Journal of Agricultural and Applied Economics (2024), **56**, 621–634
doi:10.1017/aae.2024.28

RESEARCH ARTICLE

Buyer Valuation of Angus Bull Attributes in Wisconsin

Kishore Joseph[1], Dwight R. Sanders[1], Jayakrishnan Nair[2] and Alicia L. Prill-Adams[3]

[1]Agribusiness Economics at the School of Agricultural Sciences, Southern Illinois University, Carbondale, IL, USA, [2]Animal Science at the School of Agricultural Sciences, Southern Illinois University, Carbondale, IL, USA and [3]Pioneer Farm, University of Wisconsin, Platteville, WI, USA
Corresponding author: Kishore Joseph: Email: kishore.joseph@siu.edu

Abstract

Hedonic analysis of Wisconsin Beef Improvement Association Bull Sale and Development Program data revealed buyer preferences for calving ease, growth, production weight, and carcass merit traits. Attributes like calving ease direct Expected Progeny Differences (EPD), average daily gain, birth to yearling gain EPD, and rib-eye area consistently ranked higher and significantly influenced the bull's sale price. Further analysis using a 2-Class Finite Mixture Model indicated distinct groups of buyers in the region who prioritized measured bull attributes and others who did not, confirming heterogeneity in buyer preferences.

Keywords: Expected progeny differences; Finite Mixture Model; hedonic analysis; ranking bull traits; unobserved heterogeneity

JEL classifications: Q13

Introduction

The selection of sires is a crucial aspect of breeding programs, as the sire's traits determine half of the offspring's characteristics (Dhuyvetter et al., 1996). The choice of suitable sires, guided by an operation's management objective, facilitates the development of cattle herds with desirable traits, thereby enhancing long-term profitability. Over time, producers have employed various tools for selecting bulls, including their phenotype (e.g., birth weight, ultrasound information), performance measures (e.g., average daily gain, residual feed intake, weaning weight), and most notably, Expected Progeny Differences (EPDs). EPDs (e.g., calving ease direct EPD, milk EPD) represent a bull's predicted average genetic contribution to its offspring's performance and are used in making selection decisions for desired traits in the herd (Felix and Freitas, 2023). The EPDs for a trait are calculated based on performance, pedigree, and progeny, and the difference in EPDs of two bulls estimates the expected difference in their progeny's performance, making EPDs a popular and effective tool in bull selection.

Cow-calf producers prioritize traits that reduce production costs (Lewis et al., 2015; Pendell and Herbel, 2021). Research has indicated that bulls that pass on qualities such as calving ease (Boyer et al., 2019; Dhuyvetter et al., 1996), maternal ability (Dhuyvetter et al., 1996; Jones et al., 2008; Tang et al., 2023; Vanek, Watts, and Brester, 2008), and feed efficiency (Bekkerman, Brester, and McDonald, 2013; McDonald et al., 2010) to their offspring command higher prices. Additionally, producers may prefer bulls that pass on traits such as higher growth rate, increased production weight, and superior carcass merit to their progeny (Tang et al., 2023; Vanek, Watts, and Brester, 2008) as these traits lead to higher returns during cattle sales (Lewis et al., 2015). Furthermore, factors such as the bulls' breed, pedigree, physical attributes, structural soundness, conformation, feed costs, feeder and fat cattle prices, environmental conditions, and marketing factors associated with the sale may also impact the sale price (Bekkerman, Brester, and McDonald, 2013; Chvosta, Rucker, and Watts, 2001; Dhuyvetter et al., 1996; Jones et al., 2008; Vanek, Watts, and Brester, 2008).

Previous studies have found that cow-calf producers consider bull attributes that increase economic value when making bull purchasing decisions. However, this may not apply uniformly to all attributes and should not be assumed without a thorough analysis of regional data. The economic benefits of this approach are substantial and have direct implications for the beef cattle industry. Bekkerman, Brester, and McDonald (2013) and Tang et al. (2023) found that producer preferences for beef cattle attributes vary based on management objectives, leading to a diverse demand for bulls with specific traits. Additionally, the diversity of producer preferences can add complexity to producer valuations, challenging traditional hedonic analysis of bull prices that assume homogeneous producer preferences. Tang et al. (2023) demonstrated that unobservable differences in buyer preferences could impact the producer's marginal valuation of bull traits. The authors also acknowledged the potential variability in demand for bull attributes across geographical locations and types of bull sales, underscoring the need to further examine this concept in different market settings.

The literature discusses several factors that lead to differences in buyer preferences for specific bull traits. Heterogeneity may arise in the tolerance for lower calving ease among operations using mature cows compared to those using heifers (Boyer et al., 2019). Preferences for the milk EPD trait may vary depending on whether producers aim for heavier calves with high nutritional demand and feed costs (Boyer et al., 2019; Kessler, Pendell, and Enns, 2017). Producers buying bulls to produce replacement heifers may attach a higher value to maternal characteristics and reproductive performance (Thompson et al., 2022), and operations experiencing labor constraints may prefer bulls with lower weights to minimize calving problems (McBride and Mathews, 2011; Tang et al., 2023). Producers from small, part-time operations may opt for lower-priced bulls owing to their vulnerability to higher bull prices and feed costs (McBride and Mathews, 2011). Producers may prefer the genetic superiority offered by bulls out of younger dams (Da Silva et al., 2016) or the established reproductive performance and higher weaning weight traits in older dams (Elzo, Quas, and Pollack, 1987; Kessler, Pendell, and Enns, 2017). Tang et al. (2020) noted that traditional cow-calf producers have little incentive to invest in bulls producing calves with higher carcass traits as their calves are sold at auctions on a weight basis and with limited information. However, the authors agreed with other studies (Vanek, Watts, and Brester, 2008) that there are specific segments of bull buyers, such as larger commercial operations retaining calves till the feedlot phase, which may invest in superior carcass qualities (Thompson et al., 2022). Heterogeneity may also stem from the producers' evolving preferences for specific attributes over time, which Boyer et al. (2019) and Tang et al. (2020) attributed to the introduction of grid pricing and EPDs, and their increased acceptance among producers.

