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Optimal Beef Cow Weights in the U.S. Southern Plains

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This research investigates net present value–maximizing beef cow weights for U.S. Southern Plains cow–calf operations. The relationship between cow weight and calf weaning weight was estimated and weaning weights were simulated for a 15-year time period. Annual returns were computed using cow–calf revenues and production costs for cows with mature weight between 950 and 1,800 pounds. A grid search showed that optimal cow size was 950 pounds across scenarios. Selection for growth may improve feedlot profitability but has deleterious effects on cow–calf producers. Development of smaller-framed maternal lines may improve sector profits.

Key words: calf weaning weight; frame size; mature cow weight; optimal cow weight

Introduction

According to Smith (2014), beef cow–calf producers select cattle for muscle, growth, and milk production in an effort to increase profit, resulting in increased cow weight and frame size. Using historical slaughter beef cow data and working backward to determine live weight, McMurry (2009) determined that national average mature cow weight increased from 1,050 pounds in 1975 to 1,350 pounds by 2009. Bulls with expected progeny differences (EPDs) indicating higher growth rate and muscling are often selected, and their daughters—who are more likely to be large—are often retained as replacement cows. Although these characteristics may be the most profitable in feedlot scenarios, this may not be true for replacement heifers used in cow–calf operations (Smith, 2014). With cow–calf producers focused on increasing weaning weights, the balance between cow nutritional requirements, which depend on cow weight and the natural environment, has fallen out of focus and supplementation has become the norm (Schmid, 2013). While larger cows wean heavier calves, they require more feed. Additional revenue from more pounds of calf weaned may not offset the added feed cost.

Our objective is to determine net present value–maximizing beef cow weights for U.S. Southern Plains beef cow–calf operations. Returns are calculated for several beef cow weights, two breeds (Angus and Brangus), two pasture types (native and improved), and under fall and spring calving seasons. Both calf birth and weaning weights are estimated as functions of cow weight, cow age, breed, forage type, and calving season, with cow weight varying from 950 to 1,800 pounds in 50-pound increments. Operating budgets are developed for each cow weight, breed, forage type, and calving season. Feed, one of the highest costs associated with cow–calf production, is varied based on beef cow weight, stages of gestation and lactation, calving season, forage type, and breed. As the stage of the beef cattle cycle potentially affects the economically optimal beef cow weight, the cattle cycle stage is explicitly considered in the analysis by varying the year of the cycle when a

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heifer enters the breeding herd. Using historical data for cull cow prices, calf prices, and feed prices, prices are projected for 15 years to reflect price variation and the pattern observed in a recent cattle cycle. Annual net returns are computed using cow–calf expected revenues and expected production costs for each cow weight. Under each scenario, annual net returns are simulated, discounted, and summed to find the expected net present value (NPV) of a beef cow per acre. A grid search is used to find the highest returning cow weights per acre under the eight scenarios.

Literature Review

Many factors determine the profitability of beef cow–calf production. Miller et al. (2001) analyzed financial and production information from standardized performance analysis data from Illinois and Iowa farmers and found that two of the four most influential factors on profitability were feed cost and calf birth weight, both of which are influenced by cow weight. Feed costs accounted for 63% of total annual cow cost. Heavier cows have higher energy maintenance costs, and those costs are affected by calving season. Olson et al. (1982) reported that an increase of 100 kilograms (220.5 pounds) in cow body weight (above four hundred kilograms or 881.8 pounds) increased net energy required by 25%. Schmid (2013) found the relationship between cow weight and feed requirements to be nonlinear. An increase in cow weight by 27% increased maintenance requirements by 20%, assuming high lactation levels. Bagley et al. (1987) reported that fall-calving cows require less hay but more supplemental nutrition compared to spring-calving cows, resulting in a higher feed cost for fall-calving herds.

Miller et al. (2001) reported that calf birth weight had a greater impact on profit than calf price. Ringwall (2008) compared cows ranging from 1,300 pounds to 1,600 pounds in 100-pound increments: Cows weighing 1,300 pounds or less had the highest calf weight as a percentage of cow weight. As lighter cows wean a higher percentage of body weight, economies of size (in economic terms) exist for cow–calf herds (Ramsey et al., 2005). In short, a larger number of small cows can be stocked on a fixed land base, resulting in more pounds weaned per unit area.

The economic issue, then, is to determine whether these biophysical differences result in an economic advantage for lighter-weight beef cows. Economic studies are limited in number. Doye and Lalman (2011) compared the profitability of a 100-head breeding herd of 1,100-pound cows to a 76-head breeding herd of 1,400-pound cows on 1,000 acres. They found that 1,100-pound cows were more profitable, mostly because larger cows have higher supplementation needs in the form of additional protein and energy. Similarly, Russell (2014) reported lighter-weight cows to be more profitable when forage quality was poor or pasture rent was charged per acre.

Matching forage type and breed characteristics to the environment can help producers improve weaning weights and overall profitability, which may also affect the profit-maximizing cow weight (Brown and Lalman, 2008). Similarly, Arango and Van Vleck (2002) determined that the profit-maximizing cow weight depends on forage quality and calving season. Larger cows outperformed smaller cows on higher-quality grasses but struggled to meet their nutritional needs on lower-quality grasses. As a result, smaller cows outperformed their larger counterparts on low-quality grasses. Our study builds on these analyses.

