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The Impacts of Pregnancy Status and Risk of Abortion on Replacement Cow/Heifer Values

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Introduction

The cow-calf operation is the foundation to the beef industry and spans across every state in the United States. Cow-calf producers manage cows and heifers through cycles of breeding, pregnancy, and calving (McBride and Matthews, 2011). Cows and heifers are collectively defined as replacement females throughout this manuscript. The purpose of replacement females is to produce calves as inputs for beef production. Therefore, a replacement female's asset value is in her reproductive abilities and the expected value of calves produced. A female's reproductive potential is defined as her ability to, conceive, carry a live calf to term, and wean a live calf. This study utilizes each category of reproductive potential to determine buyer valuations of replacement females at auction, primarily focusing on pregnancy status and risk of abortion

The decisions cow-calf producers make such as retention, replacement, or sales are important aspects of profitability. One long-term decision is purchasing replacement females outside the herd to introduce new bloodlines and potentially expanding herd size. By introducing new genetics into the herd, producers have the opportunity to more rapidly increase productive and economic efficiency. However, purchasing replacement females, especially pregnant ones, is a risky investment. The risks include the introduction of disease to the herd, reproductive inefficiency, and reduced value potential of future calves.

This research focuses on factors impacting the reproductive success of replacement females and the expected value of calves they produce, thus influencing the net value of replacements. Though several physical characteristics of a replacement female influence the reproductive success, the primary characteristic evaluated in this research is the length of pregnancy term and the associated risk of abortion. Producers value this characteristic of reproductive success by the probability that the replacement female will carry a live calf to term.

Abortion is defined as the early termination of pregnancy. A cow is considered to be at risk of abortion from conception until she is 260 days pregnant (Thurmond, Picanso, and Jameson, 1990). A pregnant replacement female has the highest probability (hazard rate) of aborting her calf through early and mid-gestation and a slight increased risk prior to birth (Forar et al. 1996, Silke et al., 2002; Santos et al., 2004; Longergan et al., 2016). Peter (2000) also tells the greatest risk of abortion is normally observed between 98 and 105 days, which falls between weeks 12 and 18.

Abortion risk can present a potential financial loss to a producer purchasing a pregnant replacement female. Peter states a cost of $600 to $1,000 per midterm abortion. These costs can be accrued from the loss of calf returns, additional expenses to rebreed, and the potential of having to replace the female if culled. Not accounting for the risk of abortion could send an incorrect market signal to the sellers. Because the risk of abortion and reproductive inefficiency is not directly observable, buyers must form beliefs based on visual assessment of the animal.

Scant research has been conducted in regard to the valuation of replacement females, based on physical characteristics influencing their reproductive success. Therefore, the overall aim of this research is to provide more market value information to sellers/buyers of pregnant replacement females at auction. Using individual animal data from Mississippi cattle auctions, it is intended to build upon the research by Mitchell, Peel, and Brorsen (2017) on pen aggregated data by evaluating data identifying individual pregnant replacements and their characteristics that can impact reproductive success and the productive value of calves.

Literature Review

The use of hedonic models is a common practice in estimating livestock input characteristics. The Input Characteristics Model (ICM) developed by Ladd and Martin (1976) assisted greatly in estimating the implicit marginal value products of various commodity characteristics in the agricultural industry (Parcell, Schroeder and Hiner, 1995; Neibergs, 2001; Mitchell, Peel, and Brorsen, 2017). Mitchell, Peel, and Brorsen (2017) considered the influence of aggregated bred cow attributes on the total value of a cow in Oklahoma cattle auctions using data from United States Department of Agriculture-AMS. The authors found that pens of pregnant females whose average length of pregnancy was between one and five months were discounted relative to six months pregnant.

Parcell, Schroeder, and Hiner's research (1995) determined the implicit value for individual traits in a cow-calf pair using hedonic analysis as well. The authors found substantial premiums for young, healthy cows that are already pregnant again while having a healthy calf by her side. To receive the highest price for a pair, the seller has the incentive to improve his or her management practices regarding the health of both cow and calf, hold the pair until the cow has successfully been bred back, and the calf by her side is near weaning weight.

Similar to breeding cow hedonics, Neibergs' (2001) determined the marginal value of specific attributes in Thoroughbred broodmares. A mare that was barren, or not pregnant at time of sale, had a significant discounted marginal value of $15,010. It was believed this signified uncertainty of reproductive success from the mare and additional production costs of caring for an open broodmare. This research hopes to build upon these works and become a vital asset for the valuation of breeding stock.

Conceptual Model

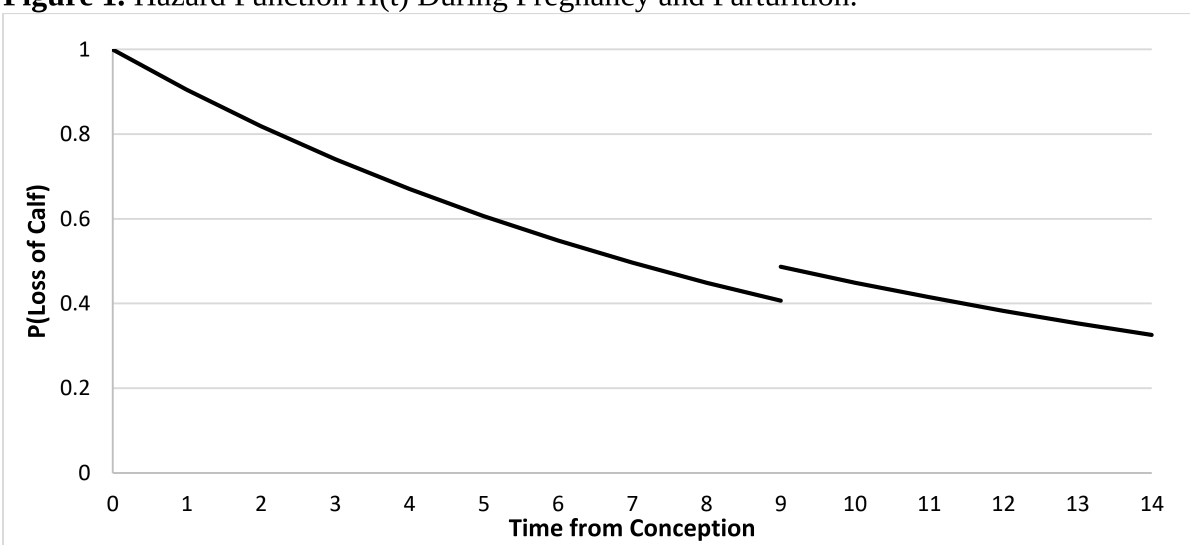
Replacement females are a capital investment. The buyer of a replacement female values this capital investment as the sum of the values of the expected fetus if pregnant and the discounted expected values of future calves. The potential number of future calves is a function of her current age. Because future productivity is not certain, a buyer must form a belief as to her future productivity by relying on value signals derived from observed physical characteristics at the time of purchase, as well as market expectations. Characteristics such as pregnancy status (either open or pregnant) and age are determined by a qualified veterinarian at the auction and are provided to the buyers at the time of sale. The live weight of the female is provided by the auction either just before or after sale depending on the location of weigh scales. All other physical characteristics, such as breed, frame, and body condition are visually assessed by the buyer during the auctioning process. Market expectations such as the future salvage value of breeding females, feeder calf prices, and input costs are derived from current market information available to the buyer.

