Producers Valuation of Feeder Cattle Characteristics: A Hedonic Model for Heterogeneous Inputs

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Abstract

Empirical evidence suggests that producers value livestock based on observable attributes. However, current literature has focused on analyzing the determinants of feeder cattle price differentials rather than to estimate producers' underlying valuation functions. The main objective of this study is to examine how feeder cattle attributes are valued by producers. A theoretical model is developed to estimate producers' willingness to pay for heterogeneous inputs, and it is applied to feeder cattle auction markets in South Texas. The proposed model is estimated in two steps. In the first step the hedonic price function is calculated. Then, the effects of input attributes on producer's valuation are recovered using profit maximization specifications.

Keywords: Discrete characteristics, hedonic regression, inverse demand function, livestock auction, South Texas, willingness to pay.

JEL Classification: Q11, Q12,

Introduction

The effect of cattle characteristics on market prices has been extensively studied (Schroeder et al. 1988, Schulz et al. 2015, and Zimmerman et al. 2012). However, limited theoretical and empirical research have been conducted to understand how those attributes are valued by producers. It has been argued that observed attribute prices reveal nothing about producers' preferences or structural demands for such characteristics. In fact, observable prices merely represent a joint envelope function matching sellers and buyers' valuation functions (Rosen, 1974).

Empirical evidence suggests that producers value livestock based on observable genetics and value-added management practices such as breed type, age, weight, sex, etc. This is the case of feeder cattle that are usually purchased at live auction markets and sent to feedlots before slaughter. Desirable feeder cattle characteristics (e.g., European breeds) are associated with higher premiums, while less desirable features (e.g., horns) are discounted in the market. Hedonic models have been used to analyze the determinants of feeder cattle price differentials rather than to estimate producers' underlying valuation functions (Schroeder et al. 1988; Schulz et al. 2015; Zimmerman et al. 2012). However, hedonic analysis provides a theoretical foundation to recover implicit demand functions for heterogeneous inputs.

The main objective of this study is to extend the current literature regarding producers' valuation of livestock characteristics. A theoretical model is developed to estimate producers' willingness to pay or inverse demand functions for heterogeneous inputs, and it is applied to feeder cattle auction prices. Compared to most of the existing hedonic literature for producers, this study focuses on the valuation of intermediate production inputs rather than final products. A practical estimation approach is also proposed.

Methods

Conceptual Framework

It is assumed that one unit of an input with m attributes or characteristics $\boldsymbol{z} = (z_1, \dots, z_m)$ is used to produce a unit of output. The production set is given by $f(X, \boldsymbol{z}, \boldsymbol{\lambda}) \leq 0$, where X represents a composite homogeneous input, and $\boldsymbol{\lambda}$ is a vector of exogenous production parameters. It is further assumed that the final quality of the output ($\boldsymbol{q}$) is a function of the quantity and quality of the inputs used. Specifically, output quality is defined as $\boldsymbol{q} \leq \boldsymbol{\Gamma}(X, \boldsymbol{z}, \boldsymbol{\lambda})$. Also, $\boldsymbol{z}$ is in the feasible space of production technology and output quality.

Input and output prices are set competitively in the market based on their attributes. Particularly, the price of the heterogeneous input (r) and output (p) are a function of their characteristics:

(1) $$r(\boldsymbol{z}) = r(z_1, \dots, z_m),$$

and

(2) $$p(\boldsymbol{q}) = p(q_1, \dots, q_k).$$

Therefore, $\frac{\partial r}{\partial z_i} = r_i(\boldsymbol{z})$ and $\frac{\partial p}{\partial q_i} = p_i(\boldsymbol{q})$ represent the market equilibrium price for the corresponding i^{th} attribute.