This paper analyzed the Bull Sale and Development Program data from 2012 to 2021 sale years collected by the Wisconsin Beef Improvement Association (WBIA). The study used hedonic pricing models to reveal the producer's marginal valuation of various bull attributes in the upper Midwest region. We analyzed the data over the entire period and for smaller subperiods to determine if producer valuations for bull attributes change over time. Additionally, we addressed the potential heterogeneity in the data using a Finite Mixture Model (FMM). The beef cattle industry in Wisconsin is quite diverse, with small farms being the dominant players. On average, each cow-calf operation consists of forty-five cows. In this region, sixty percent of farmers maintain a commercial cow-calf herd, 32 percent have seed stock enterprises, 7 percent run stocker operations, 34 percent have feedlot operations, and 20 percent directly market their beef (Center for Integrated Agricultural Systems, 2008). This diverse range of beef enterprises provides an excellent geographical setting to analyze the heterogeneity in producer demand for bull traits. Furthermore, the WBIA data has the added advantage of being compiled from a single bull performance test and sale program, enhancing the value of the study.

The analysis of pooled data revealed that producers place high importance on calving ease, growth, production weight, and carcass quality traits when selecting bulls. Subsequent analysis using a 2-Class FMM identified two distinct buyer segments in the region. One segment values specific bull attributes, while the other segment does not. These results are consistent with earlier findings and highlight the diversity in buyer demand for bull attributes, influenced by the management goals of operations in the region.

Data

The WBIA has been conducting bull performance tests and sales under its Bull Development and Sale Program since 1970. The bulls undergo carcass characteristic evaluation and must pass a breeding soundness test before being sold. A sale catalog is created, which includes detailed EPD profiles, performance data, and video documentation. The best-performing bulls are sold through in-person and online auctions (WBIA). The bull sale catalog contained detailed records on various performance measures, including breed, birth date, birth weight, final weight, on-test weight, weight per day of age, color, frame score, height, dam's age, average daily gain, and ultrasound data such as average back fat, rib-eye area, and marbling score, along with detailed EPD profiles. The EPDs in the dataset included the calving ease direct EPD, birth weight EPD, weaning weight EPD, yearling weight EPD, and maternal milk EPD.

Data from 2012 to 2021 WBIA sale catalogs and testing records were compiled and analyzed. To avoid heterogeneity arising from breed differences and due to data availability, only polled Black Angus breed was included in the study. The number of bulls that passed the test during the study period was 470. After removing observations with no sales and missing values, our final dataset contained 398 observations. A summary of variables used in the analysis is presented in Table 1. Consistent with prior research (Tang et al., 2023), the sale price ($/head) was adjusted to 2021 equivalents using the Producer Price Index for Slaughter Cattle from the Bureau of Labor Statistics. The bulls in the dataset are in the 351 to 457-day age range. The average sale price for bulls in the dataset is $3,022.6, and there is considerable variation in the sale price, with bulls selling for as low as $1,744.40 and as high as $7,629.96. The mean and standard deviation of bull attributes in our data were consistent with the values reported by earlier studies.

Research methods

We used a hedonic regression framework for analysis, with the bull sale price as the dependent variable and genetic and phenotypic indicators, EPDs, and year dummies as independent variables (Dhuyvetter et al., 1996; Kessler, Pendell, and Enns, 2017; Tang et al., 2020; Vanek, Watts, and Brester, 2008). To account for the non-normal price distribution, we applied a log transformation to the dependent variable (Boyer et al., 2019; Jones et al., 2008; Tang et al., 2023) and used Ordinary Least Squares (OLS) to estimate the model. The model we used is the following semi-log model.

$$y_i = \beta_0 + \sum_{j=1}^{J} \beta_j X_{ij} + \sum_{k=1}^{K-1} \delta_k Z_k + \varepsilon_i. \tag{1}$$

Here, y_i is the natural log of the sale price ($/head) for the bull, i; X_{ij} represents the bull traits $j = 1, \ldots, J$ of bull i; and Z_k includes dummy variables that control for the K sale year fixed effects. β_0 is the intercept term; β_j is the marginal valuation of each bull trait j by the producers to be estimated; δ_k are the shifts from discrete dummy variables; and ε_i is the *i.i.d.* error term.

The expected signs of parameter estimates are presented in Table 2. Previous studies have shown conflicting results on the impact of age and frame score attributes on bull sale prices (Boyer et al., 2019). The value of older, mature bulls, which producers generally prefer, may decrease as

Table 1. Summary statistics of Angus bull attributes (2012–2021 sale year)

Variable	Mean	Std. Dev.	Min.	Max.
Price				
Sale price ($/head)	3,022.67	937.18	1,744.40	7,629.96
Natural log (Sale price)	7.97	0.28	7.46	8.94
Genetic and Phenotypic Indicators				
Age (Days at sale)	397.63	24.07	351.00	457.00
Birth weight (lb.)	78.40	7.50	53.00	102.00
Final weight (lb.)	1,320.50	110.23	1,045.00	1,620.00
Average daily gain (lb./day)	4.42	0.49	3.15	6.05
Weight per day of age (lb.)	3.54	0.25	2.91	4.32
Average back fat (Inches at 12th Rib)	0.39	0.10	0.19	0.72
Rib-eye area (Sq. Inches at 12th Rib)	14.55	1.21	11.40	19.00
Marbling score (USDA Scale 1–10)	4.61	1.24	2.05	8.53
Scrotal circumference (cm)	39.12	2.65	31.00	47.50
Frame score (BIF Scale 1–9)	5.78	0.66	3.60	8.10
Dams' age (Years)	4.98	2.55	2.00	14.00
Expected Progeny Differences				
Calving ease direct EPD (%)	6.29	4.31	−8.00	18.00
Birth weight EPD (lb.)	1.50	1.47	−2.60	5.30
Yearling weight EPD (lb.)	105.83	16.91	62.00	173.00
Birth to yearling gain EPD (lb.)	104.32	16.71	60.20	170.10
Weaning weight EPD (lb.)	59.28	10.49	32.00	99.00
Milk EPD (lb.)	26.25	5.24	10.00	41.00

Notes: Number of observations (N) = 398; Birth to yearling gain EPD is computed by subtracting the birth weight EPD from yearling weight EPD. The bull sale price is adjusted to 2021-dollar values.

