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Purebred Nellore Prices in Brazil: Morphological, Genetic, Physical, and Market Factors in Auctions

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The Nellore breed is the cornerstone of Brazil's successful beef production. However, Nellore seedstock pricing has yet to be understood. We performed a hedonic analysis under a hierarchical model to explore how physical, morphological, genetic, and market factors affect the prices of purebred animals sold at auctions. The findings indicated that visual scores, expected progeny differences, farm reputation, and auction type explain variations in prices. In addition, the morphological index brought higher premiums than the genetic index. The results have implications for farmers, genetic improvement programs, and policymakers as they indicate relevant factors in the seedstock cattle price formation process.

Key words: decision-making, demand, farm management, finance, hedonic model, hierarchical model, production

Introduction

Brazil is a crucial player in the world beef market (Calil and Ribera, 2019): In 2017, it was the world's second-leading producer and exporter and third-largest consumer (US Department of Agriculture, 2018). In 2016, the meat supply chain accounted for 6% of Brazilian gross domestic product (GDP) and 30% of agribusiness GDP (Centro de Estudos Avançados em Economia Aplicada, 2017). Brazil's competitiveness is rooted in the success of the Nellore breed—which accounts for over 80% of Brazilian beef cattle—and the country's extensive grasslands (Rosa and Menezes, 2016). Although the country is relevant in the international beef market, surprisingly few studies have examined Brazilian livestock prices.

Researchers have long used hedonic models to examine how physical, market, regional, temporal characteristics affect cattle prices, particularly in US livestock auctions. The majority of the studies address feeder cattle (Buccola, 1980; Faminow and Gum, 1986; Schroeder et al., 1988; Bailey and Peterson, 1991; Williams et al., 2012; Zimmerman et al., 2012; Schulz, Dhuyvetter, and Doran, 2015; Mallory et al., 2016; Blank, Saitone, and Sexton, 2016), but researches have also scrutinized cow–calf pairs (Parcell, Schroeder, and Hiner, 1995), cull cows (Mintert et al., 1990), bred heifers (Parcell et al., 2010), bred cows (Mitchell, Peel, and Brorsen, 2018), and purebred bulls.

Relatively few projects have studied purebred bull prices. Dhuyvetter et al. (1996) use a hedonic model to investigate physical, market, and genetic characteristics in seven breeds in Kansas auctions. Chvosta, Rucker, and Watts (2001) examine market, performance, and genetic attributes of Angus cattle in Nebraska, South Dakota, and Montana auctions using a hedonic model. To evaluate the economic value of Angus seedstock traits, Vanek, Watts, and Brester (2008) use data from four

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US ranches and Jones et al. (2008) use data from 11 US states. Vestal et al. (2013) explore Angus performance and genetic features in Oklahoma auctions, combining revealed and stated preferences in a hedonic model. All of these studies analyze breeds derived from European stocks, adapted to temperate climates. Less research has investigated livestock originated from Indian stocks, suitable to a tropical environment (i.e., hot and arid climates). Brahman, Nellore, and Guzerat are examples of these breeds (zebu breeds) characterized by a hump on their backs (Garrick and Ruvinsky, 2014). Brahman is an essential breed in southern US beef production. Although some research investigates Brahmans' influence in feeder cattle prices differentials (Williams et al., 2012; Zimmerman et al., 2012; Mallory et al., 2016), no investigation has examined purebred animals from this group.

This research uses a unique dataset from Brazilian cattle auctions with 25 attributes for each Nellore seedstock lot. Given the lack of knowledge about zebu breed price determinants and prompted by the studies mentioned above, our research addresses physical, morphological, genetic, and market factors that influence the price of Nellore purebred bulls sold at auctions in Brazil. Further, contrasting the implicit prices of US Angus and Brazilian Nellore attributes contributes insights about livestock production priorities in both markets.

Studying seedstock farms is relevant to the beef sector. Purebred farms drive genetic improvements through selective breeding and supplying bulls to the market, especially in auctions. Genetic improvements are an essential component of beef farm profitability since they influence yearling weight, carcass weight, cow weight, calving ease, heifer pregnancy, marbling, and other performance measures. As a result, a commercial farmer can anticipate better efficiency once the sire of his choice passes these desirable features to its offspring. Thus, seedstock distributes the desired results throughout the production system.

In the selective breeding process, Brazilian seedstock farmers have two indices at their disposal: EPMURAS and MGTe. The EPMURAS morphological index, constructed by BrasilcomZ (2018b), sums body structure, precocity, muscling, prepuce, conformation, soundness of feet and legs, and reproductive soundness scores. The National Association of Breeders and Researchers (Associação Nacional de Criadores e Pesquisadores, ANCP) developed the Economic Total Genetic Merit (MGTe) index, a weighted average of genetic attributes such as expected progeny differences (EPD) for precocity, maternal ability, pre- and post-weaning growth, fertility, stayability, and carcass (Associação Nacional de Criadores e Pesquisadores, 2018). Findings suggest higher premiums for the EPMURAS index than for the MGTe index.

