

THE INFORMATION CONTENT OF SELLER-PROVIDED
PRESALE DATA IN CATTLE AUCTIONS

by

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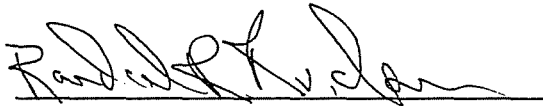
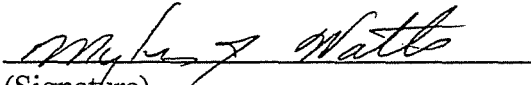
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ABSTRACT

Both buyers and sellers of goods whose exact characteristics are uncertain have incentives to develop methods of reducing duplicative buyer presale measurements. This thesis examines this issue in the context of the cattle industry where sellers provide different types of presale information to reduce buyers' presale measurement activities. Of particular interest are marketing mechanisms that have developed in auctions for breeding bulls. At auctions of yearling bulls, sellers often provide buyers with information on such characteristics as the bull's birth, weaning, and yearling weights, as well as the bull's pedigree. A primary focus of this thesis is to compare the information contained in these simple performance measures (SPMs) with the information contained in recently developed alternative measures of prospective performance. This alternative—expected progeny differences (EPDs)—uses statistical methods not only to incorporate information on the characteristics of the sale bull, but also the bull's relatives.

The statistical method employed for this comparison is multiple regression analysis. The sale price of a bull is regressed on the bull's performance measures and other terms specified in the seller-buyer agreement.

The regression results suggest that the simple performance measures (SPMs) contain substantial information in addition to that contained in expected progeny differences (EPDs). Conversely, it was found that EPDs contain some information in addition to that contained in SPMs, but this information is very limited. This finding is unexpected. EPDs, by construction design, contain the information found in SPMs, plus additional information on traits of related animals. Thus, it was hypothesized that the SPM measurements would contain no additional information beyond that contained within EPDs. The results of this research, however, suggest the contrary. An important question to be addressed by the cattle industry, therefore, is whether the costs of further development of EPDs are warranted.

CHAPTER 1

INTRODUCTION

Maintaining high quality standards is an important, yet complex, aspect of beef production. Although farmers must have detailed knowledge of feed resources, climate, and the market, quality of the breeding animals may be the most crucial element of the production process. Breeding animals often are purchased at auctions where buyers have only limited knowledge of the animals' precise characteristics. Because of this lack of specific information, buyers typically obtain their own measurements by expending time and effort examining and evaluating sale animals. Clearly, if all buyers engage in these presale measurement activities, the resulting high level of duplicity in the gained information is socially wasteful. Duplicity of measurements may also involve increased costs for the seller, insofar as special arrangements with the buyers are required to make taking of measurements possible. Facilitating these special arrangements could become so prohibitively costly for the seller that ultimately no goods would be exchanged—because people will exchange goods only if they perceive the value of what they get to be more than what they give.¹ Therefore, to minimize costs, the seller often is willing to provide prospective buyers with certain information on sale animals. The level of

¹ For a detailed discussion on measurement costs, see Barzel (1982). Barzel cites many instances in which buyers are willing to undertake their own measurements in order to limit the bias in the information on which the selection decision is based.

information provided is determined by the equilibrium of the marginal gain from the last unit of information and the marginal cost of this unit. Such information generally is made available to the buyer through auction catalogues.

A farmer choosing a bull considers several factors: price, reputation of the breeders, market conditions, pedigree, simple performance measures (birth, weaning, and yearling weights), and alternative measures of the future performance of the bull. Currently, the most common alternative measures are designated as expected progeny differences (EPDs). EPDs are used for the evaluation of a number of genetic traits. For every sale bull, each trait is assigned an EPD value. This value serves as an indicator of how the progeny of the bull will perform regarding this trait. In calculating EPDs, information on ancestors (sire and dam), descendants, and brothers and sisters is used. Descendants include progeny with records, progeny that are parents themselves, and grand progeny. All information about the animal and its ancestry is summarized into a single value, denoted by the EPD for each trait. In contrast, simple performance measures (SPMs), which also are used for trait evaluations, are obtained simply by weighing the animals.

In earlier times, breeders relied on the reputation of sellers, pedigrees, and visual evaluations to assess the quality of animals. Although this technique was used for many years, it could not accurately determine the animals' true breeding values. The early foundations of the theory of heredity were developed by Mendel in the late eighteenth century. Based on Mendel's theory, many inbreeding and crossbreeding experiments

were conducted. Thus, by the beginning of the twentieth century, progress in genetics brought new evaluation methods.

Because of the differences in opinions among geneticists, the results of genetic research had little impact on animal breeding up to the mid-1930s. A dramatic breakthrough occurred in 1930, however, when the first U.S. Range Livestock Research Station was established in Miles City, Montana. The research performed at the Miles City station clearly changed the history of animal testing procedures and techniques, and even today producers continue to benefit from this work through the measurement applications of estimated breeding values (EBVs) and expected progeny differences (EPDs).

Animal evaluation through the use of expected progeny differences is relatively new in the beef industry. This measuring technique was developed based on various studies conducted by noted researchers C. R. Henderson, R. L. Quaas, and E. J. Pollak in the mid-1970s and early 1980s (see, e.g., Henderson, 1973 and 1976; Henderson and Quaas, 1976; Pollak and Quaas, 1981a,b and 1983; Quaas and Pollak, 1980). The calculations for EPDs are derived by using the Best Linear Unbiased Prediction (BLUP) Theory and the maximum likelihood (ML) estimation method. Due to the amount of data used in the computations, the EPD measurement system is very complex. It is unusual for a typical breeder to possess a thorough knowledge of the calculation procedures. This limited knowledge of the system may be one of the reasons why EPDs are not fully trusted by many producers. Another possible reason for the limited credibility of EPDs is

that data for their computations (provided by the seller) could be biased.² As demonstrated by Klein and Leffler (1982), the seller is facing a tradeoff of whether to provide unbiased high quality information and gain in the long run, or to provide biased information and maximize short-term gains by selling low quality animals at high quality prices.

Alternatively, simple performance measures (SPMs) are obtained by the uncomplicated procedure of weighing the animals, where weights are later adjusted for age differences between animals. The SPM values do not incorporate data from related animals. This straightforward performance measure was developed based on experiments conducted at a number of different testing stations.

The primary focus of this thesis is the economic evaluation of expected progeny differences (EPDs) and simple performance measures (SPMs) as basic factors in making selection decisions. A related purpose is to provide a comparison of the information contained within simple performance measures (SPMs) and expected progeny differences (EPDs). To address these issues, a hedonic regression model will be constructed. The analysis will be performed on sample data collected from a total of 16 Nebraska, South Dakota, and Montana Angus breeders, containing over 8,500 observations.

Many researchers have examined the factors affecting cattle selection decisions, including studies concerned with the visual appraisal of animals, the importance of

² Because larger inaccuracies in data are now likely to be detected by the system of calculations, the incentives of the seller to provide biased information are reduced. In the past, however, inaccurate information has been entered in the calculations. In some cases, it was determined that breeders had even fabricated their own EPDs.

genetic improvement, and the heritability of economic characteristics. Several studies have addressed the determinants of cattle prices and estimated the demand for various cattle characteristics.³

Researchers in this field have employed many different approaches. Perrin (1981) used the Henderson genetic model to determine the value of information in sire selection. Greer and Urick (1988) developed a distributed lag model to examine price behavior in the bull market. Melton, Colette, and Wilham (1994) developed a production model that used regression analysis to estimate the production function, as well as linear mathematical programming methods. Most recently, Dhuyvetter et al. (1996) studied the factors affecting bull prices using a hedonic price model.

With the increasing importance of the economic value of animals and multiple-trait selection in the last 20 years, EPDs have become more widely used. The expansion of their application to most breeds in the United States not only brought about the improvement of current selection methods (as many experts agree), but also has prompted a debate concerning the usefulness of EPDs. Critics suggest that EPDs do not provide any additional helpful information over that offered by SPMs, that the EPD measurements are computationally difficult to obtain, and that far too much money is spent on the computation process.⁴ On the other hand, many researchers and producers

³ For a more detailed discussion of visual appraisal, genetic improvement, and heritability of economic traits, refer to the literature review provided in Chapter 3.

⁴ This statement is based on interviews with individual breeders. Some of them criticized the EPDs for very limited reliability and high costs associated with their computations.

have emphasized the usefulness of EPDs. Despite this controversy, to date there have been no detailed studies addressing this issue.

This thesis is divided into seven chapters. The following chapter describes the development of genetics and animal testing. The experiments and experiment stations that have most significantly changed the history of animal testing are discussed at the end of the chapter. Chapter 3 offers a review of literature. A description of the construction and use of measurements for expected progeny differences (EPDs) and simple performance measures (SPMs) is provided in Chapter 4. The data set construction used in the empirical analysis is explained in Chapter 5. In Chapter 6, a specification of the econometric model is presented, followed by a description of the regressions and a discussion of the empirical results obtained. The regressions are divided into four parts: the combined models, regressions with the simple performance measures (SPMs) only, regressions with expected progeny differences (EPDs) only, and residual regressions. The thesis concludes with Chapter 7, where explanations of the results and final conclusions are offered.

CHAPTER 2

HISTORY OF PERFORMANCE TESTING⁵Practical Beginnings

Since the beginning of the human race, people have been concerned with having enough food to satisfy their nutritional needs. In early times, food was obtained by hunting and fishing and by gathering fruits and seeds in their natural habitat. With the evolution of human skills and knowledge, people were able to develop more advanced techniques. Farming and animal agriculture became relatively stable providers of diverse food sources, and as the domestication of plants and animals progressed, the quality of life became more satisfactory. Although quantity of food was still a concern, the early farmers could rely on their skills, and so the uncertainty of food supply from their natural habitat was reduced.

These developments have relatively recent origin. Most records and archaeological evidence suggest that the domestication of animals began approximately 10,000 years ago. Prior to domestication, natural selection determined the animals that were best adapted for survival and reproduction. Those types that survived most effectively and reproduced more abundantly dominated the local and environmental

⁵ The primary literature resources for this chapter are the historical works of Legates and Warwick (1990), Johansson and Rendel (1968), and Lerner and Donald (1966).

niches available to them. As domestication progressed, animals began to be selected by humans for special purposes. The desire of humans for food, draft, or clothing began to influence their choice of animals for the production of offspring. Thus, intervention by humans was imposed upon the process of natural selection. As these additional requirements were imposed, the heredity of the animals was modified. Environmental and managerial adjustments, such as aid in feed supply and protection from predators, were implemented to permit animals with the best genetic traits to survive and reproduce.

The first recorded scientific experiments in animal breeding were conducted by Robert Bakewell (1725–1795) in the middle of eighteenth century. Bakewell's greatest contribution to animal breeding was that he tried out new methods of breeding and succeeded so well that he gained many followers. He is credited with conducting the first systematic progeny tests of bulls and rams. Bakewell purchased animals from many different sources and locations for use in his breeding experiments, selecting only those individuals that he considered to be the most suitable for his purposes. He then inbred intensively for several generations to consolidate the type, rejecting all animals with undesirable characteristics. The best animals were leased out to other breeders, but Bakewell retained the right to inspect the progeny. The best bulls were returned to Bakewell for further breeding experiments. Among his many pupils and followers was Charles Colling, who, together with his brother Robert, founded the Shorthorn breed. During the nineteenth century, the Shorthorn became the most famous of all cattle breeds. It was used in the formation of many other breeds, including the renowned Swedish Red and White cattle.

The formation of new breeds based on inbreeding began with the work of Bakewell and continued throughout the nineteenth century.⁶ Inbreeding has always played an important role in the formation of new breeds. Even today, new breeds are being formed by inbreeding. It is well known, however, that this method is associated with a great risk of degeneration.

The first of the official herd books for the new breeds was published for the Shorthorn breed in 1822. This was followed by the publication of other herd books, including the Dutch Friesian cattle herd book in 1875 in Holland. These early herd books contained only information about the pedigree. Later, at the end of the century, measuring and recording methods were implemented, and recording of production data began for some herds. In the late 1800s, three methods for the determination of fat content of milk were developed—the first by Lindstrom in 1889, the second by Babcock in 1890, and the third in 1893 by Gerber. In 1895, the first association of farmers monitoring the milk content was established. The recording of growth rate, food consumption, and carcass quality was also introduced that year.

After the introduction of herd books, it became necessary to set standards for ideal animals for each breed. All animals in the breed were required to conform to these standards as closely as possible.

⁶ Inbreeding is defined as the mating of closely related animals that may have inherited the same genes from common ancestors.

Summary of Breeding Theories Before 1900

There was little theoretical background underlying early animal breeding efforts. Breeders experimented with animals on the basis of trial and error. Although the experiments of Bakewell and Colling had advanced breeding techniques, there still remained a large gap in their theory, making further progress difficult.

In 1809, the French zoologist Lamarck (1744–1829) developed a theory of evolution purporting that species undergo progressive adaptation to prevailing environmental conditions. Lamarck declared that organs used regularly develop more strongly than organs used just occasionally. According to this theory, all information about organs is recorded in the germ cells and thereby transmitted to progeny.

Charles Darwin (1809–1882) is the best known proponent of the theory of evolution. While he did not formulate the original theory, he was instrumental in bringing about its acceptance. According to Darwin, the theory of evolution could be summarized by the following points:

- (1) Organisms vary, i.e., they are not exactly like their parents.
- (2) These variations are or may be hereditary, i.e., they may be passed along to descendants.
- (3) Due to the dynamics of reproduction in all species, there is a continual struggle for existence in nature.
- (4) Those best adapted to survive in a given environment will be the most likely to survive, and therefore should leave the most descendants.

In his famous 1859 treatise, The Origin of the Species, Darwin collected enough evidence to scientifically prove that evolution takes place, progressing from the lower to the higher organisms. Further, he explained how nature directs the path of evolution. Darwin also provided a partial explanation for the possible causes of the variations that occur in plants and animals.

Darwin's theories provided a solid background for many of his followers. One of them, German zoologist August Weismann, presented a theory in 1892 of the continuity of the germ plasm. Weismann was also among the first to associate the hereditary determiners with chromosomes of the cells.

Another theory, based upon the Lamarckian concept of inheritance of acquired characters and the principle of consistency, claimed that the breed as well as the individual is a product of the soil and the area where it has been developed. In other words, if an individual lives under consistent environmental conditions, it adjusts and achieves a high degree of adaptation and uniformity. This theory was embraced by Professor Prosch of Copenhagen, who warned in 1861 against imports of foreign breeds to countries with different environmental conditions.

Based on Darwin's theory, Francis Galton (1822–1911) developed the first statistical methods for conducting heredity studies. By doing so, Galton established a new branch of science called "biometry." He added quantitative precision to the characterization of variation introduced by Darwin. Galton's law stated that given a correlation of 0.5 between parent and offspring in a population, with minimum inbreeding

and a highly hereditary trait, the correlation between an animal and a more remote ancestor is halved for each preceding generation.

Genetics as a Basic Factor of Animal Breeding

The foundations of modern genetic theory were laid by Gregor Mendel in 1865. He suggested that pairs of alternative characteristics are essentially controlled by corresponding pairs of "factors" in the parents, and that in the production of a fertilized egg, one of each pair of factors is contributed by each parent. These factors became known as genes. Theories of heredity were not new, but this one, involving pairs of alternative factors, explained the regularities of inheritance that Mendel observed. These regularities are now expressed by Mendel's laws. Unfortunately, these laws, originally formed in 1865, were forgotten for the next 35 years. After their rediscovery in 1900, intensive work began in many countries to test them on different species of animals and plants.

William Bateson (1861–1926) appears to be the first researcher to demonstrate the Mendelian inheritance of qualitative characters in farm animals. He published a paper in 1902 on inheritance of hornedness and polledness in cattle.

Up to the middle of the 1930s, the results of genetic research had little effect on animal breeding. This was not because of lack of interest on the part of breeders, but because animal geneticists were not able to develop methods that could be applied by breeders in practice. There was a significant change, however, when research was intensified and results of practical value to the breeders were obtained. These important

results were achieved primarily in the fields of population genetics and inbreeding, crossbreeding, selection experiments, and disease resistance.

During the first two decades of this century, there was a sharp difference of opinion in England between the experimental geneticists, represented by Bateson, and biometry, represented by Francis Galton and later his successor, statistician Karl Pearson (1857–1936). It was first thought that biometrics and experimental genetics contradicted each other. However, the research of Ronald A. Fisher and Sewall Wright showed that these two sciences could be integrated. In 1918, Fisher published a paper on the correlation between relatives based on the assumption of Mendelian inheritance. A few years later, Wright published a series of papers on the genetic effects of different mating systems and on correlation and causation. In one of his later papers, Wright developed his method of path coefficients, which is closely related to Fisher's analysis of variance. Wright's path coefficients played an important role in population genetics research with farm animals, although his method is now used primarily to demonstrate causal relationship. Fisher's analysis of variance, on the other hand, has increased in importance in all fields of biological research.

As early as 1908, the English mathematician, Hardy, and the German physician and geneticist, Weinberg, had independently formulated what is now called the Hardy-Weinberg law, which, together with the work of Fisher and Wright, is the foundation of population genetics. By founding population genetics, a solid scientific background was developed and breeding investigation in practice was begun.

The pioneer in the application of population genetics was Dr. Jay L. Lush. He developed a general theory that can be applied to the analysis of the inheritance of quantitative characteristics as well as to estimating the breeding value of animals and the effect of selection. The influence of Lush and his students has shaped animal breeding and practice for the last 60 years.

The Last Sixty Years of Animal Breeding

Research in the beginning of the twentieth century progressed enough so that it was possible to establish a scientific background for practical animal testing. A major breakthrough occurred in 1930, when the first U.S. Range Livestock Research Station was established by the U.S. Department of Agriculture (USDA) in Miles City, Montana. Progress continued through the 1940s with the beginning of research in New Mexico and California, and with the development of feeder cattle grade standards by the USDA. Three regional research programs also were established by the USDA: Western (W-1), Midwest (NC-1), and Southern (S-10).