the bull ages (Kessler, Pendell, and Enns, 2017; McDonald et al., 2010). The preference for a bull's frame may depend on the buyer's inclination towards calving ease and weaning weight traits and the availability of feed resources (Dhuyvetter, 1995). Desirable traits in a bull, such as higher average daily gain, average back fat, rib-eye area, marbling score, scrotal circumference, calving ease direct EPD, and birth to yearling gain EPD are expected to have a positive effect on the sale price (Boyer et al., 2019; Kessler, Pendell, and Enns, 2017; Tang et al., 2023). The impact of milk EPD can vary and may depend on weaning weights and feed costs targeted by the cow-calf operation (Boyer et al., 2019; Tang et al., 2023). The influence of the dam's age on the sale price of the bull may depend on the producer's preference for superior calving ease (Kessler, Pendell, and Enns, 2017) and carcass traits of younger dams (Da Silva et al., 2016), as opposed to the emphasis on proven reproductive performance and weaning weight traits of older dams (Kessler, Pendell, and Enns, 2017). It is also important to note that specific bull attributes, such as the age of the bull, average back fat, dam's age, and scrotal circumference, may have a preferred range, affecting the sale price of the bulls in the sample. For a more detailed discussion of the potential impact of bull attributes on sale prices, readers are referred to Brimlow and Doyle (2014), Dhuyvetter et al. (1996), Jones et al. (2008), Kessler, Pendell, and Enns (2017), and Boyer et al. (2019).

Table 2. Description of explanatory variables and expected sign of coefficients

Variable	Definitions	
Genetic and Phenotypic Indicators		
Age	Measured in days on sale day	(+/–)
Average daily gain	Measure of animal's average gain on test in pounds	(+)
Average back fat	Ultrasound measurement of back fat depth in inches at 12th rib	(+)
Rib-eye area	Ultrasound measurement of rib-eye area in sq. inches at 12th rib	(+)
Marbling score	Ultrasound measurement of marbling % (USDA Scale 1-10)	(+)
Scrotal circumference	Scrotal circumference measured in cm	(+)
Frame score	Skeletal size based on hip height and age (BIF Scale 1-9)	(+/–)
Dam's age	The age of the sire's dam measured in years	(+/–)
Expected Progeny Differences		
Birth to yearling gain EPD	Difference between yearling weight EPD and birth weight EPD	(+)
Calving ease direct EPD	Sire's ability to transmit the calving ease trait measured by the difference in % of unassisted births when bred to first-calf heifers	(+)
Milk EPD	Sire's ability to transmit mothering ability to his daughters measured in pounds	(+)

Notes: Birth weight EPD is the sire's ability to transmit birth weight to his progeny measured in pounds, and yearling weight EPD is the sire's ability to transmit yearling weight to his progeny measured in pounds.

Bull traits are measured using different scales, and ranking them solely based on the magnitude of coefficient estimates from hedonic regression models can lead to incorrect conclusions (Tang et al., 2023; Vanek, Watts, and Brester, 2008). Pindyck and Rubenfield (1998) recommended standardizing variables using their means and standard deviations before ranking coefficients from the regression. In the standardized model, the coefficients indicate how the standard deviation of the log bull price changes for each standard deviation change in the attribute, and the absolute value of the coefficients can be used to rank bull attributes by their importance in determining the log bull price.

Identifying latent classes and addressing unobserved heterogeneity

The heterogeneity in buyer preferences is addressed using a FMM. A mixture model is a probabilistic model that assumes that a bull's price P_i arises from a population that is a mixture of a finite number of distributions called classes (S), in proportions π_s. The probabilities π_s are constrained such that $\sum_{s=1}^{S} \pi_s = 1$ and $\pi_s \geq 0$ for $s = 1, \ldots, S$. (Tang et al., 2023; Wedel and Kamakura, 2003). Class membership is not determined a priori and is assigned by the model from the data.

Following Tang et al. (2023), an S-component FMM of bull price is represented in the general form as

$$f\left(y_i | \boldsymbol{x}_i, \boldsymbol{\beta}, \boldsymbol{\pi}\right) = \sum_{s=1}^{S} \pi_s f_s\left(y_i | \boldsymbol{x}_i, \boldsymbol{\beta}_s\right). \tag{2}$$

Here, X and Z from Equation (1) are concatenated into a single vector $\boldsymbol{x}_i$; y_i is the natural log of bull price; $f_s(.)$ represents the probability density function for the s^{th} latent class parameterized by $\boldsymbol{\beta}_s$; $\boldsymbol{\beta} = (\boldsymbol{\beta}_1, \boldsymbol{\beta}_2, \ldots, \boldsymbol{\beta}_S)$ is the vector representing the set of parameters for all latent classes; π_s represents the average probability that an observation i is assigned to a given class s; and

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

$\boldsymbol{\pi} = (\pi_1, \pi_2, \ldots, \pi_S)$ is the vector of mixing proportions (weights) for all latent classes. Each class s is assumed to follow a normal distribution with mean $\mu_{i,s} = \boldsymbol{x}_i\boldsymbol{\beta}_s$ and variance σ_s^2, and the probability density function

$$f_s(y_i|\boldsymbol{x}_i, \boldsymbol{\beta}_s) = \frac{1}{\sqrt{2\pi\sigma_s^2}} exp\left(\frac{-(y_i - \boldsymbol{x}_i\boldsymbol{\beta}_s)^2}{2\sigma_s^2}\right). \tag{3}$$

For a mixture of linear regression models, the likelihood function for the observed bull price P_i, is given as

$$L(\boldsymbol{\beta}, \boldsymbol{\pi}|\boldsymbol{x}) = \prod_{i=1}^{N}\left[\sum_{s=1}^{S} \pi_s f_s(y_i|\boldsymbol{x}_i, \boldsymbol{\beta}_s)\right], \tag{4}$$

and the log-likelihood function is

$$Log\ L(\boldsymbol{\beta}, \boldsymbol{\pi}|\boldsymbol{x}) = \sum_{i=1}^{N} \log\left[\sum_{s=1}^{S} \pi_s f_s(y_i|\boldsymbol{x}_i, \boldsymbol{\beta}_s)\right]. \tag{5}$$