The objective of producers buying the heterogeneous input is to maximize profit $\pi = p(\boldsymbol{q}) - c(r, \boldsymbol{z}, \boldsymbol{q}, \boldsymbol{\lambda})$ by choosing $\boldsymbol{q}$ and $\boldsymbol{z}$ optimally; where $c(\cdot)$ is the cost function derived from minimizing factor costs subject to the output technology and quality constraints. The cost function represents the minimum cost to produce one unit of output of quality $\boldsymbol{q}$ using a heterogeneous input with $\boldsymbol{z}'$ attributes. Producers' cost-minimization problem is given by:

(3) $$c(r, \boldsymbol{z}, \boldsymbol{q}, \boldsymbol{\lambda}) = \min_X \{[r(\boldsymbol{z}) + X] \mid f(X, \boldsymbol{z}, \boldsymbol{\lambda}) \leq 0, \boldsymbol{q} \leq \boldsymbol{\Gamma}(X, \boldsymbol{z}, \boldsymbol{\lambda}), \boldsymbol{z} = \boldsymbol{z}', \text{and } X \geq 0\},$$

where the price of X is set to one.

Producers value the attributes of the heterogeneous input according to their valuation function $\theta(\boldsymbol{z};\ \pi, \boldsymbol{q}, \boldsymbol{\lambda})$. The valuation function represents producers' willingness to pay for an input with characteristics $\boldsymbol{z}$ at a given profit level and production parameters. Specifically, the maximum offer for a unit of the heterogeneous input requires:

(4) $$\pi = p(\boldsymbol{q}) - c(\theta, \boldsymbol{z}, \boldsymbol{q}, \boldsymbol{\lambda}).$$

It can be shown that optimal choice of $\boldsymbol{q}$ and $\boldsymbol{z}$ is attained when

(5a) $$p_i(\boldsymbol{q}) = \frac{\partial c}{\partial q_i} = c_{q_i}, \quad i = 1, \ldots, k,$$

and

(5b) $$\theta_{z_i} = -\frac{\partial c}{\partial z_i} = -c_{z_i}, \quad i = 1, \ldots, m,$$

where $\theta_{z_i} = \frac{\partial \theta}{\partial z_i}$. Since $r(\boldsymbol{z})$ is the minimum price of the heterogeneous input in the market and θ is the maximum bid producers are willing to offer, profit is maximized when $\theta(\boldsymbol{z}^*;\ \pi^*, \boldsymbol{q}^*, \boldsymbol{\lambda}) = r(\boldsymbol{z}^*)$ and $\theta_{z_i}(\boldsymbol{z}^*;\ \pi^*, \boldsymbol{q}^*, \boldsymbol{\lambda}) = r_i(\boldsymbol{z}^*)$, $i = 1, \ldots, m$, where *'s denote optimum quantities. Note that the inverse demand function is equal to the negative of the marginal change in cost. Thus, producers are willing to pay a positive amount for those characteristics that reduce the cost of production, and vice versa.

<u>Model Estimation</u>

The proposed theoretical model is estimated in two steps. In the first step the hedonic price function is calculated. In the second step, the effects of input attributes on producer's valuation are recovered using profit maximization specifications. Also, model estimation has to consider some of the intrinsic features of feeder cattle. Particularly, observable feeder cattle characteristics are classified as discrete attributes with S levels (e.g., hide color: black, white, spots, etc.), and continuous attributes (e.g., weight). Consequently, the first-order conditions required to optimize profits cannot be estimated for all characteristics. The true valuation of discrete characteristics is not directly observed, and some parametrization is required to assess the corresponding producers' willingness to pay functions (Bajari and Kahn, 2005).

It is assumed that the input hedonic price function (1) is given by:

(6) $$r = \beta_0 + \sum_{k=1}^{d} \sum_{\substack{s=1 \\ s \neq \delta_k}}^{S_k} \beta_{ks} z_{ks} + \sum_{j=d+1}^{m} (\beta_j z_j + \beta_{n-d+j} z_j^2) + \beta_t t + \varepsilon,$$

where β's are hedonic parameters, d is the number of discrete characteristics, z_{ks} is an indicator variable for the s^{th} level of the k^{th} discrete attribute, δ_k is the baseline attribute level, $m - d$ the number of continuous attributes, t is a daily trend to account for temporal effects, and ε is an independent error term with zero mean and finite variance. Then, the marginal implicit price for the s^{th} level of k^{th} discrete characteristic is given by:

(7) $$r_{ks} = \begin{cases} r(\mathbf{z}|z_{ks} = 1) - r(\mathbf{z}|z_{ks} = 0) = \beta_{ks} & \text{if } s \neq \delta_k \\ 0 & \text{if } s = \delta_k \end{cases}.$$

On the other hand, the marginal implicit price for the j^{th} continuous characteristic is equal to $r_j = \beta_j + 2\beta_{n-d+j} z_j$. The hedonic price function in equation (6) is estimated for each auction location to avoid potential identification problems (Brown and Rosen, 1982), and the marginal prices are inferred for each observation.

