129	0.246	0.061	0.040	-0.121	-0.146
ADG	-0.232	0.031	-0.045	0.049	-0.014	0.061
DGR	-0.116	0.134	0.000	0.007	0.038	0.079
YW	0.007	0.335	-0.080	0.064	-0.307	-0.066
YHT	-0.104	0.262	0.040	-0.003	0.086	0.395
FSC	-0.104	0.261	0.041	-0.003	0.086	0.396
ASCR	-0.049	0.145	0.101	-0.008	0.186	0.003
YH	0.073	0.263	-0.009	-0.061	0.022	0.350
SCR	0.015	0.063	0.084	-0.019	0.059	-0.033
CE_m	0.236	-0.017	-0.078	0.243	0.178	0.162
MM	0.104	0.063	0.050	0.059	0.092	-0.379
CWT	0.153	0.115	0.167	-0.189	0.222	0.010
MB	0.190	-0.104	0.350	0.040	-0.114	0.107
RE	0.275	0.130	0.009	-0.134	0.284	-0.145
FT	-0.119	-0.107	0.287	0.166	0.150	-0.212
IMF	0.126	-0.057	0.314	0.090	-0.171	0.193
IMFR	0.023	-0.087	0.318	0.134	-0.203	0.164
REA	-0.162	0.127	-0.011	-0.005	0.365	-0.023
REAR	-0.070	0.117	-0.024	-0.052	0.374	-0.114
RBFT	-0.175	0.069	0.249	0.203	0.106	-0.050
RBFR	-0.083	0.050	0.279	0.252	0.082	-0.102
RPFT	-0.034	0.004	0.038	0.028	0.022	0.012
RPFR	-0.073	0.051	0.209	0.236	0.049	-0.133
$EN	-0.188	-0.239	-0.046	0.023	0.010	0.272
$W	0.188	0.096	-0.090	0.284	-0.022	-0.087
$F	0.104	0.345	-0.049	0.026	-0.224	-0.068
$G	0.348	0.040	0.119	-0.073	0.009	0.041
$QG	0.275	-0.038	0.314	-0.002	-0.041	0.069
$YG	0.248	0.124	-0.221	-0.130	0.073	-0.022
$B	0.310	0.139	0.148	-0.146	0.117	0.005

Table 4.7. (Continued) Loadings corresponding to the first 11 PCs computed from predictor variables provided in catalogs describing Angus bulls offered for sale by the KS Ranch.

Variable	PC7	PC8	PC9	PC10	PC11
AGE	0.266	-0.046	0.023	0.048	-0.404
CE_d	-0.002	0.084	-0.107	-0.062	0.139
BWT	-0.043	-0.037	-0.059	-0.040	0.283
BWR	0.000	0.014	-0.093	-0.115	0.269
BW	0.001	-0.052	0.074	0.046	-0.014
WWT	0.246	-0.060	-0.311	0.015	0.094
WWR	0.059	0.078	-0.169	-0.050	0.359
WW	0.078	-0.093	0.156	0.078	-0.022
YWT	0.176	0.148	-0.147	0.038	-0.001
YWR	-0.029	0.269	-0.077	-0.002	0.278
ADG	-0.236	0.434	0.028	-0.126	-0.196
DGR	-0.260	0.563	0.097	-0.052	-0.191
YW	0.037	-0.014	0.188	0.070	-0.051
YHT	-0.075	-0.195	-0.114	-0.198	-0.051
FSC	-0.077	-0.195	-0.114	-0.199	-0.048
ASCR	0.022	0.066	-0.327	0.474	-0.076
YH	-0.197	-0.159	0.063	-0.056	-0.060
SCR	-0.155	0.073	-0.255	0.559	-0.189
CE_m	-0.074	0.061	-0.014	0.084	0.212
MM	-0.097	-0.071	-0.353	-0.379	-0.313
CWT	-0.259	-0.003	0.179	0.107	0.015
MB	0.088	0.155	-0.073	-0.067	0.086
RE	0.010	0.009	0.147	-0.035	-0.042
FT	-0.230	-0.090	-0.022	-0.172	0.067
IMF	0.212	0.114	0.077	-0.056	-0.142
IMFR	0.204	0.155	0.027	-0.094	-0.155
REA	0.382	0.081	0.129	-0.098	0.009
REAR	0.215	0.206	0.298	-0.113	0.102
RBFT	0.168	-0.198	0.159	0.102	-0.137
RBFR	-0.153	-0.143	0.305	0.111	0.025
RPFT	0.084	-0.124	0.024	0.115	0.031
RPFR	-0.188	-0.126	0.234	0.034	0.056
$EN	0.104	0.079	0.162	0.210	0.265
$W	0.054	-0.029	-0.036	0.027	0.059
$F	-0.022	0.009	0.176	0.068	-0.044
$G	0.161	0.119	-0.020	-0.023	0.002
$QG	0.029	0.115	-0.073	-0.038	0.065
$YG	0.251	0.055	0.065	0.012	-0.085
$B	-0.089	0.053	0.087	0.059	-0.002

Figure 4.2. Eigenvalues and cumulative percent variance explained by principal components that summarize data from purebred bulls offered for sale by the CO Ranch. (The black vertical line designates the cut-off for PCs that satisfy the Kaiser (1960) criterion).