During the first 40 years of the twentieth century, beef cattle breeding research was characterized by slow progress. Black (1936) reported on the survey results of a questionnaire which had been sent to each of the 48 State Agricultural Experiment Stations. The questionnaire sought information on birth weights, gains, efficiency of feed utilization, and quality of the animal and carcass. Responses were received from 18 stations, and of these, only five reported having any definite breeding project with cattle.

By 1955, several State Extension Beef Cattle Improvement programs had begun. During this same time period, computers were introduced for use in the processing of information. On March 25, 1954, the Texas Red Angus Association was founded in Fort Worth. In 1955, the first Beef Cattle Improvement Association was founded and Performance Registry International was established. The Beef Cattle Registry Association began to formalize the collection of records by its members in 1959, and the Angus Herd Improvement Record Program was initiated by the American Angus Association.

In the 1960s, performance programs began to flourish, providing valuable information that breeders could use in making selection decisions. The Beef Improvement Federation (BIF) was founded in 1968, and began to develop the framework for standardized and systematic procedures. One of the first tasks of the BIF was to establish guidelines for the national sire evaluations (NSEs). These guidelines were approved by the board of BIF in 1971, and shortly after their publication in 1972 became accepted as the performance "bible" by the beef industry. In 1971-72, the American Simmental Association published the first "National Sire Summary," which introduced a dramatic change in the industry. Bulls could now be compared across herds and generations. The scientific effort and development in the field of data processing in the 1960s permanently changed the industry.

In his paper presented at the 1973 American Society of Animal Science meetings, C. R. Henderson introduced his mixed-model procedures providing best linear unbiased

prediction (BLUP) of breeding value.⁷ In 1974, R. L. Wilham presented a paper at the BIF regional meeting in Montgomery, Alabama, outlining a procedure for generating estimated breeding values (EBVs). The research of Henderson and Wilham established a solid base for the future structure of beef cattle improvement programs. The concept of EBVs was soon adopted for the Angus, Hereford, and Simmental breeds. Even though significant progress was made in the evaluation methods, the models constructed in the 1960s were only able to compare animals within contemporary groups. This made within-herd selection easier, but did not have a wide impact on improving breed genetics. In order to make within-breed comparisons, contemporary groups had to be connected by the use of some sires over more than one contemporary group. Each contemporary group was required to have at least two sires represented. This resulted in the introduction of a new evaluation tool, called "expected progeny differences" (EPDs), which assumed that sires had been mated to comparable sets of cows and that progeny were treated similarly within contemporary groups.

The EPD models used in the early 1970s were based on the mixed-model procedures using BLUP, as described by Henderson in 1973. These procedures were fully implemented in the analysis of Angus, Herefords, Polled Herefords, and Limousin breeds by 1977.

In the following decade, many changes were recorded in the sire evaluation procedures, and a transition from single-trait evaluation to multiple-trait evaluation took

⁷ Breeding value is a subjective measure that refers to the physical characteristics of an animal that contribute to genetic improvement. It is based on the animal's ability to produce offspring that have better qualitative characteristics than their parents.

place. Breeders realized that while the growth trait is an important factor in animal selection, if the growth potential is overemphasized, ease of calving could be threatened. The development of computers made it possible to analyze larger models that accounted for more of the factors that could bias the EPDs. In 1973, Henderson proposed a model that enhanced the accuracy of genetic prediction by incorporating pedigree information into the model and accounting for genetic trend. It was computationally impossible at that time, however, to fully address the complexities of this problem. This method was dramatically improved in 1976, when Henderson published a paper describing a rapid method for computing the inverse of a relationship matrix. His revolutionary improvement was not recognized immediately, but his later applications to the models changed the sire evaluation program substantially. Relationships among sires were first included in analyses by the Limousin and Red Angus associations in 1983. In 1984, use of the relationship matrix was begun for Angus, Polled Herefords, and Herefords.

Even though the model was substantially improved in the 1970s, numerous concerns to both researchers and breeders remained. One problem was that the dams were not mated randomly to the sires, and sire evaluation reports did not include the dam effect. With the improvement of computers, it became possible to include the dam effect for the first time in the sire evaluation reports in 1984. Another problem was the lack of information available to breeders at time of purchase. Breeders usually buy breeding bulls when they are one year of age. Because of the time lag in the publication of the national sire summary reports, however, data on the bulls were not available to breeders until the bulls had already reached an older age. Because the sire evaluations were not

available for these young animals, breeders were making selection decisions based on different information than that contained in the sire summary reports. The information on the breeding potential of yearling bulls was greatly enhanced in 1976, when Henderson and Quaas introduced a model using large numbers of relatives as well as the individual's own records.

The Henderson-Quaas model was further improved by Quaas and Pollak (1980) and Pollak and Quaas (1981a,b). The new model for the first time provided predictions of progeny performance for dams and young animals that had not yet produced any progeny. This model also largely eliminated the bias due to nonrandom mating; however, the complexity of the model resulted in computational difficulties. It was not until the mid-1980s that scientific computer software became advanced enough to solve these complex problems. In late 1984, the model was adopted by the associations for the Limousin and Brangus breeds. Today most of the evaluation programs are based on the Quaas-Pollak model.

The application of the Quaas-Pollak reduced animal model (RAM) solved many problems in the predicting of genetic values. Among its advantages over older models are that it incorporated dam information and it provided genetic values for young bulls with no progeny. Although this model provided genetic values for several traits, these values were determined in an independent manner—the model was still unable to provide simultaneously determined values for multiple traits. The model that achieved this goal for the first time was introduced in 1986 by the Simmental and Gelbvieh associations. In 1987, the Limousin and Brangus sire summaries also began using the multiple-trait

analysis model. By 1988, associations for nearly all breeds accepted simultaneous multiple-trait analyses as a basic structure of their evaluations.

Long-Term Research Experiments

The Roman L. Hruska U.S. Meat Animal Research Center

The Roman L. Hruska U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964. MARC is administered by the USDA's Agricultural Research Service (ARS) in cooperation with the University of Nebraska. Scientists there investigate major biological, physical, and managerial influences on production efficiency and product quality. Their research activities provide new technology for the U.S. livestock industry by extending investigations into areas that previously have not been adequately studied.

The goal of genetic and breeding research is to develop mating and selection procedures that increase genetic resistance to disease and enhance genetic capacity for efficient beef production. The primary objective is to determine the optimum performance capability under different feed environments and production situations, with emphasis on matching the genetic potential of breed resources to specific feed resources and consumer preferences. The program focuses on both male and female reproductive efficiency. Currently MARC is playing an important role in a research project developing across-breed expected progeny differences. The concept of across-breed EPDs was presented in 1987 by David Notter of Virginia Tech. Notter collaborated with MARC's Larry Cundif in 1991 to develop the program based on data from MARC's

crossbreeding project. Though Notter and Cundif have continued to update the research since 1991, the Beef Improvement Federation (BIF) has not yet set an official policy on across-breed EPDs.

The reaction to the research from officials of the 12 breeding associations included in MARC's evaluations has ranged from enthusiasm to disappointment. The concept was accepted by several organizations, including Simmental and Hereford. However, most of the officials representing the breeding associations were concerned that the MARC program, despite being the longest running and largest crossbreeding study, still does not reflect true conditions in all regions of the country.

The Northwest Branch Experiment Station⁸

The University of Georgia initiated research at the Northwest Branch Experiment Station (NWBS) at Calhoun, Georgia, in 1977. The project was designed to analyze long-term selection on Hereford cattle, with the primary focus on sire evaluation as a basic tool in making selection decisions. The program was set up in three phases, as detailed below.

Phase 1. This phase included the years 1978 through 1985. In the first six years of selection, the animals were selected for yearling weight using the yearling weight EPD as the single selection criterion. While yearling weight for the horned Hereford population had been changing at a rate of approximately 5.3 pounds per year, during the

⁸ Refer to Benyshek et al. (1996) for additional information concerning research conducted at the NWBS.

time period of 1978–1983, the NWBS selection line was changing at more than 11 pounds per year. This represents the change that could be expected if a herd started at the average of the breed and used those progeny tested bulls who had the best yearling weight EPDs. Rapid change in yearling weight continued until 1983, when the selection criterion was changed. The selection criterion was changed because the increase in yearling weights also brought an increase in birth weights, which resulted in calving problems for heifers. The birth weight was changing in the horned Hereford population at a rate of approximately 0.4 pound per year, while the NWBS line was changing at a rate of one pound per year during the 1978–1983 period. Birth weight EPD was first considered as an important selection factor in the 1983 season, and in the following seasons birth weight began to decrease. However, some reduction in yearling weight was also observed during this period.

The single-trait selection for yearling weight also had a negative impact on maternal weaning weight. During this period, average maternal weaning weight was declining at approximately 1.1 pounds per year in the NWBS herd, while the horned Hereford population was increasing at 1.1 pounds per year. Phase 1 demonstrated that rapid genetic change could be accomplished using EPDs, and also identified problems associated with single-trait selection.

Phase 2. This phase commenced in 1987 and continued through 1991. The animals were again selected for yearling weight, and sires came from outside of the herd. The first line was continued as in Phase 1, with selection based on yearling weight EPDs.

The second line used the best bulls from central test stations. The third line used the best young bulls available based on nonparent yearling weight EPDs. None of the bulls from the third line had produced progeny at the time they were selected for the test.

In a comparison of these three lines, the first line continued to increase the yearling weight at a rate of 11 pounds per year. The third line, where the young nonparent bulls were used, also showed favorable results; yearling weight increased at a rate of 10 pounds per year. In the second line, the yearling weight increased initially, and then began to regress back to the Hereford average.

Comparing the birth weights, the first line continued to change rapidly because no attention was paid to the birth weight in the selection decisions. Surprisingly, the third line birth weight changed just slightly. The second line actually reflected a slight decline for the birth weight—a result explained by the fact that the bulls chosen for testing by test stations are generally selected for lighter birth weights.

When comparing the maternal weaning weight in the three project phases and the overall Hereford population trend, there was a decline in maternal weaning weight for the first and third lines. The second line improved slightly, again because of the preselection of bulls being tested at the central test stations.

Phase 2 indicated that yearling bulls with EPDs can be selected to make significant genetic changes at almost the same rate as progeny tested bulls. The dangers of single-trait selection were again pointed out in this phase.

Phase 3. This phase includes the years 1992 through 1997 (and therefore is still underway at the time of this writing). Phase 3 is an attempt to use multiple-trait selection through an independent culling level procedure. The current program includes two selection lines. The first line is concerned with birth weight and growth trait selection, while the second involves birth weight, growth, and maternal weaning weight. None of the bulls selected for testing had produced progeny at the time of the selection decision. In this phase, the purpose of the test is to simulate the selection process that commercial breeders undergo every year at the auctions. The selection criterion for birth weight is that the bulls selected must not be above the population average birth weight EPD for the year in which they were born. After the birth weight criterion is met, the largest yearling weight EPD bulls are selected. In the second line, high maternal weaning weight is added as a selection criterion after the first two criteria are met.

In a comparison of these two lines, the first line currently is showing the larger increase for yearling weight. While the increase is not as rapid as in the previous two phases, it is maintaining a sizable difference compared to the Hereford average. The reduction in rate of change is due to multiple-trait selection.

When comparing the birth weights, both lines have moved below the average of the horned Hereford population and appear to be maintaining this lower birth weight. Since the maternal weaning weight selection criterion is not considered in the first line, the maternal weaning weight breeding value has fluctuated over the period of the experiment. The second line (where the maternal weaning weight selection criterion is

considered) has moved above the horned Hereford average and appears to be maintaining this higher value.

According to Benyshek et al. (1996), if these results hold through the next two calf crops, the project will demonstrate the usefulness of EPDs for selecting young bulls in a multiple-trait selection program.

Sire Testing in Montana: The U.S. Range
Livestock Research Station, Miles City

In 1931, the USDA's Bureau of Animal Industry began a long-term project to study and test whether heritability estimates of economic traits could be measured, and at what levels they are inherited and passed on to the next generation. The research was initiated because of the increasing importance of these characteristics for both commercial and purebred breeders. In the early days of animal testing, breeders emphasized the physical appearance and show ring performance of their animals, and the ability of the animals to gain weight was considered secondary. Increasing competition in the beef and animal markets and an increase in demand for quality beef products, however, changed this priority. Emphasis shifted to a breeding program based on inbreeding where selection is determined by weight gains, carcass qualities, and other economic considerations.

The project was assigned to the U.S. Range Livestock Research Station at Miles City, Montana. The station, in cooperation with the Montana Agricultural Experiment Station, undertook the production of several inbred lines of cattle, basing selection on economic performance. Three lines of cattle were started between 1936 and 1938. Since

that time, several more lines have been added; however, to date, Hereford Line 1 has proved to be the most successful.

The foundation of Line 1 was purchased from a Colorado breeder, and the cows were bred at the station. The original breeding program called for half-brother-sister mating whenever possible, but this requirement could not be strictly adhered to.

Records of this testing program indicate that the rate of weight gain for this line has increased without any apparent loss in quality of carcass. The progress of Line 1 during the last 40 years has encouraged other purebred breeders of beef cattle to develop lines in which selection is based on economic performance. All beef performance testing programs now active in the United States (and many others throughout the world) are built on the foundation established by the Miles City Hereford experiments.

In addition to the facilities cited above, there are many other research centers and testing stations throughout the country that have contributed to the development of genetic improvement and sire testing of animals. This chapter has offered a selective discussion of research facilities that are credited with significant scientific contributions and whose projects are closely related to the research focus of this thesis.

CHAPTER 3

REVIEW OF LITERATURE

This chapter offers a review of relevant literature with emphasis on a discussion of research addressing the determinants of bull prices and the economic value of genetic information.

Development of Statistical Methods
for the Study of Heredity

The first attempt to introduce statistical methods into the study of heredity was by Francis Galton in 1889. In his book, Natural Inheritance, he presented a theory of heredity based on experiments with sweet peas and analysis of data on height and eye color in humans. In analyzing the inheritance of height, he converted the height of adult women to that of men by using a correlation factor of 1.08 for the female data. Based on the parental averages and correlation factor, Galton calculated the regression of offspring. He observed that the deviation of the offspring from the population average (P) was two-thirds of the parental average deviation from the same average. Based on this finding, Galton formulated the following law of regression: The deviation of the sons from P is,

on average, equal to one-third of the deviation of the parent from P , and in the same direction.⁹

In a later publication, Galton (1897) extended his findings and stated a statistical law of inheritance that appeared to be universally applicable to bisexual descent. It was formulated as follows: Two parents contribute between them, on average, one-half (or 0.5) of the total heritage of the offspring; the four grandparents, one-quarter [or $(0.5)^2$]; the eight great-grandparents, one-eighth [or $(0.5)^3$]; and so on. Thus, the sum of the ancestral contribution is expressed by the following series:

$$(3.1) \quad [(0.5) + (0.5)^2 + (0.5)^3 + \dots + (0.5)^n] = 1,$$

which accounts for the entire heritage.

Galton, not yet aware of Mendel's laws (formulated in 1865, but not "rediscovered" until 1900), committed some serious mistakes in the interpretation of his results. Nevertheless, his "law of regression and inheritance" represents an important step in the construction of selection indexes.

Hazel (1943) attempted to construct a selection index that would provide the maximum genetic progress by assigning the proper weights to each trait in multiple-trait selection. He was among the first to observe that multiple-trait selection is a more efficient tool of genetic improvement than selection for one trait at a time or for several traits with an independent culling level for each trait.

⁹ Galton's term, "regression," originally denoted a step back from the parental averages toward the population average, rather than the increase in height of the offspring for each unit increase in the average height of the parents.

According to Hazel, the net genetic improvement by selecting among a group of animals is the sum of the genetic gains made for the several traits that have economic importance. The gains for each trait (\bar{G}_i) are weighted by the relative economic value of that trait (a_i). Thus, the average genetic superiority of a selected group over the group to which it is compared (\bar{H}) is shown as follows:

$$(3.2) \quad \bar{H} = a_1\bar{G}_1 + a_2\bar{G}_2 + \dots + a_n\bar{G}_n.$$

Because the animals vary in breeding value and in the phenotype for each of the several traits, the aggregate value of the animal is the sum of its several genotypes, with each genotype being weighted according to the relative economic value of that trait.¹⁰

Thus, the aggregate genotype of the animal is expressed as follows:

$$(3.3) \quad H = a_1G_1 + a_2G_2 + \dots + a_nG_n.$$

Because environmental influences and dominant and recessive factors¹¹ may result in phenotypic performance unlike the genotype for that trait, animals having the highest values for H may not be recognized directly with high accuracy. Therefore, the selection

¹⁰ Genotype refers to the actual genes that an organism carries and is capable of passing on to the next generation. Phenotype refers to the actual appearance (in terms of traits) that an organism displays. Sometimes, but not always, phenotype reflects genotype, as in the case of doubly recessive genes; but if an organism has one dominant and one recessive gene, the phenotype is that of the dominant trait, thereby masking the presence of the recessive gene. The importance of this distinction is in its stress on the fact that the only way to determine genotype is through breeding experiments, not simply through examination of an organism's phenotype.

¹¹ A dominant factor is a factor whose effect is manifested in the phenotype wholly or partially, regardless of which other factors are present. Conversely, a recessive factor is a factor whose effect is not observable when present with a dominant member.

for improved breeding value must be practiced indirectly by selecting directly for a correlated variable (I) based on the phenotypic performance as follows:

$$(3.4) \quad I = b_1X_1 + b_2X_2 + \dots + b_nX_n,$$

where the X 's represent phenotypic performance and the b 's are multiple regression coefficients that are chosen so as to make the correlation between genotype and phenotype as large as possible.

Over the years since its development, Hazel's model has been criticized for several reasons. First, breeding objective functions are often more complex than the linear and additive breeding objective function specified by Hazel. Attempts to introduce quadratic terms into the equations were made, for example, by Wilton and Van Vleck (1968, 1969). Second, the procedure could be applied only in cases where the information available on each candidate for selection was the same. This limitation of the model was overcome by Henderson (1973). Although many other researchers had attempted to improve Hazel's model, success was not achieved until 1973, when Henderson presented a thorough statistical basis for mixed-model equations to simultaneously provide best linear unbiased estimates (BLUEs) of nongenetic fixed effects and best linear unbiased predictions (BLUPs) of genetic effects.

