Journal of Agricultural and Resource Economics 45(3):518–532 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.302500

Temporal Changes in Angus Bull Attribute Valuations in the Midwest

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Past attempts to price bull attributes have relied on static marginal valuations due to cross-sectional data limitations. This analysis investigates whether bull buyers' marginal valuations of Angus bull attributes have changed over time using 17 years of bull auction data from Indiana. Results indicate statistically significant time effects on some traits (e.g., ribeye area, percentage intermuscular fat, ribeye-area expected progeny difference [EPD], and maternal-milk EPD). Not all of these effects align with prior expectations. Nonetheless, results have important implications for the beef industry in terms of signaling quality ques and incorporating proven information in the form of EPDs.

Key words: beef cattle, bull price, carcass quality, expected progeny differences (EPD), hedonic model, temporal variation

Introduction

Unlike pork and poultry, the beef industry supply chain is characterized by several disaggregated sectors: seed-stock, cow–calf, stocker/backgrounder, feedlot, and processor. The lack of coordination among these sectors makes it difficult to signal consumer preferences upstream to cattle producers. Despite attempts by the beef industry to better align the quality and consistency of beef products with consumer preferences, there remains a lack of evidence that the industry's breeding sectors (seed-stock and cow–calf) are properly incentivized to invest in genetic improvements necessary to meet these demands (Thompson, 2018). One way to evaluate the effectiveness of translation of consumer demand into producer investment in genetic improvement is to directly investigate producers' valuations of bull attributes. Bull selection is one of the most important decisions faced by cow–calf producers. Herd bulls represent half of the genetic makeup of marketable calves and are the quickest way to influence genetic progress in the beef herd. Better understanding how producers in the industry's breeding sectors value herd bull characteristics provides an important perspective into the beef industry's progress toward addressing the broader problem of aligning beef products with consumer preferences.

Bull auctions are a common mechanism for the purchase/sale of bulls, making available unique data on both sale price and detailed production information. For this reason, hedonic analyses of bull auction data have been performed by a number of researchers (e.g., Chvosta, Rucker, and Watts, 2001; Jones et al., 2008; Bekkerman, Brester, and McDonald, 2013). However, due to data

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Support for Tang was provided by a Purdue Research Foundation Research Grant. The authors also thank the Indiana Beef Evaluation Program for sharing the data for this study.

Review coordinated by Darren Hudson.

limitations, existing studies tend to focus on the average valuation of carcass quality traits at a particular point in time.

There are a variety of reasons why bull buyers' marginal valuations of some bull attributes may have changed over time, but two likely reasons for shifts in these values could be due to the introduction of grid pricing and increased acceptance of expected progeny difference (EPD) technology. First, grid pricing was introduced in the mid-1990s with the purpose of aligning the quality and consistency of beef products with consumer preferences. Growth in the market share of grid pricing has been steadily increasing as the grid premium and discount structure has slowly adjusted carcass quality market signals to incentivize marketing on a grid (Fausti et al., 2010, 2014). If this value-based marketing approach has been successful at signaling consumer preferences up the beef cattle supply chain, the marginal valuation of carcass quality characteristics (e.g., marbling and ribeye area) among the industry's breeding sectors should have changed over time to better align end products with consumer preferences. This would be reflected by increasing (decreasing) marginal valuations of carcass traits over time for traits positively (negatively) correlated with higher beef quality.

Second, the perception of information contained in EPDs may be subject to changing valuations among producers. EPDs indicate performance potential of a bull's progeny; they were initially introduced for production traits and have been further developed for carcass performance traits (Walburger, 2002; Franken et al., 2012). According to diffusion theory, time is one of the four main elements in the diffusion of innovation (Rogers, 2003). Therefore, it is hypothesized that producers may increase the value placed on EPDs for certain traits as they become more familiar with this technology and learn how to apply it. Although EPDs have been around for over 3 decades, EPD information is believed to be currently underutilized by cow–calf producers (Decker, 2018). Although the concept of learning and familiarization associated with EPDs has been previously discussed (Franken et al., 2012), the time effects of learning on valuation of EPDs are not well studied. It is also possible that the valuations of EPDs have decreased over time if producers initially overvalued the information contained in EPDs.

Researchers have sought to examine the impact of carcass-quality traits and EPDs on the price of bulls. Walburger (2002) examined and compared the roles of reproduction traits (e.g., scrotal circumferences and birth weight), average daily gain, and ribeye area in determining the price of bulls using bull sales in east-central Alberta, Canada, from 1989 to 1993 and from 1989 to 2000. Their study identified a fallen trend in importance of reproduction traits relative to average daily gain and ribeye area, which they interpreted as a sign of a shift in attribute selection in response to increasing market demand for high quality beef. Jones et al. (2008) also found that one of the carcass EPDs (i.e., ribeye area) has a significantly greater marginal effect on price than either birth-weight EPD or yearling-weight EPD. Vanek, Watts, and Brester (2008) estimated ranch-specific hedonic regressions using standardized bull auction data from four registered U.S. Red and Black Angus producers during 2005–2006. Parameter estimates were ranked and compared within each regression to decide the relative influence of bull attributes on the price of bulls. They found carcass quality traits ranked as either the first or second most important across the four regressions.