An estimate of $(\hat{\boldsymbol{\beta}}, \hat{\boldsymbol{\pi}})$ can be obtained by solving the log-likelihood Equation (5) with respect to model parameters $(\boldsymbol{\beta}, \boldsymbol{\pi})$, subject to the restrictions on π_s discussed earlier. The first-order conditions of the log-likelihood function are solved numerically using the quasi-Newton method, and the posterior probability can be computed using Bayes' Rule.[1] The posterior probability of each observation i in class s is given by

$$\hat{\pi}_{i,s} = \frac{\widehat{\pi}_s f_s\left(y_i|\boldsymbol{x}_i, \widehat{\boldsymbol{\beta}}_s\right)}{\sum_{s=1}^{S} \widehat{\pi}_s f_s\left(y_i|\boldsymbol{x}_i, \widehat{\boldsymbol{\beta}}_s\right)}. \tag{6}$$

The FMM is estimated using PROC FMM in SAS 9.4 (SAS Institute, Inc., 2015). The final model selection is based on the Akaike Information Criterion (AIC), Corrected Akaike Information Criterion (AICC), and Bayesian Information Criterion (BIC). To further assess the separation of classes for different class models, we computed an entropy statistic (E_S) using the formula

$$E_S = 1 - \frac{\sum_{i=1}^{N} \sum_{s=1}^{S} - \pi_{i,s} \ln\ (\pi_{i,s})}{N \ln\ (S)}. \tag{7}$$

E_S is a relative measure and is bound between 0 and 1. A value close to one suggests a greater degree of separation between latent classes, and a value close to zero implies that the classes are not well separated (Tang et al., 2023; Wedel and Kamakura, 2003). The entropy statistic cannot be used to choose the number of classes, but it is a helpful comparison tool to check the over-extraction of latent classes from the model (Tang et al., 2023). According to Tang et al. (2023), the probability-weighted estimation of attribute valuations in the FMM does not allow for standardization within each class, making ranking based on standardized variables less meaningful. Additionally, the latent class models are not analyzed in subperiods due to the potential for class membership changes and sample size limitations.

Results and discussion – Pooled model and models in subperiods

We used the Pearson correlation coefficient to assess correlations and dropped highly correlated variables from the model to control multicollinearity.[2] Prior research has established the role of

[1]In the FMM, the mixing proportion or weight (π_s) for class s is updated as the average of the posterior probabilities ($\pi_{i,s}$) across all observations such that $\hat{\pi}_s = \frac{1}{N}\sum_{i=1}^{N} \hat{\pi}_{i,s}$ for all s.

[2]The results are currently not presented; however, they can be made available upon request.

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

weight in determining the price of the bull (Bekkerman, Brester, and McDonald, 2013; Jones et al., 2008). However, the final weight and weight per day of age attributes of the bull were correlated with several attributes of interest, including age, rib-eye area, weaning weight EPD, and the yearling weight EPD, and were therefore dropped.[3] A new variable, the birth to yearling gain EPD, was constructed by subtracting the birth weight EPD from the yearling weight EPD (Bekkerman, Brester, and McDonald, 2013), and the highly correlated weaning weight EPD and yearling weight EPD attributes were dropped. The birth to yearling gain EPD was used as the primary indicator of the sire's ability to transmit higher growth and weight to its progeny compared to other sires. Calving ease direct EPD is a comprehensive measure computed using birth weight and the calving score and was used as the primary indicator of calving ease. Consequently, the correlated birth weight and birth weight EPD variables were dropped.

The final model included age, average daily gain, average back fat, rib-eye area, marbling score, scrotal circumference, frame score, dam's age, birth to yearling gain EPD, calving ease direct EPD, and milk EPD attributes. Year dummy variables with 2021 as the base year were included to account for changes in cattle inventory, fat cattle price, feed cost, labor cost, and other marketing and environmental factors that may influence a bull's sale price (Bekkerman, Brester, and McDonald, 2013; Chvosta, Rucker, and Watts, 2001; Kessler, Pendell, and Enns, 2017; Tang et al., 2023). Assessing multicollinearity in the final pooled model using the Variance Inflation Factor (VIF) showed a value lower than five for all variables with an overall VIF of 1.8, indicating no severe multicollinearity issues. Consistent with prior research, robust Huber-White standard errors were used to calculate reliable estimates of standard errors in the presence of heteroskedasticity related to variables included in the model (Jones et al., 2008; Kessler, Pendell, and Enns, 2017; Tang et al., 2023).[4] Residual diagnostics using the Q-Q plot showed a mild departure from normality.[5]

The pooled model presented in Table 3. has an R^2 of 0.51.[6] All bull attributes except scrotal circumference and dams' age were statistically significant at an $\alpha = 0.05$ and had expected signs.[7] The model coefficients were transformed to estimate the dollar change in bull price from a unit change in each attribute and are reported as the "Value ($)" in Table 3.[8] For example, the premium paid for a bull in the sample increased by an average of $4.36 as the age increased by a day. The bull's age signifies biological maturity, and its positive sign is consistent with the buyer's preference for larger mature bulls mentioned in other studies (Boyer et al., 2019; Thompson et al., 2022). The average daily gain increased the bull's expected sale price, showing the value producers attach to growth. Rib-eye area and marbling score attributes increased the bull's sale price,

[3]Principal Component Analysis was used to reduce the dimensionality of correlated data. The first five principal components (PCs) had an eigenvalue greater than one. The first PC was influenced by weight and growth indicators, the second by maternal ability indicators, the third by carcass merit indicators, the fourth by phenotypic indicators such as age, scrotal circumference, and dam's age, and the fifth by age, carcass merit, and growth traits. Together, these five components explained 63.52% of the total variance.

[4]Modeling the underlying heteroscedasticity in the pooled model and estimating the results using a Feasible Generalized Least Squares model (Boyer et al., 2019) resulted in comparable outcomes.

[5]The natural log of bull prices and the average back fat, marbling score, and dam's age attributes show a skewed distribution with a heavier left tail and a slight skew to the right. All other explanatory variables followed a normal distribution. To ensure the robustness of the analysis, we repeated the analysis after excluding six data points with bull prices over $6,000. Additionally, we also analyzed the data using a nonparametric kernel regression model. The results from both analyses were similar to the original pooled model, and we continued our study using all 398 data points.