We compare the weights of these indices constructed by animal scientists with the marginal value of weights derived from our hedonic model. The results point to the valuation of characteristics related to precocity and functional biotype. The marginal value of each attribute can play a fundamental role in establishing the characteristics that will be privileged during the selective breeding process. Moreover, the rancher can use these marginal values to price the remaining animals not traded in the auction. Further, generating and maintaining a database to construct these indexes is costly, so it is necessary to understand its usefulness.

We determine premiums and discounts for some market characteristics. Adding to work by Chvosta, Rucker, and Watts (2001) and Jones et al. (2008), we investigate farm reputation (brand). Our database allows us to compare auctions broadcast live with bids collected both on the premises and by phone and auctions broadcast with videos of lots recorded with bids collected only by phone. The former is more costly than the latter because, in general, when bidders are physically present in the event, the farmer has additional costs such as labor, food, and drinks. Therefore, understanding the lot price differences between the two auction types allows producers to better evaluate the two alternatives. The results not only contribute to ranchers' decisions about how to market their animals but also extend the research that found no structural price differences between traditional and satellite video auctions (Bailey and Peterson, 1991).

The results provide relevant information for both buyers and sellers. Buyers can use attribute values as a benchmark to decide whether to buy a bull. Sellers can understand purchasers' preferences for traits and, consequently, strategically decide which ones to foster in their herds.

Nellore Purebred Model

Physical, morphological, and genetic characteristics make Nellore purebred bulls a heterogeneous product. Following Ladd (1978), the literature considers the price paid for such goods as the sum of the monetary value of the product's characteristics. The hedonic method is a well-established approach to assess the value of traits and their effects on sale prices. Seminal work by Lancaster (1966), Rosen (1974), and Ladd and Martin (1976) provides a theoretical hedonic price framework to investigate livestock price determinants.

Nellore purebred bull prices reflect supply and demand in a specific market—in this case, an auction—and point in time. In each auction, the number of lots offered is fixed; in the short run, therefore, the supply function is inelastic, and the demand function varies only by the value of different lot characteristics (Faminow and Gum, 1986). The benefit of using the hedonic approach is that the framework captures the value of distinct lot characteristics. As a result, researchers have employed the hedonic method to model either commercial cattle (e.g., Schroeder et al., 1988; Williams et al., 2012; Zimmerman et al., 2012; Schulz, Dhuyvetter, and Doran, 2015; Mallory et al., 2016) or purebred herd (e.g., Dhuyvetter et al., 1996; Chvosta, Rucker, and Watts, 2001; Jones et al., 2008; Vanek, Watts, and Brester, 2008; Vestal et al., 2013; Mitchell, Peel, and Brorsen, 2018) prices as a function of market, physical, morphological, and genetic traits.

Guided by previous literature on livestock price determinants, especially the one about seedstock, our conceptual model splits lot characteristics into four categories: physical (P), morphological (MP), genetic (G), and market (M). The Nellore purebred model can be generally written as

$$Price_{it} = \sum_k a_{ikt} P_{ikt} + \sum_l b_{ilt} MP_{ilt} + \sum_m c_{imt} G_{imt} + \sum_h d_{ht} M_{ht}, \tag{1}$$

where i is the individual lot sold at time t; k, l, and m are specific physical, morphological, and genetic traits, respectively; h is a market factor; a, b, and c are the marginal values of purebred Nellore traits k, l, and m, respectively; and d is the marginal effect of market factor h (adapted from Schroeder et al., 1988). According to equation (1), the price of each lot corresponds to the sum of the marginal implicit values of each trait multiplied by the amount of the variable (Ladd and Martin, 1976; Schroeder et al., 1988).

Implementing a similar approach to those used by Mitchell, Peel, and Brorsen (2018) and Williams et al. (2012), we estimate two hedonic empirical models. The first works with aggregate morphological and genetic indexes in addition to multiple physical and market characteristics. The second model uses multiple morphological, genetic, physical, and market attributes, allowing us to compare the component weights in indices constructed by animal scientists with the marginal value obtained from the second model. Both hedonic models are estimated with hierarchical mixed-effect structures. Auction location is treated as a random effect, and all other variables are considered fixed effects. Model 1 can be rewritten as

$$\begin{aligned} Log_Price = & \beta_0 + \sum_{j=3}^{5} \beta_{1j} EPMURAS_{ij} + \sum_{j=2}^{5} \beta_{2j} MGTe_{ij} + \sum_{j=1}^{10} \beta_{3j} Wt_{ij} + \beta_{4j} SC_i \\ & + \sum_{j=1}^{2} \beta_{5j} Age_{ij} + \sum_{j=2013}^{2017} \beta_{6j} Year_{ij} + \sum_{j=1}^{7} \beta_{7j} Farm\ R_{ij} + \sum_{j=1}^{5} \beta_{8j} LotS_i \\ & + \beta_{9j} LotN_i + \sum_{j=1}^{2} \beta_{10j} AucT_{ij} + \mu_{s(i)} + \varepsilon_i, \end{aligned} \tag{2}$$

where i denotes each sale lot observation, $\mu_{s(i)}$ is the random effect of each auction location, and ε_i is the random error term for each lot. The EPMURAS and MGTe indices are presented in the

sale catalog with a star classification ranging from 2 to 5. Each of these indices represents a dummy variable that captures the star categories. Scrotal circumference is a continuous variable, as in Vestal et al. (2013). Table 1 describes the variables.