Few efforts have been made to systematically investigate the temporal change of bull attribute valuations over a continuous time frame. Boyer et al. (2019) estimated and compared yearly hedonic regressions from 2006 to 2016 to examine whether Southeast U.S. cow–calf producers' valuation of bull attributes changed over time using bull sale data from Tennessee. Year-to-year regression results offer a nonparametric approach to examining changes in the valuation of various traits. However, inconsistent influences of some bull attributes on the price of bulls over time make it difficult to identify systematic trends in the marginal valuation of bull attributes that a more parametric approach would afford. In addition, their study failed to incorporate carcass quality traits due to data limitations. Franken et al. (2012) estimated the average value of a relatively complete set of bull attributes from a pooled model using bull sale data in Missouri from 2000 to 2010. The authors mention an attempt to model time-varying parameters but ultimately rely on a "more conventional" pooled model given "no systematic trends were identified" (Franken et al., 2012). Applications of hedonic price models to other contexts have more explicitly taken up the issue of changing preferences for attributes over time, mainly in the real estate literature (e.g., Chen and Harding, 2016; Hanson, Sherrick, and Kuethe, 2018). A more systematic evaluation of potential time effects on bull attribute valuations is needed to address important industry questions, such as quality signaling and learning and familiarization associated with EPDs. Even a null result serves to inform these issues and has implications for the beef industry.

This study investigates whether producers' marginal valuations of Angus bull attributes in the Midwest have changed over time. Previous literature has largely overlooked potential temporal effects on the marginal valuations of bull attributes, and those that have considered these effects have fallen short of addressing important industry questions. Data used in this study contain a more complete set of bull attributes observed over an extended time series compared to previous research allowing investigation of potential systematic trends in producers' marginal valuations of bull attributes parametrically. Hedonic price models are estimated using 17 years of bull auction data (2002–2018) from bull auctions in the state of Indiana to investigate the hypothesized changes in producers' valuations of Angus bull attributes over time. It is important to acknowledge that our results are limited in scope by both the period available and the geography of the data used in this study. Readers should be careful not to generalize our results given that producers in other regions may have responded differently to incentives and information changes for a variety of reasons.

Study results indicate that some Angus bull attributes exhibit statistically significant changes in valuation over time for Midwest bull buyers. Specifically, bull buyer valuations of carcass traits adjusted ribeye area, ribeye-area EPD, adjusted percentage intermuscular fat, and marbling EPD and reproductive and maternal traits adjusted scrotal circumference and maternal-milk EPD show statistically significant changes over the period studied. However, not all of these effects move in the hypothesized directions. For example, the effects of time on the carcass traits show mixed directional impacts on bull values (some increasing in value and others decreasing). Nonetheless, important industry implications can be drawn from these results.

Conceptual Framework

The price of a bull is determined by the value of the characteristics and attributes it possess. Rosen (1974) set forth the theoretical foundation for the hedonic pricing model adopted in this study. Each individual bull, $Q_i\,(i=1,\ldots,n)$, possesses a bundle of characteristics or attributes $X_{ij}\,(j=1,\ldots,J)$. Collectively, the J attributes in X_{ij}, where $X_{ij}=\{X_{i1},\ldots,X_{iJ}\}$, make up Q_i. The price of bull i, P_i, can be specified as a function of its characteristics, $P_i = f(X_{ij})$. Coefficient estimates from the hedonic regression, β_j, then indicate the marginal valuation of attribute j.

Temporal variation of β_j in the hedonic model has rarely been investigated. Most existing studies applying the hedonic model to bull prices implicitly enforce the assumption of constant valuation of bull attributes over the period evaluated. Constant valuation may be reasonable in the short run when market structure is stable, especially in cases where cross-sectional data are used. That is, at any point in time, the supply of bull attributes is fixed because many bulls are available for sale at various competing auctions (Blank, Saitone, and Sexton, 2016). Therefore, prices of a particular set of bull attributes are ultimately determined by the demand for them, and the demand is largely driven by prevailing economic factors (Vestal et al., 2013).

In the case of cross-sectional time-series bull auction data, the above assumption of constant attribute valuations is violated given that changes in market factors may directly influence the valuation of certain traits, and β_j becomes the average marginal effect across the entire period evaluated, hiding potentially important time effects. For example, changes in incentives and information are likely to influence the value that producers place on certain bull attributes. Therefore, time plays an important role and needs to be internalized into the valuation of bull attributes. Expressing the marginal valuation of attribute j as a function of time t, $\beta_j(t)$, represents the marginal

Table 1. Summary Statistics of Bull Attributes (*N* = 1,705)

Variable	Mean	Std. Dev.	Min.	Max.
Sale price ($/head)[a]	2665.81	1253.59	1100.00	11000.00
Age at sale (days)	423.71	33.86	348.00	539.00
Average daily gain (lb/day)	4.06	0.40	3.02	5.63
Birth weight (lb)	79.67	9.17	49.00	117.00
Adjusted scrotal circumference (cm)[b]	36.91	2.38	32.00	48.00
Adjusted ribeye area (square inches at 12th rib)[b]	13.04	1.33	9.40	19.40
Adjusted percentage intramuscular fat (%)[b]	3.73	1.15	1.25	8.82
Birth-weight EPD (lb)[c]	1.97	1.52	−4.20	6.90
Maternal-milk EPD (lb)	24.27	5.22	7.00	41.00
Ribeye-area EPD (in^2)	0.33	0.27	−0.39	1.63
Marbling EPD[d]	0.33	0.95	−0.24	1.33