To begin the development of the conceptual model's details, assume a risk neutral buyer believes the replacement female is pregnant at the time of sale. The buyer valuation process would then begin with the determination of the likelihood the fetus will survive at least until birth. Survival of the fetus to calf is uncertain due to abortion.

An important physical characteristic that signals the likelihood of abortion is the number of months pregnant at the time of sale. Past dairy herd research has found that as pregnancy moves closer to term, the risk of pregnancy loss (abortion) decreases until birth, with the highest degree occurring within the first two weeks after fertilization and a slight increase prior to birth (Forar et al. 1996; Silke et al., 2002; Santos et al., 2004; Lonergan et al., 2016). To assess the likelihood the fetus reaches parturition, buyers form beliefs based on length of time until birth and other female characteristics that may impact the likelihood of carrying the calf to term, such as body condition. Finally, expected fluctuations in weather conditions such as extremely hot or cold months can also likely impact the risks of abortion (Parish and Rhinehart 2015).

Until now, only the risk of abortion after purchase has been addressed. However, parturition has its own set of dystocia risks resulting in increased death of the calf and reduced future reproductive potential (Short et al., 1990). Though the risk of abortion and dystocia are zero after a successful birth, new risks arise for the newborn calf's survival such as morbidity, or illness (scours, pneumonia etc.), nursing difficulty, and possibly predation (Parish, Rhinehart, and Boland 2016). A representation of the risks of loss is illustrated from conception to weaning in Figure 1. Notice that during parturition there is a sudden spike in the risks. This is due to the increased risk of death due to dystocia. Typically, after approximately a month, the risk of loss steadily decreases as the calf ages and becomes more accustomed to the environment.

Figure 1. Hazard Function H(t) During Pregnancy and Parturition.



When a producer bids on a pregnant replacement female, an important partial value determination is the expected value of the current fetus. The fetus is the first calf available to sell by the new owner. The fetus, $f \in [1, F \mid a]$, is one out of a possible F calves remaining in her useful life. The number of possible calves is naturally conditional upon her current age, $a \in [2, A]$, where it is assumed the minimum age for having a calf is two years old and the expected maximum useful life may be $A = 10$ years old, for a female in good condition. If the female has her first calf at two years old and is five years old at the time of sale, the calf she is currently carrying is at best her 4th calf, which is $f = 1$ for the new owner and $F = 5$ possible calves.

The expected net return for the first calf when sold is defined as follows. Let gestation time of the fetus range from $t \in [0, b]$ where $t = 0$ is conception and $t = b$ is the successful birth of the first calf. Additionally, the planned production time of the calf after birth ranges from $\tau \in (b, T]$, where $\tau = T$ is the age of the calf when sold. The potential loss of calf after purchasing a pregnant female due to the abortion or death ranges in time $d \in [t, T]$. The discrete expected net return of the first calf over the development and growth periods is defined as

1) $$\mathrm{E}\left[V_{f=1}\right]_t = P(b \mid t \le b) P(T \mid b)\left[R(T)_{f=1} - \sum_t^{T-t} C_{f=1,t}\right] - P(t \le d \le T)\sum_t^{d-t} C_{f=1,t}\ .$$

In equation 1), $P(b \mid t \le b) P(T \mid b)$ is the joint conditional probability of sale, conditioned on the probability of live birth and survival to market. The net returns of the calf sold at some future time (T) is $R(T)_{f=1} - \sum_t^{T-t} C_{f=1,t}$, which is the sales revenue less the accrued costs of gestation, birth, and production. The expression $P(t \le d \le T)\sum_t^{d-t} C_{f=1,t}$ represents the expected accrued costs if the fetus/calf dies prior to marketing, the magnitude of which is contingent on the date of death.

When a producer estimates the net present value of a replacement female (possibly pregnant), the female's value is a function of the sum of the discounted expected net future value of all possible calves and her expected salvage value. The net present value for the $i \in [1, N]$ buyer of the $k \in [1, K]$ replacement female at auction is identified as

$$\text{2)} \qquad \text{NPV}_{ik} = \delta_i \left[\text{E}\left[V_{f=1}\right]_{t,k} + \lambda(a)_k \left(\sum_{f=2}^{F|a_k} \text{E}\left[V_{f>1}\right]_k + \psi(A+z)_k \right) \right],$$

where δ_i is the buyer's discount factor. The expression, $\sum_{f=2}^{F|a_k} \text{E}\left[V_{f>1}\right]_k$, is the sum of the expected net future returns of the remaining possible calves, similarly calculated as $\text{E}\left[V_{f=1}\right]_{t,k}$ from equation 1). For instance, assuming the cow is currently pregnant and 5 years old, the buyer may expect more calves until 10 years of age. The expression $\psi(A+z)_k$ is the expected salvage value at age $A+z$, $z \in [t=0, w]$, possibly around age 11 after weaning (w) her last calf. Finally, the expected future values of calves and the salvage value of the female are weighted by the discrete expected survivals of the female at various ages $\lambda(a)_k$, where $\lambda'(a)_k < 0$ under classical assumptions of continuous survival functions. The net present value is therefore, influenced by the age of the female. The relationship between age and net future values of the calves is negative by definition because there are fewer future calves the older the female. Additionally, the survival rate of older females is expected to be lower. Overall, the older the female is at auction, the less value she is to the buyer.