Model

To evaluate economic returns from cows of varying mature weights, we first developed a culling model to find the probability that a cow was still in the breeding herd at a given age. These probabilities were used to weight revenues and costs. Cow revenue is a function of weaning weight and cull cow weight. Estimating weaning weight was a two-step process, starting with a birth-weight model. We estimated calf birth weight as a function of calf gender, cow weight, age, breed, and environmental variables. Then we estimated calf weaning weight as a function of these same variables and calf birth weight. Calf revenue was simulated using weaning weight predictions and a feeder calf price slide by gender. Total annual expected revenue included calf revenues, cull cow revenue, and cull bull revenue. Costs included feed costs, other variable costs, and fixed costs. Monthly feed costs for cows were calculated by breed, weight, forage, calving season, and stage of gestation and lactation. Expected annual revenues and costs were computed for mature weights of 950–1,800 pounds. Expected annual cow–calf returns were divided by the number of acres needed per cow (based on weight, breed, pasture, and calving season), then discounted and summed. The mature cow weights with the highest NPV for each of the scenarios were found using a grid search.

Cow Culling Model

The first step in calculating per acre profitability is to establish a culling model. At each year of age, we computed the probability a cow would be culled:

$$(1)\qquad Prob(Cull\ at\ Age_t) = Prob(Cull|Age_t) \times \left(1 - \sum_{i=1}^{t-1} Prob(Cull\ at\ Age_i)\right),$$

where $Prob(Cull\ at\ Age_t)$ is the probability the cow is culled at age t, given she has not been culled in a previous year and $Prob(Cull|Age_t)$ is the probability the animal is culled given she is age t (taken from Azzam et al., 1990).

Expected Annual Revenue

Annual expected revenue includes calf revenue, cull cow revenue, and cull bull revenue. Bull weight was determined by assuming mature cow weight (or cow weight at 6 years of age) ($CowWght_{i6}$ as in equation 2) is 70% of bull weight. Bull service rates were assumed at 25 cows per bull, so bull revenues and costs were distributed across 25 cows and then further divided by five to indicate bulls were replaced every 5 years (Parish, 2006). The annual expected revenue was computed as

$$(2)\qquad \begin{aligned} Expected\ Revenue_{it}|CowWght_{it} = {} & \left(\frac{SteerWeanWght_{it}}{2} \times SteerPrice_{it}(SteerWeanWght_{it})\right. \\ & + \frac{HeiferWeanWght_{it}}{2} \times HeiferPrice_{it}(HeiferWeanWght_{it}) \\ & \left. \times\ (1 - retain)\right) \times (1 - Prob(Cull\ at\ Age_t)) \\ & + CowWght_{it} \times CullCowPrice_t(Season_i) \times Prob(Cull\ at\ Age_t) \\ & + \frac{CowWght_{i6}}{0.7} \times CullBullPrice_t(Season_i) \times \left(\frac{1}{125}\right), \end{aligned}$$

where $SteerWeanWght_{it}$ denotes steer weaning weight in year t and steer sale price is given as $SteerPrice_{it}$.[1] Similarly, $HeiferWeanWght_{it}$ denotes heifer weaning weight in year t and $HeiferPrice_t$ is calf sale price for heifers. The percentage of each heifer crop retained for breeding purposes is denoted as $retain$. The probability that a cow is culled at her given age in year t is $Prob(Cull\ at\ Age_t)$. $CowWght_{it}$ is the weight of the cow as a function of cow age and $CullCowPrice_{it}$ is the price of cull cows in year t as a function of season calved (spring, fall). The weight of cull bulls is assumed to be 10/7 mature cow weight ($CowWght_{i6}$) with a price of $CullBullPrice_t$ as a function of calving season. Implicit in equation (2) is that smaller cows are cheaper to purchase than larger cows. Mitchell, Peel, and Brorsen (2017) found that smaller cows were indeed cheaper per head than larger cows, although price per pound decreased slightly at higher weights.

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[1] Both steer and heifer weights are divided by two to represent the probability of each gender being born to a cow in any given year.

Birth-Weight Model

Given that revenues and weaning weights are influenced by birth weight, a calf birth weight ($CalfBirthWght_{it}$) model was estimated using the MIXED procedure in SAS Enterprise Guide 5.1 (SAS Institute, Inc., 2012):

$$\begin{aligned} CalfBirthWght_{it} &= \beta_0 + \beta_1 CowAge_{it} + \beta_2 CowAge_{it}^2 \\ &+ \sum_{j-0}^{11} \beta_{3+j}\, DamBreed_{it} + \sum_{j-0}^{9} \beta_{3+j}\, SireBreed_{it} + \beta_{25} Sex_{it} \\ &+ \beta_{26} \ln(CowWght_{it}) + \sum_{j=0}^{3} \beta_{27+j}\, Forage_i + \beta_{31} Season_{it} + e_{it} + v_t, \end{aligned} \tag{3}$$

where the subscript i denotes the individual cows in our data.[2] The effect of cow age ($CowAge_{it}$) is estimated in quadratic form. The dam's breed is denoted as $DamBreed_{it}$, similarly for sire breed ($SireBreed_{it}$). Calf sex is denoted as $Sex_{it} = 0$ for steers and 1 for heifers. The natural log of cow weight ($CowWght_{it}$) is used to allow for a concave response without a downward sloping section as with a quadratic. Four forages in the data are denoted as $Forage_i$. Calving season is given as $Season_{it} = 0$ for spring and 1 for fall. The error terms e_{it} and the random effects for years v_t were assumed to be independent and normally distributed.