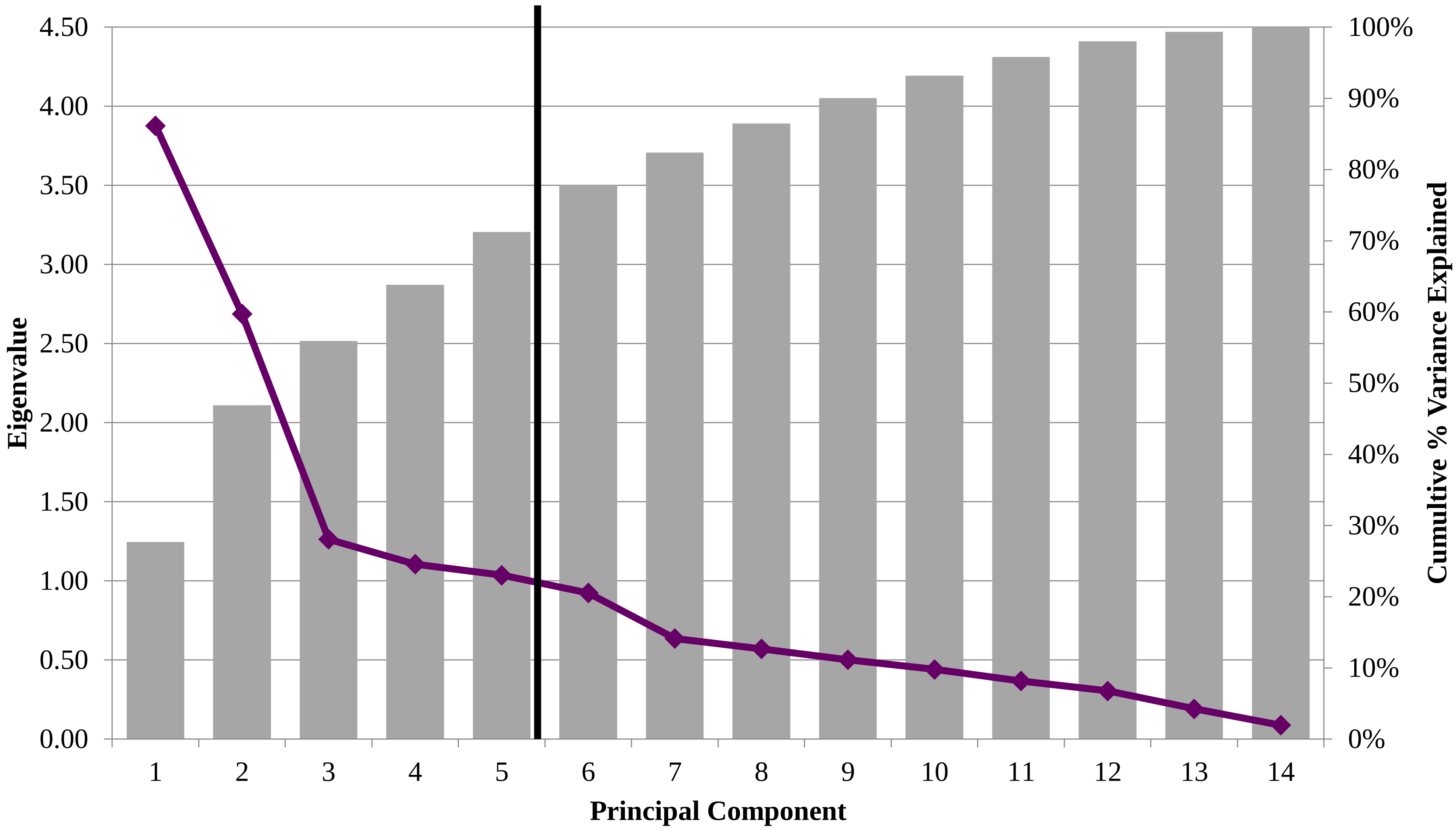


Figure 4.3. Eigenvalues and cumulative percent variance explained by principal components that summarize data from Stabilizer bulls offered for sale by the CO Ranch. (The black vertical line designates the cut-off for PCs that satisfy the Kaiser (1960) criterion).