Notes: [a] Sale prices were adjusted into 2018 dollars using the producer price index by commodity for farm products: steers and heifers (U.S. Bureau of Labor Statistics, 2019).
[b] Adjusted measures of scrotal circumference, ribeye area, rib fat, and percentage intermuscular fat are all adjusted to a common age of 365 days.
[c] Expected progeny differences (EPDs) measure a bull's genetic ability to transmit a particular trait to his progeny compared to that of other bulls.
[d] Marbling EPD is measured on a numerical scale of marbling scale. A numerical score of 1 is associated with Utility and 10 is Prime Plus on the USDA quality grade scale.

valuation of attribute j at time t. In other words, bull attribute valuations are specified as a function of time to test the hypothesis of temporal variation in bull buyer valuations of bull attributes and investigate the time path of these changes.

Data

Data used in this study were provided jointly by Indiana Beef Evaluation Program (IBEP) and bull owners who subscribed their bulls for testing. The IBEP for bull testing and sale has been conducted for more than 40 years at Feldun-Purdue Ag Center in Bedford, Indiana (Indiana Beef Evaluation Program, 2019). This performance test program provides cattle producers with an opportunity to evaluate their bulls for growth performance and carcass characteristics as well as structural and breeding soundness. IBEP bull sales consist only of bulls in the upper 67% for growth performance within each respective breed or on the entire test and have also passed evaluations for good disposition as well as structural and breeding soundness. This selection criterion is in place to help improve the quality of beef cattle herd across the state of Indiana and its neighboring states. IBEP bull tests are conducted biannually in the summer and winter, where the summer test is for bulls born between May 1 and October 31 of the previous year and the winter test is for bulls born between January 1 and April 30 of that year. The bulls are allowed a 21-day pretest period before test and the test lasts 125 days. Summer-tested bulls are sold in October and winter-tested bulls are sold in April.

Data collected during the test include body weight at various ages, scrotal circumference, ultrasound scan data, and average daily gain. Bull owners are required to submit pretest information such as bull birth date, birth weight, weaning weight, and breed registration number. Expected progeny differences are obtained on each bull from their respective breed association. These data are recorded, compiled, and reported to the bull owners and disseminated to potential buyers at auction through sale catalogs. Sale data for this study span from 2002 to 2018. Bull prices are converted to 2018 dollars (U.S. Bureau of Labor Statistics, 2019). Because the majority (74%) of the bulls sold during this period were Angus, this study only considers Angus bulls. Excluding bulls that were not sold or bulls with incomplete information, 1,705 observations were available for this study. Table 1 reports summary statistics.

Methods and Procedures

Pooled Hedonic Model

Prior to estimating a model with time-varying parameters, the first step is to estimate the conventional pooled hedonic model as a baseline, where the value of each bull is estimated with a standard log-linear hedonic model:

$$\ln p_{it} = \beta_0 + \sum_{j=1}^{J} \beta_j X_{itj} + \sum_{k=1}^{K} \delta_k Z_{itk} + \varepsilon_{it}, \tag{1}$$

where $\ln p_{it}$ is the logged form of price for bull i in time t and X_{itj} contains $j = 1, \ldots, J$ simple performance measures, ultrasound information, and EPD values available to buyers in the sale catalog. Simple performance measures include age at sale, average daily gain, actual birth weight, and adjusted scrotal circumference.[1] Ultrasound measures are provided for adjusted ribeye area and adjusted percentage intermuscular fat. EPDs characterizing birth weight, maternal milk, ribeye area, and marbling are also included in X_{itj}. Z_{itk} contains variables to control for sale order, season of the sale (1 = spring, 0 = fall), and a time trend; ε_{it} is the independently and identically distributed error term; and β_0, β_j, and δ_k are parameters to be estimated.

The general pooled hedonic model is also useful for identifying the model specification used throughout the rest of the paper. That is, additional bull attributes beyond what is provided in the regressions here are available to buyers in the sale catalog. However, many of these traits are correlated and thus present potential multicollinearity problems. Similar to Boyer et al. (2019), we investigate multicollinearity using Pearson correlation coefficients and variance inflation factors for all available possible independent variables. Based on the results of this analysis, we chose a subset of relevant bull attributes to be included as independent variables in the hedonic regression models to ensure that multicollinearity is not an issue in our estimation.

Biyearly Hedonic Models

Using the general specification identified in the pooled hedonic regression in equation (1), with the exception of the time trend variable, we also estimate individual hedonic regression models for 2-year subperiods. These biyearly models (eight regressions in total) were selected over annual regressions to provide a smaller number of overall models for review and to increase the number of observations in any one regression model. The results from these models are used to nonparametrically investigate temporal changes in the bull attribute valuations over time.