[6]OLS estimation using sale year dummy variables yielded consistent results regardless of the use of nominal or real sale prices. The model utilizing real sale prices exhibited a higher R^2, due to the reduction in noise from inflation.

[7]The dummy variables, except for the years 2016 and 2020, were significant at $\alpha = 0.5$ and had a negative sign. These results are not provided in Table 3 but are available upon request.

[8]In the semi-log specification, the percentage change in bull price from a one-unit change in the j^{th} bull attribute equals $100 \times (e^{\beta_j} - 1)$. Multiplying this value by the average bull sale price for the sample and dividing it by a hundred gives an estimate of the change in bull sale price in dollars for a unit change in the attribute's value.

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

Table 3. Results from the full sample and the subperiods

Variable	2012–2021 Coefficient Est.		2012–2021 Value ($)	2012–2016 Coefficient Est.		2012–2016 Value ($)	2017–2021 Coefficient Est.		2017–2021 Value ($)
Age	0.0014	***	4.36	0.0016	***	4.61	0.0010		3.45
Average daily gain	0.1519	***	495.93	0.1576	***	489.36	0.1369	***	482.05
Average back fat	0.4431	***	1,685.15	0.5083	***	1,898.43	0.3061	***	1,176.04
Rib-eye area	0.0551	***	171.27	0.0635	***	187.95	0.0459	***	154.21
Marbling score	0.0224	**	68.57	0.0173		49.89	0.0308	*	102.65
Scrotal circumference	0.0012		3.67	0.0030		8.64	0.0006		1.86
Frame score	0.0406	**	125.33	0.0277		80.58	0.0680	***	230.96
Dams' age	−0.0023		−6.88	−0.0016		−4.51	−0.0016		−5.39
Birth to yearling gain EPD	0.0028	***	8.53	0.0023		6.56	0.0031	***	10.31
Calving ease direct EPD	0.0175	***	53.32	0.0128	***	36.80	0.0244	***	80.96
Milk EPD	0.0055	***	16.53	0.0071	***	20.30	0.0020		6.61
Intercept	5.0100	***	–	4.8952	***		5.2655	***	–
Sale year fixed effects	Yes			Yes			Yes		
N	398			235			163		
Percent of sample (%)	100			59			41		
R^2	0.51			0.47			0.52		
AIC	−118.21			−56.47			−51.22		
BIC	−34.5			−1.12			−1.72		
AICC	−115.75			−53.98			−47.49		
Average sale price ($/head)	3,022.67			2,865.86			3,284.45		

Notes: The dependent variable is the natural log of bull price adjusted to 2021-dollar values. Value ($) is the impact of a one-unit increase in the independent variable on the bull sale price. N is the number of observations. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The model is estimated using Stata/MP 18.

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

revealing the producer's interest in improving carcass quality. While Brimlow and Doyle (2014) and Thompson et al. (2022) reported a negative relationship between average back fat and sale price, our results showed a positive relation. The sample mean of the average back fat attribute is 0.39 inches and within the range that increases a bull's premium, which likely explains this result. A higher frame score led to increased sale prices for the bulls in the sample, indicating a preference for greater bull weight and maturity. The birth to yearling gain EPD attribute increased the sale price of a bull, showing the importance of growth-related attributes in deciding the sale price of the bull. The bull's value also increased with higher calving ease direct EPD and milk EPD, signifying the value producers attach to reproductive and maternal traits.[9] While the magnitude of estimated coefficients and our overall findings are comparable to other contemporary studies (Bekkerman, Brester, and McDonald, 2013; Boyer et al., 2019; Brimlow and Doyle, 2014; Tang et al., 2023; Thompson et al., 2022), the effect of bull attributes on the sale price may be overestimated due to variables omitted from the model.[10] Nonetheless, our results show that consumer preferences are transferred upstream, and producers pay premiums for value-enhancing bull attributes.

Data for the pooled model spans a 10-year period, which may cause potential changes in producer valuation of bull attributes (Boyer et al., 2019; Tang et al., 2020). The interaction of variables with time in the pooled model was evaluated using a linear time trend variable ($t = 1, \ldots, 12$) and its square without including the sale year dummies. The results indicated changes in the way producers valued calving ease direct EPD and average daily gain attributes over time. Time interaction with calving ease direct EPD was significant at $\alpha = 0.05$ when the time trend variable was used. However, the time interaction with other variables was insignificant. On the other hand, only the average daily gain attribute showed significant interaction at $\alpha = 0.10$ when both time and time square interactions were introduced. We examined the temporal differences in producer marginal valuation of bull attributes by analyzing data in two subperiods: 2012–2016 and 2017–2021. To enable comparison, a specification similar to the pooled model was adopted.

The results from different periods are also presented in Table 3. The most significant changes were observed in the buyers' valuation of the marbling score, frame score, birth to yearling gain EPD, and calving ease direct EPD attributes, which nearly doubled in value in the second subperiod. The buyer valuations for average daily gain and rib-eye area decreased slightly, while those of average back fat decreased moderately in the second subperiod. In the second subperiod, age was no longer significant, possibly due to increased valuations of the marbling score and frame score, which became more correlated with age. The milk EPD attribute was not important in explaining the bulls' sale price in the second subperiod. Tang et al. (2020) also found similar results, which they attributed to varying producer preferences for the milk EPD trait. The dam's age and scrotal circumference attributes did not influence the bull's sale price in either subperiod.

The rankings of bull attributes by their importance in explaining the bull sale price in different periods are presented in Table 4. Calving ease direct EPD, average daily gain, and rib-eye area were consistently the top predictors of bull value. Birth to yearling gain EPD, marbling score, and frame score attributes increased in importance in the latter subperiod, while average back fat, milk EPD, and age decreased in ranking. Scrotal circumference and the dam's age attributes were consistently ranked lower. The findings align with other recent studies and show that producers value calving ease, growth, production weight, and carcass merit attributes in their cattle. However, as Tang et al. (2023) noted, using pooled data may impact producers' valuation of bull attributes if there is heterogeneity in producers' demand for specific bull traits.