The discussion of the elements of the valuation equation 2) identified the impacts of only one physical characteristics of a replacement female: age. However, buyers at auction form an estimate of NPV_{ik} given a more extensive vector of observed physical characteristics $(\mathbf{K})$, such as breed and body condition to name a few. These characteristics may influence the buyers' beliefs about the value of her calves, as well as her reproductive potential. For instance, in equation 2), the values of the first and subsequent calves are a function of the physical characteristics the calf possess (Parish et al., 2018). It is expected that a subset of the mother's physical characteristics $(\boldsymbol{\kappa} \subseteq \mathbf{K})$ will be expressed in the physical characteristics of her calves $(\boldsymbol{\Omega})$. The characteristics of the mother are signals of growth potential and value of the calves, such as breed, muscling, and frame. Because the mother is expected to pass on only a portion of her genetics to the calf (Parish, Undated) the observable characteristics of the mother are expected only to be positively correlated $\Omega'(\kappa) > 0$. Other physical characteristics are related to the expected reproductive success ($\boldsymbol{\zeta} \subseteq \mathbf{K}$, some of which may equal $\boldsymbol{\kappa}$). These characteristics may influence the female's ability to conceive, carry a live fetus to term, parturition, produce milk, mothering ability, all of which lead to ultimately weaning a healthy calf. This may include characteristics such as frame or body condition. Therefore, equation 2) can further be detailed as a characteristics-based function

3) $$\mathrm{NPV}_{ik} = \delta_i \left[\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k} + \lambda\left(\mathbf{K}, a\right)_k \left(\sum_{f=2}^{F|a_k} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_k + \psi(\mathbf{K}, A+z)_k \right) \right].$$

The net present value of the *k* replacement female can be estimated using the female's physical characteristics $(\mathbf{K})$ as signals of her potential success as a replacement female and the value of her calves. The marginal impacts of each characteristic in $\mathbf{K}$ on the various elements of equation 3) can be complicated and may not be strictly positive or negative for all elements. For instance, the age of the female, a_k, can increase the join conditional probability of live birth and survival to market (Herring, 1996). However, the expected number of future calves, $F \mid a_k$, is necessarily reduced. Depending on the weights the buyer places on the consequences of age, the impact on NPV_{ik} could be net positive, negative, or neutral. Given the buyer's weighting and beliefs of impacts are unobservable to the econometrician, the net marginal values of the vector of physical characteristics can be indirectly estimated by a hedonic analysis as proposed by Ladd and Martin's input characteristic model (ICM).

Ladd and Martin's (1976) ICM represents an extensive contribution to agriculture by evaluating the values and price determinants of livestock (Parcell, Schroeder, and Hiner, 1995; Neibergs, 2001; Williams et al., 2012; Mitchell, Peel, and Brorsen, 2017). In industries such as cattle, the price received cannot vary by changing the amount of output produced. However, the price received is affected by the levels of various characteristics. When considering product heterogeneity in outputs, the authors viewed production inputs as a collection of characteristics, allowing comparable products the flexibility of having varying amounts of the same characteristics present in one product but absent in the other.

Finally, the price of the k replacement female observed at auction, P_k, can be characterized as the summation of the winning bidder's net present values for various physical characteristics, $\mathbf{K}_k$, as well as current and expected market factors, $\mathbf{M}$, such as production inputs. A general representation of the hedonic pricing model is

4) $$P_k = f\left(\mathbf{K}_k, \mathbf{M}\right).$$

Data

Data for this research were collected at auctions located in Mississippi. Because of the study being strictly observational, approval from the Institutional Animal Care and Use Committee (IACUC) was not necessary. Acknowledgements and appreciation are expressed to the

Mississippi Beef Council, Southeast Mississippi Livestock, Mississippi Beef Cattle Improvement Association, and Livestock Producers Association Stockyard for their support financially. However, these organizations are not affiliated with the data collection, findings, or interpretations of this research.

The data for this research was collected by trained livestock evaluators from May 5, 2014 to May 4, 2015 at seven stockyards in Mississippi. The auctions were located in northeast, southeast, and southwest Mississippi. As a condition for data collection, anonymity of stockyard locations is maintained. To collect the physical characteristics within the short window of time it takes to sell an animal (roughly 30 seconds), trained evaluators worked in teams of two to three per sale (Parish et al., 2018). All evaluators were given a standard key with defined characteristic levels to use throughout the collection process to avoid scoring discrepancies among evaluators.

At the end of the data collection process, a total of 11,932 market and replacement cattle were evaluated. This data contained 7,633 market cows and 4,299 replacement females. A market cow is a cow whose purpose is slaughter for beef production; therefore, the value comes from the pounds of beef the female is expected to produce. A replacement female for this research is defined as a female intended specifically for breeding to produce calves for beef production. If the female was sold by the head, they were reported as replacements and by the pound selling prices were reported as market cows. After excluding missing values, the final data set contains 7,759 market cows and 3,571 replacement females. The variables collected and used in this analysis are reported in Table 1. Along with descriptions are the variables' means or frequencies, classes, and reference categories used in this analysis. Following Table 1 are the expectations and importance of each variable in the model.

Table 1. Variable definitions, scales, and summary statistics $N = 3{,}571$

Characteristic	Description and Summary Statistics (mean $\pm$ SD OR percent frequency)
$Price_k$ (Dependent Variable)	Price per head of the k replacement female (1569.06 ± 477.19)
Age_k [b]	Age of k replacement female in years (4.59 ± 1.69)
$Pregnant_{kj}$	0 or 1 dummy variable if female is pregnant; j classes = Pregnant (74.60%); reference = Open (25.40%).
$Pregnant_{kj} MonthsBred_k$ [a]	If pregnant, length of term in pregnancy for k pregnant female (3.45 ± 2.64)
$DueDate_{kj}$ [a]	Expected month k pregnant female will calve. 0 or 1 dummy variable for month, j classes = January (11.07%), February (11.45%), April (11.04%), May (9.38%), June (7.62%), July (5.07%), August (4.80%), September (4.50%), October (5.52%), November (7.51%), December (9.80%); reference= March (12.24%).
$Pair_{kj}$	0 or 1 dummy variable if calf by side; j classes = Pair (16.97%); reference = No calf (83.03%).
Wt_{kj}	k replacement female's weight in pounds (lbs.) (1000.27 ± 187.81).
$Udder_{kj}$	Udder suspension score of k female; 5-Point scale (1=Very tight and pronounced suspensory ligament small, 5=Very loose and very weak suspensory ligament). 0 or 1 dummy variable, j classes= Udder 1 (17.19%), Udder 2 (41.25%), Udder 3 (32.12%); reference= Udder 4 to 5 (9.44%).