Hedonic Model with Continuous Time Trend Interaction

Previous examples of empirical investigations of temporal changes in attribute valuations in a hedonic model framework are limited, with most found in the hedonic real estate literature (e.g., McMillen, 2008; Rambaldi and Rao, 2011; Fesselmeyer, Le, and Seah, 2012; Chen and Harding, 2016; Hanson, Sherrick, and Kuethe, 2018). The existing literature generally suggests two methods to estimate the change in attribute valuation over time: (i) breaking the data into discrete periods and (ii) incorporating a time trend interaction for characteristics of interest. The nature of the hedonic model favors the latter, given that splitting the data forces a subjective choice of when to break the data and occludes independent testing of an overall trend versus separate trends for

[1] Adjusted measures are adjusted to a common age of 365 days.

individual attributes. Hence, the focus of our analysis is on a hedonic model with continuous time trend interactions.[2]

The focus is then on functional form of these time trend interaction variables. Discussions of functional form in hedonic price models are well established (e.g., Halvorsen and Pollakowski, 1981; Cassel and Mendelsohn, 1985; Cropper, Deck, and McConnell, 1988) and generally rely on the Box–Cox (1964) transformation test. Based on the assumption that attribute valuations change gradually over time as producers adjust and adapt to incentives and information, the elements of β_j in equation (1) can be represented as a continuous function of time (t):

$$\beta_j(t) = b_{0j} + b_{1j}t^{(\lambda)}, \tag{2}$$

where $t^{(\lambda)}$ is the Box–Cox (1964) transformation:

$$t^{(\lambda)} = \begin{cases} \frac{t^{\lambda}-1}{\lambda}, \ if\ \lambda \neq 0 \\ \ln(t), \ if\ \lambda = 0. \end{cases} \tag{3}$$

The Box–Cox transformation embodies several common functional forms that may represent the relationship of bull attribute valuations with time, including logarithmic $(\lambda = 0)$, square root $(\lambda = 0.5)$, and linear $(\lambda = 1)$. The parameter λ can also be estimated by maximum likelihood estimation to determine the transformation that best fits the data. In addition, a quadratic form of the change in attribute valuation over time is also considered, where

$$\beta_j(t) = b_{0j} + b_{1j}t + b_{2j}t^2. \tag{4}$$

This allows the flexibility for the change in attribute valuation over time to change direction over the sample period.

Inserting equation (2) into equation (1) yields

$$\ln p_{it} = \beta_0 + \sum_{j=1}^{J} \left(b_{0j} + b_{1j}t^{(\lambda)}\right) X_{itj} + \sum_{k=1}^{K} \delta_k Z_{itk} + \varepsilon_{it}. \tag{5}$$

Equation (5) can be estimated by including a continuous time trend interaction with X_{ij}, where t represents the year of the sale, $t = 1, \ldots, 17$. In practice, only a subset of the variables in X_{ij} that are hypothesized to change with time are interacted with the time trend variable.

While the functional form of the time trend interaction is important for understanding the time path of changes in producer preferences, it is important to point out that the primary objective here is a descriptive analysis of the general trends in attribute valuations over time and not a predictive analysis of future bull buyer preferences. Hence, while it is important to consider the robustness of the functional form assumption, the ultimate functional form is not critical for gaining insights into general trends in attribute valuations.

Further, we only apply the Box–Cox transformation test to the time trend interaction variables. A similar investigation of functional form could also be applied to the baseline characteristics and even price. However, given that the focus of this manuscript is dealing with changes in attribute valuations over time, we focus our efforts on the treatment of functional form for the time trend interactions specifically and leave the treatment of functional form for the other variables for future research.

[2] Models evaluating changes in attribute valuations across discrete periods (e.g., a "Chow-like" test for the equality of parameters between discrete periods and an Oaxaca–Blinder decomposition) were performed to test robustness of our results. Results from these models were generally consistent with the results of the time trend interaction models and are available from the authors upon request.

Results

Pooled and Biyearly Hedonic Regressions

Parameter estimates from the pooled and biyearly hedonic price models are reported in Table 2. All of the independent variables in the pooled model are statistically significant and generally consistent with previous literature (Dhuyvetter et al., 1996; Walburger, 2002; Jones et al., 2008; Vanek, Watts, and Brester, 2008; Franken et al., 2012; Kessler, Pendell, and Enns, 2017; Boyer et al., 2019). Nonetheless, the marginal effects in the pooled model represent average marginal effects across the entire 17-year period and may be masking important changes in evolving bull buyer preferences over time.

Biyearly hedonic price models allow for a first glimpse at these potential changes in bull attribute valuations in a nonparametric framework. As expected, traits such as age, actual birth weight, average daily gain, and birth-weight EPD have a consistent and statistically significant impact on bull prices. However, traits such as adjusted ribeye area and maternal-milk EPD are only consistently statistically significant in the latter part of the period evaluated. Adjusted scrotal circumference is generally negative and statistically significant in the first half of the period. A number of other traits offer inconsistent effects on bull prices. Therefore, a more robust investigation of potentially changing bull buyer preferences is warranted.

Hedonic Model with Continuous Time Trend Interaction

A hedonic model with continuous time trend interactions is fitted to parametrically trace changing preferences in bull buyer valuations of bull attributes. Five functional forms of the time trend interaction were considered as part of a Box–Cox transformation test (see Table 3). The logarithmic, square root, and linear models performed similarly in terms of model fit statistics. Estimating the Box–Cox transformation that best fit the data resulted in a $\lambda = 0.85$, which resulted in parameter estimates very similar to the linear model, where $\lambda = 1$. However, model fit statistics clearly indicated that the quadratic functional form provided the best overall fit (Table 3). For this reason, the discussion of results below will focus on the results from the quadratic time trend interaction model unless noted otherwise.