We assign indicator variables for weight and age since they may not have a linear effect on price. Some investigations have tested the linear and quadratic forms of these variables and observed nonlinear relations with price (Jones et al., 2008; Williams et al., 2012; Zimmerman et al., 2012; Schulz, Dhuyvetter, and Doran, 2015; Mallory et al., 2016). Weight is divided into 10 categories of 100 pounds, as suggested by Mitchell, Peel, and Brorsen (2018). Age has two classes: above and below 27 months. The Brazilian breeding season generally occurs from October to February. Our database makes it clear that the lots sold at auction come from breeding stations 2 or 3 years ago. The age dummy captures this pattern.

Year, lot size, and farm reputation are categorical variables. Our lot size ranges from 1 to 5. Other researchers have used a continuous variable for lot size, but their range is considerably larger (Williams et al., 2012; Zimmerman et al., 2012; Schulz, Dhuyvetter, and Doran, 2015; Mallory et al., 2016). For example, Mallory et al. (2016) use a range of 1–315 for lot size. The purebred bull literature only considers individual lots (Dhuyvetter et al., 1996; Jones et al., 2008; Vanek, Watts, and Brester, 2008; Vestal et al., 2013). Farm reputation is a categorical variable for the seven seller names/brands that appear in the sales catalog. Schulz, Dhuyvetter, and Doran (2015) work with 190 sellers, while for Williams et al. (2012), reputation is the seller announcement (or lack thereof).

Lot number is a proxy for sale order because the lots do not necessarily enter in the expected order. Although all auctions were broadcast via satellite and collected bids countrywide, some had physical animals and bidders present during the event, while others did not have a physical event. Auction type is a binary variable that captures these two distinct sales features. Auction place is a categorical variable that corresponds with cattle location during the auction and where they were sent from.

Model 2 differs from Model 1 on morphological and genetic variables. Rather than estimating the impact of the indices, we estimate the impact of the index components:

$$
\begin{aligned}
\log_{Price_i} = {} & \beta_0 + \beta_{1j}E_i + \beta_{2j}P_i + \beta_{3j}M_i + \beta_{4j}U_i + \beta_{5j}R_i + \beta_{6j}A_i + \beta_{7j}S_i \\
& + \beta_{8j}MP120_i + \beta_{9j}DP210_i + \beta_{10j}DP450_i + \beta_{11j}DPE365_i \\
& + \beta_{12j}DPE4500_i + \beta_{13j}DSTAY_i + \beta_{14j}D3P_i + \sum_{j=1}^{10}\beta_{15j}Wt_{ij} + \beta_{16j}SC_i \\
& + \sum_{j=1}^{2}\beta_{17j}Age_{ij} + \sum_{j=2013}^{2017}\beta_{18j}Year_{ij} + \sum_{j=1}^{7}\beta_{19j}FarmR_{ij} + \sum_{j=1}^{5}\beta_{20j}LotS_i \\
& + \beta_{21j}LotN_i + \sum_{j=1}^{2}\beta_{22j}AucT_{ij} + \mu_{S(i)} + \varepsilon_i.
\end{aligned} \tag{3}
$$

Both hedonic models are estimated with maximum likelihood using the MIXED procedure in STATA. The robust standard errors (Huber–White estimators) are estimated with the "robust" command to control for heteroskedasticity. Multicollinearity was tested in the models using the variation inflation factor (VIF).[1] Farm categories F and G presented values in disagreement with the standard threshold of 10. The baseline lot is EPMURAS regular, MGTe regular, weight of 1,501–1,600 lb, over 27 months of age, lot size of two head, year 2013, sold by Farm A in a virtual auction.

[1] STATA mixed-model performance does not support a VIF test. Instead, we run ordinary least squares (OLS) regressions for both models and performed the VIF test.