[9]Initially, there was concern that the calving ease direct EPD might not accurately predict calving ease in mature cows as it is based on calving ease in first-calf heifers. Using all three measures of calving ease (birth weight, birth weight EPD, and calving ease direct EPD) in the model showed no statistically significant impact from birth weight and birth weight EPD.

[10]The sale year fixed effects (dummy variables) account for time-specific unobserved factors that uniformly impact all bulls within a given year. However, they do not account for unobserved factors whose impact varies between individual bulls.

Table 4. Ranking of bull attributes

	2012–2021			2016–2021			2017–2021		
Variable	Coefficient Est.		Rank	Coefficient Est.		Rank	Coefficient Est.		Rank
Calving ease direct EPD	0.0753	***	1	0.0512	***	3	0.1049	***	1
Average daily gain	0.0747	***	2	0.0818	***	1	0.0674	***	2
Rib-eye area	0.0669	***	3	0.0753	***	2	0.0557	***	3
Birth to yearling gain EPD	0.0471	***	4	0.0248		7	0.0524	***	4
Average back fat	0.0422	***	5	0.0508	***	4	0.0291		7
Age	0.0347	***	6	0.0383	***	5	0.0253		8
Milk EPD	0.0286	***	7	0.0368	***	6	0.0105		9
Marbling score	0.0278	**	8	0.0224		8	0.0382	*	6
Frame score	0.0267	**	9	0.0179		9	0.0446	***	5
Dams' age	0.0058		10	0.0038		11	0.0042		10
Scrotal circumference	0.0032		11	0.0079		10	0.0015		11
	N = 398			N = 235			N = 163		

Notes: The dependent variable is the natural log of bull price adjusted to 2021-dollar values. The ranking is based on the absolute value of estimated coefficients from the model using standardized variables. N is the number of observations. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The model is estimated using Stata/MP 18.

Results and discussion – Latent class model

The sample size and the degree of separation among latent classes presented challenges for parameter estimation in the FMM. As a result, unobserved heterogeneity is addressed to the extent possible after careful data analysis. Models from two to six latent classes were estimated, and rigorous evaluation was performed before choosing the number of classes.[11] The results from the FMM are presented in Table 5. The AIC, AICC, and BIC values were lower for the 2-Class FMM compared to the 3-Class FMM. Additionally, the entropy statistic was higher for the 2-Class FMM (0.91) relative to the 3-Class FMM (0.68), suggesting an over-extraction of classes with the 3-Class FMM. Based on the AIC, AICC, and BIC values and the computed entropy statistic values, we used the 2-Class FMM for further discussion.[12]

The bulls were categorized into two classes based on their estimated posterior probabilities. Class 1 is the smaller of the two classes, comprising 16.08% of the observations with 64 bulls, and is

[11]The dual quasi-Newton optimization algorithm is used to estimate the FMM. Data analysis using 2-6-Class FMMs revealed a higher value of the entropy statistic for 2-Class FMM compared to all other classes. The BIC value is the lowest for the 2-Class FMM across all classes examined, but the AIC and AICC values are lower for classes 4 to 6 compared to classes 2 and 3. As Wedel and Kamakura (2003) noted, AIC and AICC tend to favor models with more classes, whereas BIC tends to favor models with fewer classes. Residual diagnostics for each class using the Q-Q plot showed a mild departure from normality. We also performed a robustness check using the FMM procedure in STATA MP/18 software. The Berndt-Hall-Hall-Hausman algorithm and the Newton-Raphson algorithm were employed to estimate the 2-Class FMM. The proportion of observations in Class 1 and Class 2 changed to 20.85% (N = 83) and 79.15% (N = 315), respectively. While the results for Class 1 changed with the change in class proportions, those of Class 2 and our overall conclusions were consistent with the results from the SAS procedure. These results are available upon request.

[12]Examining the impact of inflation adjustment on the FMM revealed that the results are responsive to changes in the scale and distribution of the data. The model using real prices demonstrated a higher log-likelihood value and lower AIC, AICC, and BIC values than the model using nominal prices. Further analysis using an alternative deflator, the Producers Price Index for Steers and Heifers, yielded results similar to the original model with slightly higher AIC, AICC, and BIC values. These results are available upon request.

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

Table 5. Latent class model results

Variable	Class 1			Class 2		
	Coefficient Est.		Value ($)	Coefficient Est.		Value ($)
Age	0.0001	*	0.24	0.0016	***	4.94
Average daily gain	−0.0139	***	−34.34	0.1579	***	534.80
Average back fat	−0.1329	***	−308.68	0.4135	***	1,601.12
Rib-eye area	0.0106	***	26.48	0.0659	***	213.08
Marbling score	0.0002		0.51	0.0383	***	122.01
Scrotal circumference	0.0010	**	2.55	−0.0022		−6.87
Frame score	−0.0103	***	−25.34	0.0474	***	151.90
Dams' age	0.0170	***	42.45	−0.0050		15.67
Birth to yearling gain EPD	0.0011	***	2.78	0.0061	***	19.04
Calving ease direct EPD	0.0014	***	3.56	0.0165	***	51.89
Milk EPD	0.0003		0.65	0.0050	**	15.61
Intercept	7.8167	***	–	4.8951	***	–
Sale year fixed effects	Yes			Yes		
N	64			334		
Percent of sample (%)	16.08			83.92		
Average sale price ($/head)	2,480.39			3,126.58		
−2 Log-Likelihood	−313.10					
AIC	−223.10					
BIC	−43.75					
AICC	−211.40					
Relative entropy	0.91					

Notes: The dependent variable is the natural log of bull price adjusted to 2021-dollar values. Value ($) is the impact of a one-unit increase in the independent variable on the bull sale price. N is the number of observations in each class. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The model is estimated using PROC FMM in SAS 9.4.