As computer science advanced and computer capability increased, sire evaluation procedures were expanded to provide more accurate predictions for more complex models. In 1976, Henderson published a method for computing the inverse of a numerator relationship matrix, which is needed to incorporate data from records of large

numbers of relatives. Quaas (1976) developed a modified algorithm for this method. Henderson and Quaas (1976) successfully demonstrated the method using an example from cattle breeding.

In succeeding years, many scientists attempted to reduce the computational requirements of the model. Quaas and Pollak (1980) constructed a reduced animal model (RAM), designed to evaluate sires, dams, and progeny deviations as separate model elements. RAM provides the same solutions as the animal model introduced by Henderson in 1973, but reduces the overall number of equations to be solved. The reduction in number of equations is accomplished by absorbing the equations for nonparents into the equations for parents. The steps leading to the RAM model equations were published by Pollak and Quaas in 1983.

Today, expected progeny differences (EPDs) are calculated by the University of Georgia, Cornell University, and Colorado State University. The University of Georgia works with 11 beef cattle breeds (Horned and Polled Hereford, Black Angus, Limousin, Shorthorn, Brahman, Brangus, Beefmaster, Santa Gertrudis, Chianina, and Canadian Charolais). The University of Georgia currently uses a single- or multiple-trait reduced animal model (RAM) to predict EPDs. Cornell University analyzes records from the American Simmental, American Simbrah, and Canadian Simmental breeds. Weight traits, calving ease traits, and carcass traits are analyzed in three separate multiple-trait mixed-model analyses using Henderson's mixed-model equations. Colorado State University analyzes records from the Charolais, Gelbvieh, Red Angus, RX3, Salers, and

Tarentaise breeds. Colorado State University is using single- and multiple-trait mixed models that fit parent effects using the reduced animal model (RAM).¹²

Determinants of Purebred Bull Prices

Historically, farmers used visual appraisals to determine the genetic and economic value of animals. Because the performance of an animal is not based solely on its physical appearance, this method has very limited reliability. Knapp and Clark (1950), using a technique known as the half-sibling correlation method, reported the birth weight to be 53 percent heritable, weaning weight 28 percent heritable, final feed lot weight 86 percent heritable, gain in the feedlot 65 percent heritable, and weaning score 28 percent heritable. They concluded that heredity plays a major part in the determination of post-weaning growth rate, and therefore individual performance can be used as a basic factor for predicting progeny weights or gains.

Shelby, Clark, and Woodward (1955) examined heritability of economic characteristics of beef cattle and suggested that too much emphasis is placed on visual conformation in the selection of breeding stock in beef cattle. Their empirical findings indicated that there is little relationship between visual conformation and most economically important traits. The authors emphasized the need for development of more adequate measures of performance.

¹² All models are currently estimated using the maximum likelihood (ML) method. For specific details on EPD calculation methods, refer to the Guidelines for Uniform Beef Improvement Programs, published by the Beef Improvement Federation (BIF, 1996).

Nelsen et al. (1985) investigated the relationship among weight, height, heart girth, and visual conditions in Hereford and crossbred cows. They reported that although the relationship is positive, the correlation between the measurements and visually assigned conditions is far from being 1.

With the improvement of sire selection methods, breeders acquired more advanced methods of animal selection. First, the single-trait evaluation method was used, where breeders placed an emphasis on the selection of growth traits. Later, due to large increases in birth weights, multiple-trait selection was implemented. The advantages of multiple-trait selection over single-trait selection and visual evaluations have been examined by many researchers and breeders.

Benyshek et al. (1996) pointed out the dangers of single-trait selection and the advantages of multiple-trait selection in their discussion of experiments performed by the University of Georgia Experiment Station. When single-trait selection was practiced, the increase in yearling weights was accompanied by a very significant increase in birth weights. However, when multiple-trait selection was employed, the yearling weights of the animals increased, but birth weights stayed constant. Gardiner (1989) reported a 300-pound increase in the weight of steers between 1980, when multiple-trait selection was implemented, and 1988.

Perrin (1981) studied the economic value of genetic information in selecting sires. He was primarily concerned with the final choice made by the commercial producer, for whom the objective is to maximize the economic value of the individual animals used in the final stage of production. Perrin used the standard Henderson model, which specifies

that the j th observed phenotypic outcome of the i th genotype is determined by the following formula:

$$(3.5) \quad Y_{ij} = \underline{X}_{ij} \underline{b} + g_i + e_{ij},$$

where Y_{ij} is measured outcome, $\underline{X}_{ij} \underline{b}$ is the contribution of a vector \underline{X}_{ij} of observable variables to Y_{ij} , g_i is an unobservable genetic component of Y_{ij} , and e_{ij} is an unobservable random component. Genetic selection is then a problem of choosing between alternative genotypes ($i = 1, \dots, k$) without having perfect information about g_i , the additive effect of each alternative. The previous model can be simplified by dropping the j subscript (since there is generally only one outcome for each genotype) and by expressing outcomes as departures from average: $y_i = Y_i - \bar{X}_i \underline{b}$. The additive genetic model is then specified as follows:

$$(3.6) \quad \underline{y}_i = \underline{g}_i + \underline{e}_i,$$

where \underline{y}_i is a vector of observed phenotypic characteristics, expressed as departures from average; \underline{g}_i is a vector of genetic components; and \underline{e}_i is a vector of environmental components. Given the economic weights (marginal value products) of the characteristics represented by \underline{w} , the economic value of any individual animal is then shown as:

$$(3.7) \quad V_i = \underline{w}' \underline{y}_i = \underline{w}' \underline{g}_i + \underline{w}' \underline{e}_i = v_i + \varepsilon_i,$$

where \underline{w} is a vector of economic weights; $\underline{v}_i = \underline{g}_i + \underline{e}_i$, where \underline{e}_i is a vector of environmental components and \underline{g}_i is a vector of genetic components; ε_i is the random component of the value of individual i ; v_i is the genetic value of individual i ; and V_i is the observed, or phenotypic value of individual i . A commercial producer selecting sires is interested in the genetic value, v_i , which can be estimated by constructing various selection indexes.

Perrin attempted to estimate the value of swine test information by comparing the value of boars with different levels of information provided. He concluded that a commercial producer would be willing to pay from \$80 to \$160 to know a sire's selection index prior to choosing between that sire and another sire about which nothing is known. Based on his analysis, Perrin found that the information provided by the selection index was of relatively small value compared to the sire's phenotypic record itself.

A number of researchers have also proposed methods for estimating the value of input characteristics. Ladd and Martin (1976) argued that the price of a purchased input equals the sum of the values of that input's characteristics to the purchaser, implying that the demand for an input is directly affected by the input's characteristics. They concluded that multiple regression is one of the best methods for estimating the monetary values of input characteristics. Their conclusion is applicable to the analysis of the determinants of bull prices where a given bull's price is determined by bull quality measures, i.e., EPDs and SPMs. Ladd and Martin also proposed a linear programming approach to measure the marginal values of individual inputs. They stated a basic linear programming problem as:

$$(3.8) \quad \min \sum_{j=1}^m p_j x_j$$

subject to:

$$\sum_j a_{ij} X_j \geq a_{i0}, \quad i = 1, 2, \dots, m_0,$$

$$\sum_j a_{ij} X_j \geq a_{i0}, \quad i = m_0 + 1, m_0 + 2, \dots, m,$$

$$x_j \geq 0, \quad j = 1, 2, \dots, n_0,$$

$$x_j \text{ unrestricted}, \quad j = n_0 + 1, n_0 + 2, \dots, n,$$

where p_j is the price of the j th ingredient, x_j is the quantity of the j th ingredient used per unit of output, a_{ij} is the quantity of the i th nutrient or other characteristic in a unit of purchased input, and a_{i0} is the amount of the i th nutrient or characteristic required in one unit of output. Applying their input characteristics model (ICM) to the problem of the optimal use of corn shipped from a central Iowa elevator, Ladd and Martin discovered, for example, that the shadow price of one pound of corn was 2.29¢. In other words, the firm could have increased its net revenue by 2.29¢ if it had been endowed with one more pound of corn.

LaFrance and Watts (1986) used a linear programming model to examine the value of protein in feed barley. Because there is no premium paid for high protein barley in the feed market, the authors attempted to identify the reasons for its absence by examining a hypothetical scenario to determine the value of a protein premium. They created a least-cost feed rations model and used it to analyze the marginal value of additional protein in feed barley to livestock breeders. They concluded that the

transactions costs of measuring protein levels and of separate handling of barley with different protein contents would be higher than the value of feeding higher protein barley. A protein premium in the feed barley market thus does not appear to be economically justified.

Melton, Colette, and Wilham (1995) developed an input characteristics model (ICM) and method of analysis by extending prior ICMs to estimate economic values for genetically determined input characteristics. They proposed an approach that involved analyzing output from a linear programming ICM using multiple linear regression. The researchers reported that the model and the method of analysis developed are less restrictive than prior ICMs in both data requirements for estimation and the necessity of specifying, a priori, causal genetic relationships. However, shortly after its publication, this model was criticized by Amer and Fox (1995) for serious inconsistencies in theory and very limited applicability to the problem of input optimization. Amer and Fox suggested that future economic considerations of changes in genetic characteristics continue along the lines first proposed by Hazel (1943): First, answer the question of whether a genetic change in a specific characteristic could be achieved, and then estimate how much such a change would be worth.

Several studies have investigated the determinants of cattle prices. Marsh (1983) used a rational distributed lag model to examine determinants of quarterly fed cattle and feeder cattle prices. He described the behavior of these two classes of prices by the following equations:

(3.9) Fed Steer Prices:

$$PFED_t = f_1[QFED_{t-j}, QNFED_{t-j}, BPV_{t-j}, PCARC_{t-j}, E(PFED_{t-p}), D_i, U_{t-j}],$$

(3.10) Feeder Steer Prices:

$$PFDR_t = f_2[QPL_{t-j}, PFED_{t-j}, PCORN_{t-j}, E(PFDR_{t-p}), D_i, U_{t-j}],$$

$$(3.11) \quad \begin{aligned} t &= 1, 2, \dots, T, \\ \text{lag } j &= 0, 1, 2, \dots, k, \\ p &= 1, 2, \dots, P, \\ \text{quarter } i &= 2, 3, 4, \\ k &\leq P, \end{aligned}$$

where $PFED$ is the price of Choice grade slaughter steers, $QFED$ is the quantity of commercial cattle slaughter of fed steers and heifers, $QNFED$ is the quantity of commercial cattle slaughter of nonfed steers and heifers, BPV is steer by-product value, $PCARC$ is the wholesale price of steer carcasses, D represents a seasonal dummy variable, U is a disturbance term, E is the expectation operator, $PFDR$ is the price of Choice grade feeder steers, QPL denotes the quantity of cattle placed on feed in 23 major cattle feeding states, and $PCORN$ is the price of No. 2 yellow corn.

The equations were estimated by Marquardt nonlinear least squares and compared to alternative models using autoregressive-moving average error and a static specification with serially correlated disturbances. Marsh concluded that a rational lag structure adequately described the behavior of cattle prices, and was generally better than purely

autoregressive and static approaches. Fed cattle prices geometrically decline in response to changes in slaughter supplies, but fully adjust within one quarter to changes in carcass prices and by-product value. Feeder cattle prices tend to follow a stable declining oscillatory lag pattern, reflecting the beef price cycle.

Rucker, Burt, and LaFrance (1984) constructed a model of cattle inventories using a rational distributed lag model. They suggested that ranchers based their decisions about herd size on their expectations of future cattle and feed prices and feed availability.

Therefore, the form of their model was expressed as follows:

$$(3.12) \quad y_t^d = f(P_t^e, F_t^e, W_t),$$

where y_t^d is the desired herd size in period t , P_t^e is a vector of expected cattle prices, and W_t denotes weather conditions in period t . The model was estimated by nonlinear least squares, and the results strongly support the theory that calf and feed prices are important determinants of cattle inventories.

Greer and Urick (1988) extended the work of Marsh by applying the model to bull prices. Their model was specified as follows:

$$(3.13) \quad BP_t = f(CP_t, CI_t, HI_t, BP_{t-1}, D78, D79),$$

where BP is the average Miles City Hereford-1 line yearling bull price, CP is the No. 1 steer feeder calf price, CI is the January 1 inventory of cows and heifers that have calved, HI is the January 1 inventory of heifers 500 pounds and over, and $D78$ and $D79$ represent dummy variables for 1978 and 1979. The model also was estimated using a modified

Marquardt nonlinear least squares algorithm. The statistical results of the Greer and Urick study supported the hypothesis that prices and other economic information are incorporated into bull purchase decisions.

Parcell, Schroeder, and Hiner (1995) examined the determinants of cow-calf pair prices using the hedonic regression model first proposed by Rosen (1974). Hedonic prices (the implicit prices of the characteristics) are estimated by regression analysis where a product's price is regressed on its characteristics. Using the model, where

$$(3.14) \quad \textit{Price} = f(\textit{Cow Characteristics}, \textit{Calf Characteristics}),$$

the researchers determined how breeders in the auctions in their data sample valued various cow-calf characteristics. They showed that buyers were willing to pay a significant premium for the breeding and growing value demonstrated by a young, quality; healthy cow with a large calf. Holding pairs until calves are near weaning weight resulted in higher per pair prices, as uncertainty regarding growth potential is reduced.

Dhuyvetter et al. (1996) used a hedonic price regression to study the determinants of purebred beef bull prices. Their study provides insights about factors affecting bull prices and, along with the present study, is the first to recognize expected progeny differences (EPDs) as an important bull price determinant. Following Ladd and Martin (1976), Dhuyvetter et al. specified the model for their study as follows:

$$(3.15) \quad r_i = \sum_j T_j x_{ji},$$

where i refers to a particular bull; j refers to physical, genetic, and performance characteristics of the bull; r_i is the price of the bull; T_j is the marginal implicit price paid for the j th characteristic; and x_{ji} is the quantity of characteristic j the bull possesses. Given the prices and characteristics data, the marginal implicit prices can be estimated using a hedonic regression. Dhuyvetter et al. split the bull characteristics into two categories: physical and genetic characteristics, and expected performance characteristics. Physical and genetic characteristics refer to the bull's own traits, while expected performance characteristics refer to progeny characteristics. After adding marketing factors, their model was specified as follows:

$$(3.16) \quad \text{Bull Price}_i = f(\text{Physical and Genetic Characteristics}_i, \text{Expected Performance Characteristics}_i, \text{Marketing Factors}_i).$$

To determine the importance of recently adopted EPD measures on bull prices, two models were estimated by Dhuyvetter et al.—one that included actual weights without EPDs and another that included actual weights and EPDs. A comparison of these two models indicated how much additional information EPDs provide. Both models were estimated using ordinary least squares (OLS).¹³ The authors concluded that bull prices are determined by genetic, physical, and expected performance characteristics of the bull, and by marketing techniques. Absolute price levels varied by breed, but after

¹³ The data used for their empirical analysis were collected from 26 purebred bull sales in Kansas during the spring of 1993. The data include information on 1,700 bulls and represent seven different beef breeds. Because of the cross-sectional nature of their data, Dhuyvetter et al. were unable to examine intertemporal issues associated with the development of EPDs. Such issues are one focus of the empirical analyses of this thesis.

accounting for differences in characteristics, breed generally had no effect on price.

Buyers used expected performance measures in their purchasing decisions; however, the information used varied by breed. EPDs were found to be statistically significant in explaining the price of Angus, Gelbvieh, and Simmental breeds, but were less significant in other breeds. The R^2 for the regression that included only SPMs was 0.62. When both EPDs and SPMs were included in the model, the R^2 increased from 0.62 to 0.72. This increase suggests that EPDs contain information in addition to that provided by SPMs and genetic characteristics.

CHAPTER 4

CONSTRUCTION AND USE OF EPD AND SPM

QUALITY MEASUREMENTS

This chapter begins with a general discussion of performance measure construction and use. Next, statistical methods for the calculation of expected progeny differences (EPDs) and simple performance measures (SPMs) are reviewed.

Expected Progeny Differences

The goal of national cattle evaluation, as stated by the Beef Improvement Federation (BIF, 1996), is to produce the best genetic predictions of breeding value on all animals available as breeding stock for all traits of economic importance in commercial beef production. All breed associations are encouraged by the BIF to conduct cattle evaluation programs for their breeders to enable them to enhance their selection of breeding animals.

An expected progeny difference (EPD) is a prediction, based on the available data, of the breeding value of an animal. The purpose of this prediction is to evaluate and compare the ability of a sire to transmit growth rate and other desirable characteristics to his progeny. The term “expected progeny difference” suggests a comparison. Comparisons can be made regarding many features such as birth, weaning, and yearling

weights, and maternal breeding value, carcass, and marbling.¹⁴ For a better understanding of this comparison, consider an example with two Angus bulls. Assume that the weaning weight EPD for bull A is 30 pounds, and for bull B is 10 pounds. Subtracting the EPD for bull B from the EPD for bull A shows a difference of 20 pounds at weaning. This suggests, on average, that the progeny of bull A will be 20 pounds heavier at weaning than the progeny of bull B.

EPDs are obtained from genetic evaluations. The information from ancestors, descendants, and siblings is generally used in the computations. Descendants include progeny with records, progeny that are parents themselves, and grand progeny. All information about the animals is summarized into a single value—the expected progeny difference (EPD). The current evaluations are based on the Best Linear Unbiased Prediction (BLUP) Theory, which was discussed in detail in Chapter 3.

Each EPD value is accompanied by an accuracy value.¹⁵ As described above, the EPDs estimate the transmitting abilities based on available information. Because the available information varies, the accuracy of the prediction also varies. For animals with a great deal of information (progenies), the accuracy of prediction is high, but for individuals with limited information, the accuracy of the EPD predictor can be low.