Table 1. Definition of Variables Used in the Purebred Nellore Hedonic Model

Variable	Definition
$ln(Price)_i$	Natural log of inflation-adjusted prices
Physical characteristics	
Age_{ij}	Binary variables for age
	$j = 1, 2$, where $1 \leq 27$ months and $2 > 27$ months. Base: > 27
Wt_{ij}	Binary variables for weight
	$j = 1, \ldots, 10$, where 1 < 1,200, 2 = 1,201–1,300, 3 = 1,301–1,400, 4 = 1,401–1,500, 5 = 1,501–1,600, 6 = 1,601–1,700, 7 = 1,701-1,800, 8 = 1,801-1900, 9 = 1,901–2,000, and $10 > 2,000$. Base: 1,501–1,600
SC_i	Scrotal circumference (in centimeters)
Morphological characteristics	
E_{ij}	Structure quality index, $j = 3, 4, 5, 6$
P_{ij}	Precocity quality index, $j = 3, 4, 5, 6$
M_{ij}	Muscling quality index, $j = 3, 4, 5, 6$
U_{ij}	Prepuce quality index, $j = 1, 2$
R_{ij}	Conformation quality index, $j = 2, 3, 5$
A_{ij}	Soundness of feet and legs quality index, $j = 2, 3, 5$
S_{ij}	Reproductive soundness quality, $j = 2, 3, 5$
$EPMURAS_{ij}$	Binary variables for EPMURAS morphological quality index score
	$j = 3, 4, 5$, where 3 = 25–28 (good), 4 = 29–31 (very good), 5 = 32–34 (excellent). Base: 3 (good)
Genetic characteristics	
MGT_{ij}	Binary variables for total genetic merit (MGT) index
	j=2,...,5, where 2 = 31%–50% (regular), 3 = 16%–30% (good), 4 = 6%–15% (very good), 5 = 0.1%–5% (excellent). Base: 4 (very good)
$MP120_i$	Expected progeny differences (EPD) predictor of maternal body weight at 120 days of age (percentile)
$DP210_i$	EPD predictor of body weight at 210 days of age (percentile)
$DP450_i$	EPD predictor of body weight at 450 days of age (percentile)
$DPE365_i$	EPD predictor of scrotal circumference at 365 days of age (percentile)
$DPE450_i$	EPD predictor of scrotal circumference at 450 days of age (percentile)
$DSTAY_i$	EPD predictor of stayability (percentile)
$D3P_i$	EPD predictor of probability of precocious calving (percentile)
Marketing factors	
$Year_{ij}$	Year
	j=2013,...,2017. Base: 2013
$FarmR_{ij}$	Binary variables for farm reputation
	$j = 1, \ldots, 7$, where 1 = Farm A, 2 = Farm B, ..., 7 = Farm G. Base: Farm D
$LotS_{ij}$	Number of heads in a lot (head)
	$j = 1, \ldots, 5$
$LotN_i$	Lot number (a proxy for order)
$AucT_{ij}$	Binary variables for auction type
	$j = 1, 2$, where 1 = virtual; 2 = virtual and physical
LOC_{ij}	Binary variables for location
	$j = 1, \ldots, 4$, where 1 = Barra do Garca, 2 = Barreiras, 3 = Jau, 4 = Uberaba. Base: Barra do Garca

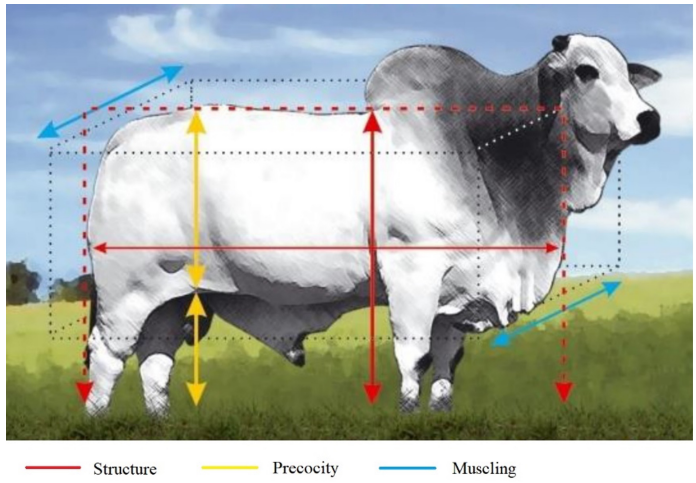

Figure 1. Morphological Variables: Structure, Precocity, and Muscling

Source: Adapted from BrasilcomZ (2018a).

Data

Table 2 reports summary statistics for the cross-sectional data, which were collected in 16 auctions in four Brazilian locations from 2013 to 2017. Auction customers were seedstock producers and commercial cattle producers. Sale catalogs, available to customers before and during the events, provide information for each lot. We recorded information about the sale price and physical, morphological, genetic, and market characteristics and deleted missing and misreported data. Inflation-adjusted lot prices were calculated using the Brazilian General Price Index (IGP-DI).

The physical variables recorded were age (months), weight (lb), and scrotal circumference (cm). Market characteristics collected from the catalog include the number of head in each lot, lot number, auction type, farm name (brand), and auction place. There are two types of auctions. One kind is broadcast live, with bids collect on the premises and by phone. Another kind is broadcast with recorded lot videos, with bids collected only by phone. We refer to the first as "virtual and physical" and the second as "virtual."

The morphological variables consisted of the score for body structure (E), precocity (P), muscling (M), prepuce (U), conformation (R), soundness of feet and legs (A), reproductive soundness (S), and EPMURAS morphological quality index. Morphological traits are visual scores evaluated by BrazilcomZ.

Koury Filho (2005) develops the EPMURAS morphological index. The ANCP and Brazilian Zebu Breeders Association (ABCZ), two major Brazilian breeding programs, use EPMURAS methodology as a selection tool. Traits E, P, and M are ranked from 1 (inferior) to 6 (excellent); traits R, A, and S are classified from 1 (inferior) to 4 (excellent). Grades of 2, 3, or 4 are for functional prepuce (U) and 1, 5, and 6 for not-functional prepuce. The EPMURAS index is the sum of all scores (except for prepuce, which adds four points for a score of 2, 3, or 4, two points for 1 or 5, and 1 point for 6). Although the prepuce score ranges from 1 to 6, the database only presents the classification nonfunctional and functional. Thus, we assign a binary variable (1 and 2) to the prepuce, as shown in Tables 1 and 2.