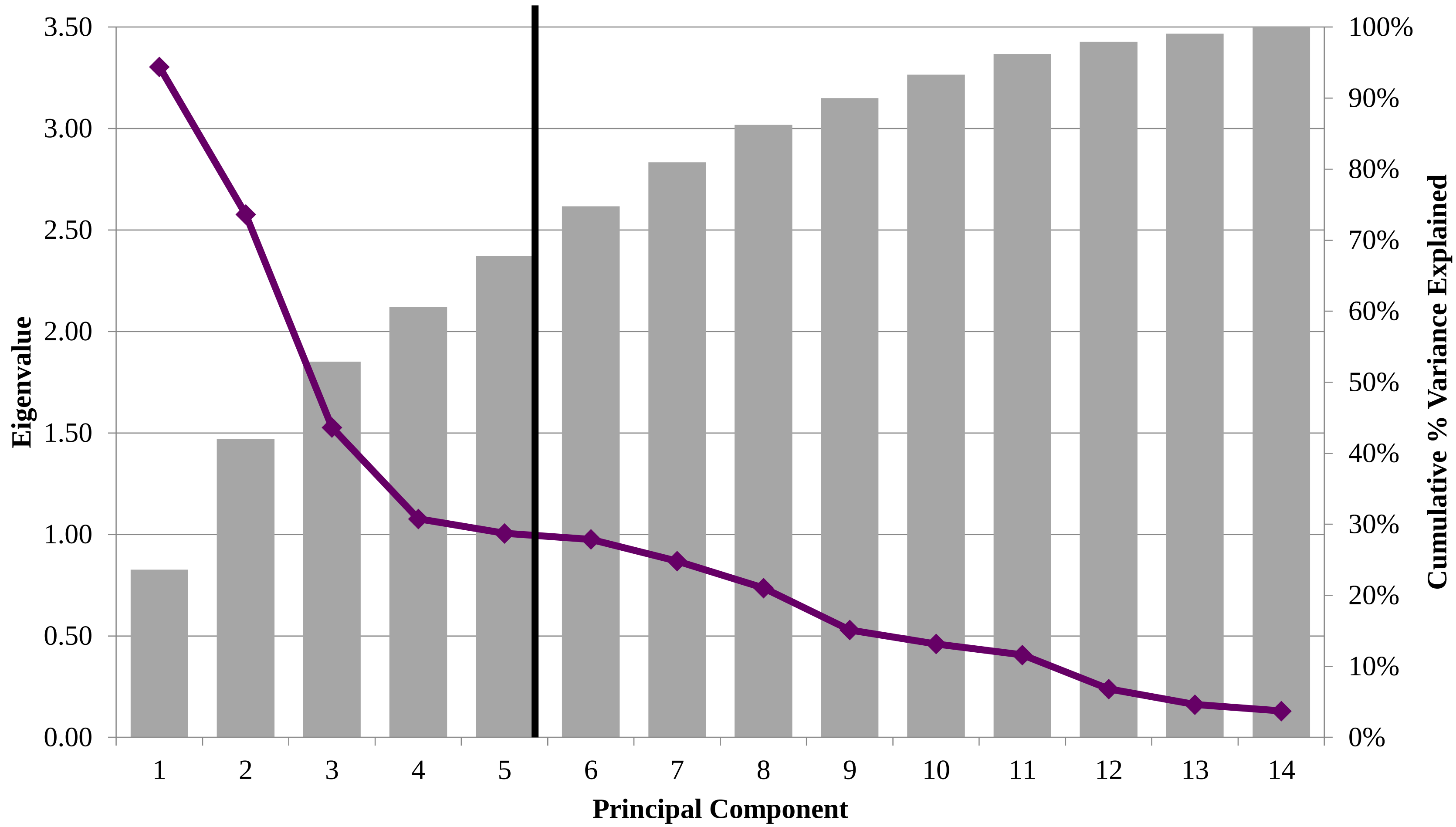


Table 4.8. Loadings corresponding to the first 5 PCs computed from predictor variables provided in catalogs describing purebred bulls offered for sale by the CO Ranch.

Variable	PC1	PC2	PC3	PC4	PC5
AGE	-0.083	0.094	0.481	0.565	-0.041
BWT	0.029	0.473	0.045	-0.289	-0.184
CES	0.003	-0.505	-0.132	0.111	0.175
DSP	0.018	-0.011	-0.590	-0.118	0.112
BW	0.180	0.454	0.185	-0.049	-0.005
WW	0.384	0.164	-0.210	0.030	0.275
MM	0.351	-0.034	0.243	-0.007	0.281
YW	0.433	0.152	-0.189	0.064	0.144
FG	-0.154	0.107	0.243	-0.245	0.759
MW’	0.006	0.322	-0.328	0.540	0.028
MB	0.391	-0.053	0.104	0.112	0.066
RE	0.295	-0.081	0.158	-0.421	-0.338
$R	0.279	-0.340	0.159	0.038	0.045
$P	0.400	-0.122	0.003	0.145	-0.221

Table 4.9. Loadings corresponding to the first 5 PCs computed from predictor variables provided in catalogs describing Stabilizer bulls offered for sale by the CO Ranch.

Variable	PC1	PC2	PC3	PC4	PC5
AGE	0.022	-0.144	-0.041	0.536	0.188
BWT	0.391	0.018	-0.242	-0.141	0.048
CES	-0.453	-0.092	0.225	0.068	-0.045
DSP	0.049	-0.058	0.021	0.729	-0.304
BW’	0.489	0.065	-0.159	-0.075	0.037
WW’	0.217	0.477	0.193	0.106	-0.008
MM’	-0.180	0.281	-0.028	-0.094	0.124
YW’	0.227	0.425	0.310	0.146	-0.041
FG	-0.014	-0.028	0.143	0.182	0.901
MW’	0.184	0.041	0.627	-0.024	-0.098
MB’	-0.199	0.243	0.161	-0.198	0.115
RE’	-0.018	0.323	-0.515	0.176	0.079
$R	-0.404	0.215	-0.117	0.036	-0.089
$P	-0.178	0.515	-0.107	0.070	-0.033

Table 4.10. Results of stepwise regression of log10(sale price/1000) on principal component scores for Angus bulls sold by the Kansas ranch.