Accuracy values provide breeders with an indication of the level of uncertainty or risk associated with selection decisions. They are calculated for each trait evaluation,

¹⁴ For the complete list of traits evaluated by EPDs and their explanations, see Table 8 in the Appendix.

¹⁵ The accuracy values are not used in the empirical analyses of this thesis because of restricted variance of accuracy values. On yearling bulls, accuracy values typically range from 0.04 to 0.1, therefore making the analyses very limited.

with values ranging between zero and one. Larger values indicate greater accuracy.¹⁶ The possible change in yearling weight EPDs for two bulls with different accuracies is demonstrated by the following example (illustrated in Figure 1). Suppose the first bull has a yearling weight EPD of +40 pounds with an accuracy of 0.20. The second bull has the same yearling weight EPD, but its accuracy is higher (0.80). Due to the differences in accuracies, the first bull's EPD will have a standard error of approximately ± 15 pounds, while the standard error for the second bull's EPD will be only ± 9 pounds.¹⁷ This means that the yearling weight EPD of the first bull could vary from +25 pounds to +55 pounds, while that for the second bull would vary, on average, within a smaller range of +31 pounds to +49 pounds.

In the evaluations, each genetic trait of an animal is compared with the genetic base. A genetic base for the Angus breed has been established so that the average EPD for purebred Angus born in 1976 is equal to zero for each trait. The choice of the base is arbitrary; however, once chosen, the pattern for the distribution of EPDs is established and the base directly affects the magnitudes and signs of the EPDs.

As illustrated in Figure 2, because of upward trends in the breed average values for all four of the traits shown, EPDs calculated before 1976 have a negative magnitude; all EPDs calculated after 1976 are positive. From Figure 2, we can also observe how different characteristics of the Angus breed have changed over the last 20 years. For example, for birth weight, cows sired by an average 1995 bull would be expected to

¹⁶ For a listing of accuracy values and related prediction errors, see Table 9 in the Appendix.

¹⁷ For specific details on accuracy calculation methods, see Guidelines for Uniform Beef Improvement Programs, published by the Beef Improvement Federation (BIF, 1996).

produce progeny that are, on average, 3.2 pounds heavier than cows sired by an average 1972 bull.¹⁸

Figure 1. Yearling Weight EPDs with Possible Change Values.

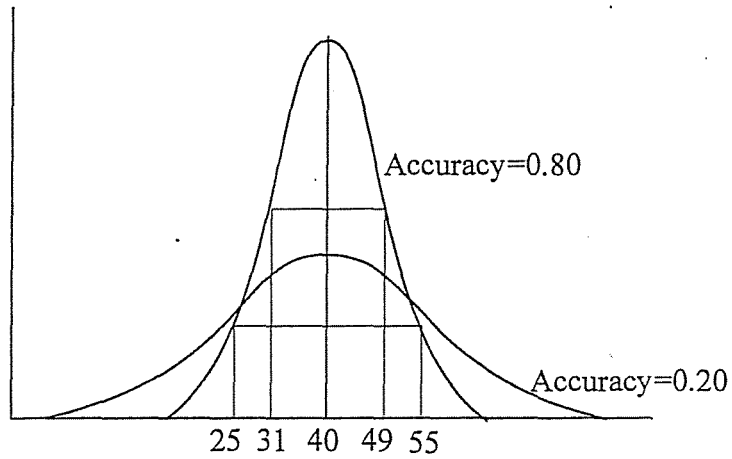
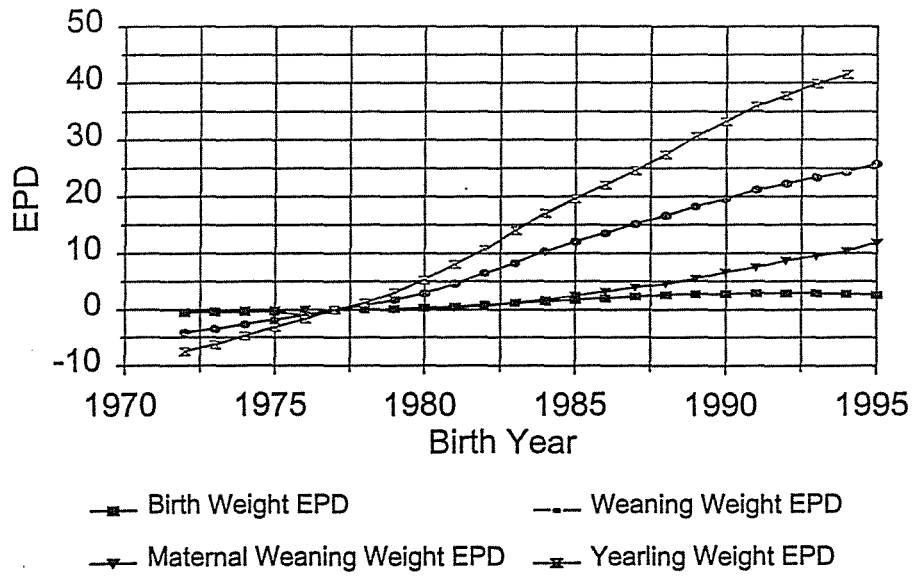


Figure 2. Angus Breed Average EPDs by Birth Year.



¹⁸ For additional details on the Angus breed average EPDs, see Table 10 in the Appendix.

Simple Performance Measures

Simple performance measures (SPMs) are computations of individual weights and measurements taken at various times in an animal's life. Some of the measures are adjusted through a mathematical procedure to a common base. The SPMs that are used in this thesis are listed and described below.

- (1) Birth Weight: The actual weight of a calf, taken within 24 hours of birth.
- (2) Weaning Weight: The actual weight of a calf at the time of weaning, taken at about seven months of age.
- (3) Adjusted Weaning Weight: The weight of an animal adjusted to a common age of 205 days. The adjusted weaning weight is derived as follows:

Adjusted 205-Day Weight =

$$\frac{\text{Actual Weaning Weight} - \text{Birth Weight}}{\text{Age Days}} \times 205 + \text{Birth Weight}.$$

- (4) Yearling Weight: The weight of an animal at 12 months of age.
- (5) Adjusted Yearling Weight: The weight of an animal adjusted to a common age of 365 days. The adjusted yearling weight is calculated as follows:

Adjusted 365-Day Weight =

$$\frac{\text{Actual Final Weight} - \text{Actual Weaning Weight}}{\text{Number of Days between Weights}} \times 160 \\ + \text{Adjusted 205-Day Weight}.$$

CHAPTER 5

DESCRIPTION OF DATA

This chapter describes the construction of the data sets used in the empirical analysis for this thesis. A number of data sets were created to examine the usefulness of simple performance measures (SPMs) and expected progeny differences (EPDs).

The first data set was provided by a single reputable Montana breeder and consists of approximately 1,030 observations. Observations were taken during the period 1982–1996; for each sale bull, the information provided includes price, simple performance measures (SPMs), expected progeny differences (EPDs), pedigree, shared interest, and several other measures of bull performance. The summary statistics for this breeder are presented in Table 1.¹⁹

The second data set consists of 393 observations obtained from four Montana breeders having a common sale in 1995 and 1996. The information provided was similar to that obtained from the single Montana breeder whose observations were used for the first data set. Summary statistics for these four breeders are shown in Table 2.

¹⁹ The number of observations for which summary statistics were calculated differ (in both Table 1 and Table 3) from the total number of observations because the empirical analyses were performed with observations containing the complete information only. Observations missing either EPDs or SPMs were deleted from the sample. All simple performance measures (SPMs) and expected progeny differences (EPDs) are detrended to control for genetic and technological advances. The formulas used for detrending SPMs and EPDs are discussed in the text that follows.

Table 1. Summary Statistics for Data Set 1, Single Montana Breeder.

Summary Statistics (n = 614)				
Variable	Mean	Standard Deviation	Minimum	Maximum
Bull Price	2,990.11	2,748.34	929.15	29,542.92
Retained Share (2/3)	0.053	0.225	0	1
Price of Feeder Cattle	83.026	13.934	60.037	99.754
Price of Feed	2.729	0.540	2.133	3.689
Age of Bull in Days	411.657	22.316	341	573
Simple Performance Measures				
Birth Weight	100.179	9.509	67.255	132.480
205-Day Weight	100.171	8.370	74.265	128.545
365-Day Weight	100.099	6.433	83.389	124.228
EPD Performance Measures				
Birth Weight EPD	100.525	37.503	-26.075	208.600
Weaning Weight EPD	100.308	23.528	10.753	182.042
Yearling Weight EPD	100.200	22.116	7.031	157.403

Note: All prices are reported in 1992 dollars and are deflated by the Chain Price Index. Minimum and maximum values are minimum and maximum detrended performance measures, market conditions, and contract terms after detrending.

Table 2. Summary Statistics for Data Set 2, Four Montana Breeders.

Summary Statistics (n = 365)				
Variable	Mean	Standard Deviation	Minimum	Maximum
Bull Price	2,047.42	1,695.48	929.37	18,095.24
Retained Share (2/3)	0.07	0.26	0	1
Age of Bull in Days	399.90	15.80	365	436
Simple Performance Measures				
Birth Weight	99.97	10.47	68.82	127.60
205-Day Weight	99.89	7.24	75.27	120.96
365-Day Weight	99.93	5.92	81.83	118.73
EPD Performance Measures				
Birth Weight EPD	100.22	62.13	-83.93	291.53
Weaning Weight EPD	99.59	17.66	46.41	158.31
Yearling Weight EPD	100.17	18.43	56.79	147.65

The third data set contains similar information on approximately 7,000 Angus breeding bulls sold by 11 different South Dakota and Nebraska Angus breeders between 1986 and 1996. Table 3 identifies the locations of the farms, years during which data were available, and number of observations obtained from each of the 11 breeders. Summary statistics for the 11 Angus breeders who contributed to the third data set are presented in Table 4.

Table 3. Location of Farm, Years of Data Availability, and Number of Observations for 11 Angus Breeders (Data Set 3).

Angus Breeders	Location of Farm	Years of Data Availability	Number of Observations
Breeder 1	South Dakota	1989–1995	273
Breeder 2	Nebraska	1993	133
Breeder 3	South Dakota	1989–1995	332
Breeder 4	Nebraska	1990–1996	222
Breeder 5	South Dakota	1986–1995	801
Breeder 6	Nebraska	1990–1995	732
Breeder 7	South Dakota	1990–1995	274
Breeder 8	Nebraska	1991, 1993–1995	351
Breeder 9	Nebraska	1990–1996	761
Breeder 10	Nebraska	1986–1995	455
Breeder 11	Nebraska	1994–1996	270

Table 4. Summary Statistics for Data Set 3, 11 South Dakota and Nebraska Angus Breeders.

Summary Statistics (n = 4,604)				
Variable	Mean	Standard Deviation	Minimum	Maximum
Bull Price	3,102.13	1,969.78	857.142	37,174.72
Retained Share (2/3)	0.021	0.142	0	1
Retained Share (1/2)	0.003	0.055	0	1
Price of Feeder Cattle	86.506	11.247	60.037	99.754
Price of Feed	2.595	0.411	2.133	3.689
Age of Bull in Days	407.607	76.585	212	2,205
Simple Performance Measures				
Birth Weight	99.970	10.552	56.492	136.173
205-Day Weight	99.937	7.517	66.138	127.454
365-Day Weight	100.021	6.753	77.448	133.528
Avg. Birth Weight	103.275	4.732	95.870	115.867
Avg. Weaning Weight	111.178	7.056	94.747	130.894
Avg. Yearling Weight	112.995	6.590	96.875	129.541
EPD Performance Measures				
Birth Weight EPD	99.438	53.510	-167.168	397.466
Weaning Weight EPD	99.852	23.791	-2.708	206.489
Yearling Weight EPD	99.975	22.353	9.811	179.530
Avg. Birth Weight EPD	123.824	30.119	57.408	187.944
Avg. Weaning Weight EPD	127.730	20.967	59.870	183.498
Avg. Yearling Weight EPD	124.344	18.671	73.591	166.744

For each of the data sets, the price of feeder cattle is the Oklahoma City market price in dollars/cwt for feeder steers, Medium No. 1, 600–650 pounds. Because young cattle are usually sold for slaughter in the fall, the price of feeder cattle was calculated by the following formula:

$$\begin{aligned} \text{Price of Feeder Cattle}_t = & \\ & \left\{ \text{Feeder Cattle Price}_{\text{September}_{(t-1)}} + \text{Feeder Cattle Price}_{\text{October}_{(t-1)}} \right. \\ & \left. + \text{Feeder Cattle Price}_{\text{November}_{(t-1)}} \right\} \div 3, \end{aligned}$$

where t is the year of auction. Price of feed is the Chicago Commodity Exchange average price in a marketing year for No. 2 yellow corn (\$/bushel).²⁰ All bull sale prices, prices of beef, and prices of feed were deflated using the Chain Price Index.²¹

All simple performance measures (SPMs) and expected progeny differences (EPDs) were detrended to control for genetic and technological advances by dividing each sale bull's performance measures by the annual herd average performance measure as follows:

$$\begin{aligned} \text{Detrended Performance Measure}_{it} = & \\ & \frac{\text{Performance Measure}_{it}}{\text{Performance Measure Herd Average}_t} * 100, \end{aligned}$$

²⁰ The marketing year for corn begins in September. For example, the average price of corn in the marketing year starting in September 1990 and ending August 1991 is defined to be the price of feed for 1991.

²¹ Plots of deflated prices of beef and feed are displayed in Figures 3 and 4 in the Appendix.

where *Performance Measure_{it}* is a performance measure of bull *i* in time *t*, and *Performance Measure Herd Average_t* is the herd average of the particular performance measure in time *t*.²² Herd average simple performance measures (SPMs) and average expected progeny differences (EPDs) were detrended by dividing each herd average performance measure by the annual Angus breed average of the measure. The detrended average performance measure is of the form:

$$\text{Detrended Herd Average Performance Measure}_t = \frac{\text{Herd Average Performance Measure}_t}{\text{Angus Breed Average Performance Measure}_t} * 100,$$

where *t* is a year of the auction.

The age of the sale bulls was calculated as the difference between the date of auction and the date of birth, as follows:

$$\text{Age} = \text{Date of Auction} - \text{Date of Birth}.$$

Sire variables are used to indicate the 18 sires used 10 times or more by the single Montana breeder (for data set 1). Sires used fewer than 10 times were assigned to the control group. Table 5 shows the frequencies of use for these 18 bulls.

For all of the breeders, data were obtained for this study from catalogues that the breeders provided to prospective buyers. The catalogues contain information on

²² Detrending was performed on a data set containing all observations. Therefore, because not all observations had the complete information required for the analysis, in the summary statistics tables, SPM and EPD averages are not exactly equal to 100.

characteristics of the sale bulls as well as information on the characteristics of the sires and dams of many of the bulls.

Table 5. Frequency of Use of Sires by Single Montana Breeder (Data Set 1).

Sire No.	Frequency	Sire No.	Frequency	Sire No.	Frequency
1	97	7	19	13	15
2	68	8	16	14	14
3	43	9	16	15	11
4	25	10	16	16	10
5	22	11	16	17	10
6	20	12	15	18	10

Characteristics of the sale bulls that were reported throughout the entire sample period include the SPMs—birth, 205-day, and 365-day weights. Since the late 1980s, EPD values for birth, weaning, and yearling weights also have been reported in most of the breeder catalogues. A shared interest is reported on about 4 percent of the sale bulls. This usually means that the buyer and seller will share either semen or revenue from artificial insemination at a rate specified by the seller. A common revenue-sharing interest is a 1/3 or 1/2 share for the seller, and a 2/3 or 1/2 share for the buyer.

CHAPTER 6

MODEL SPECIFICATION

In the last section of the literature review in Chapter 3, several studies of the determinants of cattle prices were discussed. In a number of those models, the authors focused on the estimation of cattle price responses to changes in the availability and price of various inputs. The most frequently used modeling techniques were linear programming and estimating regression equations with distributed lags. The models provide useful insights into how prices respond to changes in input characteristics at aggregate levels in cattle or other commodity markets; however, very few of them examine issues directly related to the problems associated with identifying the determinants of bull prices using disaggregate data.

Breeding bull investments are very important for both purebred and commercial breeders because most genetic improvement is accomplished through introducing new sires to the herd (Wagner et al., 1985). Therefore, the ability to evaluate the quality of traits is essential for the successful management of cattle operations. While some measurements are easy to obtain, others can pose difficulties. For example, determining the birth weight of an animal appears to be an easy and accurate process. Because bulls are bought for breeding purposes, however, the sale animal's birth weight represents only a portion of the exact information the buyer wants to obtain. The buyer is more interested

in knowing the birth weight of the bull's progeny, which can only be estimated imperfectly from the bull's actual birth weight. Such uncertainty motivates the buyer to expend resources and perform independent measurements to obtain more comprehensive information on various attributes of the sale bull. As noted earlier, individual measurements by buyers can lead to a high level of duplicity in the information collected, and can result in considerable social waste. The parties who bear the cost of inefficient measurement have strong incentives to develop buying/selling restrictions and market mechanisms that limit such measurements.²³ A group of buyers, for example, might reduce their individual costs by collectively hiring an unbiased third party to gather information. Sellers, who bear a portion of the cost of buyer measurements, can also reduce the incentives of prospective buyers to undertake presale measurements in a variety of ways. In bull auctions, for example, the sellers provide prospective buyers with information on sale animals. This information is usually distributed to the buyer through auction catalogues. Information typically provided to the buyers in bull auctions consists of simple performance measures (SPMs), expected progeny differences (EPDs), and pedigrees.

Discussion in the earlier chapters indicated that EPDs are relatively new in the beef industry. Their adoption by breeders has proceeded at a slow pace, and even today many breeders are not convinced of their reliability and effectiveness. Surprisingly, few systematic studies addressing the impacts of EPDs have been conducted. The only

²³ For a detailed discussion of presale measurements, measurement costs, and organization of the markets, see Barzel (1982), and Leffler and Rucker (1991).

research that explicitly considered EPDs as a factor affecting prices paid at bull auctions was done by Dhuyvetter et al. (1996). Although many breeders and researchers have reported that EPDs have helped them to improve their herds economically or genetically, this claim has not been demonstrated with any type of rigorous analysis.