To attribute the morphological scores, a qualified technician evaluates each animal individually within the same group composed of contemporaneous bulls subject to the same food and sanitary conditions. Structure captures bull height and body length. The relationship between rib depth and limb height expresses the precocity characteristic. Muscling reveals muscle distribution and length. Figure 1 illustrates structure, precocity, and muscling traits.

Table 2. Summary Statistics

Variables	Mean	St. Dev.	Min.	Max.
Price (R$/lot)	9,997.20	4,097.40	3,571.60	39,446.10
Physical				
Age (months)	31.43	4.4	19.63	58.07
Weight (pounds/lot)	1,554.40	188.8	992.8	2,171.60
Scrotal circumference (cm)	36.76	2.59	26.5	46
Morphological (EPMURAS scores)				
Body structure: *E*	4.83	0.65	3	6
Precocity: *P*	5.57	0.64	3	6
Muscling: *M*	5.51	0.69	3	6
Prepuce: *U*	1.89	0.32	1	2
Conformation: *R*	3.2	0.6	2	4
Soundness of feet and legs: *A*	3.17	0.48	2	4
Reproductive soundness: *S*	3.94	0.23	2	4
EPMURAS quality index	30.07	2.45	20.33	34
Genetics (EPD in percentiles)				
Total genetic merit index: *MGT*	11.77	11.56	0.1	100
Maternal body weight at 120 days of age: *MP*120	22.91	21.15	0.1	100
Body weight at 210 days of age: *DP*210	20.99	18.16	0.1	100
Body weight at 450 days of age: *DP*450	13.77	13.28	0.1	80
Scrotal Circumference at 365 days of age: *DPE*365	15.98	15.24	0.1	90
Scrotal Circumference at 450 days of age: *DPE*450	17.64	16.91	0.1	100
Stayability: *DSTAY*	18.05	18.46	0.1	100
Probability of precocious calving: *DP*3	33.69	27.36	0.1	100
Market Factors				
Number of heads in a lot (head)	1.64	0.88	1	5
Number of the lot (proxy for order)	81.96	37.88	1	149
Farm reputation	5.41	1.77	1	7
Auction type	1.79	0.41	1	2
Auction place	2.35	1.41	1	4

Notes: The sample size consists of 1,275 lots of purebred Nellore males.

The ANCP issues expected progeny differences (EPDs) and percentile ranking tables for various traits. The catalog expresses the genetic variables in percentile ranking, referred to as TOPs, showing each animal's range. For instance, if a lot has TOP 5% for a particular characteristic, it means that the lot is among the 5% best Nellore in the breeding program for this attribute. Likewise, a TOP 1% lot ranks better than a TOP 5%. So, we expect an inverse relationship between percentiles and prices. Thus, the regression coefficient of EPDs variables expressed in percentiles are expected to be negative.

The genetic variables, expressed in percentiles, are scrotal circumference at 365 days of age (*DPE*365), scrotal circumference at 450 days of age (*DPE*450), maternal weaning weight (*MP*120), body weight at 210 days of age (*DP*210), body weight at 450 days of age (*DP*450), stayability (*DSTAY*), precocious calving probability (*D*3*P*), and total economics genetic merit (*MGTe*). The MGTe index summarizes genetic value. The ANCP estimates weights based on the profitability impact of these genetic characteristics on full-scale commercial beef cattle operations (breeding, rearing, and fattening) located in Midwest Brazil (Associação Nacional de Criadores e Pesquisadores, 2018). MGTe weights are as follows: 6% age at first calving (*DIPP*), 9% *D*3*P*, 3%

*MP*120, 5% *MP*210, 16% *DP*210, 24% *DP*450, 22% *DSTAY*, 3% *DPE*365, 3% *DPE*450, and 9% ribeye area (*DAOL*). Since *DIPP* and *DAOL* were not available in the auction's catalog, our dataset does not include them.

The morphological index components physically describe the lot, resembling a judge's analysis in a competitive livestock show. Genetic factors indicate what the bull may pass on to its offspring. Combining information from both indexes brings advantages to bull purchasers. For example, if a buyer who wants to increase the body weight at 450 days of his herd looks only to the genetic information, he may end up buying one animal with a pendulous prepuce prone to injury, which would hinder that bull from mating the cows adequately. Therefore, the rancher will not achieve his goal.

Results

Table 3 reports the parameter estimates for the Nellore hedonic model. A likelihood ratio test rejects the linear–linear model in favor of the log-linear model at the 5% level; Akaike information criterion/Bayesian information criterion tests confirm this result. Most of the characteristics are significant at the 5% level. Estimates represent premiums and discounts for all variables. Model 1 works with overall indexes (EPMURAS and MGTe). Model 2 adds the results for index components.

Effect of Morphological Characteristics

Most morphological characteristics are statistically significant in determining the price of a purebred Nellore lot. An "excellent" EPMURAS index classification is worth a substantial premium for auctioned bulls. Brazilian markets pay more for lots that exhibit precocity, muscling, breed conformation, correct set of feet and legs, and reproductive soundness quality.