Weaning-Weight Model

Next, the calf weaning weight equation was also estimated using the MIXED procedure:

$$\begin{aligned} CalfWeanWght_{it} &= \gamma_0 + \gamma_1 CowAge_{it} + \gamma_2 CowAge_{it}^2 + \sum_{j=0}^{11} \gamma_{3+j}\, DamBreed_{it} \\ &+ \sum_{j=0}^{9} \gamma_{15+j}\, SireBreed_{it} + \gamma_{25} Sex_{it} + \gamma_{26} \ln(CowWght_{it}) + \sum_{j=0}^{3} \gamma_{27+j}\, Forage_i \\ &+ \sum_{j=0}^{1} \gamma_{31+j}\, Season_{it} + \gamma_{33} CalfBirthWght_{it} + u_{it} + w_t, \end{aligned} \tag{4}$$

where the error terms u_{it} and the random effects for years w_t are assumed to be independent and normally distributed.

Cow Weight by Year

The estimated birth and weaning weight equations were used to simulate the economic outcomes associated with various mature cow weights, breeds, forages, and calving seasons. Mature cow weights were varied from 950 pounds to 1,800 pounds in 50-pound increments, a range that is representative of our data. From table 1, the range of cow weights was 635 to 1,922 pounds. There was one cow over 1,900 pounds in the data. The light-weight cows (<950 pounds) are mostly young cows (first calf heifers). Only 73 (2.4%) 4-year-old and older cows from our data weighed less than 950 pounds. Cows were assumed to reach mature weight at age 6. It was also assumed that cows reached 65% of their mature weight at age 1, 85% of their mature weight at age 2, and gained an additional 4% of their mature weight in years 3 through 5 (Selk, 2005).

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[2] The Mixed procedure allows for "class" variables and can correct for heteroskedasticity.

Table 1. Summary Statistics of Cattle Characteristics

Item	Mean	SD	Minimum	Maximum
Observations (*N*)	3,041	–	–	–
Cow age (years)	4.9	1.8	1.8	11.0
Year born	2,000.5	6.9	1,988.0	2,009.0
Cow weight (lb)	1,190.1	206.1	635.0	1,922.0
Calf birth weight (lb)	83.7	15.6	40.0	168.0
Weaning weight (lb)	505.6	93.7	195.0	875.0
Calf weaning age (days)	208.5	22.2	132.0	277.0

Category	Frequency	Percentage	Category	Frequency	Percentage
Season calved			Calf sex		
Fall	390	12.8	Heifer	1,515	49.8
Spring	2,651	87.1	Steer	1,526	50.2
Breed of dam			Breed of sire		
Angus	1,111	36.7	Angus	963	31.7
Angus x Brangus	220	7.3	Brangus	395	13.0
Brangus	1,087	35.9	Bonsmara	110	3.6
Brangus x Angus	193	6.4	Charolais	166	5.5
Bosmara x Brangus	73	2.2	Gelbvieh	67	2.2
Charolais	65	2.1	Herford	833	27.4
Gelbvieh	85	2.8	Maine	323	10.6
Herford	88	2.9	Red Polled	90	3.0
Maine	1	0.0	Romosinuano	59	1.9
Romosinuano	68	2.2	Simmental x Angus	35	1.1
South Devon	35	1.2			
Unknown	15	0.2	Location		
			Booneville, AR	1,215	39.9
Forage			El Reno, OK	1,095	36.0
Bermuda	623	20.5	OSU North Range, OK	731	24.0
Fescue	430	14.1			
Native Plain	1,826	60.0			
Rye	162	5.3			

Expected Annual Costs

Annual expected costs include feed costs, other variable costs, and fixed costs. Annual costs are computed as

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\begin{aligned}
Expected\ Cost_{it}|CowWght_{it} \quad = \quad & FeedCost_{it}|CowWght_{it} \times (1 - Prob(Cull\ at\ Age_t)) \\
& + FixedCost_t|CowWght_{it} \times (1 - Prob(Cull\ at\ Age_t)) \\
& + OtherVarCost_t|CowWght_{it} \times (1 - Prob(Cull\ at\ Age_t)) \\
& + BullCost \times \left(\frac{1}{125}\right),
\end{aligned} \tag{5}
$$

where $FeedCost_{it}$ is the cost of feeding a cow, her calf, and 1/25 of a bull; $FixedCost_{it}(CowWght_{it})$ are the fixed costs associated with a cow, her calf, and 1/25 of a bull in year t as a function of cow weight and varying with forage (native, Bermuda) and calving season; and $OtherVarCost_t$ are the other variable costs associated with a cow, her calf, and 1/25 of a bull in year t as a function of cow weight. Bull purchase costs (*BullCost*) were assumed to be \$3,400 per bull and then divided by 25 to represent the cost to each individual cow, and further divided by five to represent a five-year replacement schedule. Fixed costs and other variable costs were sourced from Doye and Lalman (2011).