Independent Variable	Parameter estimate ± SE	F - statistic	Partial R^2, %
Intercept	0.684 ± 0.002		
PC2	0.030 ± 0.001	1392.1	20.00
PC5	0.027 ± 0.001	499.8	7.18
PC1	0.015 ± 0.001	405.2	5.82
PC8	0.027 ± 0.002	305.2	4.38
PC4	0.017 ± 0.001	270.5	3.89
PC14	-0.032 ± 0.002	263.8	3.79
PC23	0.051 ± 0.003	220.0	3.16
PC11	-0.022 ± 0.002	158.9	2.28
PC21	0.035 ± 0.003	153.9	2.21
PC3	0.011 ± 0.001	128.2	1.84
PC16	0.024 ± 0.002	119.9	1.72
PC7	0.015 ± 0.001	103.6	1.49
PC20	-0.025 ± 0.003	85.4	1.23
PC26	-0.031 ± 0.006	58.2	0.84
PC31	0.039 ± 0.006	39.9	0.57
PC15	0.013 ± 0.002	37.3	0.54
PC19	-0.013 ± 0.003	28.2	0.41
PC12	0.009 ± 0.002	25.9	0.37
PC24	0.018 ± 0.004	25.8	0.37
PC13	-0.007 ± 0.001	12.2	0.18
PC6	0.004 ± 0.001	9.8	0.14
PC22	0.009 ± 0.003	9.4	0.13
PC34	-0.040 ± 0.014	8.5	0.12
PC10	-0.005 ± 0.001	7.6	0.11
PC28	0.011 ± 0.004	5.9	0.08
PC18	-0.006 ± 0.002	5.5	0.08
PC37	0.066 ± 0.032	4.1	0.06
PC17	0.004 ± 0.002	3.4	0.05
PC25	-0.006 ± 0.004	2.8	0.04

Table 4.11. Results of stepwise regression of log10(sale price/1000) on principal component scores for purebred bulls sold by the CO Ranch.

Independent Variable	Parameter estimate ± SE	F - statistic	Partial R^2, %
Intercept	0.505 ± 0.006		
PC1	0.026 ± 0.003	71.2	9.09
PC2	-0.028 ± 0.004	58.2	7.43
PC3	-0.031 ± 0.005	34.5	4.41
PC13	-0.080 ± 0.014	34.1	4.36
PC11	0.057 ± 0.010	33.2	4.25
PC5	-0.025 ± 0.006	17.9	2.28
PC7	0.030 ± 0.007	15.7	2.01
PC9	0.033 ± 0.008	14.9	1.91
PC6	-0.015 ± 0.006	5.9	0.75
PC4	0.012 ± 0.006	4.1	0.53

Table 4.12. Results of stepwise regression of log10(sale price/1000) on principal component scores for Stabilizer bulls sold by the CO Ranch.

Independent Variable	Parameter estimate ± SE	F - statistic	Partial R^2, %
Intercept	0.565 ± 0.003		
PC2	0.058 ± 0.002	966.0	29.09
PC1	-0.036 ± 0.002	468.2	14.10
PC9	0.046 ± 0.004	125.4	3.78
PC4	0.030 ± 0.003	110.0	3.31
PC8	0.036 ± 0.003	106.7	3.21
PC13	0.063 ± 0.007	71.6	2.16
PC3	-0.013 ± 0.002	29.2	0.88
PC12	-0.027 ± 0.006	19.5	0.59
PC5	-0.012 ± 0.003	17.5	0.53
PC11	0.016 ± 0.005	11.6	0.35

Chapter 5 - Discussion

Particularly for the KS ranch, but also for the CO ranch, several pieces of information have part-whole relationships that force moderate to large correlations among them. These relationships create an opportunity to overemphasize some information through "double counting" relative to other pieces of information (Berry, 2005; Garrick, 2005; Veerkamp, 1998). Striking examples of these part-whole relationships include feed efficiency with growth rate and intake, the various economic indexes with their component traits, and serially measured weights at various ages. In addition, there are other pairs of variables such as intramuscular fat as measured using ultrasound and marbling score as subjectively assigned at harvest which may be correlated through similar underlying physiological processes (Herring, 2005). Upon the completion of the PC analyses, the number of measures needed to describe much of the variability in the data was reduced by more than half in all 3 datasets. Thus, the principal component analysis served its intended purposes of reducing the dimensionality of the data and providing uncorrelated independent variables for subsequent regression analyses.

The PC analyses produced linear combinations of all of the variables presented by these seedstock breeders to their buyers. This can make interpretation of the principal components difficult (Zou et al., 2006). As the Kaiser (1960) criterion becomes closer to 1.0 and variance of principal component scores are reduced, bulls at the extremes of the principal component are more similar.

Using multiple regression with potentially strong collinearity among the independent variables results in the possibly of elevated levels of Type I and Type II errors (Tu et al., 2005). In addition, collinearity can sometimes lead to serious stability problems in regression analysis (Weisberg, 1985).