Lots with an "excellent" EPMURAS morphological index receive, on average, a R$551 premium, 23.4% above the base lot price (see Table 3, Model 1). No statistical significance was found for other classification levels, although the coefficient has the expected sign. This finding may be due to buyers not clearly recognizing the differences among "good," "very good," and "regular" lots, confounding the categorization.

Model 2 of Table 3 breaks down the EPMURAS index by its components. In the second model, two traits are not statistically significant: structure (E) and prepuce quality (U). To explain cattle price differential, working with breeds other than Nellore, Avent, Ward, and Avent, Ward, and Lalman (2004) and Bulut and Lawrence (2007) show frame to be significant, while Zimmerman et al. (2012) and Williams et al. (2012) do not find these characteristics to be significant.

The marginal premiums paid for conformation (R) and the soundness of feet and legs (A) were 3.4% and 5.1%, respectively. Dhuyvetter et al. (1996) report a conformation marginal premium at least twice that of than correctness, contrasting our results. Each incremental increase in precocity and reproductivity soundness score leads to an appreciation of 4.8% and 4.2%, respectively.

In the EPMURAS index, structure (E), precocity (P), and muscling (M) each have a weight of 6/34, prepuce quality (U), conformation (R), soundness of feet and legs (A), and reproductive soundness (S) have weights of 4/34. Although the morphological index uses the same weight for E, P, and M, we find precocity (P) to be the most relevant trait. At the same time, R, A, and S are statistically significant, while structure (E) is not. Further research should establish an index that reflects the implicit value of each attribute.

Comparing "excellent" and "regular" lots in both indices reveals higher premiums for the morphological index: EPMURAS (+23.4%) and MGTe (+6.4%). However, this result has not previously been described in the literature. We therefore suggest that the market pays more for visual characteristics than for genetic information. This finding may be somewhat limited by how the index is categorized.

Table 3. Parameter Estimates for Hedonic Pricing Model

Dependent Variable:		Log of Real Prices		
		Model 1		Model 2
Lot Characteristics		Estimate	Variable	Estimate
EPMURAS	32–34 (excellent)	0.210**	E	−0.0232
	29–31 (very good)	0.0868	P	0.0465**
	25–28 (good)	0.0257	M	0.00830*
	20–24 (regular)	base	U	0.000981
			R	0.0337***
			A	0.0501*
			S	0.0407***
MGT_e	0.1%–5% (excellent)	0.0617**	$D3P$	0.000554*
	06%–15% (very good)	−0.00883	$DSTAY$	−0.000867**
	16%–30% (good)	0.0155	$DPE450$	−0.000217
	31%–50% (regular)	base	$DPE365$	0.000288
	100%–51% (inferior)	0.0211	$DP450$	−0.000714***
			$DP210$	−0.000346**
			$MP120$	−0.00107***
Weight	$< 1,200$	−0.112**		−0.222**
	1,201–1,300	−0.0950***		−0.184*
	1,301–1,400	−0.121***		−0.160***
	1,401–1,500	−0.0494***		−0.0489*
	1,501–1,600	base		base
	1,601–1,700	0.0269*		0.0418
	1,701–1,800	0.0322		0.0523***
	1,801–1,900	0.161***		0.201***
	1,901–2,000	0.219***		0.237***
	$> 2,000$	0.384***		0.382***
Scrotal circumference		0.0149***		0.0159***
Age	≤ 27 months	0.0860***		0.0209*
	> 27 months	base		base
Year	2013	base		base
	2014	−0.0481***		−0.0678***
	2015	0.353***		0.500***
	2016	0.279***		0.260***
	2017	0.19		0.173
Lot size	1	0.0763**		0.125***
	2	base		base
	3	−0.000816		0.00658
	4	−0.0543**		0.03
	5	−0.0476		−0.0184
Lot number		−0.000468		−0.000357

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Table 3. – continued from previous page

Dependent Variable:		Log of Real Prices	
		Model 1	Model 2
Lot Characteristics		Estimate	Estimate
Farm	A	base	base
	B	0.197	
	C	0.456***	0.369**
	D	0.456***	0.311*
	E	0.455***	0.391**
	F	0.381***	0.222
	G	0.587***	0.397**
Auction type	1	base	base
	2	0.160***	0.180*
Intercept		7.765***	7.486***
Random effect variance		0.00172	0.0024753
Variance of error term		0.0288	0.288069
Sample size		1,275	982

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively.

Overall, our analysis of morphological variables shows that Brazilian cattle buyers look for precocious animals with recommended breed conformation. Body weight traits at standard ages are routinely measured on Brazilian farms and are the most common selection goals in the country (Paterno et al., 2017). Producers can add value to their lots with visual scores once the results show that the market pays not only for weight but also for weight composition. Moreover, adding visual scores to the selection process is not costly and can be done at the same time as weight measurement (Paterno et al., 2017).

Effect of Genetic Characteristics

Genetic traits are statistically significant for describing price changes in Nellore auctions. Bulls categorized as "excellent" in the MGTe index received higher premiums. EPDs for milk, stayability, and weight were the most relevant genetic traits in determining animal value. The results in Table 3 indicate that the MGTe index explains variations in Nellore prices. According to Model 1, lots classified as "excellent" receive a 6.4% premium compared with the base lot, an increase of R$149.94 over the base price. Model 2 displays the findings obtained from the MGTe components.