Annual feed costs were calculated as

$$\begin{aligned} FeedCost_{it}|CowWght_{it} \quad = \quad & Cubes_{it}(CowWght_{it}|Breed_i, Forage_i, Season_i) \times CubePrice_i \\ (6) \qquad\qquad\qquad & + \; Hay_{it}(CowWght_{it}|Breed_i, Forage_i, Season_i) \times 1.21 \times HayPrice_t \\ & + \; \frac{Forage_{it}(CowWght_{it}|Breed_i, Forage_i, Season_i)}{ForageYield(Forage_i)} \times ForagePrice_i. \end{aligned}$$

where $FeedCost_{it}|CowWght_{it}$ denotes the feed cost for cow–calf pair i in year t given cow weight. Feed costs include the cost of protein supplements (cubes), grazed forage, and hay; grazed forage is the lowest-cost source of nutrition but is of low quality and limited quantity in winter months, when hay is fed to supplement grazed forage. Protein is additionally supplemented when grazed forage quality is low and hay fails to meet a cow's protein requirements. The mix of these feed sources varies by breed, forage type, stage of gestation and lactation, and month of the year. To compute costs, the quantity of grazed forage ($Forage_{it}$) is divided by the amount of forage produced per acre (*ForageYield*) to get the acres needed by forage type ($Forage_i$) and multiplied by the rental rate per acre for that particular forage type. The quantity of cubes fed ($Cubes_{it}$) is a function of cow weight given breed, forage, and season with a price given as $CubePrice_t$. The quantity of hay (Hay_{it}) denotes hay quantity fed as a function of cow weight given breed, forage, and season. Hay quantity is multiplied by 1.21 to represent hay wasted during feeding (Stotts, 2011). $HayPrice_t$ denotes hay price.

Cow rations were generated each month of the cow's life using predicted calf birth weight, breed type (Angus or Brangus), forage type (Bermuda or native range), and season (spring or fall) using CowCulator (Lalman and Gill, 2010), based on National Research Council (2000) recommendations. Spring-calving cows were modeled as calving on April 10 and fall-calving cows modeled as calving on September 15 based on the average calving dates in the dataset. Values for Bermuda and native range quality (protein and energy) by month were taken from Brorsen et al. (1983) and Doye and Lalman (2011) and entered into CowCulator. Cow rations were developed to allow an increase from a body condition score of 5.0 to a body score of 5.5 during mid-gestation to early lactation and fall from a body condition score of 5.5 to a body condition score of 5.0 during early through late lactation. The intake ratio and crude protein ratio were maintained at a level of 1.00. Average daily gain was used to assure body condition score goals were being met. A total of 10,368 monthly rations were developed.[3]

From Brorsen et al. (1983), Bermuda grass in Oklahoma yielded 7,720 pounds per acre with a 35% utilization rate, while native range pasture yielded 4,970 pounds per acre with a 20% utilization rate (Doye and Lalman, 2011). Bermuda grass pasture rent was assumed to be \$21.01 and native range pasture rent \$13.39 per acre (Doye and Lalman, 2011). Feed costs were then scaled to range from 60% of baseline to 150% of baseline cost, in 10% increments, representing variations in feeding management and variations in the quality of range at individual farms.

Forecasts reflecting past cattle cycle price fluctuations were calculated for calf, cull cow, cull bull, alfalfa hay, wheat mid, cottonseed, and molasses prices by adjusting past prices to 2014 levels using the percentage change between years (U.S. Department of Agriculture, 2015a; University of Wisconsin, 2015). Historical annual prices were taken from 1990–2004. Prices were adjusted by calculating the percentage change between annual prices in the historical years and imposing those established changes on the 2014 prices to simulate possible price fluctuations associated with the

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[3] Rations were developed for 2 calving seasons, 2 forage types, 2 breeds, each calendar month, 18 different mature cow weights, and 8 years of productive life ($2 \times 2 \times 2 \times 12 \times 18 \times 8 = 10,368$).

cattle cycle for 2014–2028. A price discount of \$3.48/cwt was assumed for Brangus calves (Williams et al., 2012). Price forecasting for range cubes were not available. Range cube prices were forecasted by combining the forecasted prices for wheat mid, cottonseed, and molasses in the same proportion of the ingredients in a 20% range cube.

Annual Expected Net Returns and Net Present Values

Annual expected net return was calculated from probability-weighted revenues generated by calves, cull cows, and heifers and cull bulls minus probability weighted costs associated with feeding and managing livestock. Annual expected net returns were computed as

$$(7)\qquad Expected\ NetRet_{it}|CowWght_{it} = Expected\ Revenue_{it}|CowWght_{it} - Expected\ Cost_{it}|CowWght_{it},$$

where expected revenues were calculated as in equation (2) and expected costs were calculated as in equation (5). NPV on a per acre basis, assuming a 10-year maximum productive cow life and a 5% discount rate, was then calculated as

$$(8)\qquad NPV_i|CowWght_{it} = \sum_{t=1}^{10} \frac{Expected\ NetRet_t|CowWght_{it}}{(1+0.05)^t \times Acres\ per\ Cow_i}.$$

Acres per cow is calculated assuming that Bermuda pasture yields (net of utilization) 2,702 pounds of grass per acre and native pasture yields 994 pounds per acre (Doye and Lalman, 2011; Brorsen et al., 1983):

$$(9)\qquad Acres\ per\ Cow_i = \frac{\sum_{t=1}^{10} Forage_{it}(CowWght_{it}|Breed_i, Forage_i, Season_i)/10}{Forage\ Yield(Forage_i)}.$$

We assumed the objective function for maximizing the NPV of expected annual returns per acre with a lifetime of 10 years by choosing mature cow weight or weight as a 6-year cow (denoted as $CowWght_6$).