A primary objective of this thesis is to contribute to a better understanding of mechanisms in bull markets that have been developed as a result of the uncertainty accompanying bull selection decisions. In the past, buyers made their cattle selections solely on the basis of observable traits, prior familiarity with particular lines, and the reputation of the breeder. Indicators of performance that have been developed in recent decades are designed to reduce the uncertainty in bull sale transactions by providing information about those traits that are not directly observable. These data are generated from the performance of the animal and its relatives, and under certain conditions can provide useful information on more difficult-to-observe traits. Such information will have value insofar as it improves predictions of the future performance of an animal and its offspring. The development of these performance measures, however, is not without expense, and there are continuing costs associated with collecting data and maintaining the data bases required for the calculations. Moreover, because these performance measures are based on the information controlled by the seller, buyers may be concerned about their credibility. As noted by Klein and Leffler (1982), the seller faces a tradeoff between initially providing unbiased, high quality information and gaining in the long run, or providing biased information and maximizing short-term gains by selling low quality animals at high quality prices.

A primary empirical focus of this thesis is to compare the information contained in two different indicators of performance—simple performance measures (SPMs) and expected progeny differences (EPDs). Researchers and breeding associations have argued that the newness of EPDs in the market could be a factor in their lack of industry acceptance. EPDs were developed in the late 1970s, tested by breeders in the early 1980s, and have recently become more widely used by both purebred and commercial breeders. Even though all major U.S. breed associations have adopted the use of EPD calculations for their cattle, the controversy still continues.²⁴ If the lack of general acceptance of EPDs is caused by their newness in the market, their explanatory power should improve with time. Whether there have been changes in the explanatory power of EPDs in the last decade is another issue examined in this thesis.

Research Methods

As noted earlier, a primary focus of this thesis is to compare the information contained in simple performance measures (SPMs) with that contained in expected progeny differences (EPDs). The statistical method employed for this comparison is multiple regression analysis. The sale price of a bull will be regressed on the bull's physical and genetic attributes and other terms specified in the seller-buyer agreement. This type of model, known as a hedonic regression, was first developed by Rosen (1974). Since then, it has been used by many researchers for modeling consumer choice decisions

²⁴ Based on interviews with breeders from the industry, there is still heavy reliance on simple performance measures (SPMs), performance ratios, and visual evaluation to select their cattle. Many of them reported that the usefulness of EPDs is limited. On the other hand, researchers and breeding associations continue to emphasize the importance of complete adoption of EPDs by the industry and encourage the development of new EPDs for traits not yet evaluated.

and determinants of prices. The hedonic approach applied to breeding bulls can be viewed as an effort to determine how buyers in bull auctions value various bull characteristics.

Price, reputation of the seller, market conditions, pedigree, simple performance measures, and alternative measures of future performance of the bull are among the factors considered by the buyers in their selection decisions. Therefore, the general empirical specification of determinants of bull prices paid in auctions is of the form:

$$(6.1) \quad \text{Bull Price} = f(\text{Price of Feeder Cattle, Price of Feed, Shared Interest, Age, SPMs, EPDs, Sire}),$$

where, for a given bull, *Price of Feeder Cattle* and *Price of Feed* are expectations of future feeder cattle and feed prices, *Shared Interest* is a 0-1 dummy variable to indicate bulls on which the seller has retained an interest in the semen to be produced by the sale bull, *Age* is the actual age of the sale bull in days at the time of the sale, *SPMs* are simple performance measures, *EPDs* are expected progeny differences, and *Sire* is a series of 0-1 dummy sire variables to capture the effects of well known sires.

Particular performance measures and market conditions whose influences will be examined include price of feeder cattle and price of feed; shared interest; age; birth, weaning, and yearling weights; birth, weaning, and yearling EPDs, and pedigrees. An increase in price of feeder cattle will increase the breeder's returns from production, and is predicted to have a positive impact on the bull sale price. An increase in the price of feed is expected to have a negative impact on the bull sale price. The algebraic sign of

the coefficient on the *Shared Interest* dummy variable may be negative or positive depending on the size of the influence of opposing factors. The fact that the seller keeps a share of the semen may tend to reduce the amount buyers are willing to pay for a bull because the revenue received by the buyer from semen sale is diminished. Conversely, the fact that the seller wants to keep a portion of the semen may be perceived by buyers as a signal that the seller views the bull as having exceptionally good breeding characteristics. If these exceptionally good breeding characteristics are measured imperfectly by the SPMs and EPDs, then the estimated coefficient on the interest share variable may be measuring the effects of these omitted traits and the coefficient can be positive.

An increase in the age of a breeding bull, while holding all other performance measures constant, increases the likelihood that the bull will be able to produce more semen in the forthcoming season. Because the revenue from the sale of the bull's semen also depends on its quantity, the estimated coefficient on the age variable is expected to have a positive algebraic sign.

The estimated regression coefficient on birth weight is expected to be negative. Other factors constant, a bull with lower birth weight is more valuable to the farmer because an increase in birth weight indicates greater calving problems. Increases in weaning weight and yearling weight measures are predicted to have a positive impact on the price. Young cattle usually are sold shortly after weaning or as yearlings, and therefore heavier animals at weaning or yearling age are considered more valuable. Sire variables are included in the regression to test for possible effects of well known sires. If

we suppose that the frequency of sire use in the operation reflects the demand for sires, the coefficients on the most frequently used sires might be expected to have positive (and significant) algebraic signs. If, however, these sires are in higher demand because of their exceptional characteristics, and if the regressions effectively control for these effects and capture the influence of characteristics through the SPM and EPD variables, then the coefficients on the sire variables will not be statistically significant.

When comparing the explanatory power of expected progeny differences (EPDs) and simple performance measures (SPMs) as determinants of bull sale prices, EPDs might be expected to have greater power. This is because EPDs include information on the performance of the sale bull's relatives that is not included in the SPMs. If this information is considered useful by the bull buyers, EPDs should outperform SPMs in explaining bull prices.

Empirical Estimation

The regressions examining the relative abilities of simple performance measures (SPMs), expected progeny differences (EPDs), and other bull characteristics to explain bull sale prices were run on three different samples. The first sample (data set 1), provided by a reputable Montana Angus breeder, is used for detailed regressions including 0-1 dummy variables for sire, and type, location, and size of the buyer operation. The regression results from this sample are then verified by regressions performed on the second sample (data set 2), obtained from four Montana Angus breeders based on two auctions held in 1995 and 1996 in Montana. The third sample (data set 3),

provided by the American Angus Association, contains data from 11 South Dakota and Nebraska Angus breeders. If the regressions estimated using this sample provide results consistent with those obtained from the first two sets of regressions, then the conclusions here can be generalized and interpreted as reflecting the situation in the general Angus breed population.

Regressions Based on Data Set 1:
Single Montana Angus Breeder

The regression model for the single Montana breeder sample is specified as follows:

$$\begin{aligned}
 (6.2) \quad PRICE_{it} = & \alpha_0 + \alpha_1 * FEEDER \ CATTLE \ PRICE_{t-1} + \alpha_2 * FEED \ PRICE_t + \alpha_3 * INT66_{it} \\
 & + \alpha_4 * AGE_{it} + \alpha_5 * BIRTH \ WEIGHT_{it} + \alpha_6 * 205-DAY \ WEIGHT_{it} \\
 & + \alpha_7 * 365-DAY \ WEIGHT_{it} + \alpha_8 * (BIRTH \ WEIGHT_{it})^2 \\
 & + \alpha_9 * (205-DAY \ WEIGHT_{it})^2 + \alpha_{10} * (365-DAY \ WEIGHT_{it})^2 \\
 & + \alpha_{11} * BIRTH \ WEIGHT \ EPD_{it} + \alpha_{12} * WEAN \ WEIGHT \ EPD_{it} \\
 & + \alpha_{13} * YEARL \ WEIGHT \ EPD_{it} + \alpha_{14} * (BIRTH \ WEIGHT \ EPD_{it})^2 \\
 & + \alpha_{15} * (WEAN \ WEIGHT \ EPD_{it})^2 + \alpha_{16} * (YEARL \ WEIGHT \ EPD_{it})^2 \\
 & + \sum_{k=17}^{34} \alpha_k * SIRE_k + u_{it},
 \end{aligned}$$

where *INT66* denotes 2/3 shared interest for the buyer. The results for this regression are reported as Regression 1 in Appendix Table 12. The explanatory variables are jointly significant at the 0.0001 level, and all coefficients have the expected algebraic signs.

The impacts of expected future feeder cattle prices are measured by including a first-order lag on the price of feeder cattle. The estimated coefficient on the price of feeder cattle is positive and significant at the 0.05 level. The price paid increased by about \$26 for each \$1/cwt increase in the expected price of feeder cattle.²⁵ The impacts of expected future feed prices are measured by including average feed price in the marketing year. The coefficient on the price of feed is negative as expected, but is not significant at the 0.05 level.²⁶

The estimated coefficient on the interest share variable is positive and highly significant. The animals that sold with 1/3 and 2/3 shared interest, respectively, for the seller and buyer brought a premium of \$3,500, suggesting that buyers interpret the seller's willingness to retain a share in the bull's future semen production as a strong signal that the bull has some high quality attributes not captured by the performance measures. This signal is considered so strong by the buyers that they are willing to accept a reduction in

²⁵ All regression results are reported as a marginal change in the price of the bull due to a one-unit change in the independent variable. Consider, for example, the following simplified bid price equation with quadratic terms included:

$$PRICE_{it} = \alpha_0 + \alpha_1 * BIRTH\ WEIGHT_{it} + \alpha_2 * (BIRTH\ WEIGHT_{it})^2.$$

The marginal effect on the bid price of a change in a performance measure is then calculated at the sample average level of the performance measure as follows:

$$\frac{\partial PRICE_{it}}{\partial BIRTH\ WEIGHT_{it}} = \alpha_1 + 2 * \alpha_2 * BIRTH\ WEIGHT_{it}.$$

Because all SPMs and EPDs are normalized by dividing the actual bull performance measure by the herd average, a one-unit change in EPDs or SPMs is simply a 1 percent change.

²⁶ The lack of significance for the price of feed may be due to limited variation in the price during the years 1988–1996. When the same regression was run using the entire data sample (1982–1996), during which there was more variation in price, the coefficient on feed price was negative and significant at the 0.05 level. The regression using the entire sample period includes SPMs, but excludes EPDs because they are not published in the catalogues for the years 1982–1987.

their future profit from the sale of semen (imposed by the shared interest with the seller) and still offer a substantial price premium.

The coefficient on the age variable is positive as expected, and significant at the 0.05 level. The buyers paid about \$11 for each additional day of age. Since the amount of semen produced by bulls is highly correlated with age, the interpretation of this result is that buyers value the increased ability of older yearling bulls to breed more effectively in the forthcoming season.

The only SPM coefficients that are significant at the 0.05 level are the coefficients on the linear and quadratic 365-day weight variables. The buyers valued each additional 1 percent increase in 365-day weight at \$104. The only significant EPD coefficient at the 0.05 level is the coefficient on the squared value of the weaning weight EPD.²⁷

The coefficients on the individual sire variables in general are not significant. This finding indicates that the bulls used most frequently by the single Montana Angus breeder are valued for their quality breeding characteristics, and that these characteristics are well measured by SPMs and EPDs.

F-tests were performed for the joint significance of the sire, SPM, and EPD variables. As can be seen at the bottom of Appendix Table 12, the sire coefficients are not jointly significant at the 0.10 level. All SPM coefficients are jointly significant at the 0.01 level. The EPD and EPD squared coefficients are not significant at the 0.05 level.

²⁷ The quadratic terms are included in the regression to allow for nonlinear price responses to changes in SPMs and EPDs. If the quadratic terms were excluded from the regression, then the coefficients on weaning weight and birth weight SPMs and EPDs also were significant at the 0.05 level.

The F -values for the SPM coefficients are always substantially higher than those for the EPD coefficients.

Industry observers have indicated that, holding the quality of animals constant, bull prices paid at auctions may vary for different groups of buyers. For example, it has been suggested that out-of-state buyers pay more than instate buyers. In addition, it has been suggested that purebred buyers pay more than commercial buyers and that buyers from large operations pay more than buyers from small operations. To test these hypotheses, a regression including 0-1 dummy variables for instate/out-of-state, purebred/commercial, and small/large size is estimated as follows:²⁸

$$\begin{aligned}
 (6.3) \quad PRICE_{it} = & \alpha_0 + \alpha_1 * FEEDER \ CATTLE \ PRICE_{t-1} + \alpha_2 * FEED \ PRICE_t + \alpha_3 * INT66_{it} \\
 & + \alpha_4 * AGE_{it} + \alpha_5 * BIRTH \ WEIGHT_{it} + \alpha_6 * 205-DAY \ WEIGHT_{it} \\
 & + \alpha_7 * 365-DAY \ WEIGHT_{it} + \alpha_8 * BIRTH \ WEIGHT \ EPD_{it} \\
 & + \alpha_9 * WEAN \ WEIGHT \ EPD_{it} + \alpha_{10} * YEARL \ WEIGHT \ EPD_{it} \\
 & + \sum_{k=11}^{28} \alpha_k * SIRE_k + \alpha_{29} * PUREBRED_{it} + \alpha_{30} * INSTATE_{it} \\
 & + \alpha_{31} * SMALL \ SIZE_{it} + u_{it},
 \end{aligned}$$

²⁸ Some industry experts have also suggested that expected progeny differences (EPDs) might be used differently by commercial and purebred buyers. To test this suggestion, the single Montana breeder data set (data set 1) was divided into thirds based on yearling weight EPD. If we suppose that purebred breeders are buying high quality animals with the greatest growth potential, then bulls from the highest third of the sample were purchased for purebred breeding operations. Compared to purebred buyers, commercial buyers typically purchase lower quality animals. Therefore, bulls from the first third were likely to be purchased for commercial operations. The bulls from the second third were excluded from the data sample because it could not be determined whether they were purchased by commercial or purebred buyers. The regression results indicated, however, that there is not a substantial difference in the use of EPDs by these two groups of buyers because for both groups the estimated coefficients and their t -values are comparable.

where *PUREBRED* is a 0-1 dummy variable indicating the type of buyer operation.²⁹ *INSTATE* is a 0-1 dummy variable indicating whether the buyer is running a cattle operation in Montana or in a different state. Out-of-state buyers were defined as the control group. *SMALL SIZE* is a 0-1 dummy variable indicating size of buyer operation. For purposes of this thesis, a farm having more than 300 cows is considered as large and is defined as the control group.³⁰

The results of this regression are presented as regression 2 in Appendix Table 12. The explanatory variables are jointly significant at the 0.0001 level. The coefficients of the variables that control for type, location, and size of breeder operation are not significantly different from zero at the 0.05 level, either individually or as a group. Even though some buyer groups paid higher prices on average than other groups, the regression results suggest that after accounting for the effects of the characteristics included in the regression, there is not a significant difference in the bull price paid. All other regression results are consistent with results of regression (6.2).

Because both SPM and EPD variables are included in the model, it is possible that collinearity among variables in the results presented so far is decreasing the statistical significance of some variables. To alleviate this potential problem, and also to examine the information content of EPDs compared to SPMs, the following procedure was used.

²⁹ Commercial operations were defined as the control group. The dummy variable is assigned a value of one if a buyer is a purebred producer or a producer running both purebred and commercial operations. When the model was originally estimated with squared terms included, none of the estimated coefficients on performance measures were significant at 0.05 level.

³⁰ The data sample size was reduced from 614 to 365 observations because the information needed for these analyses was obtained only for these 365 observations.

A regression was estimated as specified in equation (6.2), but with the EPD measures omitted:

$$\begin{aligned}
 (6.4) \quad PRICE_{it} = & \alpha_0 + \alpha_1 * FEEDER CATTLE PRICE_{t-1} + \alpha_2 * FEED PRICE_t + \alpha_3 * INT66_{it} \\
 & + \alpha_4 * AGE_{it} + \alpha_5 * BIRTH WEIGHT_{it} + \alpha_6 * 205-DAY WEIGHT_{it} \\
 & + \alpha_7 * 365-DAY WEIGHT_{it} + \alpha_8 * (BIRTH WEIGHT_{it})^2 \\
 & + \alpha_9 * (205-DAY WEIGHT_{it})^2 + \alpha_{10} * (365-DAY WEIGHT_{it})^2 \\
 & + \sum_{k=17}^{34} \alpha_k * SIRE_k + u_{it}.
 \end{aligned}$$

The residuals obtained are then regressed on individual EPD measures:

$$\begin{aligned}
 (6.5) \quad RESIDSPM_{it} = & \beta_0 + \beta_1 * BIRTH WEIGHT EPD_{it} + \beta_2 * WEAN WEIGHT EPD_{it} \\
 & + \beta_3 * YEARL WEIGHT EPD_{it} + \beta_4 * (BIRTH WEIGHT EPD_{it})^2 \\
 & + \beta_5 * (WEAN WEIGHT EPD_{it})^2 + \beta_6 * (YEARL WEIGHT EPD_{it})^2 \\
 & + v_{it},
 \end{aligned}$$

where *RESIDSPM* denotes the residuals from regression (6.4).

The estimation results of regressions (6.4) and (6.5) are presented in Appendix Tables 13 and 14, respectively. The explanatory variables in regression (6.4) are jointly significant at the 0.0001 level, and the adjusted R^2 of the model is 0.49. All coefficients (except sires) have the expected algebraic signs.

The estimated coefficient on the price of feeder cattle is positive as expected, and significant at the 0.05 level. The price paid at auctions increased by about \$34 for each

\$1/cwt increase in the expected price of feeder cattle. The coefficient on the price of feed is negative as expected, but is not significant at the 0.05 level.

The positive and significant estimated coefficient on the shared interest variable again indicates that buyers view this contract provision as a strong signal of high animal quality. When the seller retained a 1/3 interest share in semen, buyers were willing to pay approximately \$3,600 more than for a similar animal without a seller interest share.