Contrary to expectations, there is no evidence that the EPD for scrotal circumference (at either 365 or 450 days of age) influences lot prices. No associations were found in the literature between scrotal circumference and price. One of the main characteristics associated with males' reproductive performance is testicular volume (Martínez-Velázquez et al., 2003). Scrotal circumference and age at first calving are inversely correlated for both Nellore (Gressler et al., 2000) and Angus (Notter, McFadden, and Bergmann, 1993). Fertility is one of the main reasons for the Nellore breed's success in Brazil (Viacava et al., 2000). Scrotal circumference is particularly relevant for buyers looking to generate offspring to replace females since the trait is highly correlated with daughter fertility (Eler et al., 2004). However, stayability—the probability of cow producing at least three calves before reaching 76 months of age—is statistically significant in explaining lot prices.

Consistent with some literature, we found premiums related to the EPD that captures the effect of mother's milk in offspring weight. A 1-standard-variation deviation upward in the $MP120$ EPD is associated with a 2.3% premium above the base lot. Investigating two models, Jones et al. (2008) list statistically significant premiums for milk EPD (0.5% and 0.7%) for Angus cattle. Dhuyvetter

et al. (1996) also report premiums for milk EPDs of 0.8%–2.8% when examining seven taurine breeds, but only three of these were significant. However, Vestal et al. (2013) do not find evidence that weaning weight due to milk production explains price.

EPD for body weight (at 210 and 450 days of age) influences lot prices. A 1-standard-deviation variation in body weight corresponds to premiums/discounts of only 0.6% and 0.9% for *DP*210 and *DP*450, respectively. Several prior studies have noted the importance of weaning weight (Dhuyvetter et al., 1996; Vanek, Watts, and Brester, 2008; Vestal et al., 2013), whereas one investigation did not observe statistical significance for weaning weight (Jones et al., 2008).

Some EPDs that comprise the MGTe index do not explain variations in Nellore prices, while others have a small impact. One possible explanation for this might be that auction buyers are just looking for "excellent" animals, since the MGTe index summarizes the main characteristics weighted by specialists. Another possible explanation is buyers' lack of knowledge about how to use EPDs appropriately as a selection tool. As a result, the latter ends up buying the bull based on the index rather than purchasing a specific animal to meet the needs of his herd.

To construct an economic genetic index, our findings in Table 3 suggest we should use slightly different weights for EPDs than those used by the ANCP. According to our results, EPDs for stayability and milk should receive more emphasis. The Brazilian breeder program gives 22% and 8% to these traits, respectively. For the ANCP, growth (EPDs for weight gain) receives more weight, 40%. Caution is needed here since this intriguing contrast could be because of buyer profiles and the heritability of each MGTe component.

Buyers' farm operations may have different endpoints. Cow–calf producers that sell calves at weaning are concerned about weaning-weight EPD, while fattening farmers who sell steers to the slaughterhouses are concerned about growth and carcass EPDs. Aligning operation endpoints and index market endpoints is essential to enterprise profitability. Different programs have developed a selection index for use by seedstock and commercial producers (Weaber, 2016). For instance, Angus has four indices: W (weaning), F (feedlot), G (grid), and B (beef).

Future research should investigate how buyer profiles and characteristics (e.g., breeder producer, commercial farmer, operation size) affect marginal value estimations of genetic and morphological characteristics. Further work is also needed to evaluate the impact of birth weight EPD on the price of Nellore cattle. Birth weight is statistically significant in explaining variations in Angus price. Failure to control for birth weight can lead to calving problems in the herd. Birth weight is also correlated with weaning and yearling weight. The producer, whose goal is only to maximize MGTe, may have future calving problems since EPDs for weight make up 40% of the MGTe index.

Effect of Physical Characteristics

All three physical variables investigated explain variations in Nellore prices. Heavier animals with a larger scrotal circumference are more valued. Younger animals also received higher bids. There is consistency between the results from Model 1 and Model 2. Model 2 comes from a regression with fewer observations since one farm did not report specific EPDs.

Weight has a positive impact on price in both models. In Model 1, sires weighing 1,301–1,400 lb receive a R$268.07 discount (11.4%) compared with lots of 1,501–1,600 lb. Lots weighing 1,901–2,000 lb receive a R$578 premium (24.5%) compared to lots of 1,501–1,600 lb.

An increase in scrotal circumference (SC) implies a high average lot price. In either model, we reject the null hypothesis at the 5% level that SC does not affect the log of prices. In Model 1, a 1-centimeter increase in SC receives a premium R$35.44. Model 2 predicts a R$28.54 premium for each additional 1 cm of SC. However, these results have not previously been described. Vestal et al. (2013) find that SC does not affect prices for purebred Angus bulls.

What stands out in the physical characteristics is the effect of age. Interestingly, young bulls receive premiums relative to older bulls in both models. In Model 1, animals under 27 months of

age receive a 9.0% premium (R$211.64) compared to lots above this age threshold.[2] This outcome contrdicts Jones et al. (2008), Chvosta, Rucker, and Watts (2001), and Dhuyvetter et al. (1996), who find that buyers pay a premium for older bulls but at decreasing rate.