A functional cost function could be used to estimate the effect of input attributes and production variables on the valuation function. Namely, as suggested in equation (4), producers' willingness to pay for the i^{th} attribute can be recovered if we are able to estimate the marginal cost function. However, little is known about the theoretical properties of the cost function in terms of input characteristics. Theory suggests that θ_{z_i} is a function of input attributes and production parameters. In this study, the marginal valuation of z_i is approximated by the linear function:

(8)
$$\theta_{z_i} = \alpha_i + \sum_{k=1}^{d} \sum_{\substack{s=1 \\ s \neq \delta_k}}^{S_k} \alpha_{iks} z_{ks} + \sum_{j=d+1}^{n} \alpha_{ij}\, z_j + \alpha_{it} t + \alpha_{il} l + u_i,$$

$$= \boldsymbol{z}'\boldsymbol{\alpha}_i + u_i, \qquad i = 1, \dots, m,$$

where $\boldsymbol{\alpha}_i = [\alpha_i, \dots, \alpha_{il}]$ is a vector of preference parameters, l is auction location, and u_i is an independent error term with zero mean and finite variance. For continuous attributes, profit maximization implies that $\theta_{z_j} = r_j(\boldsymbol{z})$, and equation (8) is estimated using ordinary least squares techniques.

Special considerations need to be taken to estimate and interpret the marginal valuation of discrete input characteristics (Bajari and Kahn, 2005). Particularly, the implicit attribute price is not necessarily equal to the corresponding marginal valuation. However, revealed preference choices imply that producers' valuation of the s^{th} level of the k^{th} input attribute is equal or greater than its associated price. It is further assumed that there is a natural valuation ordering of the attribute level alternatives given by equation (8). Therefore, profit maximization implies that:

(9)
$$z_k = s \qquad \text{if } r_{ks} \leq \theta_{z_k} < r_{ks+1}, \qquad k = 1, \dots, d, \quad s = 1, \dots, S_k,$$

where r_{k1} is set to $-\infty$, and $r_{kS_k+1} = \infty$. It is further assumed that $u_k,\ k = 1, \dots, d$, is normally distributed with a mean 0 and unit variance. Then, the probability that the s^{th} level of the k^{th} input attribute is selected is given by:

(9)
$$\Pr(z_k = s|\boldsymbol{z}) = \Pr\left(r_{ks} \leq \theta_{z_k} < r_{ks+1}\right)$$

$$= \Pr(r_{ks} \leq \boldsymbol{z}'\boldsymbol{\alpha}_k + u_k < r_{ks+1})$$

$$= \Pr(r_{ks} - \boldsymbol{z}'\boldsymbol{\alpha}_k \leq u_k < r_{ks+1} - \boldsymbol{z}'\boldsymbol{\alpha}_k)$$

$$= F(r_{ks+1} - \boldsymbol{z}'\boldsymbol{\alpha}_k) - F(r_{ks} - \boldsymbol{z}'\boldsymbol{\alpha}_k),$$

where F is the standard normal cumulative density function. Given a sample of N producers, $\boldsymbol{\alpha}_k$ is obtained by maximizing the log-likelihood function (Cameron and Trivedy, 2005):

(10) $$lnL(\boldsymbol{\alpha}_k) = \sum_{h=1}^{N} \sum_{s=1}^{S_k} z_{hks} \ln p_{hks}, \qquad k = 1, \ldots, d,$$

where p_{iks} is the probability that the h^{th} producer selects the s^{th} level of the k^{th} input attribute, and z_{hks} its corresponding indicator variable. The log-likelihood function is jointly estimated for all locations with different r_{ks} by auction facility.

Data

The dataset used to analyze producers' valuation of feeder cattle characteristics consists of 4,119 beef calf sales collected at 8 livestock auction facilities across South Texas during 2014-2017. Calves were sold individually rather than in lots of several head, allowing observation of individual attributes. Data were randomly collected by County Extension Agents during auction sale events, and a minimum of 30 transactions were recorded each time. County Extension Agents were trained to standardize the data collection process. Gathered information includes calf's sale price and physical characteristics such as hide color, sex, frame size, fill, body condition, muscle score, Brahman influence, dehorn status and weight.