The price paid at auctions was higher for older yearling bulls. Each additional day of a bull's age was valued at about \$11 by auction buyers.

As in regression (6.2), the only SPM coefficients significant at the 0.05 level are the coefficients on 365-day weight and 365-day weight squared. The premium paid for each 1 percent increase in the 365-day weight was \$122.³¹

Only three of the 18 coefficients on the sire variables are statistically different from zero at the 0.05 level. Results of an F -test for the joint significance of the sire coefficients showed that they are not jointly significant at the 0.10 level.

Appendix Table 14 presents the results of the regression of the estimated residuals from the SPM-only regression on the individual EPD measures. An F -test for the joint significance of the explanatory variables indicated statistical significance at the 0.0001 level. The adjusted R^2 of the model is only 0.01, however, and none of the EPD coefficients are significantly different from zero at the 0.10 level.

³¹ The limited significance of SPM coefficients is again caused by the high collinearity between the SPMs and SPMs squared. When squared terms are excluded from the regression, all three SPM coefficients are significant and have the expected signs.

Tests for the joint significance of EPDs and EPDs squared indicated that the coefficients on EPDs and EPDs squared are not jointly significant at the 0.10 level.

The model specified in equations (6.4) and (6.5) provides an indication of how much additional information is contained in EPDs beyond that contained in SPMs. To determine the reverse, i.e., how much information is contained in SPMs in addition to the information contained in EPDs, these regressions were run in reverse order and are specified as follows:

$$(6.6) \quad \begin{aligned} PRICE_{it} = & \alpha_0 + \alpha_1 * FEEDER CATTLE PRICE_{t-1} + \alpha_2 * FEED PRICE_t + \alpha_3 * INT66_{it} \\ & + \alpha_4 * AGE_{it} + \alpha_5 * BIRTH WEIGHT EPD_{it} + \alpha_6 * WEAN WEIGHT EPD_{it} \\ & + \alpha_7 * YEARL WEIGHT EPD_{it} + \alpha_8 * (BIRTH WEIGHT EPD_{it})^2 \\ & + \alpha_9 * (WEAN WEIGHT EPD_{it})^2 + \alpha_{10} * (YEARL WEIGHT EPD_{it})^2 \\ & + \sum_{k=17}^{34} \alpha_k * SIRE_k + u_{it}; \end{aligned}$$

$$(6.7) \quad \begin{aligned} RESIDEPD_{it} = & \beta_0 + \beta_1 * BIRTH WEIGHT_{it} + \beta_2 * 205-DAY WEIGHT_{it} \\ & + \beta_3 * 365-DAY WEIGHT_{it} + \beta_4 * (BIRTH WEIGHT_{it})^2 \\ & + \beta_5 * (205-DAY WEIGHT_{it})^2 + \beta_6 * (365-DAY WEIGHT_{it})^2 + v_{it}, \end{aligned}$$

where *RESIDEPD* denotes the residuals from regression (6.6).

The results for regressions (6.6) and (6.7) are presented in Appendix Tables 15 and 16, respectively. The explanatory variables in the first regression are jointly significant at the 0.0001 level, but the adjusted R^2 is only 0.38, which is more than 25 percent lower than that for the corresponding regression for the SPMs.

The estimated coefficient on the price of feeder cattle is positive as expected, and statistically significant at the 0.05 level. The price paid increased by about \$24 for each \$1/cwt increase in the price of feeder cattle. Although not significant at the 0.05 level, the coefficient on the price of feed is negative as expected.

Once again, the coefficient on the shared interest variable is positive and highly significant. The animals selling with a 1/3 retained interest for the seller brought a premium of about \$5,000. The coefficient on the age variable is positive as expected, and significant at the 0.05 level. Buyers paid a premium of about \$12 for each additional day of age.

The only statistically significant EPD coefficients at the 0.05 level are those on weaning weight EPD and weaning weight EPD squared.³² This indicates that the price paid by buyers at the Montana breeders' auctions increased by about \$38 for each 1 percent increase in the weaning weight EPD.

Only three of the 18 sire coefficients are statistically different from zero at the 0.05 level. The *F*-test for joint significance of sires again indicated no joint significance at the 0.05 level.

Appendix Table 16 presents the regression results of the estimated residuals from the EPD-only regression on the individual SPMs. An *F*-test of the joint significance of the explanatory variables showed statistical significance at the 0.0001 level. The adjusted

³² When the quadratic terms are excluded from the regressions, all three coefficients on EPDs are statistically significant at the 0.05 level.

R^2 is 0.12, which is more than 10 times greater than the adjusted R^2 for the SPM-only residual regression results reported in Appendix Table 14.

At the means, the marginal impacts of the performance measures are as expected; however, only the coefficients on the 365-day weight variables are statistically significant. The premium paid by buyers for a 1 percent increase in the 365-day weight was about \$75.

F -tests for the joint significance of SPMs and SPMs squared indicated that all combinations of estimated SPM coefficients from these tests were consistently and substantially higher than the F -values from corresponding tests performed on the EPDs (Appendix Table 14).

Regressions Based on Data Set 2:
Four Montana Angus Breeders

To verify the findings from regressions (6.4), (6.5), (6.6), and (6.7) performed on the single Montana breeder sample data set, similar regressions were run on the sample provided by four Montana breeders for 1995 and 1996 (data set 2).³³

The results of the SPM-only regression (6.4) for these breeders are presented in Appendix Table 17. The explanatory variables are jointly significant at the 0.0001 level, and the adjusted R^2 of the model is 0.50. The results of this regression are in general consistent with the corresponding single Montana breeder regression results (data set 1).

³³ Because the data are available for 1995 and 1996 only, prices of feeder cattle and feed represent a linear combination of other variables and are excluded from the model. Sire variables are also excluded because the information required was not collected.

The coefficients on shared interest and age are positive and statistically significant. Buyers placed a higher value on animals with lower birth weights. The discount for each 1 percent increase in the birth weight was about \$17. The coefficient on 205-day weight is significant but negative. There is no reason to believe that buyers discounted animals that were heavier at weaning. Once again, the 365-day weight is highly significant. Buyers paid a premium of about \$92 for each 1 percent increase in the 365-day weight.

The results of regression (6.5) of the estimated residuals from the SPM-only regression on the individual EPD measures for the sample of four Montana breeders are presented in Appendix Table 18. The explanatory variables are not significant at the 0.10 level. The adjusted R^2 of the model is -0.0003 . The only individually statistically significant EPD coefficients are coefficients on weaning weight EPD and weaning weight EPD squared. The algebraic sign on the combined weaning weight EPD coefficient, however, is negative, which does not meet our expectation.

F -tests of joint significance were performed for EPDs and EPDs squared. None of the EPD groups tested are jointly significant at the 0.10 level.

Appendix Table 19 presents results of the EPD-only regression (6.6) for the four Montana breeder sample. The explanatory variables are jointly significant at the 0.0001 level, but the adjusted R^2 is only 0.40, which is almost 25 percent lower than that for the corresponding SPM-only regression.

Once again, shared interest and age coefficients are positive as expected, and are highly significant. The only statistically significant EPD coefficients are coefficients on

the weaning weight EPD and weaning weight EPD squared. Buyers at the auctions paid a premium of \$6 for each 1 percent increase in the weaning weight EPD.

Appendix Table 20 gives the results of regression (6.7) of the estimated residuals from the EPD-only regression on the individual SPM measures. The adjusted R^2 is 0.13, which is more than 13 times greater than the adjusted R^2 for the SPM-only residual regression results reported in Appendix Table 18. All individual SPM coefficients are statistically different from zero at the 0.05 level. The buyers discounted each 1 percent increase in the birth weight at about \$9. As in the previous regressions, buyers placed a higher value on heavier animals. The premium paid for each 1 percent increase in the 365-day weight was about \$62. The combined coefficient on 205-day weight has a negative algebraic sign.

F-tests for the joint significance of the SPM coefficients indicated that both groups tested are jointly significant at the 0.01 level.

Regressions Based on Data Set 3: Eleven South Dakota and Nebraska Angus Breeders

The results of regression (6.2) for the sample of 11 Angus breeders (data set 3) are presented in Appendix Table 21.³⁴ The explanatory variables are jointly significant at the 0.0001 level, and all estimated coefficients have the expected algebraic signs.

The estimated coefficient on the price of feeder cattle is positive as expected, and is significant at the 0.05 level. The price paid by buyers increased by about \$18 for each

³⁴ Sire variables are not included in any regressions performed on the 11 Angus breeder sample. Average SPM and EPD variables, which are added to the model to control for differences across the 11-breeder sample, play a role similar to seller dummy variables.

\$1/cwt increase in the price of feeder cattle. The coefficient on the price of feed is negative as expected, and highly significant. The price paid at the auctions fell by approximately \$492 when the price of feed per bushel increased by \$1.

The estimated coefficients on the interest share variables are positive and highly significant. The animals sold with a $\frac{1}{3}$ retained share for the seller brought a premium of \$2,600. The animals with $\frac{1}{2}$ share for the seller brought an even higher premium of \$9,100. The coefficient on the age variable is significant and positive. The buyers paid about \$2 for each additional day of age.

All of the SPM coefficients except birth weight and average 365-day weight are statistically different from zero at the 0.05 level. The coefficient on birth weight is negative as expected, but is not significant at the 0.05 level. The bull's 205-day weight had a positive impact on the bid price, indicating that buyers place a higher value on animals that are heavier at weaning. The regression suggests that buyers are willing to pay a premium of about \$20 for each additional 1 percent increase in the 205-day weight. The 365-day weight coefficient is positive and significant. Buyers paid a premium of about \$84 for each 1 percent increase in the 365-day weight.

The coefficient on the average birth weight is significant at the 0.05 level and negative as expected. This indicates that the bulls from herds with higher average birth weights sell for less. The discount for each additional 1 percent increase in the average birth weight was about \$53. Increases in the average 205-day and 365-day weights have a positive impact on bull sale price, although the average 365-day weight is not significant

at the 0.05 level. The buyers valued each additional 1 percent increase in the average 205-day weight at \$36.

The only statistically significant EPD coefficients are those on the birth weight EPD and the average yearling weight EPD. The discount paid by the buyers for each 1 percent increase in the birth weight EPD was about \$8. Animals from herds with higher birth weights were discounted at about \$4 for each 1 percent increase in the average birth weight EPD of the herd. A 1 percent increase in the average yearling weight EPD brought a premium of \$12.

F-tests were performed for the joint significance of different groups of SPMs and EPDs. All SPM and EPD groups tested (except EPDs squared) are significant at the 0.05 level.

The estimation results for regressions (6.4) and (6.5) performed on the 11 Angus breeder sample are presented in Appendix Tables 22 and 23, respectively. The explanatory variables in the SPM-only regression (6.4) are jointly significant at the 0.0001 level, and the adjusted R^2 is 0.37. All coefficients have the expected algebraic signs, and 12 out of 14 coefficients are significant at the 0.05 level. The only insignificant coefficients are on the variables of birth weight and birth weight squared. As in the previous regressions, buyers valued animals that were heavier at weaning. They paid a premium of about \$20 for each 1 percent increase in the 205-day weight. The 365-day weight coefficients are statistically significant at the 0.05 level, and are positive as predicted. The buyers paid a premium of \$96 for each 1 percent increase in the 365-day weight.

All three of the average SPMs are significant at the 0.05 level and have the expected algebraic signs, including the coefficient on average 365-day weight that is not statistically significant in the regression results reported in Appendix Table 21. The regression results suggest that the buyers paid \$58 less for each 1 percent increase in the average birth weight of the herd. Each increase of 1 percent in the average 205-day and 365-day weights brought a premium of \$33 and \$31, respectively.

The estimated coefficients on the price of feeder cattle, price of feed, shared interest, and age have the expected algebraic signs and are highly significant.

Appendix Table 23 presents the results of regression (6.5) of the estimated residuals from the SPM-only regression on the individual and herd average EPD measures for the sample of 11 Angus breeders.

An F -test for the joint significance of the explanatory variables showed statistical significance at the 0.0001 level, but the adjusted R^2 of the model is only 0.02. Only the coefficients on the birth weight EPD and the birth weight EPD squared are statistically significant at the 0.05 level.

F -tests for the joint significance of EPDs and EPDs squared, and EPDs, EPDs squared, and average EPDs indicated that with the exception of the coefficient on the squared EPD values, the estimated coefficients are jointly significant at the 0.01 level.

The results for EPD-only regressions (6.6) and (6.7) for this sample are presented in Appendix Tables 24 and 25, respectively. The explanatory variables in regression (6.6) are jointly significant at the 0.05 level, but the adjusted R^2 is only 0.28, which is again almost 25 percent lower than in the corresponding regression for SPMs. Once again, this

regression suggests that bulls with higher birth weight EPDs sell at a discount compared to the bulls with lower birth weight EPDs. The coefficients on the weaning and yearling weight EPDs are positive, but not significant at the 0.10 level.

All three average EPD coefficients are significant and have the expected algebraic signs. Bulls from herds with higher birth weight EPDs sell for less compared to the bulls from herds with lower birth weights. Buyers pay premiums if the bulls are from herds with higher weaning and yearling EPDs.

The coefficients on the price of feeder cattle, shared interest, and age variables are positive as in previous regressions. The coefficient on the price of feed is highly significant and negative.

Appendix Table 25 presents the results from regression (6.7) of the estimated residuals from the EPD-only regression on the individual and herd level SPMs. An *F*-test for the joint significance of the explanatory variables showed statistical significance at the 0.0001 level. The adjusted R^2 is 0.12, which is six times greater than the R^2 in the corresponding SPM-only residual regression (Appendix Table 23). All coefficients in the regression have the expected algebraic signs, and six of the nine coefficients are significant at the 0.05 level. The premiums paid for a 1 percent increase in 205-day and 365-day weights, respectively, were approximately \$9 and \$67.

The coefficients on the average birth weight and average 205-day weight are highly significant and have the expected algebraic signs. The coefficient on the average 365-day weight is negative, but not significant at the 0.10 level.

F-tests for joint significance of SPMs and SPMs squared, and SPMs, SPMs squared, and average SPMs indicated that all of these combinations of estimated SPM coefficients are jointly significant at the 0.01 level. *F*-values from these tests are always higher than the *F*-values from corresponding tests performed on EPDs (Appendix Table 19).

As noted earlier in this chapter, some researchers and breeders have suggested that the general lack of acceptance of EPDs could be caused by their newness within the industry. To determine whether breeders' acceptance of EPDs has increased over recent years, regressions (6.4), (6.5), (6.6), and (6.7) were performed on the sample of 11 Angus breeders (data set 3) on a yearly basis for the period 1988–1996. Of particular interest here are the R^2 s of regressions (6.5) and (6.7) performed on the SPM-only and EPD-only regression residuals (see Table 6). If acceptance of EPDs is indeed increasing over the years, the R^2 of regression model (6.5) should be increasing with time. As can be seen from Table 6, however, the hypothesis of increased trust in EPDs did not prove to be correct—there is not a positive trend in the R^2 values displayed.

Another suggestion made by the industry observers was that EPDs may play an important role when buyers choose among sellers. If this is the case, the coefficients on average EPDs should reflect a higher significance than coefficients on average SPMs. The regression results (Appendix Tables 21–25) indicated, however, that average SPMs reflected the bull prices as well as or better than did average EPDs; in most regressions, the *t*-values on average SPMs were equal to or higher than *t*-values for the corresponding average EPDs.

Table 6. R²s of Regressions (6.5) and (6.7) Performed on a Yearly Basis for the 11 Angus Breeder Sample (Data Set 3).

Regression Results			
Year	Number of Observations	Adjusted R ² s of EPD Regression (6.7)	Adjusted R ² s of SPM Regression (6.5)
1988	128	0.11	0.13
1989	211	0.03	0.37
1990	551	0.01	0.03
1991	484	0.03	0.14
1992	546	0	0.05
1993	691	0.01	0.06
1994	867	0.02	0.16
1995	781	0.02	0.16
1996	356	0	0.11

Summary of Regression Results

In this chapter, several regression models were estimated using the ordinary least squares (OLS) method.³⁵ In the initial regressions, both SPM and EPD measures were included in the same model. In the single Montana breeder regression (data set 1), all SPM and EPD coefficients had the expected algebraic signs; however, only the coefficients on 365-day weight and weaning weight EPD were significant at the 0.05

³⁵ The White and Breusch-Pagen tests performed indicated the presence of heteroskedascity; therefore, our models were also estimated using methods correcting for its presence. The obtained coefficients, however, were consistent with those obtained by OLS.

level. The coefficients on price of feeder cattle, shared interest, and age were highly significant and had the expected algebraic signs. The coefficient on the price of feed was negative as expected, but not significant at the 0.05 level.

To test the hypothesis that bull prices paid at auctions vary for different groups of buyers, variables that control for the type, location, and size of the buyer's operation were added to the single Montana breeder regression (data set 1). The results show that the coefficients on these variables were not significantly different from zero at the 0.05 level, either individually or as a group.

To verify the results obtained from the single Montana Angus breeder regressions (data set 1), similar regressions were performed on the four Montana Angus breeder sample (data set 2). In general, the regressions performed on this data set provided results consistent with the single Montana Angus breeder results.

A similar specification, when estimated using the 11 Angus breeder sample (data set 3), yielded results consistent with those obtained from regressions run on the single Montana breeder sample (data set 1) and the four Montana Angus breeder sample (data set 2). All of the SPM coefficients in this regression had the expected algebraic signs, and six of the eight SPM coefficients were significant at the 0.05 level. The only statistically significant EPD coefficients at the 0.05 level were the coefficients on birth weight EPDs and the average yearling weight EPD.

The F -tests of joint significance for SPMs and EPDs were performed for all three samples. All F -values were greater for SPMs than for EPDs.

Because of high collinearity among variables, two alternative specifications were estimated to obtain better measures of the impacts of the individual SPMs and EPDs. In the first specification, the price of feeder cattle, price of feed, shared interest, SPMs, and sires were included, and the EPDs were excluded. The residuals obtained from this regression were then regressed on EPDs. The second specification reversed the roles of SPMs and EPDs. These regressions were performed on all three samples.