The final step was to compute the mature cow weight (weight at age 6) for each scenario. A grid search was done over the 18 different mature cow weights (950, 1,000, ..., 1,800). Six scenarios were assessed (2 calving seasons, 2 forages, and 2 breeds).

Data

Data on cows, calves, bulls, calving season, and forage type were collected from two Oklahoma research stations—Oklahoma State University North Range and El Reno—and one Arkansas research station, Booneville. The data were from 1988–2009 and include 3,041 observations on year, cow age, cow weight, dam breed, sire breed, calf birth weight, season calf was born, calf weaning date, calf weaning weight, age at weaning in days, and forage type by location. Table 1 shows the summary statistics. Most of the observations (87.1%) come from spring-calving cows, with Angus as the predominant breed of both cows (36.7%) and bulls (31.7%), followed by Brangus cows (35.9%) and Hereford bulls (27.4%).

Forage and Feed Prices

Cattle rations consisted of grazed forage (Bermuda or native range), 20% protein range cubes, and hay (Bermuda or Prairie). Forage prices on a per acre basis were from Doye and Lalman (2011). These prices varied little over the time period, so constant rental rates were used. Annual historical price data for Bermuda hay, Prairie hay, and cubes were used to determine percentage changes in price between years throughout a full cattle cycle, 1990–2004. Bermuda and Prairie annual hay price data for 1990–2004 were from U.S. Department of Agriculture (2015a). Historical price data for 20% protein range cubes were not available. It was assumed 20% range cubes are composed of 65% wheat mids, 30% cottonseed, 3% molasses, and 2% minerals and binders. Historical data from those ingredients were used to approximate historical annual prices per ton of 20% protein range cubes. Wheat mids, cotton seed, molasses, soybean, and corn price data were obtained from the University of Wisconsin (2015). Wheat mids, cottonseed, and molasses prices were available for 1992–2004. Wheat mid and wheat prices are positively correlated, so wheat prices were used to approximate 1990 and 1991 prices for wheat mids. Wheat price data were sourced from the U.S. Department of Agriculture (2015b). The average wheat mid price as a percentage of wheat price was calculated for 1992 to 2004. Wheat prices for 1990 and 1991 were then multiplied by that average to approximate 1990 and 1991 wheat mid prices. As cotton seed and molasses prices were unavailable for 1990 and 1991, cotton seed and molasses prices for those years were approximated using soybean and corn prices, respectively, using the same method as for wheat mid prices.

Weaned Calf Prices

The last complete cattle cycle was determined by graphing historical cattle prices and the number of head in the United States. The number of cattle in the United States was at a relative low in the early 1990s. Numbers rose, peaking in 1996, and then fell to a new relative low in 2004 (U.S. Department of Agriculture, 2015a). This period was used to simulate price trends depicting a complete cattle cycle. U.S. Department of Agriculture (2015a) auction data collected at the National Stockyards in Oklahoma City were used to determine calf, cull cow, and cull bull prices. Calf prices from 1996–2004 were used to compute a percentage change from year to year during a cattle cycle. Taking 2014 feeder-calf prices as the starting point, future years' prices were simulated by imposing the percentage changes from the 1996–2004 cycle. Prices were given for steers and heifers within the weight range of 300–700 pounds, in 50-pound increments. Linear interpolation was used to approximate calf prices for predicted calf weaning weights. Calves were assumed to be weaned at 205 days. Fall-born calf prices were taken from April 1, each year, plus or minus seven days. Spring-born calf prices were taken November 1, each year, plus or minus seven days. Brangus calves were assumed to be discounted in price at the sale barn by $3.48/cwt. when compared to Angus (Williams et al., 2012).

Cull Cow and Bull Prices

Oklahoma City data did not include historic cull cow and cull bull prices. Colorado auction data were used to establish cattle cycle price trends for cull cows by determining the percentage change in prices for historical years. The price variations were then applied to the recorded 2014 Oklahoma City data to establish a forecast. It was assumed that open cows are culled 41 days after the end of the breeding season. Cull price was recorded annually on January 17, plus or minus seven days for fall-calving cows, or on August 12, plus or minus seven days for spring-calving cows. Bull prices from as early as 1990 were not available, so the year-to-year relationship to cull cow prices was used to model cull bull prices.

Other Cost Data

Non-feed cost data—including veterinary care, marketing, fuel, labor and operating interest—as well as fixed costs were from Doye and Lalman (2011). Costs for only two cow weights—1,100 and 1,400 pounds—were reported, so linear interpolation/extrapolation was used to approximate fixed and variable costs for cows of 950–1,800 pounds, in 50-pound increments.

Results

Multicollinearity in the calf birth-weight and weaning-weight models was tested by using Variance Inflation Factor (VIF), an index of how model coefficient's variance increases due to collinearity (Kutner, Nachtsheim, and Neter, 2004). VIF values over 20 can indicate the presence of multicollinearity (Greene, 2003), but Kutner et al. suggest a more conservative value of 10 as a benchmark. All variables showed a VIF value of less than 5, so multicollinearity was judged to not be problematic. White's heteroskedasticity test (White, 1980) was used to detect heteroskedasticity. The variables *CowWght* and *CowAge* showed signs of heteroskedasticity in both models. To correct for heteroskedasticity, we used maximum likelihood estimation, assuming multiplicative heteroskedasticity with cow weight and cow age as the variables in the variance equations for the two models.