[a]New Variables to be estimated.
[b] $N = 2{,}724$; Excludes broke, short, and smooth mouth cattle.

Table 1. Variable definitions, scales, and summary statistics $N=3,571$

Characteristic	Description and Summary Statistics (mean $\pm$ SD OR percent frequency)
$Teat_{kj}$	Teat size score of k female; 5-Point scale (1=Very small and symmetrical, 5=Very large and variable size). 0 or 1 dummy variable, j classes= Teat 1 (43.38%), Teat 2 (39.37%), Teat 3 (14.28%); reference=Teat 4 to 5 (2.97%).
BCS_{kj}	Body Condition Score of k cow; 9-Point scale (1=Emaciated, 9=Excessively Obese). 0 or 1 dummy variable, j classes = BCS 4 (18.82%), BCS 5 (40.46%), BCS 6 (26.88%), BCS 7 (9.30%), BCS 8 to 9 (1.38%); reference= BCS 1 to 3 (3.16%).
$Frame_{kj}$	Skeletal size of k replacement female. 0 or 1 dummy variable, j classes = small (7.64%), large (14.37%); reference= medium (77.99%).
$Muscle_{kj}$	Muscling of k replacement female, 4-Point Scale (1=Very thick, 4=Very Thin). 0 or 1 dummy variable, j classes = Very thick $(1;\ 4.12\%)$, moderately thick $(2;\ 36.66\%)$, thin $(3;\ 50.94\%)$; reference = very thin $(4;\ 8.29\%)$.
$Locomotion_{kj}$	Locomotion score, 5-Poing scale (1=Sound, 5=Extremely lame). 0 or 1 dummy variable, j classes= Sound $(1;\ 87.03\%)$, mildly lame $(2;\ 11.68\%)$; reference = moderately lame, lame, extremely lame $(3-5;\ 1.29\%)$.

[a]New Variables to be estimated.
[b] $N=2,686$;Excludes broke, short, and smooth mouth cattle.

Table 1. Variable definitions, scales, and summary statistics $N = 3{,}571$

Characteristic	Description and Summary Statistics (mean $\pm$ SD OR percent frequency)
$Breed_{kj}$	Breed composition of k cow. 0 or 1 dummy variable, j classes = Angus Cross (12.29%), Beefmaster or Beefmaster Cross (1.71%), Brangus (20.64%), Brangus Cross (1.57%), Brahman (0.81%), Brahman Cross (7.17%), Charolais (1.82%), Charolais Cross (5.82%), Hereford (3.81%), Hereford Cross (0.50%), Holstein (1.32%), Holstein Cross (0.62%), Red Angus (3.16%), Red Angus Cross (0.17%), Red Brangus or Red Brangus Cross (2.49%), Simmental (1.46%), BeefOther (6.38%), DairyOther (1.32%); reference= Angus (26.86%).
$MonthSold_{kj}$	Month k female is sold. 0 or 1 dummy variable for month, j classes = January (5.24%), February (4.96%), April (8.93%), May (7.22%), June (4.06%), July (8.23%), August (13.55%), September (11.37%), October (12.57%), November (9.13%), December (6.89%); reference = March (7.84%).
$MktCow_k$ [a]	Average price market cows in the sale $(\$1.30/\text{lb} \pm 0.32)$.
$FeederCalves_k$	Average price feeder calf in sale $(\$2.76/\text{lb} \pm 0.27)$.
$CornFutures_k$	Average corn futures price week of sale $(\$3.76/\text{bushel} \pm 0.38)$.

[a]New Variables to be estimated.
[b] $N = 2{,}724$;Excludes broke, short, and smooth mouth cattle.

Expectations (Physical Characteristics)

A summary of the expectations is provided in Table 4 along with the empirical results.

Age

For this research, the age of replacement females ranges from one-year-old to nine-years old. As shown in Table 1, 2,724 data points are utilized to find the average age. This is due to 847 replacement females being marketed as broke, short, or smooth mouth. If the actual age was not reported, the auction would classify the female as broke, short, or smooth mouth. A short mouth cow is one which has all or most of her teeth but show wear. A broke mouth cow is missing teeth, or some teeth are broken. A smooth mouth cow has lost all her teeth or are extremely smooth, thus causing difficulty eating (Parish and Karisch, 2015). When marketed as short, broke, or smooth mouthed, there is no definitive way to verify the true age of the female. Even if the female is younger, with worn or lack of teeth, the female's probability of survival decreases, and both reproductive success and number of calves produced decreases. Therefore, any female reported as broke, short, or smooth mouthed is categorized as a ten-year-old.

The age of a female signifies the expected number of calves the female could produce in what is left of her lifespan. As a female's age increases, the number of calves she will produce decreases as mentioned earlier and expressed as, $\sum_{f=2}^{F(a)} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_k' < 0$. Therefore, it is expected that the value of the replacement female decreases with age.

Pregnant

Pregnancy status is confirmed by a qualified veterinarian at the auction who reports if a replacement female is open or pregnant. In the data, 907 replacements were sold as open. A producer deciding to buy an open replacement female risks the likelihood that she is incapable of conceiving or carrying a live calf to term. If a heifer has gone through a breeding season and not become pregnant, a lifetime study conducted by the United States Department of Agriculture at a Montana experiment station found open heifers to only have a 55% pregnancy rate in the future.

If the probability of having a live calf decreases, the value of the expected calf decreases, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} < 0$. Therefore, it is expected that the value of the replacement female should decrease.

Months Pregnant

Once pregnancy is verified by the veterinarian, he or she determines how far along the female is in gestation. The length of pregnancy ranges from one month pregnant to nine months pregnant in the data. When a producer knows how many months pregnant a replacement is, he or she takes into consideration the probability of abortion. Research has found the risk of abortion of is highest early on and typically decreases until birth (Forar et al. 1996; Silke et al., 2002; Santos et al., 2004; Lonergan et al., 2016).

The loss of a calf due to abortion can drastically reduce the reproductive success of a replacement female and have excessive costs for the producer with no returns from a calf. Therefore, it is expected that as months pregnant increases, the probability of abortion decreases and the expected value of the calf will increase, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} > 0$. Therefore, the net present value of a replacement female is expected to increase as well.