Of primary interest for the purpose of identifying the determinants of bull prices and determining the information content of SPMs and EPDs are the *F*-tests of the SPMs and EPDs on residual regressions. As indicated in Table 7, the estimated *F*-values for the *F*-tests of joint significance were always higher for SPMs than for EPDs.

Another indicator of the information contained in SPMs relative to EPDs was obtained by comparing the R^2 values from residual regressions. As demonstrated in Appendix Tables 14, 16, 18, 20, 23, and 25, the R^2 values were always considerably higher for SPM regressions. EPDs explained about 1 or 2 percent of the residual variance from the SPM-only regressions, while SPMs explained approximately 10 times as much of the residual variance from the EPD-only regressions.

Evaluation of animals by EPDs is relatively new in the beef industry. It has been suggested by some industry observers that farmers initially did not trust these values, but have developed confidence in this evaluation system over the ensuing years. Based on the adjusted R^2 s of regressions on SPM-only regression residuals and EPD-only regression residuals run on a yearly basis for the period 1988–1996, however, this

suggestion did not prove to be correct. The R^2 s from these annual regressions did not reflect a pattern that would support this notion.

Table 7. Results of F -Tests for Joint Significance of SPMs and EPDs.

<i>F</i> -Tests	<i>F</i> -Values		
	Single Montana Angus Breeder Sample (Data Set 1)	4 Montana Angus Breeder Sample (Data Set 2)	11 Nebraska/South Dakota Angus Breeder Sample (Data Set 3)
All SPMs			70.51
SPMs and SPMs Squared	15.56	10.41	78.87
SPMs	6.89	6.38	6.68
SPMs Squared	8.15	7.15	10.06
Average SPMs			50.80
All EPDs			10.93
EPDs and EPDs Squared	1.92	0.98	9.23
EPDs Squared	0.75	1.87	6.51
EPDs	0.75	1.92	1.57
Average EPDs			12.58

In general, the algebraic signs on the coefficients in the estimated regressions were as expected. The coefficients on future feeder cattle and feed prices had the expected algebraic signs and were highly significant in the 11-breeder regression (data set 3). Buyers were willing to pay a premium of \$10 to \$40 for each additional \$1/cwt increase in the price of feeder cattle. If the price of feed went up, the buyers discounted each

\$1/bushel increase at the rate of \$400 to \$600. This result indicates that breeders are paying attention to the market conditions and if the situation is favorable to them, they are willing to invest more in their breeding stock.

The estimated coefficients on shared interest were positive and highly significant. The animals that sold with a 1/3 shared seller interest brought a premium of \$2,500 to \$3,600. Those animals that sold with a 1/2 shared interest brought an even higher premium of about \$9,000. This suggests that buyers interpret the seller's willingness to retain a share of the bull's future semen production as a signal that the bull has some high quality attributes not captured by the performance measures. An increase in the share retained by the seller is interpreted by the buyers as an even more overt signal that the sale bull has an exceptional quality.

The estimated coefficient on the age of the bull in days was positive and significant in all of the regressions. For young animals, the ability to breed in the next season was highly correlated with age. Therefore, each additional day of age was valued by buyers at \$2 to \$20.

The coefficient on birth weight was negative, although typically not significant at the 0.10 level. The coefficient on average birth weight was always highly significant, and the discount for a 1 percent increase in the average birth weight was \$45 to \$60. The premium paid for a 1 percent increase in the 205-day weight ranged from \$10 to \$25. Average 205-day weight was always highly significant, and premiums paid for each 1 percent increase in the 205-day weight ranged from \$33 to \$35. The 365-day weights also were highly significant variables. Buyers paid a premium of \$60 to \$122 for each 1

percent increase in 365-day weight, and approximately \$30 for each 1 percent increase in the average 365-day weight. The high significance of average SPM coefficients indicates that herd level differences have important impacts on price. Buyers are willing to pay premiums for bulls that come from herds with desirable characteristics.

In general, the *t*-values were lower on the estimated coefficients for EPDs than for SPMs. The most significant EPD coefficient was usually the coefficient on the birth weight EPD.

All regressions and tests of joint significance indicated that the SPMs contain substantial information in addition to information provided in EPDs. Conversely, EPDs contain some information in addition to that in SPMs, but this information is very limited.

CHAPTER 7

CONCLUSIONS

The central objective of this thesis has been to contribute to a better understanding of the selection decisions characterizing bull market operations by examining the different measurement factors that affect bull prices and comparing the information contents of these factors. The primary focus of this study was to compare the information contained in simple performance measures (SPMs) and expected progeny differences (EPDs). This was accomplished through the construction of three data sets and the application of statistical analysis.

The regression results presented in Chapter 6 suggest that the simple performance measures (SPMs) contain substantial information in addition to that contained in expected progeny differences (EPDs). This finding was unexpected. EPDs, by construction design, contain the information found in SPMs, plus additional information on traits of related animals. Thus, it was hypothesized that the SPM measurements would contain no additional information beyond that contained within EPDs. However, the results of this research suggest the contrary, and therefore raise some important questions for the cattle industry.

Industry experts have offered the following observations that may provide an explanation for the findings of this study:

- (1) The EPD measurement system is too complex for the typical breeder/buyer to possess a thorough knowledge and understanding of the EPD calculation procedures. As a result, when faced with a choice between SPMs and EPDs, the SPM evaluation procedure is generally favored because of its simple construction and easier understandability. In other instances, breeders expect EPD evaluations to provide different answers than those they actually get. They do not take into account that EPDs also incorporate trait information from related animals. For example, if a bull has a poor physical appearance but good EPDs, buyers may assume that the EPDs are not calculated correctly. Consequently, they may highly discount an animal that in fact has a good breeding potential.
- (2) Sellers sometimes provide biased information for EPD calculations, and so buyers place limited faith in the EPD factors. Data used for EPD evaluations are acquired from farmers who perform all of the measurements; i.e., the farmers are expected to weigh the cattle, record the birth weights, and perform many other related tasks generally comprising the measurement-taking process. Measurements of these magnitudes are subject to human error and, in some cases, deliberate falsification. The greater the variability of the measurement around the true value, the lower the quality of information obtained from this measurement. Although breeders should be concerned with accuracy, their methods sometimes are unreliable. There are instances, for example, where the weight of cattle is estimated only by visual observation, and accurate records are not maintained. Such practices create skepticism concerning the information provided. In some

cases, cattle weights are purposely overestimated by less reputable sellers who choose to profit in the short run rather than to provide accurate information and enhance their profits in the long run.

The impact of biased information provided by the seller on EPD accuracy depends on the amount of information available for the animal. For animals with a great deal of information (many progenies), small inaccuracies do not have a dramatic influence on EPD reliability. In contrast, when information on the animal is limited (few progenies), the high bias brought about by errors in measurements will result in seriously compromised EPDs with very limited reliability. Most breeding bulls are sold when they are about one year of age with no progeny, and therefore very limited information about these animals is available. Based on the potential for biased information, many breeders are concerned that EPDs do not accurately reflect the breeding potential of these bulls. On the other hand, due to their simple construction and easier observability, SPMs are perceived by many breeders to be more accurate.

- (3) The results of this study suggest that buyers do not pay much attention to expected progeny differences (EPDs) when making their selection decisions at auctions. This does not necessarily imply, however, that EPDs have no value. EPDs may, for example, be a useful tool for the internal management of herds because they reduce breeders' costs associated with making culling decisions.

A research effort to extend the analysis presented in this thesis is currently under way at Montana State University to construct a data set on Hereford bulls that is comparable to the Angus data set used for this thesis. Some industry observers have suggested that EPDs may be more widely accepted for the Hereford breed than for Angus. If this is the case, tests similar to those reported here for Angus bulls may yield quite different results for Herefords. If the findings of this thesis are supported by similar results obtained for Herefords and other breeds, however, the industry may want to seriously examine the usefulness of EPDs and determine whether the costs of maintaining and further developing this system are warranted.

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APPENDIX:

FIGURES AND STATISTICAL TABLES

Figure 3. Price of Feed (in 1992\$).

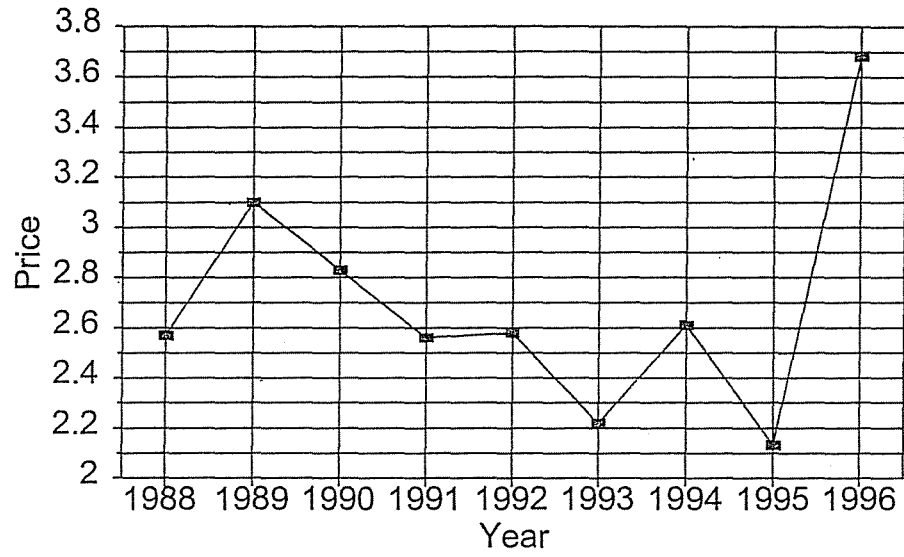


Figure 4. Price of Feeder Cattle (in 1992\$).

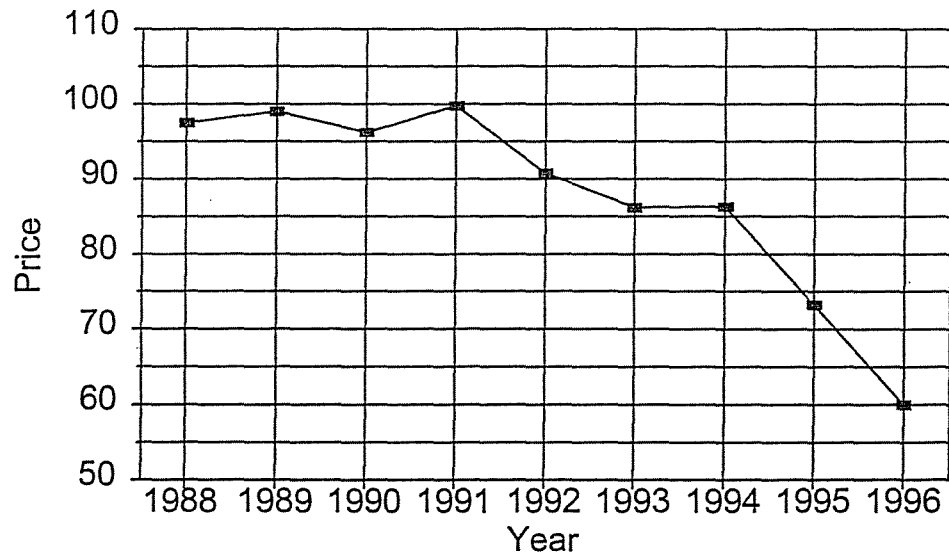


Table 8. List of Traits Evaluated by EPD Measurements.

Expected Progeny Difference	Description
Birth Weight EPD	Predicts the difference among sires in average weight of calves at birth.
Weaning Weight EPD	Predicts expected differences among sires in the average 205-day weight of calves.
Yearling Weight EPD	Predicts the difference among sires in the average 365-day weights of progeny.
Weaning Weight Maternal EPD (Milk)	Portion of the daughter progeny weaning weight that can be attributed to nutrition or milk. It is an indirect contribution of a sire, through his daughters, to his grand progeny.
Combined Maternal Value EPD	The total genetic contribution of growth and milk to weaning weight.
Mature Daughter Weight and Height EPD	Difference in transmitting ability for mature daughter size expressed in pounds and inches.
Scrotal Circumference EPD	Transmitting ability of scrotal size expressed in centimeters. This measure is related to fertility in bulls and age of puberty in females.
Carcass Weight EPD	Difference in transmitting ability for the carcass weight adjusted to a common age of 480 days.
Marbling EPD	Percent of a marbling score above or below the average of the sires represented in the data base.
Ribeye Area EPD	Transmitting ability of ribeye between the 12th and 13th ribs expressed in square inches.
Fat Thickness EPD	Transmitting ability expressed in inches of external carcass fat over the 12th rib.

Sources: American Angus Association (1994), and Brownson (1994).

Table 9. Accuracy Values and Associated Possible Change.

Accuracy Value	Possible Change			
	Birth Weight EPD	Weaning Weight EPD	Maternal Weaning Weight EPD	Yearling Weight EPD
0.05	2.60	12.2	10.8	16.3
0.10	2.55	11.9	10.6	15.9
0.15	2.50	11.6	10.3	15.6
0.20	2.45	11.3	10.1	15.2
0.25	2.40	11.0	9.8	14.9
0.30	2.35	10.7	9.5	14.5
0.35	2.30	10.4	9.3	14.0
0.40	2.20	10.1	9.0	13.6
0.45	2.10	9.7	8.7	13.2
0.50	2.00	9.4	8.4	12.7
0.55	1.90	9.0	8.1	12.2
0.60	1.80	8.6	7.7	11.7
0.65	1.70	8.2	7.3	11.1
0.70	1.60	7.7	7.0	10.5
0.75	1.50	7.2	6.5	9.8
0.80	1.40	6.7	6.0	9.1
0.85	1.30	6.0	5.5	8.3
0.90	1.20	5.3	4.9	7.3
0.95	1.00	4.3	4.0	6.1

Table 10. Angus Breed Average EPD Values by Birth Year.

Birth Year	Angus Genetic Trend EPDs			
	Birth Weight EPD	Weaning Weight EPD	Maternal Weaning Weight EPD	Yearling Weight EPD
1972	-0.5	-4.1	-0.3	-7.4
1973	-0.4	-3.4	-0.2	-6.2
1974	-0.3	-2.6	-0.1	-4.7
1975	-0.3	-1.8	-0.1	-3.1
1976	-1.0	-0.9	0	-1.7
1977	0	0	0	0
1978	0.1	0.8	0	1.3
1979	0.2	1.8	0	3.1
1980	0.4	3.0	0.2	5.3
1981	0.6	4.7	0.4	8.1
1982	0.9	6.5	0.7	10.7
1983	1.2	8.3	1.3	14.0
1984	1.5	10.4	1.8	17.1
1985	1.8	12.1	2.6	19.7
1986	2.1	13.6	3.3	22.1
1987	2.4	15.2	4.0	24.6
1988	2.7	16.7	4.6	27.4
1989	2.8	18.3	5.5	30.6
1990	2.9	19.7	6.7	33.3
1991	3.0	21.2	7.6	36.0
1992	3.0	22.3	8.7	37.8
1993	3.0	23.4	9.5	39.9
1994	2.9	24.3	10.4	41.5
1995	2.7	25.8	11.9	—

Table 11. SPM and EPD Correlation Matrices.

Correlation Coefficients (Data Set 1, Single Montana Breeder)						
	Birth Weight	205-Day Weight	365-Day Weight	Birth Weight EPD	Weaning Weight EPD	Yearling Weight EPD
Birth Weight	1.00	0.19	0.26	0.69	0.31	0.33
205-Day Weight	0.19	1.00	0.71	0.23	0.50	0.32
365-Day Weight	0.26	0.71	1.00	0.23	0.47	0.46
Birth Weight EPD	0.69	0.23	0.23	1.00	0.49	0.55
Weaning Weight EPD	0.31	0.50	0.47	0.49	1.00	0.75
Yearling Weight EPD	0.33	0.32	0.46	0.55	0.75	1.00
Correlation Coefficients (Data Set 2, Four Montana Breeders)						
	Birth Weight	205-Day Weight	365-Day Weight	Birth Weight EPD	Weaning Weight EPD	Yearling Weight EPD
Birth Weight	1.00	0.24	0.20	0.76	0.19	0.11
205-Day Weight	0.24	1.00	0.68	0.19	0.44	0.13
365-Day Weight	0.20	0.68	1.00	0.21	0.46	0.43
Birth Weight EPD	0.76	0.19	0.21	1.00	0.38	0.27
Weaning Weight EPD	0.19	0.44	0.46	0.38	1.00	0.77
Yearling Weight EPD	0.11	0.13	0.43	0.27	0.77	1.00

(continued)

Table 11. Continued.

Correlation Coefficients (Data Set 3, 11 Angus Breeders)						
	Birth Weight	205-Day Weight	365-Day Weight	Birth Weight EPD	Weaning Weight EPD	Yearling Weight EPD
Birth Weight	1.00	0.23	0.25	0.72	0.24	0.22
205-Day Weight	0.23	1.00	0.67	0.21	0.54	0.40
365-Day Weight	0.25	0.67	1.00	0.23	0.42	0.49
Birth Weight EPD	0.72	0.21	0.23	1.00	0.42	0.41
Weaning Weight EPD	0.24	0.54	0.42	0.42	1.00	0.82
Yearling Weight EPD	0.22	0.40	0.49	0.41	0.82	1.00

Table 12. Results of Regressions (6.2) and (6.3) Including SPMs and EPDs, Single Montana Breeder (Data Set 1).