Although the Kaiser criterion identifies those principal components that are important in explaining the variation among the traits they summarize, principal components with low variance can still impact a dependent variable (Jolliffe, 1982). Previous studies using principal components in regression have shown that low variance components explaining less than 1% of the variation in the original variables had a significant impact on the dependent variable (Kung and Sharif, 1980; Smith and Campbell, 1980; Hill et al., 1977). Therefore, all principal components were taken into consideration for the regression analysis. However, the regression coefficients and partial R^2 statistics estimated under the Kaiser (1960) criterion conditions were unchanged relative to when all PC were considered because the principal components are orthogonal. For all three datasets, the observed differences in residual variance, R^2, BIC, and C_p support including the low variance PC in the regression analyses.

Three components in the KS Ranch dataset each individually explained more than 5% of the variation in sale price: PC2, PC5, and PC1. Principal component 2 explained 20% of the variation in sale price. Principal component 2 emphasized growth traits at the expense of the Cow Energy Value index ($EN). The highest weighted variables within this component were various traits characterizing growth to weaning and yearling ages. Being negatively influenced by growth traits and positively affected by measures of ribeye area, PC5 explained an additional approximate 7% of variation in price. Historically, weaning and yearling weight are positively correlated with sale price (Turner, 2004; Chvosta et al., 2001; Dhuyvetter et al., 1996). However, more recent research has shown that carcass EPD and ultrasound data, when they are available, to also influence price (Turner, 2004). Principal component 1 was the last component to explain more than 5% of the variation in price and found economic selection indices ($YG, $QG, $B and $G) and the EPD for ribeye area and maternal calving ease were important positive contributors within. Bulls that themselves had greater postweaning ADG and yearling weight were penalized in PC1. Economic productivity and profitability are the foundation to the efficiency to any system. In beef production, the goals of selection indexes are to simplify genetic selection and allow producers to put appropriate weight on traits that have significant economic importance for a particular production system. Greer and Urick (1988) validated relationships exist between economic variables and purebred bull prices, and determined bull prices at the time were positively correlated and proportional to feeder calf prices and cowherd inventory. The emphasis on dollar indices within this dataset shows that producers have perhaps realized the benefits of economic selection criterions through their bottom line.

Both PC1 and PC2 were the most important predictors of sale price for both purebred and Stabilizer datasets for the CO Ranch. Principal component 1 in the purebred dataset and PC2 for the Stabilizer dataset explained the largest amount of price variation at approximately 9% and 29%, respectively. Greater values for the selection indices and correlated traits led to larger values for these principal components. These components show the importance of economic selection indices in sire selection at sales conducted by this ranch. As previously stated, profitability is essential to an operation’s sustainability, and economic selection indices simplify this process by taking multiple traits and their respective economic weights into consideration. In previous research, traits moderately correlated with $Weaning and $Profit have also been found to be positively associated with price (Turner, 2004; Chvosta et al., 2001; Dhuyvetter et al., 1996).

At the CO Ranch, PC2 and PC1 explained approximately 7% and 14% of the variation in prices paid for purebred and Stabilizer bulls, respectively. Both purebred and Stabilizer bulls characterized by greater birth weight and less expected calving ease were more highly valued.

Birth weight has seemed to be a top selection criterion since the beginning of bull valuation research. Simms et al. (2004) determined that calving ease is the top priority for 25% of producers and was in the top 3 most important traits by almost 50% of producers. Furthermore, birth weight EPD has proved to be influential in price determination across British and Continental breeds of cattle (Dhuyvetter et al., 1996). However, within this analysis, birth weight traits received high positive factor loadings within both of these components, while the calving ease score received a large negative weighting in both components. This would suggest that low birth weight calving ease sires may not be as valuable has high growth sires. Alternatively, calving ease may have been seen as being adequate, perhaps because bulls with extremely heavy birth weights were not offered for sale, and buyers then placed emphasis on growth. These findings are further supported by the large positive loadings given to weaning, yearling, and mature weight traits within these components. Nonetheless, growth traits have been commonly found to be positively associated with sale price, so the value in growth traits within these components is not unusual (Turner, 2004; Chvosta et al., 2001; Dhuyvetter et al., 1996).

Conclusion

Historically, regression analyses have been used to determine bull value based on the genetic and physical characteristics possessed. However, in this case study, a principal components analysis was used to reduce the dimensionality of the data and remove collinearity among the independent variables used to predict sale price. Physical and genetic performance predictors provided to buyers in sale catalogs influenced prices paid for the bulls. In general, the same types of traits were important in determining the price of bulls at both KS and CO ranches. Growth traits, carcass characteristics, and economic selection indices were most prominent in the principal components explaining sale price. Economic selection indexes were most likely highly weighted in part due to their part-whole relationships with several traits included in the analyses.

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Appendix A - Factor loadings of standardized variables describing Angus bulls offered for sale by the KS Ranch for principal components 12 through 39.