Calf Birth-Weight Model

Regression results for the calf birth-weight model are given in table 2. The coefficient for cow age squared is negative and statistically significant. Combined with the linear variable, these two coefficients indicate that birth weight increases with cow age at a diminishing rate, with a maximum birth weight at age 6. The coefficients for all sire breeds except Angus are statistically greater than Simmental–Angus crosses (the base breed), similar to Dodenhoff et al. (1999). Of the breeds in our simulation, birth weight increases by 8.85 pounds for a Brangus bull and 6.7 pounds for a Herford bull, compared to the base breed.

Five cow breeds and crosses, including Angus, significantly influenced birth weight compared to the base breed. However, only two breeds, Angus and Brangus, comprised at least 10% of the dams in our data. Collectively, Angus and Brangus cows accounted for over 72% of the observations. Relative to a base of unknown dam breed, birth weight increases by 6.78 pounds for an Angus cow. The coefficient for the calf sex dummy variable is statistically significant, with heifer calves weighing 2.81 pounds less than steer calves at birth, consistent with Zalesky, LaShell, and Selzer (2007). The coefficient for the natural log of cow weight is positive and statistically significant. A cow weighing 1,800 pounds will give birth to a calf 16 pounds heavier than a cow weighing 950 pounds, ceteris paribus. The calving season coefficient is not statistically significant, consistent with Bagley et al. (1987). The coefficients for Bermuda and native forage type dummy variables are statistically significant with a base of Rye grass. Bermuda grass decreases birth weight by 2.49 pounds and native range increases birth weight by 4.47 pounds.

Calf Weaning Weight Model

Regression results for the calf weaning-weight model are also reported in table 2. When comparing these estimates to similar studies (Minyard and Dinkel, 1965; Selk and Buchanan, 1990; Zalesky, LaShell, and Selzer, 2007), most coefficients are similar in sign and significance. The coefficient for cow age is positive and statistically significant, as in Minyard and Dinkel (1965). The coefficient for cow age squared is negative and statistically significant. These two coefficients indicate, *ceteris paribus*, that weaning weight increases with cow age at a diminishing rate, with a maximum weaning weight at age 7. This result is similar to those reported by Minyard and Dinkel (1965) and Zalesky, LaShell, and Selzer (2007). Minyard and Dinkel (1965) found maximum calf weaning weight occurred at 8 years of age, with only a small decline after age 8. Zalesky, LaShell, and Selzer (2007) found 5- to 9-year-old cows have calves with the heaviest weight per day of age at weaning.

All sire breed coefficients are significant compared to a base of Simmental–Angus sires. Similar to Dodenhoff et al. (1999), weaning weight decreases by 55.4 pounds for an Angus-sired calf and decreases by 74.0 pounds for a Brangus-sired calf. Calves from Hereford sires weighed 58.4

Table 2. Calf Birth Weight (lbs.) and Weaning Weight (lbs.) Regression Results (*N*=3,041)

	Birth-Weight Model		Weaning-Weight Model	
Variable	**Estimate**	**SE**	**Estimate**	**SE**
Intercept	−7.27	5.66	−211.38**	30.02
CowAge	6.47**	0.73	24.16**	3.53
$CowAge^2$	−0.52**	0.07	−1.73**	0.32
SireBreed (Simmental Angus base)				
Angus	0.24	2.19	−55.42**	10.48
Brangus	8.85**	2.30	−74.02**	11.05
Bonsmara	10.11**	2.55	−58.80**	12.15
Charolais	7.16**	2.35	−64.13**	11.23
Gelbvieh	12.47**	2.72	−43.15**	12.96
Herford	6.66**	2.33	−58.37**	11.12
Maine	13.79**	2.40	−80.41**	11.53
Red Poll	14.80**	2.68	−102.52**	12.91
Romosinuano	7.22**	2.78	−73.64**	13.22
DamBreed (unknown base)				
Angus	6.78*	3.11	−43.36**	15.17
Angus × Brangus	2.11	3.30	37.40*	16.04
Brangus	4.70	3.19	2.32	15.53
Brangus × Angus	3.91	3.33	47.07**	16.16
Bonsmara	10.57**	3.54	12.20	17.16
Charolais × Brangus	12.27**	3.60	4.73	17.42
Gelbvieh	10.92**	3.54	7.77	17.15
Herford × Brangus	11.03**	3.51	2.42	17.01
Maine × Brangus	−0.43	13.02	−69.66	61.94
Romosinuano	5.18	3.58	−14.47	17.35
South Devon	5.78	3.67	−36.68*	17.83
Sex (steer base)				
Heifer	−2.81**	0.45	−15.41**	2.16
ln(*CowWght*)	24.70**	1.96	40.93**	9.67
AgeWean			2.13**	0.05
CalfBirthWght			2.01**	0.09
Season (spring base)				
Fall	−1.18	0.92	−50.14**	4.42
Forage (rye base)				
Bermdua	−2.49*	1.14	39.23**	5.46
Fescue	0.77	1.18	−16.32**	5.67
Native	4.47**	1.33	24.20**	6.40

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

pounds more than the base-breed sire. Weaning weight decreases by 43.4 pounds for an Angus cow compared to the unknown base breed. The coefficient for Brangus dams was not significant.