The contrast may be partly explained by the difference in the average age of lots sold in Brazil and the United States. In the studies mentioned previously, the average age of the animals is approximately 14 months, with a range of 10–37 months; in Brazil, the average age is 31 months, with a range of 20–58 months. Given that Brazilian auctioned bulls are fit for reproduction and have a genetic profile, buyers will probably be looking for bulls that will work in their herd for a longer time, so they end up choosing younger bulls.

Effect of Market Factors

Market factors are statistically significant in explaining prices of Nellore sold at auction. The variation of years affects the appreciation of Nellore seedstock. Animals sold in smaller lots receive higher offers. Both farm reputation and auction type help explain the final bid on the lots. Both models present similar results. The findings provide valuable insights into the role of market factors in pricing livestock lots.

Auction year significantly influences the price of the Nellore's lot. Brazil suffered a severe economic crisis and political turmoil from 2014 to 2017. During this period, the country's real GDP shrank by 5.51% (World Bank, 2018) and a president was impeached. Brazil also hosted and lost the 2014 FIFA World Cup, which took place in the same season as the auctions. Despite the economic recession and political riots, purebred Nellore lot prices appreciated compared to 2013. For instance, cattle sold in 2015 received a R$995.95 premium (42.3%) relative to 2013, as shown in Table 3 (Model 1). This result may reflect the increasing demand for genetically proven superior animals given the professionalization of commercial beef production in the country. 2014 was an exception, with the lots depreciating.

Lot size significantly alters prices for Nellore cattle. Individual lots receive a R$186.75 premium (7.9%) relative to lots of two animals. Larger lot sizes receive discounts. This result is contrary to previous studies, which have suggested that the impact of lot size increases at decreasing rate (e.g., Mallory et al., 2016; Schulz, Dhuyvetter, and Doran, 2015; Zimmerman et al., 2012). These contrasts must be interpreted with caution since the studies mentioned examine commercial cattle, and our research investigates purebred livestock. Commercial cattle auctions usually have larger lots (e.g., lot size in Mallory et al., 2016, ranges from 1 to 315), while lot size in our investigation ranges from 1 to 5.

The proxy for the order of entrance does not significantly impact Nellore prices. Caution is needed here since the variable "lot number" is just a proxy for an order of entrance. The database provider pointed out that it is not uncommon for animals to enter out of the lot number sequence. According to the literature, the selling price is lower for lots sold later in each auction than those placed near the beginning. (Vanek, Watts, and Brester, 2008; Jones et al., 2008; Dhuyvetter et al., 1996).

Farm reputation is associated with a statistically significant impact on Nellore prices. As shown in Table 3 (Model 1), lots from farms C, D, E, F, and G receive premiums of 57.7%, 57.8%, 57.6%, 46.3%, and 79.8%, respectively, relative to Farm A. These findings highlight the potential usefulness of branding strategies for producers. These results further support the work done by Chvosta, Rucker, and Watts (2001) and Jones et al. (2008) on seller reputation as a relevant driver of prices for seedstock bulls. Schulz, Dhuyvetter, and Doran (2015) and Turner, McKissick, and Dykes (1993)

[2] We entertained the possibility of including *Age* and Age^2 as continuous control variables instead of categorical *Age*. In Model 1, *Age* would be statistically significant at a 5% level, indicating a reduction of approximately 2.5% in lot prices for every additional month; Age^2 would not be statistically significant. In Model 2, neither variable would be statistically significant.

show that the seller reputation likely exists for some commercial producers. These results differ from findings reported by Williams et al. (2012).

Auction type statistically dictates the Nellore price sold in Brazilian auctions. Lots sold in auctions broadcast live with a collection of bids on the premises and by phone receive a R$409.52 premium (17.4%) relative to auctions only broadcast with videos of lots recorded and bids collected by phone. This outcome is contrary to that of Bailey and Peterson (1991), who do not find structural price differences between traditional and satellite video auctions.

Conclusion

This research extends the knowledge about livestock markets, addressing the influence of morphological, genetic, physical, and market factors on the price of purebred Nellore cattle sold at auction in Brazil. A unique dataset highlighted higher premiums for the morphological index than for the genetic index, a result not previously documented in the literature, and particularly relevant given the emphasis breeders' associations have placed on genetic attributes.

Our results show cattle buyers' preferences for precocity: Farm productivity tends to increase with steers finishing early and heifers calving early. Our findings suggest strategies for producers. The choice (often neglected by many breeders) of lot size, auction type, and advertising (reputation) adds value to the bulls. Cattle operations goals should involve genetic and morphological factors since visual scores and EPDs explain price variations. Younger, heavier animals and with a larger scrotal circumference are more valued. Buyers can use this finding as a benchmark to evaluate their investments.

The current study only considered the context of purebred cattle. However, these results may not pertain to commercial livestock. Future research might explore this segment of Brazil's beef supply chain. Purebred farms and commercial farms buy purebred bulls. Thus, it would be interesting to compare how each of these two distinct groups values each lot attribute. Further study could also add carcass EPDs measures to our model. Also, new investigations may try to understand whether the size of an auction (number of lots) affects the valuation of morphological and genetic characteristics.

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