Preliminary Results and Discussion

Collected sale data are summarized in Table 1. The characteristics of each individual calf affect the value of the individual calf to the producer in terms of their ability to lower cost or increase profit. Hide color is an indication of several genetic factors that are not captured by the other observable characteristics listed. Beef from black-hided cattle can earn a premium associated with the brand Certified Angus Beef. This value is imputed through the supply chain and is associated with higher prices for cattle with at least 51% of their hide surface area colored black.

Crossbred cattle also often earn a premium due to their ability to tolerate adverse conditions (heat, insects, etc.) or to increase the value of the beef carcass (yield grade, quality grade, ribeye area, marbling, etc.) Examples of this are black-with-white-face cattle and red brindles. Black-with-white-face cattle typically have a black Angus sire and Hereford dam. Red brindle cattle are typically crosses of Hereford and Brahman cattle. In South Texas, these cattle are particularly popular for their mix of improved carcass characteristics (from the Hereford) and tolerance to heat and insects (from the Brahman).

The sex of the calf has several implications for cost and profit of the producer. In terms of feedlot performance and yield grade, steers are the best of the three (steers, bulls, and heifers). Bulls are castrated at the feedlot level to improve carcass characteristics and to minimize disposition problems, but castrating a heavy calf carries increased death risk which the feedlot passes back a portion of that risk to the cow-calf operator in the form of a lower price. Relative to steers, heifers do not gain weight as efficiently at the feedlot and their carcasses have a higher fat percentage (i.e. a higher yield grade). Complicating the effect of heifers is the fact that cattle sold in these markets can be used for other purposes. Heifers that are desirable by cow-calf operators (other than the seller) as breeding stock might earn higher prices than steers or bulls.

The effect of frame size is straightforward. Large-framed cattle have a higher potential for gain, but gain less efficiently due to a higher maintenance requirement. Small-framed cattle are less valued than medium-framed cattle due to their limited potential to put on valuable muscle. Thus, medium-framed cattle are typically the highest valued.

Condition, or the amount of subcutaneous fat on the calf, is also likely to affect sale price. Overly fat calves are likely to lose weight when introduced to the feedlot, thus buyers are likely to pay less for these calves to avoid paying for weight that does not increase their profit. Very thin calves may be less likely to gain weight in the feedlot and could also be discounted. More heavily muscled calves are also likely to earn a premium since they are likely to be more profitable for producers.

Brahman influence likely has a nonlinear effect on calf price. Brahman influence negatively affects carcass characteristics but enhances heat and insect tolerance and maternal ability. Holding other factors constant, calves with 25% or 50% Brahman influence that are fed out in relatively hot climates will have a cost advantage due to their heat tolerance. Calves with heavier Brahman influence or 100% Brahman calves will likely be discounted as the negative effects on carcass quality will outweigh the benefits of heat and insect tolerance. In females, maternal ability will function as a mitigating factor as well.

Finally, horned calves are typically discounted relative to dehorned or polled (genetically hornless) cattle. This is because horned cattle are likely to damage the hides and muscle of other cattle in the typical concentrated animal feeding operation in which most cattle in the U.S. are finished. Weight is negatively associated with price per pound, but positively associated with price per head.

Attribute marginal prices are presented in Table 2. Hide color marginal prices are calculated relative to black hided cattle. Red brindle, black-with-white-face, and dun cattle had economically significantly higher prices than black hided cattle. Cattle with spotted hides had much lower prices. Red brindle and black-with-white-face cattle receive premiums consistent with the discussion in the previous section. That is, cross breeding provides production-related benefits that lower cost and increase profits. Calves with spotted hides are likely discounted due to inferior genetics associated with *Corriente* steers.

Steers were more highly valued than bulls while heifers were the least valued. These relative marginal values reflect risk and profitability associated with each of the three sexes. Bulls present a higher death risk to feedlot operators, which is passed on to the cow-calf producer with lower prices. Heifers have more subcutaneous fat and do not gain as efficiently.