Heifer calves weigh 15.4 pounds less than steer calves at weaning, similar to Zalesky, LaShell, and Selzer (2007). A cow weighing 1,800 pounds weans 26.2 more pounds of calf than a cow weighing 950 pounds, ceteris paribus. Fall-born calves weigh 50.1 pounds less at weaning than spring-born calves, similar to Selk and Buchanan (1990). Relative to rye grass, calves on Bermuda grass have a 39.2-pound heavier average weaning weight and calves grazing native range have a 24.2-pound heavier average weaning weight. Fescue-raised calves weighed 24.2 pounds less at weaning than rye-raised calves.

Table 3. Maximum Net Present Value per Head per Acre by Breed and Forage with Varying Feed Cost Scenarios

Feed Cost as Percentage of Baseline	Angus Cows on Bermuda Fall Calving	Angus Cows on Bermuda Spring Calving	Angus Cows on Native Fall Calving	Angus Cows on Native Spring Calving	Brangus Cows on Bermuda Fall Calving	Brangus Cows on Bermuda Spring Calving	Brangus Cows on Native Fall Calving	Brangus Cows on Native Spring Calving
60%	$108	$249	$26	$52	$128	$31	$259	$55
70%	$91	$234	$24	$50	$113	$28	$246	$54
80%	$75	$219	$21	$49	$98	$26	$233	$53
90%	$58	$204	$18	$48	$83	$24	$220	$52
100%	$42	$189	$16	$46	$68	$21	$208	$50
110%	$25	$174	$13	$45	$53	$19	$195	$49
120%	$9	$159	$11	$44	$38	$17	$182	$48
130%	-$8	$144	$8	$42	$23	$14	$169	$46
140%	-$24	$130	$6	$41	$8	$12	$157	$45
150%	-$41	$115	$3	$40	-$8	$10	$144	$44

Net Present Value Results

Feed costs are higher for fall-calving scenarios than for spring-calving scenarios. The nutritional needs of the fall-calving cow do not match up well with the monthly nutritional value of the forage, requiring higher supplementation when compared to spring-calving scenarios. Feed costs for fall-calving cows were 17%–34% higher than spring-calving cows. For example, average feed cost for fall-calving Angus cows on Bermuda was $694 higher than for the spring-calving scenario. The difference in costs between the two scenarios increased as mature cow weight increased. The lightest cow scenario had a difference of $451 per year and the heaviest had a difference of $897. Fall-calving scenarios are also more sensitive to increases in feed costs than spring scenarios, resulting in negative NPVs for high feed cost scenarios. This is not surprising due to the higher supplementation needs of fall-calving cows.

The revenue per cow across her lifetime is lower for fall-calving cows when compared to spring-calving cows, driven in part by higher prices for spring-born calves. The difference in total lifetime revenue between spring- and fall-calving cows was around $2,500 regardless of weight, breed, or forage type. In all scenarios, spring-calving cows had higher revenues. The difference in revenue between Bermuda and native forage scenarios was negligible over all breed and calving season scenarios.

Given the cost and revenue advantages and higher stocking rates, spring-calving scenarios had higher maximum NPV per acre relative to their fall-calving counterparts across all forage and breed scenarios. NPV per head per acre was computed based on the number of acres of forage needed based on cow weight and calving season and are reported in table 3. The highest NPVs per acre were spring-calving cows on Bermuda, with Brangus cows having about a $10–$29 advantage over Angus cows. Bermuda forage generated higher returns than native forage under all scenarios due to the capacity for higher stocking rates. Bermuda yields more forage and thus has lower feed costs. Regardless of breed or forage, spring-calving cows were higher netting than their fall-calving counterparts. This result is driven by the higher feed costs for fall-calving cows with little difference in revenues between spring and fall calving.

As feed costs were a large driver of the difference in returns between spring and fall calving, we assessed the sensitivity of our results to changes in feed costs. Given that each individual producer has unique feeding costs, we varied feed costs in 10% increments above and below the baseline (described above), to 60%–150% of baseline costs. We then re-evaluated optimal cow weights to assess the sensitivity of the results to feed efficiency and resource quality. The maximum annual

NPV per head per acre for all feed cost scenarios are reported in table 3.[4] In each case, 950-pound cows were found to be optimal. This result is driven by three factors. First, higher stocking rates for smaller cows result in more pounds weaned per acre. Second, lighter calves sell for a higher price per cwt. Third, even though feed costs do not increase linearly with cow weight, the increased revenue from heavier weaning weights do not offset the added feed cost of heavier cows.

Discussion

We assumed smaller-framed calves did not receive a discount at the sale barn when compared to medium- or large-framed calves. Lighter 950-pound cows, however, are more likely to have smaller-framed calves. Studies conducted using Arkansas sale barn data found animals identified as small-framed cattle received a price discount of as high as $22 per head. These cattle were then followed through the feedlot. Newport (2013) reported the discount was unjustified based on their performance, as smaller animals had higher net returns. The national average cow weight is currently 1,350 pounds (McMurry, 2009). Our analysis showed a 950-pound cow's calves would have to be discounted by $43 dollars per head each year of her life for a producer to be indifferent between a 950-pound cow and 1,350-pound cow on a per acre basis. While there currently are a wide range of beef cow weights in the Southern Plains, a multiyear sale calf price and characteristics data collection effort at Oklahoma State University has found zero small-framed calves in sale barns over the last six years. So, the concern over small-framed calves might not be warranted.