Variable	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19
BWT	-0.079	0.463	0.222	0.112	0.512	0.042	0.008	-0.130
WWT	0.035	0.093	-0.294	-0.113	-0.291	0.077	0.327	-0.204
YWT	0.039	0.294	-0.189	-0.066	-0.089	0.002	0.159	-0.153
ADG	0.080	0.113	0.023	-0.126	-0.010	0.071	0.037	0.019
FSC	-0.023	-0.100	0.081	-0.046	0.020	0.030	-0.023	0.080
ASCR	-0.057	0.123	-0.039	-0.004	-0.085	0.023	-0.716	0.139
CE_d	-0.005	0.054	0.090	0.221	0.085	-0.165	-0.030	0.060
BW	-0.019	0.053	-0.014	-0.167	-0.105	-0.066	0.007	0.034
WW	-0.042	0.059	0.011	-0.237	0.114	-0.068	-0.014	0.001
YW	-0.007	0.063	-0.010	-0.096	0.062	-0.186	-0.061	0.031
YH	-0.021	-0.121	0.089	0.000	-0.070	0.101	0.011	0.069
SCR	-0.130	-0.249	0.462	-0.079	0.102	-0.121	0.436	-0.058
BWR	-0.040	0.154	0.248	0.311	-0.084	-0.071	-0.009	0.013
WWR	0.015	-0.382	-0.037	0.069	0.101	0.198	0.025	-0.036
YWR	0.055	-0.283	-0.042	0.222	-0.014	0.078	-0.035	0.061
DGR	0.091	0.188	-0.038	0.107	0.009	0.038	0.099	0.056
CE_m	0.034	-0.054	-0.092	0.241	0.192	-0.086	0.011	-0.022
MM	0.022	0.063	0.144	-0.016	0.080	-0.046	-0.041	-0.092
IMF	-0.027	-0.081	0.139	0.096	-0.041	-0.088	-0.078	-0.387
IMFR	-0.023	-0.108	0.174	0.096	0.015	-0.021	-0.232	-0.353
REA	-0.043	-0.067	0.078	-0.116	0.082	-0.201	-0.030	0.021
REAR	-0.069	-0.238	0.253	-0.242	0.025	-0.064	-0.093	0.082
RBFT	-0.066	0.166	-0.103	0.291	0.063	-0.176	0.149	0.140
RBFR	-0.113	0.097	0.066	0.204	-0.114	-0.070	0.108	0.138
RPFT	0.947	0.035	0.217	-0.029	0.038	-0.045	-0.002	0.024
RPFR	0.006	0.086	0.210	-0.023	-0.246	0.589	-0.078	-0.067
CW	0.093	-0.146	-0.356	-0.023	0.197	-0.045	-0.031	-0.377
MB	0.010	0.019	-0.020	-0.219	0.062	-0.030	0.068	0.321
RE	0.008	0.011	0.056	0.098	-0.037	0.092	0.003	-0.099
FT	-0.001	-0.077	-0.003	-0.182	0.133	-0.158	-0.080	0.100
$EN	-0.057	0.026	0.005	-0.171	0.057	0.149	0.040	-0.046
$W	-0.078	0.217	0.081	-0.362	0.321	0.276	0.000	-0.149
$F	0.018	0.070	-0.061	-0.006	0.020	-0.199	-0.063	0.057
$G	0.000	0.088	0.055	0.014	-0.072	0.124	0.080	0.273
$QG	0.022	0.035	-0.075	-0.120	0.038	0.024	0.060	0.340
$YG	-0.031	0.110	0.205	0.192	-0.184	0.191	0.062	0.023
$B	0.054	-0.020	-0.182	0.027	0.050	0.041	0.021	-0.040

(Continued.)

Variable	PC20	PC21	PC22	PC23	PC24	PC25	PC26	PC27
BWT	-0.195	-0.398	0.194	-0.044	-0.037	0.019	-0.080	-0.005
WWT	-0.148	0.059	0.341	-0.219	-0.150	0.365	-0.099	-0.061
YWT	-0.048	-0.008	-0.243	0.258	-0.084	-0.386	0.270	0.241
ADG	0.014	0.158	0.515	0.278	0.232	-0.029	0.077	-0.040
FSC	0.071	-0.012	-0.136	0.089	0.176	0.194	-0.004	-0.126
ASCR	0.078	0.012	0.085	-0.089	0.003	0.013	-0.036	-0.009
CE_d	-0.182	0.128	0.085	0.054	0.038	0.053	-0.046	-0.064
BW	0.089	-0.002	0.016	-0.132	0.296	0.089	0.518	0.042
WW	0.000	0.066	0.065	-0.188	0.178	-0.046	0.056	-0.040
YW	-0.173	0.027	-0.015	0.030	-0.041	0.096	0.040	0.007
YH	0.059	0.014	0.235	-0.178	-0.418	-0.408	0.074	0.374
SCR	-0.106	0.035	-0.060	0.071	0.033	0.001	-0.025	0.008
BWR	0.044	0.716	-0.098	0.017	-0.141	-0.007	-0.047	-0.054
WWR	0.239	-0.054	0.186	-0.137	0.352	-0.318	-0.206	0.035
YWR	0.048	-0.304	-0.244	0.240	-0.242	0.245	0.255	0.050
DGR	0.142	-0.038	-0.271	-0.444	0.012	0.103	-0.211	0.015
CE_m	-0.139	0.158	0.074	-0.265	0.220	0.004	0.552	0.023
MM	0.085	-0.056	-0.056	-0.051	-0.109	-0.100	0.260	-0.202
IMF	0.049	-0.031	-0.074	-0.338	0.010	0.078	0.014	0.130
IMFR	-0.017	-0.001	0.147	0.295	-0.025	-0.007	-0.005	-0.008
REA	-0.143	0.055	-0.098	0.032	0.196	-0.219	-0.124	-0.001
REAR	-0.034	-0.002	0.108	-0.165	-0.300	0.051	0.096	-0.203
RBFT	0.211	-0.034	-0.112	-0.016	0.146	-0.117	-0.105	-0.021
RBFR	0.345	-0.094	0.291	0.077	-0.149	0.054	0.107	-0.197
RPFT	0.080	-0.006	0.025	-0.010	-0.023	0.010	-0.007	-0.008
RPFR	-0.452	0.035	-0.183	-0.057	0.136	-0.088	0.018	-0.111
CW	0.006	0.123	-0.071	0.111	-0.034	-0.067	-0.056	-0.244
MB	-0.083	0.000	-0.029	0.000	-0.040	-0.064	0.055	-0.127
RE	0.097	0.010	0.041	0.148	0.185	0.210	-0.030	0.355
FT	-0.080	0.109	0.007	0.006	0.047	0.239	-0.104	0.600
$EN	0.177	0.103	-0.063	0.098	-0.055	0.143	0.062	0.056
$W	0.435	0.209	-0.135	0.037	-0.108	0.097	0.029	0.017
$F	-0.216	0.030	0.006	0.137	-0.059	0.130	-0.053	0.087
$G	0.025	-0.037	0.007	0.078	0.067	-0.009	-0.021	0.035
$QG	-0.055	0.018	-0.035	0.047	-0.019	-0.079	-0.062	-0.039
$YG	0.121	-0.092	0.062	0.077	0.147	0.094	0.049	0.118
$B	-0.009	0.065	0.008	0.157	0.025	-0.050	-0.092	-0.087