Expected Due Date

Because each female's pregnancy status and how many months pregnant is verified, it is possible to calculate the expected DueDate for a pregnant female. The expected DueDate is determined by

5) $$DueDate = MonthSold + (9 - Months\,\mathrm{Pr}egnant),$$

where DueDate is estimated by the summation of MonthSold and how many months are left in the pregnancy.

In the Southeastern region of the United States, calving and breeding seasons can vary due to warmer winter months and leads to the possibility of Mississippi cattle producers having a continuous calving season. Therefore, the expected due dates for this research range from January to December. The majority of replacement females sold in auction were expected to calve in the spring or winter. Therefore, March is used as the reference category.

It is expected that relative to the spring calving window of March, other months of calving will be discounted or will be no different. It is believed cows expected to calve in the summer will be discounted the heaviest due to heat stress and low forage availability for Mississippi cattle in summer months and lower expected values of calves.

Pair

A female with a calf already by her side has proven her ability to conceive, carry a live calf to term, and increases the probability that she can care for a calf until weaning. As such, it could be reasonably expected that a cow with a calf has a higher probability of conceiving again and producing future calves, $\sum_{f=2}^{F|a} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_k' > 0$. Therefore, it is expected a female with a calf will bring a higher price as shown in similar studies (Parcell, Schroeder, and Hiner 1995). In all, it is expected that a pregnant female with a calf already by her side will bring the highest premium at an auction.

Weight

A replacement female's weight can play a significant role in her ability to produce valuable calves. As a cow's weight increases, she is more likely to produce a heavier weaned and more valuable calf (Doye and Lalman 2011). Research has found that producers are willing to pay a significant premium of at least $50/head for heavier weight heifers (Parcell, et al., 2003).

It is expected that as a cow's weight increases, this will positively impact the value of the calf she is currently pregnant with, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} > 0$, and the value of her future calves, $\sum_{f=2}^{F|a} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_{k}' > 0$. Therefore, the value of the replacement is also positively impacted.

However, as a replacement's weight increases, her nutritional requirements and cost of production also increases. With feed cost being one of the most dominant factors on operation profitability (Miller et al. 2001), the added income from heavier weaned calves may not outstrip the additional feed cost necessary as shown in Bir et al. (2018). Because of the increased costs associated with a significantly heavier replacement female, it is believed as the weight increases, the price will rise at a decreasing rate until it no longer impacts the value of the replacement female.

Temperament

The temperament of a replacement female is considered her aggression or docility in the sale ring at auction. Aggression in a replacement female can have a significant impact on her reproductive success and be costly for producers. Not only can a bad temperament affect the handling and care for these females and their calves, but there is also a strong correlation between temperament and conception. Female's with a more docile disposition have a higher pregnancy rate during the breeding season of around 90% while aggressive females have a lower rate of 70% (Cooke, et al., 2009).

A replacement with an an excessively bad temperament, may negatively impact the number of future calves, $\sum_{f=2}^{F|a} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_k{}' < 0$. Replacement females who have a calmer temperament score should therefore bring a higher value at auction.

Udder and Teat Score

The soundness of a replacement female's udder and teats can impact her reproductive success and the expected value of calves. Udder suspension scores range from a score of 1 to 5. An udder scored as 1 is very tight to the body cavity while a score of 5 is extremely loose and has a pendulous attachment (Rasby 2011). Poor udder suspension can affect milk production and decrease milk consumption for a calf. Without an udder tight to the body cavity, the calf is at an increased risk of illness if udder and teats have become infected by being dragged through mud or debris. Teat size is also scored on a scale of 1 to 5. Teats scored as 1 are very small and a score of 5 indicates very large and varying size teats. Poor teat size can lead to a decreased weight in weaned calves from difficulty in nursing or force the producer to intervene, which can also be costly.

Ultimately, poor udder or teat scores can negatively impact the expected value of the calf she is currently pregnant with, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} < 0$, and future calves, $\sum_{f=2}^{F|a}\mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_{k}' < 0$. Therefore, it is expected that relative to a high (worse off) udder and teat score of 4 or 5, female replacements with lower scores will receive a premium.

Body Condition Score (BCS)

The body condition of a replacement female is considered the amount of fat cover and indicates energy reserves available at a specific time. During pregnancy and calving, a high demand is placed on these energy reserves and a poor body condition can impact all categories of reproductive success for a replacement female and the expected value of the calf.

With a low body condition score at the time of calving, females could be slower to rebreed, thus impacting the number of future calves, $\sum_{f=2}^{F|a}\mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_{k}' < 0$. Poor body condition score can also lead to the female’s inability to produce a sufficient amount of milk and increase chances of not weaning a live calf, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} < 0$.

However, over conditioned, or excessively fat cows, can also have significant calving problems and excessive feed costs (Parish and Rhinehart, 2016). A BCS of 5 is recommended for mature pregnant females who have reached their full growth potential and a BCS of 6 for females or heifers whose nutritional needs are higher. It is expected relative to a BCS score of 1, 2 or 3, scores of 5 or 6 will bring premiums. BCS scores of 7, 8, or 9 will likely bring a higher price than the base category, but premiums will be lower. Therefore, there will be no incentive to reach any higher BCS score than 6.

Frame

The frame size of a replacement female is determined by her hip height and is associated with the growth rate (Vargas et al., 1999). Although demand for a larger or medium frame size is demanded in calves (Parish, et al., 2018), the larger the frame, the greater the impact on a female's calving ease. As stated previously, the higher the BCS the better the calving rate would be. However, it is found that larger framed females have a lower BCS, thus large framed females have a 25% lower calving rate (Vargas et al., 1999).

Small and medium framed females are found to have higher conception rates and less likely to have calving difficulty; this increases the probability of having a live calf and therefore, the expected value of the calf increases $\mathrm{E}\left[V_{f=1}\left(\mathbf{K}\right)\right]'_{t,k} > 0$. Therefore, it is expected that to meet both the demands of cow-calf producers and feedlots, medium framed pregnant females receive a higher value over large and small framed replacement females.

Muscle

Muscling scores denote the degree of muscle on a female replacement. Evaluating the muscle score for replacements is useful in determining the expectations of calf muscling due to the female's genetics being passed on to the calf. Studies across the United States have found that buyers are willing to pay a premium for heavier muscled calves and discount thin muscled calves (Williams et al., 2012; Troxel and Gadberry, 2013; Parish et al., 2018). Therefore, relative to a muscling score of 4, all other scores are expected to receive a premium.