Rebreeding rates were assumed to be identical between cow weights. However, it seems reasonable to expect heavier cows to have lower rebreeding rates in nutritionally challenging environments.[5] We are unaware of any literature supporting or refuting this expectation, but if it holds, then our results are reinforced.

Finally, the model assumed identical dystocia rates for large and small cows. If bulls with low birth weight and high calving ease EPDs are used on herds with lighter cows, this may be the case. Unfortunately, no published data were found to support or reject this assumption. So a simple calculation was performed to evaluate the sensitivity of predicted optimal cow weights. For a producer to be indifferent between cows weighing 950 and 1,350 pounds on a per acre basis, dystocia rates would need to be 5% higher for the 950-pound cow.

Conclusion and Implications

This research builds on previous research considering a nonlinear relationship between cow weight and calf birth weight. Several herd scenarios common to U.S. Southern Plains beef cow–calf operations are included. Two forage types (Bermuda and native range), two breeds (Angus and Brangus), and two calving seasons (spring and fall) are considered in all possible combinations. The model computes NPVs associated with each of these scenarios and cow weights from 950 to 1,800 pounds, in 50-pound increments, and the NPV-maximizing weight was found on a per acre basis.

Data from two Oklahoma and one Arkansas research stations were utilized to determine the relationship between cow weight and calf weaning weight. Data were collected from 1988 to 2009 and included 3,041 observations. Rations were calculated using a software tool, CowCulator (Lalman and Gill, 2010). Using historical data, cow cull prices, calf prices, and feed prices were projected for 15 years to reflect price variation observed in a recent cattle cycle.

Fall-calving scenarios were found to have much higher feed costs then spring-calving scenarios. Angus cows have higher feed costs than Brangus cows. Spring-calving scenarios have higher NPVs

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[4] The year of the cattle cycle the heifer entered the herd was also varied to determine if NPV per head per acre–maximizing cow weights changes as price varies cyclically. The cattle price cycle was assumed to repeat after year 15. Optimal cow weights are constant at 950 pounds, not changing with the year of the cattle cycle heifers enter the herd.

[5] The authors are grateful to Dr. Damona Doye suggesting this possibility.

per acre than fall-calving scenarios. NPVs per head per acre are higher for spring-calving scenarios when compared to fall, Bermuda are higher than native, and Brangus are higher than Angus.

NPV per acre–maximizing cow weight does not vary with forage, feed cost, or the year in the cattle cycle in which the heifer enters the herd. The lightest cow considered, 950 pounds, was always NPV per acre maximizing. The additional revenue from larger cows is not high enough to overcome the ability to stock more light-weight cows on a fixed number of acres. In short, smaller cows produce more pounds per acre than do larger cows and sell for a higher price per pound.

The results here and elsewhere suggest that cow weights in the U.S. beef cow herd may be heavier than is economically advisable. Some studies have suggested that calves identified as small frame will be discounted (Newport, 2013). Sensitivity analysis indicated that, for price discounts less than $43 dollars per head, a 950-pound cow is more profitable than a 1,350-pound cow. If producers believe their smaller-framed calves will be highly discounted, there may be advantages to retaining ownership through the feedlot process (Newport, 2013).

Dystocia data related to cow weight were not available. There may be some concern that smaller cows will have more calving difficulties than larger-frame cows. Unfortunately, no literature was found to support or refute this concern. So, it is necessary to qualify the results of this study. The implied assumption is cow–calf producers match bull birth weight and calf ease direct EPDs with the frame size of their cows. At a dystocia rate of 5% higher for smaller cows, the optimal cow weight changes to favor heavier cows. Rogers et al. (2004) reported the relative risk of culling for cows with low breeding values (BV) for cow weight was only slightly larger than for cows with high BV. The difference in relative risk is about 0.5%, suggesting cow weight has a small causal effect on culling for all reasons and is unlikely to offset the economic advantages found here.

While smaller beef cows may be more economical, EPD selection for larger, faster-growing calves may have caused cow weights to surpass optimal weights (Smith, 2014). A possible solution is to create a maternal heifer replacement line focused on producing smaller cows while still maintaining high calving ease and fertility standards. It might be possible to accomplish the goal of reducing cow weights without damaging feedlot profitability. Research from North Dakota shows that finished steers from small- to moderate-framed cows were more profitable than steers from large-framed cows (Ringwall, 2016). The data were limited to one research herd, so generalizing to the industry level is not warranted, but it does demonstrate the potential.

While we focus on the cow–calf producer in this study, changing cow weight or frame size has implications for retailers and restaurants. As cow frame size increases, certain cuts of steak with a set shape, such as the ribeye, have larger surface areas. Larger steaks must be cut thinner to meet consumers' pound-per-package preferences. Behrends et al. (2009) reported consumers were willing to pay $1 per pound more for thicker steaks. Maples, Lusk, and Peel (2016) also find that consumers are willing to pay more for thicker steaks with a smaller surface area. Steaks from the offspring of smaller cows might be marketable to these consumers at a premium. However, the current pricing system does not reward feeders for carcasses with smaller ribeye and loin cross-sectional areas. Rather, the calculation for yield grade provides an incentive to increase ribeye area, suggesting incentives are misaligned if the industry is going to meet this demand.

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