Before looking more closely at the traits that exhibit statistically significant time trends, it is important to first take note of the traits that were not interacted with the time trend but still have significant impacts on bull prices. Traits such as age, average daily gain, birth weight, and birth-weight EPD consistently and significantly influenced bull prices in the expected directions but did not exhibit significant changes over time (Table 3). This result is not surprising given the fundamental importance of these particular traits as they relate to the common objectives of producing low birth-weight calves with high growth potential.

Traits that did exhibit significant changes over time can be divided into two groups: (i) carcass characteristics and (ii) reproductive and maternal traits. Each of the carcass characteristics exhibited evidence of statistically significant changes in bull buyer valuations over the period evaluated. Tracing out the quadratic form of these marginal effects over time can be useful for visualizing these changes. The adjusted ribeye-area marginal effect was positive throughout the period and convex with respect to time (Figure 1). That is, it is decreasing during the early subperiod and then increasing steadily in recent years. This sort of effect can be corroborated by comparing this result with the biyearly regression results (Table 2). It is also important to contrast this result with the marginal effect for ribeye-area EPD, which was concave over the period evaluated (Figure 1).

The adjusted percentage intermuscular fat marginal effect also exhibited a concave relationship with time, increasing steadily in the early part of the study period before waning in recent years (Figure 2). The marbling EPD marginal effect did not exhibit a statistically significant interaction with time in the quadratic model. However, evidence from the models with functional forms that

Table 2. Baseline Pooled Hedonic Price Model for All Years (2002–2018) and Biyearly Hedonic Price Models

Variable	Pooled (2002–2018)	Years 2002–2003	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013	2014–2015	2016–2018[a]
Intercept	4.487***	4.495***	6.726***	5.629***	6.343***	6.576***	6.181***	6.125***	6.216***
Age	0.003***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
Average daily gain	0.133***	0.223***	0.240***	0.138***	0.159***	0.150**	0.107**	0.234***	0.044
Birth weight	−0.005***	−0.003	−0.005***	−0.008***	−0.010***	−0.005**	−0.002	−0.007***	−0.004**
Adjusted scrotal circumference	0.011***	−0.002	−0.020**	0.017**	−0.01	0.011	0.003	0.001	0.006
Adjusted ribeye area	0.057***	0.090***	0.016	0.025	0.037**	−0.046**	0.038**	0.038**	0.045***
Adjusted percentage intermuscular fat	0.031***	−0.005	0.04	0.03	0.075***	0.013	0.033*	0.043**	0.01
Birth-weight EPD[b]	−0.065***	−0.049***	−0.067***	−0.055***	−0.066***	−0.077***	−0.069***	−0.052***	−0.075***
Maternal-milk EPD	0.010***	0.003	0.004	0.003	0.007	0.01	0.012***	0.009**	0.011***
Ribeye-area EPD	0.073*	−0.397***	0.159	0.274***	0.094	0.502***	0.061	−0.061	−0.057
Marbling EPD	0.103**	0.446**	−0.18	−0.05	−0.290**	0.012	−0.039	−0.02	−0.04
Sale order	−0.004***	−0.003***	−0.004***	−0.004***	−0.005***	−0.007***	−0.006***	−0.006***	−0.005***
Sale season	0.225***	0.034	0.101*	0.427***	0.455***	0.431***	0.153***	0.409***	0.396***
Sale year	0.055***								
No. of obs.	1,705	227	215	247	206	189	188	198	235

Notes: Dependent variable in all regressions is log of bull sale prices adjusted to 2018 dollars. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.
[a] Observations from 2016, 2017, and the 2018 spring sale are included in the 2016–2018 biyearly model.
[b] Expected progeny differences (EPDs) measure a bull's genetic ability to transmit a particular trait to his progeny compared to that of other bulls.

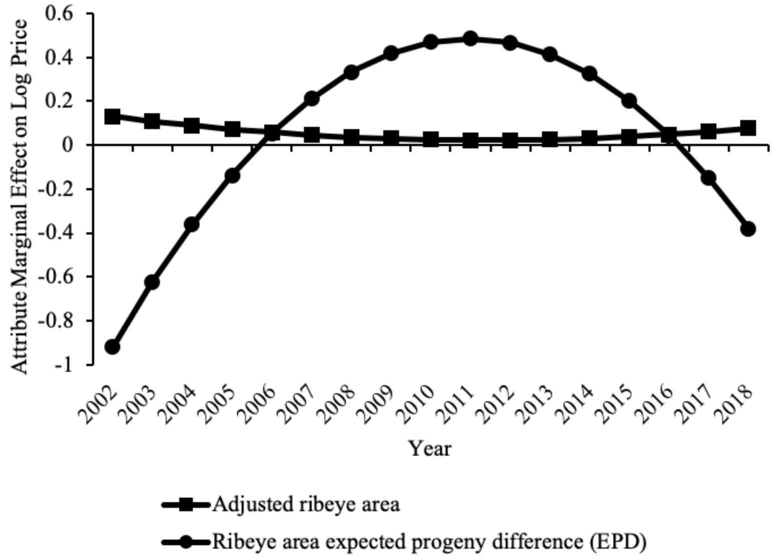

Figure 1. Bull Attribute Marginal Effects across Time for Adjusted Ribeye Area and Ribeye Area Expected Progeny Difference (EPD)