Having a thick muscling score can also impact the salvage value of a replacement. By having a thick muscling score, the female's salvage value will be higher when culled, $\psi(\mathbf{K}, A+z)_k^{'} > 0$, thus increasing the net present value of the replacement female.

Locomotion

Locomotion has a large influence on a replacement's health. A locomotion score of 1 signifies the female stands and walks normally with a level back. A score of five is extremely lame cattle with excessive arching of the back. Normally, cattle with a score of five are highly reluctant to move and can affect their ability and desire to eat. Lameness in cattle can negatively affect the reproductive success of a replacement female by impacting her body condition (Laven, 2018).

Therefore, the expected value of the current calf, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]_{t,k}^{'} < 0$, and future calves, $\sum_{f=2}^{F|a} \mathrm{E}\left[V_{f>1}(\mathbf{K})\right]_k ' < 0$. In all, it is expected that as locomotion score worsens, the present value of the female is expected to decrease.

Breed

The breed of the female not only influences reproductive success but also the expected value of the calves. When a producer selects a breed for their operation, selecting for more than one trait is normally considered. A common tradeoff that should be considered is the calving ease and lower birth weights that come with breeds such as Brahman versus a breed like Angus which produces calves that grade choice more frequently than other breeds. A breed's adaptability to the climate is also considered by Mississippi cattle producers. Therefore, with Angus as the reference category, it is expected a crossbreed female brings a higher price due to the various genetic traits she possesses and will pass to her expected calves.

Expectations (Market Factors)

Month Sold

To account for seasonality patterns of cattle sold and prices throughout the year, the month replacement females are sold is controlled for in this research. Replacement females typically see lower values in the fall months due to operation production patterns (Peel and Meyer, 2002). Because many females calve in spring months, a significant number are culled and sold in the fall after calves have been weaned. The market thus becomes saturated with replacement females and prices decrease. It is expected relative to March sold replacement females, cattle sold in the eleven other months are discounted.

Market Cow Price Average

As a female's age increases and/or her reproductive efficiency decreases, a producer makes the decision to cull the female. When a replacement female is culled, she can be sold as market or as a replacement for another herd. The market price represents a price floor for these current replacements and a naïve expectation of the salvage value for the female. Evaluated after auction, the average market cow price is calculated for each auction. This price is calculated by

6) $$AvgMktCow_k = \frac{\sum MarketCowPrices_{at}}{\sum MarketCowsSold_{at}}$$

where $AvgMktCow_i$ is found by the summation of all market cow prices for a location at time t divided by the number of market cows sold at the specific auction. It is hypothesized as the average price of market cows increases, the salvage value increases, $\psi(\mathbf{K}, A+z)_k^{'} > 0$; therefore, the net present value of a replacement female increases.

Feeder Calves

The purpose of the cow-calf industry is to produce calves used for beef production. Cattle auctions typically sell both feeder calves and replacement stock at the same auctions. For this study, the average price for feeder calves sold at each auction is calculates by the equation:

7) $$FeederCalf\,\mathrm{Pr}ice_k = \frac{\sum FeederCalf\,\mathrm{Pr}ices_{at}}{\sum FeederCalvesSold_{at}}$$

where $FeederCalf\,\mathrm{Pr}ice_k$ is found by the summation of all feeder calf prices for a location at time t divided by the total number of feeder calves sold at that specific auction for that date. The feeder calf price is used in place of feeder futures as this is the actual price producers make naïve expectations on what their feeder calves can bring at an auction location. It is expected as the average feeder calf price increases, the expected value of the calf will increase, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]'_{t,k} > 0$, thus increasing the net present value of the replacement female producing the calf.

Corn Futures

Because of the positive relationship between corn prices and maintenance costs for cattle, it is recognized that as the price of corn rises, the cost to maintain replacements and calves increases. As the price of corn increases, the costs associated with raising the calf to market increases, $\sum_{t}^{d-t} C'_{f=1,t} > 0$. The added cost leads to the expected value of the calf decreasing, $\mathrm{E}\left[V_{f=1}(\mathbf{K})\right]'_{t,k} < 0$. To determine the price of corn, nearby futures contracts for the week of the sale are used. It is expected that as corn prices increase, the value of calves will drop, thus resulting in a decrease in replacement female values.

Empirical Model and Estimation

The data has both cross-section and time series characteristics. The cross sections are auction location, and time is represented as the order animals are sold within and across auction locations over time of auction. The pooled cross-section time series attributes of the data give rise to several estimation concerns. Heteroscedasticity with respect to weight, age, and months pregnant has appeared throughout similar studies (Williams, et al., 2012; Mitchell, Peel, and Brorsen, 2017; Parish et al., 2018). Because of the time-series nature of the data and the possibility of omitted variables (i.e. degree of bidding competition), serial correlation may also be a concern. Finally, the large number of variables may give rise to multicollinearity issues.

Heteroscedasticity was found to be an issue by means of the Goldfeld-Quandt test for the variables weight, market average, feeder calves, and corn futures. The Durbin-Watson test statistic indicated the presence of positive serial correlation with a d test statistic of 1.52. To correct for heteroscedasticity and serial correlation in a panel modeling framework, the heteroscedasticity-and autocorrelation-consistent covariance matrix estimator (HAC) is used to estimate a consistent covariance matrix.

Multicollinearity is tested for by means of the variance inflation factor (VIF). A VIF of greater than twenty signifies severe multicollinearity among variables. Multicollinearity was present between the linear and quadratic variables, as well as various dummy variables. No continuous variable's VIF was above ten; therefore, multicollinearity is not a concern for interpretation of significance.