Calves with medium frames were more highly valued than those with large frames (which gain inefficiently) and those with small frames (which have limited gain potential). Calves with average condition were more highly valued than those that were very fat or thin. More heavily muscled calves were worth more at the margin, and horned cattle were worth less at the margin than polled or dehorned calves.

Calves with 25% and 50% Brahman influence were more highly valued than those with 0% and 75% Brahman influence. Cost savings associated with improved heat and insect tolerance as well as hybrid vigor outweigh the negative effects of lower carcass grades for calves with low and moderate levels of Brahman influence. The reverse is true for calves with 75% Brahman influence. The high marginal value associated with the relatively few calves with 100% Brahman influence is due to their high value as breeding bulls or heifers.

In addition to determining feeder cattle price differentials, this study will estimate the underlying valuation functions behind observed prices. Estimated producers' valuations for the different feeder cattle attributes will be compared to observed prices to identify potential market opportunities for cow-calf operators. Also, the results of this study will provide a broader breadth of understanding about how cattle producers value feeder cattle attributes. Preferred attributes by buying producers will be identified and value-added management practices will be proposed based on those preferences. Better marketing, management assistance and educational programs for feeder cattle producers can be developed based on the empirical findings of this study.

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Table 1. Description and Summary Statistic.

Variable	Frequency	Proportion (%)	Mean (Standard Error)
Observed Transactions			
2014	1,437	34.89	
2015	916	22.24	
2016	1,463	35.52	
2017	303	7.36	
Location			
Auction A	207	5.03	
Auction B	1,574	38.21	
Auction C	378	9.18	
Auction D	574	13.94	
Auction E	52	1.26	
Auction F	142	3.45	
Auction G	475	11.53	
Auction H	717	17.41	
Hide Color/Pattern			
Black	1,273	30.91	
Red Brindle	219	5.32	
Brown	216	5.24	
Black with white Face (BWF)	324	7.87	
Dun	393	9.54	
Gray	184	4.47	
Red	555	13.47	
Red with white Face (RWF)	340	8.25	
Smokey	141	3.42	
Spots	95	2.31	
White	379	9.20	
Sex			
Bull	1,332	32.34	
Heifer	1,671	40.57	
Steer	1,116	27.09	
Frame			
Medium	2,611	63.39	
Large	1,185	28.77	
Small	323	7.84	
Fill			
Average	3,014	73.17	
Full	959	23.28	
Shrunk	146	3.54	

Table 1 (cont'd). Description and Summary Statistic.

Variable	Frequency	Proportion (%)	Mean (Standard Error)
Condition			
Average	3,258	79.10	
Fleshy	473	11.48	
Thin	388	9.42	
Muscle Score			
1	156	3.79	
2	2,203	53.48	
3	1,760	42.73	
Brahman Influence			
0%	1,110	26.95	
25%	1,409	34.21	
50%	1,004	24.37	
75%	498	12.09	
100%	98	2.38	
Horns Status			
Dehorned	2,948	71.57	
Horned	1,171	28.43	
Weight (CWT)			4.97 (0.02)
Price ($/CWT)			182.49 (0.81)

Table 2. Marginal Hedonic Prices.

Variable	Weighted Mean[1]	Standard Error
Hide Color/Pattern		
Red Brindle	4.74	0.44
Brown	1.25	0.38
Black with white Face (BWF)	5.96	0.39
Dun	4.83	0.21
Gray	-4.80	0.96
Red	-2.74	0.15
Red with white Face (RWF)	2.44	0.25
Smokey	3.29	0.73
Spots	-13.26	1.42
White	2.16	0.25
Sex		
Heifer	-4.19	0.12
Steer	7.26	0.21
Frame		
Large	-0.80	0.10
Small	-0.84	0.30
Fill		
Full	-0.6	0.20
Shrunk	-23.30	1.71
Condition		
Fleshy	-3.62	0.20
Thin	-2.18	0.60
Muscle Score		
1	3.79	0.63
3	-4.02	0.19
Brahman Influence		
0%	-1.35	0.19
50%	1.38	0.25
75%	-2.30	0.34
100%	6.88	1.92
Horns Status		
Horned	-1.33	0.14
Weight	-17.59	0.12
Trend	-0.09	0.003

[1] The weight assigned to each auction location is proportional to its corresponding number of observations.