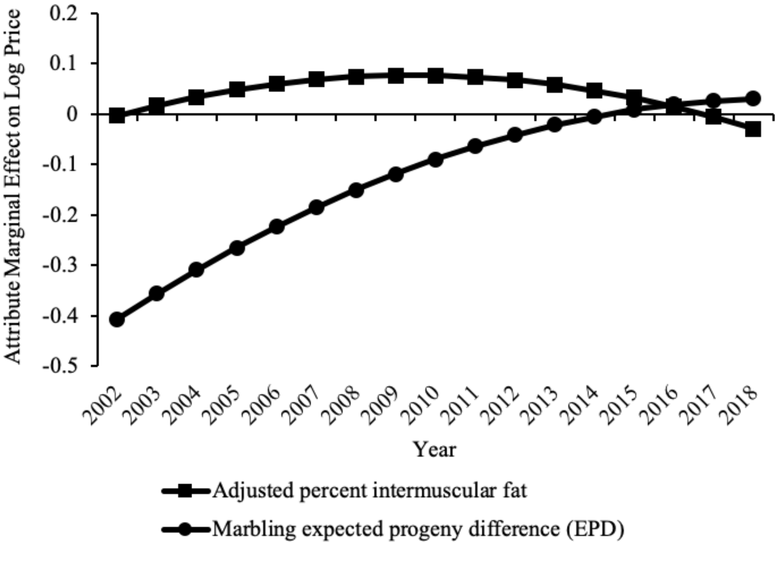

Figure 2. Bull Attribute Marginal Effects across Time for Adjusted Percentage Intermuscular Fat and Marbling Area Expected Progeny Difference (EPD)

did not impose sign reversal (i.e., logarithmic, square root, and linear) did show evidence that the marbling EPD marginal effect did significantly change over time (Table 3). Hence, although the quadratic form had the best fit overall, it does not appear to be the best fit for all of the traits evaluated. In particular, the marginal effect of the marbling EPD on bull price appears to be to have been increasing at a decreasing rate over the period studied, without actually turning down in recent years.

The second group of variables that exhibited statistically significant changes in producer attribute valuations over the period is reproductive and maternal characteristics. Adjusted scrotal

Table 3. Hedonic Price Models with Natural Log, Square Root, Linear, Box–Cox, and Quadratic Functional Forms of the Time Trend Interaction (N = 1,705)

Variable	Natural Log Time Trend Interaction	Square Root Time Trend Interaction	Linear Time Trend Interaction	Box–Cox Time Trend Interaction	Quadratic Time Trend Interaction
Intercept	4.8447***	5.1905***	5.7657***	5.7856***	5.7349***
Age	0.0024***	0.0024***	0.0024***	0.0024***	0.0023***
Average daily gain	0.1384***	0.1373***	0.1332***	0.1343***	0.1151***
Birth weight	−0.0045***	−0.0045***	−0.0047***	−0.0046***	−0.0042***
Adjusted scrotal circumference	−0.0169**	−0.0286***	−0.0244***	−0.0218***	−0.0314***
Adjusted ribeye area	0.1068***	0.0913***	0.0555***	0.0577***	0.1551***
Adjusted percentage intermuscular fat	0.1441***	0.1637***	0.1284***	0.1138***	−0.0254
Birth-weight EPD	−0.0675***	−0.0674***	−0.0654***	−0.0662***	−0.0705***
Maternal-milk EPD	−0.0102*	−0.0142**	−0.0033	−0.0045	−0.0079
Ribeye-area EPD	−0.1221	0.0618	0.2937***	0.2118*	−1.2494***
Marbling EPD	−0.4377*	−0.4945**	−0.1598	−0.2144	−0.4592*
Adjusted scrotal circumference × time trend	0.0133***	0.0131***	0.0036***	0.0048***	0.0051**
Adjusted ribeye area × time trend	−0.0261***	−0.0133*	−0.0004	−0.001	−0.0254***
Adjusted percentage intermuscular fat × time trend	−0.0490***	−0.0408***	−0.0092***	−0.0109***	0.0243**
Maternal-milk EPD × time trend	0.0091***	0.0076***	0.0012***	0.0019**	0.0027*
Ribeye-area EPD × time trend	0.1058	0.0181	−0.0180**	−0.0131	0.3482***
Marbling EPD × time trend	0.2242**	0.1721***	0.0200*	0.0347	0.0549
Adjusted scrotal circumference × time trend squared					−0.0001
Adjusted ribeye area × time trend squared					0.0012***
Adjusted percentage intermuscular fat × time trend squared					−0.0014***
Maternal-milk EPD × time trend squared					−0.0001
Ribeye-area EPD × time trend squared					−0.0175***
Marbling EPD × time trend squared					−0.0015
Sale order	−0.0041***	−0.0042***	−0.0044***	−0.0044***	−0.0046***
Sale season	0.2377***	0.2445***	0.2552***	0.2540***	0.2760***
Sale year	0.0205**	−0.0116	−0.0652**	−0.0681***	−0.0179
λ				0.8508***	
-2 LL	798.3	789.7	786.1	782.3	598.2
AIC	840.3	831.7	828.1	826.3	652.2
AICC	840.9	832.2	828.7	826.9	653.1
BIC	954.6	945.9	942.4	946	799.1

Notes: The dependent variable in all regressions is log of bull sale prices adjusted to 2018 dollars. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.