After all estimation concerns are tested for, the Hausman test is conducted and indicates the specified hedonic model must account for random effects in the error term; This empirical model can be specified as

$$\text{8)} \quad \begin{aligned} \text{Price}_k &= \beta_0 + \beta_1 Age_k + \beta_2 Age_k^2 + \beta_3 \Pr egnant_k + \beta_4 \Pr egnant_k MonthsBred_k \\ &+ \sum_{j=1}^{12} \beta_{5j} DueDate_{kj} + \sum_{j=1}^{4} \beta_{8j} Udder_{kj} + \sum_{j=1}^{4} \beta_{9j} Teat_{kj} + \beta_{10} wt_k + \beta_{11} wt_k^2 \\ &+ \beta_{12} Pair_k + \sum_{j=1}^{3} \beta_{13j} Temperament_{kj} + \sum_{j=1}^{4} \beta_{14j} BCS_{kj} + \sum_{j=1}^{2} \beta_{15j} Frame_{kj} \\ &+ \sum_{j=1}^{3} \beta_{16j} Muscle_{kj} + \sum_{j=1}^{4} \beta_{17j} Locomotion_{kj} + \sum_{j=1}^{20} \beta_{18_j} Breed_k + \sum_{j=1}^{11} \beta_{19j} MonthSold_{kj} \\ &+ \beta_{20} MktCow_k + \beta_{21} FeederCalves_k + \beta_{22} CornFutures_k + \varepsilon_k + u_{kt} \end{aligned}$$

In equation 8) $k = 1, \ldots 3{,}571$ signifies the individual head. All variables, their definitions, and reference categories are located above in Table 2. Both age and weight are also modeled in the quadratic form similar to previous studies (Parcell, Schroeder, and Hiner, 1995; Williams et al., 2012, Parish et al., 2018) to test the significance as weight and age continually increase.

Results

Parameter estimates, standard deviations, and significance for each variable are reported in Table 4). The orthodox R-square is not appropriate for the panel time series model. Instead a generalized R-Square is reported. For the specified model, an R-Square is estimated as 0.6597. Following Table 4) is a discussion of the main variables of interest, age, pregnancy, months pregnant and pairs.

Table 4. Parameter Estimates.

Variable	Parameter Estimate	Standard Error	Expectation
Intercept	509.5399	349	N/A
Age	-46.3987***	9.8376	<
Age^2	-0.56705	0.7287	<
Pregnant	-96.6817***	29.1009	>
Months Pregnant	21.02803***	3.1081	>
Due January	-3.53506	19.4833	<
Due February	-17.9953	19.4293	<
Due April	3.88732	19.4831	<
Due May	-30.2988	21.6852	<
Due June	-58.5452**	23.6174	<
Due July	-46.2949*	27.4743	<
Due August	-80.8487***	31.1427	<
Due September	-24.6843	34.2668	<
Due October	7.76458	29.3179	<
Due November	-27.0143	24.5379	<
Due December	19.65974	24.5935	<
Udder Score 1	80.2141***	26.6379	>
Udder Score 2	68.82036***	21.1766	>
Udder Score 3	50.0878***	18.3965	>
Teat Score 1	-17.1349	35.4444	>
Teat Score 2	19.47562	34.1409	>
Teat Score 3	3.168648	36.388	>
Weight	3.26268***	0.2999	>
Weight^2	-0.00103***	0.000152	<
Pair	462.2577***	29.2191	>
Temperament Score 1	-16.4446	22.3047	>
Temperament Score 2	2.696059	23.128	>
Temperament Score 3	19.24497	24.0597	>
BCS 4	60.10392**	26.7688	>
BCS 5	93.50416***	26.8792	>
BCS 6	117.5289***	29.2739	>
BCS 7	138.3056***	35.3481	>
BCS 89	156.1515***	47.1534	>
Locomotion Score 1	102.9994***	37.3843	>
Locomotion Score 2	31.32727	20.1614	>
Small Frame	-0.64555	19.7858	<
Large Frame	-38.6843**	16.5039	<

***Significant at 0.01 Significance Level
**Significant at 0.05 Significance Level
*Significant at 0.10 Significance Level

Table 4. Parameter Estimates.

Variable	Parameter Estimate	Standard Error	Expectation
Muscle Score 1	154.6663***	41.8956	>
Muscle Score 2	82.88147***	25.8042	>
Muscle Score 3	47.03115**	22.3541	>
Sold January	-289.933***	36.5397	<
Sold February	-11.1937	55.5939	<
Sold April	-130.354***	34.0312	<
Sold May	-100.212**	52.2083	<
Sold June	-288.645***	51.6331	<
Sold July	-382.668***	59.8439	<
Sold August	-343.918***	57.2067	<
Sold September	-460.846***	63.7437	<
Sold October	-410.694***	63.1384	<
Sold November	-360.36***	46.0236	<
Sold December	-196.915***	35.0401	<
AX	27.48254*	16.044	>
BMBMX	-7.54243	38.9261	>
BN	27.79033**	15.3056	<
BNX	96.15847**	43.1846	>
BR	91.48165	78.1557	<
BRX	93.74424***	28.6591	>
C	-64.0507**	31.109	<
CX	-46.4774**	21.0176	<
H	-82.3972***	22.5506	<
HX	-131.153***	44.4549	<
HO	-287.246***	51.3762	<
HOX	-78.0657	68.6872	<
RA	-53.8872**	23.7116	<
RAX	-125.561	99.237	<
RBNRBNX	-14.2175	31.8934	<
SMSMX	55.71579	36.09	<
Dairy	-132.096**	60.4693	<
other	-137.74***	22.0077	<
Market Avg	76.83003	48.4281	>
Feeder Calves	76.34473**	42.7545	>
Corn Futures	-339.26***	53.8158	<

***Significant at 0.01 Significance Level
**Significant at 0.05 Significance Level
*Significant at 0.10 Significance Level
[a]R-Square: 0.6597

Age

Because of the discussion in the conceptual model about the impact of age, it was thought to be necessary to discuss the results of this variable. Age is found to be highly significant with a parameter estimate of $-46.3987(\pm 9.84)$, meaning as the female ages, she is discounted forty-six dollars for every year older. This estimate demonstrates as the number of calves a female is expected to produce decreases, her value declines as well. Although it is believed that an older replacement is less likely to have reproductive and calving problems, buyers significantly value the number of calves she possibly has left to produce. Therefore, buyers should be willing to accept the risk of reproductive inefficiency in first calf heifers to gain the valuable longevity of these females. The quadratic term, age squared, was found to not be significant. These results are consistent with similar studies that also find discounts for aging females (Mitchell, Peel, and Brorsen, 2017; Troxel et al. 2002; Parcell, Schroeder, and Hiner, 1995).