Regression Results: Dependent Variable = Winning Bid Price for Yearling Bulls				
Variable	Regression 1 (6.2)		Regression 2 (6.3)	
	Coefficient Estimate	t-Value	Coefficient Estimate	t-Value
Intercept	67,937	4.211*	-14,585	-5.50*
Market Conditions and Contract Terms				
Price of Feeder Cattle	26.11	2.58*	18.26	1.98*
Price of Feed	-286.06	-1.49	-516.26	-2.92*
Shared Interest (2/3)	3,546.02	9.20*	3,241.45	7.69*
Age	11.12	2.49*	14.16	3.01*
Simple Performance Measures				
Birth Weight	172.88	1.36	-5.26	-0.49
205-Day Weight	-85.85	-0.45	35.03	2.45*
365-Day Weight	-1,669.58	-5.11*	77.35	4.00*
Birth Weight Squared	-0.88	-1.39	N/A	
205-Day Weight Squared	0.68	0.72		
365-Day Weight Squared	8.87	5.49*		
Expected Progeny Differences				
Birth Weight EPD	-13.73	-1.36	-8.10	-2.23*
Weaning Weight EPD	-34.43	-1.47	1.19	0.15
Yearling Weight EPD	25.24	0.90	14.44	1.96*
Birth Weight EPD Squared	0.01	0.38	N/A	
Weaning Weight EPD Squared	0.26	2.10*		
Yearling Weight EPD Squared	-0.10	-0.69		

(continued)

Table 12. Continued.

Variable	Regression 1 (6.2)		Regression 2 (6.3)	
	Coefficient Estimate	t-Value	Coefficient Estimate	t-Value
Sires				
Sire 1	366.21	1.18	22.43	0.07
Sire 2	-225.94	-0.68	-183.37	-0.64
Sire 3	-47.83	-0.13	144.51	0.41
Sire 4	343.23	0.74	184.18	0.43
Sire 5	1,266.73	2.78*	-205.86	-0.48
Sire 6	557.84	1.11	-571.11	-1.05
Sire 7	-619.79	-1.20	-521.73	-1.18
Sire 8	-354.51	-0.65	-216.55	-0.47
Sire 9	273.54	0.48	391.48	0.69
Sire 10	-259.12	-0.47	156.70	0.32
Sire 11	389.89	0.74	350.57	0.78
Sire 12	1,060.73	1.85	301.41	0.47
Sire 13	-211.39	-0.37	-341.91	-0.64
Sire 14	-88.56	-0.158	140.67	-0.21
Sire 15	214.65	0.328	-210.20	-0.29
Sire 16	116.83	0.177	427.00	0.68
Sire 17	156.66	0.237	-37.90	-0.07
Sire 18	-290.78	-0.437	-413.46	-0.74
Purebred	N/A		277.39	0.36
Instate			-147.32	-0.85
Small Size			-135.57	-0.77
Number of Observations	614		312	
F-Value	19.04*		8.29*	
Adjusted R ²	0.50		0.42	

(continued)

Table 12. Continued.

Variable	Regression 1 (6.2)		Regression 2 (6.3)	
	Coefficient Estimate	<i>t</i> -Value	Coefficient Estimate	<i>t</i> -Value
<i>F</i>-Tests for Joint Significance of SPMs and EPDs				
Sires	1.04		0.38	
SPMs and SPMs Squared	24.99*		N/A	
EPDs and EPDs Squared	3.30*		N/A	
SPMs	11.43*		17.81*	
SPMs Squared	13.54*		N/A	
EPDs	1.46		3.02*	
EPDs Squared	1.75		N/A	

*Denotes significance at the 0.05 level.

Table 13. Results of SPM-Only Regression (6.4), Single Montana Breeder (Data Set 1).

Regression Results: Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	77,716	5.02*
Market Conditions and Contract Terms		
Price of Feeder Cattle	33.85	3.43*
Price of Feed	-201.71	-1.07
Shared Interest (2/3)	3,598.63	9.30*
Age	11.17	2.61*
Simple Performance Measures		
Birth Weight	115.89	0.99
205-Day Weight	-246.98	-1.37
365-Day Weight	-1,682.77	-5.20*
Birth Weight Squared	-0.67	-1.13
205-Day Weight Squared	1.55	1.72
365-Day Weight Squared	9.02	5.63*
Sires		
Sire 1	606.64	2.16*
Sire 2	-105.04	-0.32
Sire 3	-360.95	-1.03
Sire 4	181.02	0.396
Sire 5	1,286.01	2.83*
Sire 6	321.12	0.65
Sire 7	-421.97	-0.83
Sire 8	13.44	0.03

(continued)

Table 13. Continued.

Variable	Coefficient Estimate	<i>t</i> -Value
Sires (continued)		
Sire 9	93.96	0.18
Sire 10	-303.37	-0.56
Sire 11	214.26	0.41
Sire 12	1,249.58	2.29*
Sire 13	-405.94	-0.70
Sire 14	-180.30	-0.32
Sire 15	687.27	1.07
Sire 16	324.02	0.49
Sire 17	175.28	0.27
Sire 18	-552.84	-0.83
Number of Observations	614	
<i>F</i> -Value	21.92*	
Adjusted R ²	0.49	
<i>F</i>-Tests for Joint Significance of Sires		
Sires	1.30	
SPMs and SPMs Squared	40.29*	
SPMs	14.81*	
SPMs Squared	18.02*	

*Denotes significance at the 0.05 level.

Table 14. Results of SPM Residual Regression (6.5), Single Montana Breeder (Data Set 1).

Regression Results: Dependent Variable = SPM Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	90.75	0.08
Expected Progeny Differences		
Birth Weight EPD	-9.70	-1.18
Weaning Weight EPD	-15.85	-0.79
Yearling Weight EPD	14.89	-0.79
Birth Weight EPD Squared	0.02	0.53
Weaning Weight EPD Squared	0.13	1.28
Yearling Weight EPD Squared	-0.06	-0.50
Number of Observations	614	
F-Value	1.921	
Adjusted R ²	0.01	
F-Tests for Joint Significance of EPDs		
EPDs	0.75	
EPDs Squared	0.75	

Note: None of the estimated coefficients were significant at the 0.05 level.

Table 15. Results of EPD-Only Regression (6.6), Single Montana Breeder (Data Set 1).

Regression Results:		
Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	-2,374.55	-0.85
Market Conditions and Contract Terms		
Price of Feeder Cattle	23.58	2.11*
Price of Feed	-337.66	-1.60
Shared Interest (2/3)	4,963.50	12.12*
Age	11.88	2.43*
Expected Progeny Differences		
Birth Weight EPD	-9.43	-0.94
Weaning Weight EPD	-78.44	-3.25*
Yearling Weight EPD	24.71	0.80
Birth Weight EPD Squared	-0.02	-0.45
Weaning Weight EPD Squared	0.58	4.62*
Yearling Weight EPD Squared	-0.06	-0.38
Sires		
Sire 1	440.01	1.29
Sire 2	7.29	0.02
Sire 3	331.68	0.82
Sire 4	201.91	0.40
Sire 5	1,100.31	2.18*
Sire 6	694.69	1.25
Sire 7	-957.83	-1.67
Sire 8	53.36	0.09

(continued)

Table 15. Continued.

Variable	Coefficient Estimate	t-Value
Sires (continued)		
Sire 9	752.62	1.19
Sire 10	157.30	0.26
Sire 11	297.41	0.51
Sire 12	1413.10	2.26*
Sire 13	-7.51	-0.01
Sire 14	83.27	0.13
Sire 15	-224.63	-0.31
Sire 16	464.51	0.64
Sire 17	177.06	0.24
Sire 18	-215.80	-0.29
Number of Observations	614	
F-Value	14.28*	
Adjusted R ²	0.38	
F-Tests for Joint Significance of Sires		
Sires	0.99	
EPDs and EPDs Squared	15.69*	
EPDs	4.63*	
EPDs Squared	9.25*	

*Denotes significance at the 0.05 level.

Table 16. Results of EPD Residual Regression (6.7), Single Montana Breeder (Data Set 1).

Regression Results: Dependent Variable = EPD Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	50,088	3.36*
Simple Performance Measures		
Birth Weight	152.05	1.31
205-Day Weight	84.08	0.47
365-Day Weight	-1,329.43	-4.19*
Birth Weight Squared	-0.80	-1.39
205-Day Weight Squared	-0.32	-0.36
365-Day Weight Squared	7.02	4.48*
Number of Observations	614	
F-Value	15.56*	
Adjusted R ²	0.12	
F-Tests for Joint Significance of SPMs		
SPMs	6.98*	
SPMs Squared	8.15*	

*Denotes significance at the 0.05 level.

Table 17. Results of SPM-Only Regression (6.4), Four Montana Breeder Sample (Data Set 2).

Regression Results: Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	29,337	2.17*
Market Conditions and Contract Terms		
Shared Interest (2/3)	2,889.96	11.00*
Age	19.77	4.57*
Simple Performance Measures		
Birth Weight	161.30	1.96*
205-Day Weight	356.90	1.96*
365-Day Weight	-1,298.97	-4.40*
Birth Weight Squared	-0.89	-2.14*
205-Day Weight Squared	-1.79	-1.97*
365-Day Weight Squared	6.95	4.74*
Number of Observations	365	
F-Value	47.26*	
Adjusted R ²	0.50	
F-Tests for Joint Significance of SPMs		
SPMs and SPMs Squared	16.10*	
SPMs	7.65*	
SPMs Squared	8.95*	

*Denotes significance at the 0.05 level.

Table 18. Results of SPM Residual Regression (6.5), Four Montana Breeder Sample (Data Set 2).

Regression Results: Dependent Variable = SPM Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	1,280.69	0.76
Expected Progeny Differences		
Birth Weight EPD	-0.97	-0.37
Weaning Weight EPD	-76.31	-2.26*
Yearling Weight EPD	50.89	1.43
Birth Weight EPD Squared	0.004	0.38
Weaning Weight EPD Squared	0.37	2.23*
Yearling Weight EPD Squared	-0.25	-1.44
Number of Observations	365	
F-Value	0.98	
Adjusted R ²	0	
F-Tests for Joint Significance of EPDs		
EPDs	1.87	
EPDs Squared	1.92	

*Denotes significance at the 0.05 level.

Table 19. Results of EPD-Only Regression (6.6), Four Montana Breeder Sample (Data Set 2).

Regression Results:		
Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	-4,309.58	-1.54
Market Conditions and Contract Terms		
Shared Interest (2/3)	3,440.14	12.16*
Age	18.54	4.03*
Expected Progeny Differences		
Birth Weight EPD	-1.58	-0.54
Weaning Weight EPD	-93.77	-2.46*
Yearling Weight EPD	55.48	1.40
Birth Weight EPD Squared	-0.002	-0.20
Weaning Weight EPD Squared	0.50	2.64*
Yearling Weight EPD Squared	-0.23	1.22
Number of Observations	365	
F-Value	31.127	
Adjusted R ²	0.40	
F-Tests for Joint Significance of EPDs		
EPDs and EPDs Squared	2.83*	
EPDs	2.26	
EPDs Squared	2.37*	

*Denotes significance at the 0.05 level.

Table 20. Results of EPD Residual Regression (6.7), Four Montana Breeder Sample (Data Set 2).

Regression Results: Dependent Variable = EPD Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	23,484	1.76
Simple Performance Measures		
Birth Weight	153.27	1.81
205-Day Weight	471.20	2.56*
365-Day Weight	-1,148.43	-3.85*
Birth Weight Squared	-0.81	-1.96*
205-Day Weight Squared	-2.36	-2.56*
365-Day Weight Squared	6.05	4.10*
Number of Observations	365	
F-Value	10.41*	
Adjusted R ²	0.13	
F-Tests for Joint Significance of SPMs		
SPMs	6.39*	
SPMs Squared	7.15*	

*Denotes significance at the 0.05 level.

Table 21. Results of Regression (6.2) Including SPMs and EPDs, 11 Angus Breeder Sample (Data Set 3).

Regression Results: Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	13,898	3.495*
Market Conditions and Contract Terms		
Price of Feeder Cattle	17.58	8.14*
Price of Feed	-492.69	-7.99*
Shared Interest (2/3)	2,598.29	15.80*
Shared Interest (1/2)	9,103.43	21.74*
Age	2.02	6.51*
Simple Performance Measures		
Birth Weight	42.41	1.38
Adjusted 205-Day Weight	-158.29	-2.54*
Adjusted 365-Day Weight	-246.52	-3.273*
Birth Weight Squared	-0.25	1.60
Adjusted 205-Day Weight Squared	0.89	2.86*
Adjusted 365-Day Weight Squared	1.65	4.45*
Average Birth Weight	-52.50	-8.99*
Average 205-Day Weight	35.94	8.09*
Average 365-Day Weight	6.66	1.11
Expected Progeny Differences		
Birth Weight EPD	-8.09	-6.16*
Weaning Weight EPD	5.50	0.77
Yearling Weight EPD	6.70	0.80

(continued)

Table 21. Continued.

Variable	Coefficient Estimate	t-Value
Expected Progeny Differences (continued)		
Birth Weight EPD Squared	0.01	2.48*
Weaning Weight EPD Squared	-0.03	-0.94
Yearling Weight EPD Squared	0.02	0.42
Average Birth Weight EPD	-3.15	-2.71*
Average Weaning Weight EPD	3.58	1.15
Average Yearling Weight EPD	11.30	2.90*
Number of Observations	4,604	
F-Value	130.56*	
Adjusted R ²	0.39	
F-Tests for Joint Significance of SPMs and EPDs		
SPMs and SPMs Squared	115.16*	
EPDs and EPDs Squared	15.18*	
SPMs	10.28*	
SPMs Squared	16.31*	
Average SPMs	59.67*	
EPDs	13.12*	
EPDs Squared	2.21	
Average EPDs	20.81*	

*Denotes significance at the 0.05 level.

Table 22. Results of SPM-Only Regression (6.4), 11 Angus Breeder Sample (Data Set 3).

Regression Results: Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	17,210	4.371*
Market Conditions and Contract Terms		
Price of Feeder Cattle	16.57	7.77*
Price of Feed	-571.64	-9.55*
Shared Interest (2/3)	2,659.54	15.97*
Shared Interest (1/2)	9,246.30	21.75*
Age	2.07	6.63*
Simple Performance Measures		
Birth Weight	-4.97	-0.18
205-Day Weight	-164.47	-2.69*
365-Day Weight	-248.26	-3.31*
Birth Weight Squared	-0.09	-0.71
205-Day Weight Squared	0.92	3.03*
365-Day Weight Squared	1.72	4.65*
Average Birth Weight	-58.36	-10.25*
Average 205-Day Weight	33.52	7.53*
Average 365-Day Weight	30.75	5.98*
Number of Observations	4,604	
F-Value	196.58	
Adjusted R ²	0.37	

(continued)

Table 22. Continued.

Variable	Coefficient Estimate	<i>t</i> -Value
<i>F</i> -Tests for Joint Significance of SPMs		
SPMs and SPMs Squared	173.87*	
SPMs	9.95*	
SPMs Squared	16.49*	
Average SPMs	97.36*	

*Denotes significance at the 0.05 level.

Table 23. Results of SPM Residual Regression (6.5), 11 Angus Breeder Sample (Data Set 3).

Regression Results: Dependent Variable = SPM Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	-1,409.81	-4.25*
Expected Progeny Differences		
Birth Weight EPD	-4.61	-4.185*
Weaning Weight EPD	5.20	0.755
Yearling Weight EPD	5.88	0.712
Birth Weight EPD Squared	0.01	1.94*
Weaning Weight EPD Squared	-0.03	-1.00
Yearling Weight EPD Squared	0.01	0.25
Average Birth Weight EPD	-1.63	-1.58
Average Weaning Weight EPD	4.40	1.45
Average Yearling Weight EPD	4.24	1.20
Number of Observations	4,604	
F-Value	10.93*	
Adjusted R ²	0.02	
F-Tests for Joint Significance of EPDs		
EPDs and EPDs Squared	9.23*	
EPDs	6.51*	
EPDs Squared	1.57	
Average EPDs	12.58*	

*Denotes significance at the 0.05 level.

Table 24. Results of EPD-Only Regression (6.6), 11 Angus Breeder Sample (Data Set 3).

Regression Results:		
Dependent Variable = Winning Bid Price for Yearling Bulls		
Variable	Coefficient Estimate	t-Value
Intercept	-461.02	-0.90
Market Conditions and Contract Terms		
Price of Feeder Cattle	10.85	4.70*
Price of Feed	-491.20	-7.50*
Shared Interest (2/3)	3,521.93	20.13*
Shared Interest (1/2)	10,550.00	23.42*
Age	1.55	4.70*
Expected Progeny Differences		
Birth Weight EPD	-6.79	-5.65*
Weaning Weight EPD	5.76	0.77
Yearling Weight EPD	5.98	0.67
Birth Weight EPD Squared	0	0.88
Weaning Weight EPD Squared	-0.01	-0.176
Yearling Weight EPD Squared	0.07	1.56
Average Birth Weight EPD	-4.94	-4.18*
Average Weaning Weight EPD	6.00	1.78*
Average Yearling Weight EPD	14.42	3.64*
Number of Observations	4,604	
F-Value	127.66*	
Adjusted R ²	0.28	

(continued)

Table 24. Continued.

Variable	Coefficient Estimate	<i>t</i> -Value
<i>F</i> -Tests for Joint Significance of EPDs		
EPDs and EPDs Squared		66.00*
EPDs		12.15*
EPDs Squared		1.53
Average EPDs		53.40*

*Denotes significance at the 0.05 level.

Table 25. Results of EPD Residual Regression (6.7), 11 Angus Breeder Sample (Data Set 3).

Regression Results: Dependent Variable = EPD Residuals		
Variable	Coefficient Estimate	t-Value
Intercept	11,434	2.95*
Simple Performance Measures		
Birth Weight	36.75	1.32
205-Day Weight	-155.20	-2.54*
365-Day Weight	-150.94	-2.04*
Birth Weight Squared	-0.23	-1.61
205-Day Weight Squared	0.82	2.67*
365-Day Weight Squared	1.09	2.96*
Average Birth Weight	-46.12	-8.40*
Average 205-Day Weight	34.31	7.97*
Average 365-Day Weight	-3.31	-0.66
Number of Observations	4,604	
F-Value	70.51*	
Adjusted R ²	0.12	
F-Tests for Joint Significance of SPMs		
SPMs and SPMs Squared	78.87*	
SPMs	6.68*	
SPMs Squared	10.06*	
Average SPMs	50.80*	

*Denotes significance at the 0.05 level.