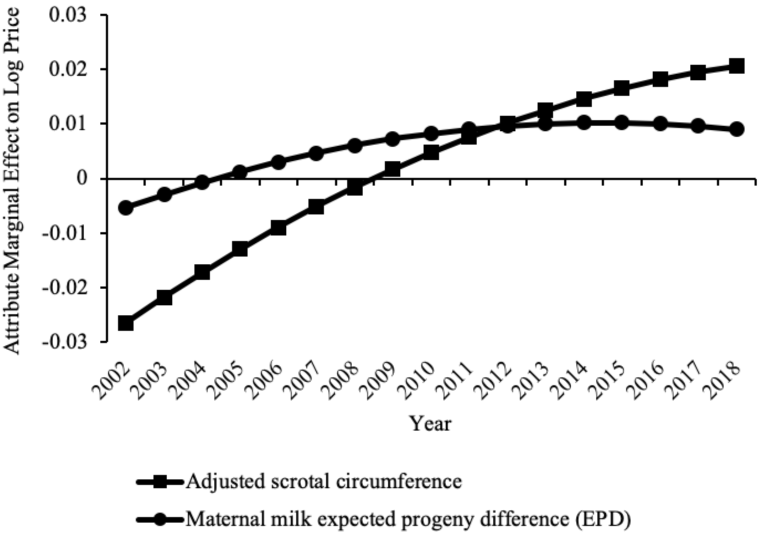

Figure 3. Bull Attribute Marginal Effects across Time for Adjusted Scrotal Circumference and Maternal Milk Expected Progeny Difference (EPD)

circumference is a direct measure of reproductive performance and is often positively associated with bull prices (Walburger, 2002). However, our results indicate that bull buyers in our sample significantly reduced the price they were willing to pay for bulls with larger scrotal circumference in the early part of the period. While it is not clear why this was the case, our results indicate that producers' marginal valuation of this trait has increased steadily over the period (Figure 3); at present, adjusted scrotal circumference does not appear to significantly affect bull prices.

Finally, maternal-milk EPD is a measure of the ability of a bull's female offspring to produce milk for her own offspring, as measured by the difference in average weaning weight between a bull's female progeny and the daughters of other sires. While there are a number of factors a producer might consider when thinking about producing replacement females, maternal-milk EPD is one component of mothering ability. Our results indicate maternal milk was largely unimportant for explaining bull prices during the early part of the period but has increased steadily and currently has a positive and significant effect on bull prices (Figure 3).

Discussion

Results from these models clearly indicate that bull buyer preferences for some traits have evolved over the past nearly 2 decades, as hypothesized. However, the directions and functional forms of these changes did not necessarily align with *a priori* expectations.

Changing Valuation of Carcass Traits

The combined results of the carcass quality trait interactions with time offer a mixed view of bull buyers' response to incentives produced by grid pricing to invest in carcass quality traits. It appears as though bull buyers are placing positive value on ribeye area, which is a key factor in determining yield grade, a key component of the grid pricing premium and discount structure. However, the two measures of ribeye area—ultrasound and EPD—have both increased and decreased at various points during the period evaluated. As for intermuscular fat/marbling, the other major component of grid pricing premiums and discounts, our results indicate that bull buyers' marginal valuations of ultrasound measures of adjusted percentage intermuscular fat have waned in recent years to a point of indifference, following steady growth early in the sample period. Marginal valuations of the marbling EPD have generally increased over the period evaluated. However, it is important to point out that this increase has been from a deleterious effect on bull prices in the early part of the sample period to not significantly different from 0 in recent years. Therefore, our results fail to offer conclusive evidence as to whether incentives provided by grid pricing are clearly signaling bull buyers in our sample to invest in improvements in carcass quality characteristics.

When considering this result, a few important points should be considered. It is important to point out that the period used here does not include the introduction of grid pricing, which happened in the mid-1990s. Hence, our period starts nearly 7 years after the initial introduction of grid pricing. Therefore, it is possible that some adjustments to bull buyer valuations of these carcass traits took place prior to what is measured here. However, our results identify statistically significant time effects over the period evaluated, suggesting continued adjustment to the incentives provided by grid pricing. Further, research has shown that growth in the market share of grid pricing has been slow and steady as the grid premium and discount structure has slowly adjusted carcass quality market signals to incentivize marketing on a grid (Fausti et al., 2010, 2014). Recent trends have seen the proportion of fed cattle marketed on negotiated grids decline slightly and those marketed via formula pricing appears to have stabilized in recent years (Schroeder, Tonsor, and Coffey, 2019).