(Continued.)

Variable	PC28	PC29	PC30	PC31	PC32	PC33	PC34	PC35
BWT	0.019	0.005	-0.023	-0.002	-0.017	-0.014	0.007	-0.002
WWT	-0.009	-0.137	0.072	-0.058	0.051	0.014	0.019	-0.016
YWT	-0.217	0.338	-0.164	0.097	-0.074	-0.012	-0.012	0.020
ADG	0.362	-0.008	-0.107	-0.072	-0.066	-0.111	-0.009	-0.034
FSC	-0.049	0.062	-0.082	0.034	-0.013	-0.012	-0.011	0.000
ASCR	0.050	0.037	-0.024	-0.007	0.018	0.038	0.003	0.006
CE_d	-0.005	0.388	0.629	0.059	-0.014	-0.030	-0.011	0.017
BW	-0.091	-0.001	0.483	0.156	0.021	-0.168	-0.096	-0.004
WW	-0.086	0.148	0.027	-0.467	-0.326	0.230	0.191	0.046
YW	0.034	0.041	-0.079	0.060	0.290	0.137	0.222	-0.098
YH	0.114	-0.144	0.234	-0.085	0.087	0.021	-0.009	-0.006
SCR	-0.015	-0.005	0.002	0.002	0.006	-0.011	0.000	-0.008
BWR	0.024	-0.008	-0.084	-0.054	-0.041	0.034	-0.011	-0.005
WWR	-0.100	0.113	-0.037	0.200	0.209	-0.043	0.000	0.001
YWR	0.264	-0.149	0.122	-0.194	-0.188	0.030	-0.002	-0.002
DGR	-0.268	-0.103	0.104	0.007	0.085	0.092	0.014	0.018
CE_m	-0.087	-0.264	-0.296	-0.044	0.043	-0.020	0.021	-0.014
MM	0.119	-0.018	0.035	0.059	0.297	0.146	0.303	0.013
IMF	0.438	0.261	-0.116	0.245	-0.196	-0.032	0.018	0.007
IMFR	-0.474	-0.269	0.116	-0.195	0.120	-0.037	0.014	-0.021
REA	0.175	-0.431	0.173	0.183	-0.165	0.355	-0.011	-0.028
REAR	-0.144	0.247	-0.136	-0.092	0.059	-0.354	0.007	0.018
RBFT	0.242	-0.078	0.045	-0.362	0.252	-0.394	0.014	0.014
RBFR	-0.164	0.048	-0.068	0.304	-0.184	0.334	-0.017	-0.011
RPFT	-0.010	0.001	0.004	0.010	-0.009	0.003	0.001	0.002
RPFR	0.067	-0.035	0.048	-0.004	0.044	-0.029	-0.003	-0.003
CW	0.080	0.162	0.100	-0.113	0.090	0.130	-0.060	-0.267
MB	0.113	0.112	-0.047	-0.160	0.287	0.318	-0.457	0.337
RE	0.001	0.160	0.003	-0.137	0.153	0.187	-0.207	-0.161
FT	-0.085	0.042	-0.057	-0.041	-0.047	0.005	0.158	0.114
$EN	0.139	0.034	0.073	0.068	0.420	0.185	0.458	0.033
$W	0.047	-0.204	0.096	0.081	-0.117	-0.175	-0.240	-0.016
$F	0.019	-0.140	-0.071	0.410	0.241	-0.218	-0.202	0.004
$G	-0.016	0.007	-0.003	0.021	-0.056	-0.053	0.216	-0.255
$QG	-0.021	-0.031	0.023	0.075	-0.139	-0.133	0.241	-0.445
$YG	-0.001	0.056	-0.037	-0.066	0.091	0.090	0.056	0.156
$B	-0.010	-0.065	0.076	0.116	-0.172	-0.171	0.337	0.686

(Continued.)