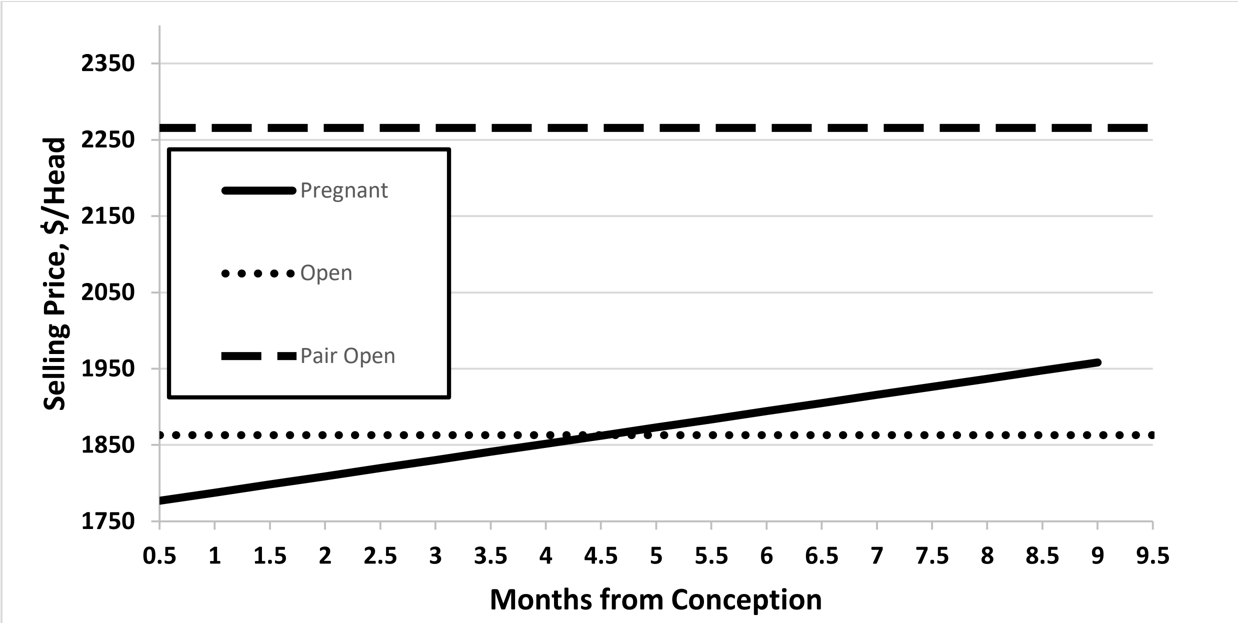
Pregnancy, Months Pregnant, and Pairs

The estimates for pregnancy status and months pregnant are not exactly as expected. It was expected that from previous studies results (Parcell, Schroeder, and Hiner, 1995) a pregnant female would bring a premium compared to open replacement females. However, estimates in this study find a pregnant female is significantly discounted $\left(-\$96.68 / \text{head} \pm 29.10\right)$ compared to an open female. This finding differs from Parcell, Schroeder, and Hiner (1995) who found buyers prefer females that are already pregnant. It is believed buyers significantly discount a pregnant replacement female because of the uncertainty around the pregnancy. Not only must buyers consider the risk of abortion or loss during calving, but buyers also might lack vital information such as the bull the female has been bred to previously. This lack of information can lead to unexpected calving problems and excessive costs for the producer.

However, although a pregnant replacement female is significantly discounted, depending on how far along she is in pregnancy a premium is possible. This study finds that for each additional month in pregnancy, a seller can receive a premium between $18-24 dollars. This signifies that although buyers heavily discount a pregnant replacement female, they are willing to pay more for the seller to assume the risk and retain the female farther into pregnancy. A seller can receive a premium for a pregnant female if he or she retains her until she is at least five months pregnant. Mitchell, Peel, and Brorsen (2017) found discounts for pens of replacement females averaging early and mid-gestation pregnancy compared to females that averaged 6 months into gestation. With the pregnancy discount, this study's results would be consistent with Mitchell, Peel, and Brorsen's findings. However, a premium is also found for 5-month pregnant replacement females.

It is expected that a replacement female who already has a calf by her side has proven her reproductive abilities and calving ability. As in previous studies (Parcell, Schroeder, and Hiner, 1995), it was expected a replacement female sold as a pair has a higher value and receives a premium. This expectation is correct and it is found that a replacement female with a calf by her side receives a premium between $433 and $491. Figure 2 illustrates the impacts that pregnancy status information has on the net present value of a replacement female.

Figure 2. Replacement Female Cattle Value: Mississippi Auction Markets, 2014 to 2015



Other Estimation Results

Although other variables were not the central focus of this paper, they are still deemed important and need discussion. Most coefficients were the expected sign with the exception of temperament. The value of a docile female was found to be no different than an extremely aggressive female. However, it is believed this is due to the lack of data collected on aggressive replacement females at auction.

Large framed cattle and pregnant females expecting in June, July, and August are discounted suggesting buyers take into account characteristics that can impact calving and potential value of calves. Buyers also significantly preferred crossbred beef breeds such as Brangus or Brahman crosses, over purebreds or dairy breeds. Feeder calf auction prices and corn futures demonstrated a significant influence from market factors on the net present value of a replacement female. The market cow average, however, was the expected sign but not significant. This could signify a producer does not form his or her expectation of the female’s salvage value on current market prices because prices have the possibility of drastic change before her sale date.

Conclusions

The purpose of this research is to provide adequate information to both sellers and buyers about the market valuation of pregnant replacement females, whose asset value is in her reproductive abilities and the value of calves she produces. Results from the hedonic pricing model of replacement females show significant results for the valuation of replacements based on their physical characteristics and market factors. With scant research being conducted in the Southeastern region of the United States on this subject matter, these results are essential to producers in this area and can allow them to make more informed decisions related to the management of their operations.

Contrary to similar studies, it has been found that pregnant female replacements are significantly discounted at $96.68 compared to open females. However, a $21.03 premium is gained for each additional month in pregnancy. Therefore, if producers so choose, this pregnancy discount can be mitigated by retaining pregnant replacements further into pregnancy. This suggests that waiting to learn of pregnancy status can lead a producer to receiving a reduced expected profit if she is in the early stages of pregnancy. By opting to pregnancy check on the operation, producers are better able to take advantage of improved profits by selecting the best time to sell. Having this information readily available, Mississippi and Southeastern cattle producers in general can begin to make better informed decisions about the marketing and purchasing strategies of female replacements. It is with optimism that this research will assist both buyers and sellers in southeastern cattle auctions.

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