The other point to consider here is the underlying incentive for cow–calf producers to invest in quality traits given the structure of the beef industry. The typical cow–calf producer has little incentive to invest in bulls that produce calves with higher carcass quality given that the majority of feeder cattle in the United States are sold via auctions in which sellers are paid by weight and information is sparse. Some previous studies, such as Vanek, Watts, and Brester (2008), have indicated that statistically significant carcass trait effects on bull prices are sufficient evidence to support cow–calf producer responsiveness to grid pricing signals. We are less enthusiastic about this point in light of the results from our analysis indicating potentially complex time effects of these traits on bull prices.

It is also important to point out that the data evaluated by Vanek, Watts, and Brester (2008) are from bull auctions at four large commercial seed-stock ranches. The buyers at those sales are likely to be larger, commercial cow–calf producers who are more likely to be involved in actively seeking value-added marketing arrangements such as private treaty sales or retained ownership. However, according to the 2017 U.S. Census of Agriculture, nearly half of all U.S. beef cattle are raised on farms with less than 100 head (U.S. Department of Agriculture, 2019). It is these smaller operations that likely represent the majority of buyers in our sample from IBEP sales, which may explain why our results are mixed with respect to producer valuations of carcass traits. Hence, we agree with Vanek, Watts, and Brester's assertion that the evidence of significant carcass trait effects on bull prices may be the result of a segment of the beef industry's breeding sector concentrating on improving carcass quality. While we are unable speak to this issue directly in this research, it is important for the industry to consider how current price signals are being transmitted to various industry segments and whether this is meeting industry objectives for improved quality and consistency of beef products.

Changing Valuation of Expected Progeny Differences

Our results do not support the hypothesis of consistently increasing emphasis on EPD measures as a result of learning and familiarization associated with the technology. Instead, results are mixed, with EPD measures for some traits significantly influencing bull prices but not changing over the period (birth-weight EPD), others increasing (maternal-milk EPD and marbling EPD), and still others increasing and then decreasing (ribeye-area EPD).

EPDs for some traits were introduced more than 10 years prior to the start of our period. So again, some learning and familiarization could have a happened prior to the start of our analysis, and our results represent a period that has already reached stabilization of bull buyer valuation of these traits. For example, the birth-weight EPD consistently and significantly influenced bull prices. This is not surprising given that the birth weight was one of the first traits for which EPDs were introduced and birth weight has been and will continue to be a fundamental trait used in bull selection.

For the EPDs that did exhibit statistically significant changes over the period evaluated, the maternal-milk EPD followed the hypothesized path of slow, steady improvement over time. However, it is difficult to distinguish how much of this increase in value came from learning and familiarization with EPD information and how much was from an increase in interest in this trait, maybe due to producers in the study region increasing their propensity to produce their own replacement heifers increasing the value of maternal milk to them as cow–calf producers. It is also important to point out that Decker (2018) identified maternal milk as a trait that producers should be careful about selecting for optimal performance given that these cattle often fail to perform at their genetic potential and often have increased maintenance requirements.

The two carcass EPDs (ribeye-area EPD and marbling EPD) offer little conclusive evidence of producer confidence in EPD technology for carcass traits. It is hard not to notice the inverse relationship between the ribeye-area EPD and the adjusted ribeye area measured by ultrasound (Figure 1). Keeping in mind that these are two measures of the same underlying trait, it is hard not to speculate about this relationship. Anecdotally, it seems as though bull buyers may have been substituting between adjusted ribeye area measured by ultrasound and the ribeye-area EPD, with a recent trend toward placing more value on adjusted ribeye area measured by ultrasound and deterioration of bull buyers' attitudes toward EPD measures of ribeye area.

In light of these results, it is important to point out that bull buyer perceptions of EPDs are tied to particular traits. That is, just because the EPD for one trait wanes in terms of its influence on what bull buyers are willing to pay for bulls, EPDs characterizing other traits, as indicated in our results, may play an important role in bull selection. Therefore, in response to Decker's (2018) point that EPD technology is underutilized by producers, our results suggest that more research is needed to understand which traits producers are using EPDs for, which traits they are not, and why. While our research is able to shed light on this issue, additional research is needed to answer these questions to improve the technology and the way that it is communicated to producers. Decker believes that this is critical to a more profitable and sustainable beef industry.

Conclusion

The objective of this paper was to investigate if Midwest bull buyers' marginal valuations of Angus bull attributes have changed over time using 17 years of bull auction data from the state of Indiana. Results indicate that bull buyers exhibit statistically significant changes in their valuation of several bull attributes over the period, including carcass traits ribeye area, ribeye-area EPD, and marbling EPD as well as reproductive and maternal traits for scrotal circumference and maternal-milk EPD. However, the directions and functional forms of these changes did not necessarily align with *a priori* expectations. Trends in carcass quality trait impacts on bull values were mixed across the period, with some increasing and others decreasing. Hence, we conclude that while there is some evidence of quality signals from grid pricing being received by bull buyers, these signals are not uniformly implemented and may be waning if these producers are not being rewarded for these investments. This is an issue that the beef industry should take very seriously in terms of providing an incentive structure that efficiently signals quality cues throughout a disaggregated supply chain. We also find a mixed effect of time on bull buyer marginal valuation of EPDs. In practice, it turned out to be very difficult to differentiate between learning and familiarization associated with EPDs and actual demand for particular traits. Nonetheless, EPDs are a proven technology, and overcoming communication and implementation barriers could improve the profitability and sustainability of beef production.

[First submitted October 2019; accepted for publication February 2020.]

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