Variable	PC36	PC37	PC38	PC39
BWT	0.002	-0.003	0.000	0.000
WWT	0.000	-0.006	0.003	0.000
YWT	-0.010	0.008	-0.001	0.000
ADG	0.013	-0.017	0.001	0.000
FSC	-0.003	0.025	0.706	0.000
ASCR	0.001	0.005	-0.001	0.000
CE_d	0.011	-0.002	0.000	0.000
BW	0.049	-0.062	0.000	0.000
WW	-0.145	0.329	-0.009	0.000
YW	0.142	-0.662	0.026	0.000
YH	0.006	-0.003	0.001	0.000
SCR	0.000	0.001	0.001	0.000
BWR	-0.003	0.001	0.001	0.000
WWR	0.010	-0.016	0.000	0.000
YWR	-0.002	0.017	-0.002	0.000
DGR	-0.006	0.013	0.000	0.000
CE_m	-0.004	-0.004	0.001	0.000
MM	-0.096	0.159	0.000	0.000
IMF	-0.009	-0.003	0.001	0.000
IMFR	-0.001	0.007	0.000	0.000
REA	0.020	-0.006	-0.001	0.000
REAR	-0.014	0.002	0.001	0.000
RBFT	-0.001	-0.004	0.000	0.000
RBFR	0.013	0.005	-0.001	0.000
RPFT	-0.002	0.000	0.001	0.000
RPFR	0.005	0.004	0.000	0.000
CW	0.357	0.125	-0.006	0.000
MB	0.050	-0.003	-0.004	0.000
RE	-0.551	-0.128	0.000	0.000
FT	0.311	0.067	0.002	0.000
$EN	-0.149	0.229	0.001	0.000
$W	0.082	-0.121	0.001	0.000
$F	-0.085	0.523	-0.018	0.000
$G	0.193	0.069	-0.002	-0.727
$QG	-0.140	-0.010	-0.001	0.558
$YG	0.543	0.138	-0.002	0.401
$B	-0.165	-0.142	0.014	0.000

Appendix B - Factor loadings of standardized variables describing purebred bulls offered for sale by the CO Ranch for principal components 6 through 14.

Variable	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14
CES	-0.144	0.038	0.189	-0.184	-0.109	0.413	0.630	-0.082	0.086
DSP	0.691	0.337	-0.055	0.146	-0.019	0.089	-0.006	0.018	0.005
BWT	-0.039	-0.153	-0.245	0.110	-0.215	0.709	0.094	-0.011	-0.014
BW	0.236	0.028	-0.072	-0.224	0.077	-0.378	0.673	0.033	0.099
WW	-0.003	-0.427	0.324	0.021	-0.022	0.015	-0.169	-0.062	0.620
YW	-0.034	-0.205	0.313	-0.084	0.033	0.026	-0.007	-0.105	-0.754
MM	0.056	0.353	-0.279	-0.589	0.180	0.231	-0.293	-0.094	0.070
MB	-0.108	0.288	-0.088	0.187	-0.769	-0.155	-0.021	0.252	0.005
RE	-0.073	0.366	0.501	0.150	0.288	0.091	0.005	0.282	0.084
MW'	-0.368	0.281	-0.089	0.091	0.308	0.121	0.055	0.387	0.058
FG	-0.117	0.157	0.020	0.446	0.141	0.013	0.079	-0.035	-0.072
$W	0.240	-0.420	-0.373	0.199	0.255	0.070	0.068	0.535	-0.071
$P	-0.095	0.114	-0.295	0.446	0.216	-0.040	0.102	-0.619	0.069

Appendix C - Factor loadings of standardized variables describing Stabilizer bulls offered for sale by the CO Ranch for principal components 6 through 14.

Variable	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14
CES	-0.085	-0.168	0.071	0.183	-0.102	0.501	0.156	0.260	0.549
DSP	-0.264	0.494	0.211	-0.016	-0.106	-0.021	0.025	-0.003	-0.011
BWT	0.035	0.266	0.196	0.363	0.409	0.586	0.070	-0.060	-0.063
BW'	0.104	0.147	0.006	-0.184	-0.020	-0.264	0.040	0.229	0.731
WW'	-0.074	-0.191	-0.013	-0.271	0.056	0.126	0.513	0.451	-0.276
YW'	-0.065	-0.212	-0.086	-0.218	-0.048	0.301	-0.316	-0.561	0.192
MM'	-0.095	0.518	-0.743	0.107	-0.083	0.069	0.090	-0.015	0.038
MB'	0.519	0.407	0.444	-0.115	-0.324	0.024	0.197	-0.183	-0.022
RE'	-0.083	-0.304	0.069	0.434	-0.345	-0.138	0.305	-0.254	0.071
MW'	0.054	-0.001	-0.014	0.620	0.140	-0.361	0.134	-0.057	0.045
FG	-0.292	0.064	0.175	-0.006	0.075	-0.070	-0.056	0.012	0.018
$W	-0.042	0.024	0.102	-0.172	0.716	-0.239	0.231	-0.257	0.191
$P	0.120	0.017	0.152	0.225	0.100	-0.081	-0.624	0.436	-0.036