difficult to characterize. Meanwhile, Class 2 includes 83.92% of the observations with 334 bulls and shared similarities with the typical cow-calf producers in the upper Midwest. The average price per head for bulls in Class 1 is $2,480.39, lower than the average price of $3,126.58 for Class 2. In Class 1, all attributes except the marbling score and milk EPD are statistically significant. The effect of attributes on the bull's sale price is much lower in Class 1 compared to Class 2. Class 1 likely consists of buyers who do not prioritize specific bull attributes but focus on buying low-priced bulls that are easy to manage. The producers in this class may also include uninformed market participants and buyers focusing on bull attributes not included in the model. The negative signs of average daily gain and frame score attributes in Class 1 suggested that producers may be selecting bulls based on herd characteristics such as lower forage and feed requirements and higher calving ease. The negative sign of the average back fat attribute is consistent with the demand for bulls with lower frame sizes. Small to medium-frame cattle require lower forage and feed resources (Barham, 2011) and can reduce calving issues, which is highly valued by producers facing labor constraints. This result is also supported by the insignificance of milk EPD, a preferred trait for operations targeting heavier calves with high nutritional demand and feed costs. Producers in this category tend to favor bulls born out of older dams, which aligns

https://doi.org/10.1017/aae.2024.28 Published online by Cambridge University Press

with their desire for proven reproductive performance and higher weaning weight traits in their herds. The emphasis on scrotal circumference is also consistent with the preference for improved reproductive efficiency. Another noticeable characteristic of Class 1 was the lower effect of calving ease direct EPD, birth to yearling gain EPD, rib-eye area, and marbling score traits on the bull's sale price. The operations in Class 1 likely represent the "value buyer" segment, including smaller, part-time operators, as highlighted in the study by Tang et al. (2023).

In Class 2, all attributes are significant at a 5% significance level, except for scrotal circumference and dam's age. The coefficients for average daily gain, rib-eye area, marbling score, frame score, birth to yearling gain EPD, calving ease direct EPD, and milk EPD attributes had the expected signs and are larger in magnitude in Class 2 than Class 1. The higher magnitude of the calving ease direct EPD signifies the importance of the calving ease to producers in this segment. Producers in Class 2 focus on growth and production weight attributes, as indicated by the significance and positive sign of average daily gain, frame score, birth to yearling gain EPD, and milk EPD attributes. The higher magnitude of the coefficients of rib-eye area and marbling score indicates that producers in Class 2 are willing to pay premiums for better carcass quality. The lack of significance of the dam's age and scrotal circumference attributes is likely due to the stronger influence of other attributes on the sale price of bulls in this class. These results suggest a clear preference among producers in Class 2 for traits associated with higher calving ease, growth, production weight, and carcass quality. These findings align with the upper Midwest cow-calf operations, selling calves post-weaning or retaining them on the farm for additional weight gain.

Given the temporal heterogeneity in producer demand for specific bull attributes (Boyer et al., 2019; Tang et al., 2020, 2023), assessing whether it affects the class membership assigned by the 2-Class FMM was essential. We analyzed the number of observations in each year and each class and performed a χ^2 test with a null of no change in proportions across years, which we failed to reject ($\chi^2 = 9.68; P - value = 0.38$). The distribution of class membership was consistent across the years in the data, suggesting that temporal heterogeneity did not influence class membership even though the producer valuation of attributes changed over time.

Conclusions and implications

The hedonic regression analysis of pooled data from the WBIA Bull Sale and Development Program showed that producers in the region are willing to pay more for traits related to higher growth, production weight, calving ease, and carcass quality. The importance of growth and production weight for cow-calf producers has been well established and is consistent with our findings on average daily gain, birth to yearling gain EPD, frame score, and milk EPD traits. Increasing pounds per cow stems naturally from calving ease or a high calving percent, which results in more pounds per cow, as does weaning or yearling weight. The increased importance of calving ease over time is also consistent with the potential for financial loss during calving. While not all cow-calf operations may benefit from superior carcass traits, buyers who focus on producing higher-quality calves and those who retain calves for weight gain would prefer these traits. Most cow-calf producers in the region may not be large enough to consider retaining ownership of calves, but buying bulls with better carcass traits provides operations with the option to build a sound genetic base, maintain the reputation as quality producers, and realize higher returns on sales through value-addition when market conditions are favorable (Tang et al., 2017). Given the beef industry's focus on carcass merit, it is poised to play a more significant role in cattle marketing.

The FMM identified two latent classes or segments, revealing heterogeneity in producer preferences. The first class of bull buyers comprised a smaller segment that prioritizes lower-priced bulls with limited emphasis on specific traits. The second, more prominent segment valued traits related to calving ease, growth, production weight, and carcass qualities. Our findings do not necessarily invalidate the presence of a distinct third segment focused primarily on superior carcass qualities, as identified by Tang et al. (2023). However, this segment may not be large enough in smaller markets, highlighting the broader relevance of regional-level analysis of heterogeneity in the cattle industry. Although temporal heterogeneity does not affect the number of buyer segments in our study, it is important to note that the marginal values assigned to specific attributes by producers change over time, emphasizing the need to evaluate industry trends continuously.

The findings of this study have several practical implications for cow-calf producers, seed stock producers, and the beef industry. Producers can benefit from investing in economically important traits relevant to their production system by selecting bulls based on their phenotype, performance, and EPDs. The estimates from the study can serve as a benchmark for producers to assess their performance against that of other regional operators. Understanding the bull attributes within each segment enhances the selection process by avoiding undesirable traits and incorporating preferred ones, ultimately leading to increased long-term profitability for operations. The WBIA can use this study to provide bull sellers with an estimate of how well their bulls performed in the auction. Seed stock producers in the region can use the information to identify the specific traits in demand and focus on incorporating them into their breeding programs. Finally, customizing future educational programs and marketing strategies for different segments can help expedite these changes and benefit the beef industry in the long term.

Data availability statement. The data that support the findings of this study are available on request from the corresponding author, Kishore Joseph. The data are not publicly available and are the property of the Wisconsin Beef Improvement Association (WBIA).

Acknowledgements. The authors would like to express their gratitude to the WBIA for providing the data for this study. Special thanks to Ms. Kimberly Van Donsel, for her valuable assistance with the data and early insights. We also thank the University of Wisconsin Platteville and Southern Illinois University Carbondale for their support of this research. Additionally, we thank the reviewers for the helpful feedback.

Author contribution. Conceptualization, methodology, analysis, and writing – Original draft: Kishore Joseph; Data – Alicia L. Prill-Adams, Kishore Joseph; Writing – Review and editing: Kishore Joseph, Dwight R. Sanders, and Jayakrishnan Nair.

Financial support. Research support from the 2021–2022 URSCA grant, the 2021-2023 Ignite Grant for Applied Research, and the 2022 travel grant from the University of Wisconsin Platteville (UW-P) is acknowledged.

Competing interests. Authors declare no known competing interest.

Declaration of AI use. The authors acknowledge using Grammarly Editor for writing and Chat-GPT-4 for coding references.

References

Barham, B. *Bull Selection and Management Guide*. Technical Bulletin MP502. University of Arkansas, 2011.

Bekkerman, A., G.W. Brester, and T.J. McDonald. "A semiparametric approach to analyzing differentiated agricultural products." *Journal of Agricultural and Applied Economics* **45**,1(2013):79–94.

Boyer, C.N., K. Campbell, A.P. Griffith, K.L. DeLong, J. Rhinehart, and D. Kirkpatrick. "Price determinants of performance-tested bulls over time." *Journal of Agricultural and Applied Economics.* **51**,02(2019):304–314.

Brimlow, J.N., and S.P. Doyle. "What do buyers value when making herd sire purchases? An analysis of the premiums paid for genetic and phenotypic differences at a bull consignment auction." *Western Economics Forum* **13**(2014):1–10.

Center for Integrated Agricultural Systems. "The Wisconsin Beef Cattle Industry: A snapshot." University of Wisconsin Madison, 2008. Internet site: https://cias.wisc.edu/wp-content/uploads/sites/194/2008/07/beefsummary1.pdf. Accessed October 30, 2023.

Chvosta, J., R.R. Rucker, and M.J. Watts. "Transaction costs and cattle marketing: the information content of seller-provided presale data at bull auctions." *American Journal of Agricultural Economics.* **83**,2(2001):286–301.

Da Silva, A.G., J.A. Musgrave, J. Nollette, A. Applegarth, and R.N. Funston. *Effect of Dam Age on Offspring Productivity*. Nebraska Beef Cattle Report, 2016.

Dhuyvetter, J. *Beef Cattle Frame Scores. Extension Bulletin AS-1091*. Fargo, ND: North Dakota State University, 1995.

Dhuyvetter, K.C., T.C. Schroeder, D.D. Simms, R.P. Bolze, and J. Geske. "Determinants of purebred beef bull price differentials." *Journal of Agricultural and Resource Economics* **21**(1996):396–410.

Elzo, M.A., R.L. Quaas, and E.J. Pollak. "Effects of age of dam on weight traits in the simmental population." *Journal of Animal Science.* **64**,4(1987):992–1001.

Felix, T.L., and T.B. Freitas. *Understanding EPDs and Genomic Testing in Beef Cattle*, Penn State Extension Report, 2023.

Jones, R., T. Turner, K.C. Dhuyvetter, and T.L. Marsh. "Estimating the economic value of specific characteristics associated with Angus bulls sold at auction." *Journal of Agricultural and Applied Economics.* **40**,1(2008):01–33.

Kessler, B.A., D.L. Pendell, and R.M. Enns. "Hedonic prices of yearling bulls: Estimating the value of pulmonary arterial pressure score." *The Professional Animal Scientist* **33**,1(2017):113–19.

Lewis, K., A. Griffith, C. Boyer., and J. Rhinehart. "Returns to Retained Ownership through Finishing for Beef Cattle Originating from Tennessee." *Selected Paper prepared for presentation at the Southern Agricultural Economics Association's 2015 Annual Meeting, Atlanta, Georgia, January 31-February 3, 2015*.

McBride, W. & K. Mathews. *The Diverse Structure and Organization of U.S. Beef Cow-Calf Farms*. Economic Information Bulletin 73. Washington, DC: USDA, 2011.

McDonald, T.J., G.W. Brester, A. Bekkerman, and J.A. Paterson. "Case study: Searching for the ultimate cow: the economic value of residual feed Intake at bull sales." *The Professional Animal Scientist* **26**,6(2010):655–60.

Pendell, D.L., and K.L. Herbel. *Differences Between High-, Medium-, and Low-Profit Cow-Calf Producers: An Analysis of 2016–2019 Kansas Farm Management Association Cow-Calf Enterprise*. Manhattan, KS: Kansas State University, Department of Agricultural Economics Extension Report, 2021.

Pindyck, R.S., and D.L. Rubinfeld. *Econometric Models and Economic Forecasts*. Boston, MA: Irwin McGraw-Hill, 1998.

SAS Institute Inc., *SAS/STAT® 15.1 User's Guide: High-Performance Procedures*. Cary, NC: SAS Institute Inc, 2018.

Tang, M., K.E. Lewis, D.M. Lambert, A.P. Griffith, and C.N. Boyer. "Beef cattle retained ownership and profitability in Tennessee." *Journal of Agricultural and Applied Economics* **49**,4(2017):571–591.

Tang, M., M.N. Thompson, C.N. Boyer, N.J.O. Widmar, J.L. Lusk, T.S. Stewart, D.L. Lofgreen, and N. Minton. "Implicit market segmentation and valuation of Angus bull attributes." *Journal of Agricultural and Resource Economics* **48**(2023):02–427.

Tang, M., N.M. Thompson, C.N. Boyer, N.J.O. Widmar, T.S. Stewart, D.L. Lofgren, and N. Minton. "Temporal changes in Angus bull attribute valuations in the midwest." *Journal of Agricultural and Resources Economics* **45**(2020):518–32.

Thompson, T., C.N. Boyer, C.C. Martinez, T.N. Rowan, and J. Rhinehart. "Valuation of genomic-enhanced expected progeny differences in bull purchasing." *Journal of Agricultural and Applied Economics* **54**,4(2022):713–722.

Vanek, J.K., M.J. Watts, and G.W. Brester. "Carcass quality and genetic selection in the beef industry." *Journal of Agricultural and Resource Economics* **33**(2008):349–363.

Wedel, M., and W.A. Kamakura. *Market Segmentation: Conceptual and Methodological Foundations*. Norwell, MA: Kluwer Academic Publishers, 2003.

Cite this article: Joseph, K., D.R. Sanders, J. Nair, and A.L. Prill-Adams (2024). "Buyer Valuation of Angus Bull Attributes in Wisconsin." *Journal of Agricultural and Applied Economics* **56**, 621–634. https://doi.org/10.1017/aae.2024.28