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Genetic Parameter Estimates and Breed Effects for Calving Difficulty and Birth Weight in a Multi-Breed Population

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GENETIC PARAMETER ESTIMATES AND BREED EFFECTS FOR CALVING DIFFICULTY AND BIRTH WEIGHT IN A MULTI-BREED POPULATION.

By

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There are multiple breeds of beef cattle available to utilize in breeding systems to maximize production and economics. Calving difficulty (dystocia) is a significant cost to beef production and is more prevalent in first-calf heifers. The objectives of this study were to estimate genetic parameters and breed differences for calving difficulty and birth weight as a first step towards the development of across-breed adjustment factors for calving difficulty.

Two models were employed to analyze birth weight (BWT) and calving difficulty (CD) recorded on 4,579 first parity females from the Germplasm Evaluation program at the U.S. Meat Animal Research Center (USMARC). Both bivariate animal models fit CD and BWT either using CD scores based on USMARC scoring system (Model 1) or CD assigned as Z scores based on the midpoint incidence rate (Model 2).

Heritability estimates (SE) for BWT direct, CD direct, BWT maternal and CD maternal for model 1 were 0.35 (0.10), 0.29 (0.10), 0.15 (0.08), and 0.14 (0.08), respectively. Heritability estimates for BWT direct, CD direct, and BWT maternal for model 2 were similar to model 1. The estimate of CD maternal from model 2 was 0.13 (0.08). Genetic correlation estimates were positive between BWT direct and CD direct

(0.63 ±0.17; model 1) and (0.64±0.17; model 2). All other genetic correlations were not significant. *Bos Indicus* influenced breeds tended to have the largest estimates of BWT direct. Calving difficulty direct breed effects ranged from -1.01 to 7.50 for model 1 and from -1.06 to 7.36 for model 2. Calving difficulty maternal breed effects ranged from -1.55 to 5.27 for model 1 and from -1.55 to 5.25 for model 2.

Diverse biological types of cattle have different effects on both birth weight and calving difficulty. These differences can be used to match breeds to complement needs of production systems. Across-breed adjustment factors are needed for producers to accurately make selection decisions between sires of different breeds to improve calving difficulty.

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Introduction

At the beginning of 2010 there were 93.9 million cattle and calves recorded in the United States excluding Alaska, of the 93.9 million, 3.99 million (4.3%) died from predator and non-predator causes (USDA, 2011). Of the 3.99 million cattle that die each year, 494,000 (13.1%) are lost due to calving problems, causing an estimated economic loss of over $274 million (USDA, 2011). USDA also reports that different states across the U.S. experience different degrees of loss due to calving problems with the best states only experiencing approximately a 3% loss and the worst states experiencing a 21% loss. Over the past decades there has been a decrease in the average number of workers per farm making it even more important for producers to keep calving difficulty in their operation to a minimum (USDA, 2013b). With cattle prices at an all-time high since 2013 (USDA, 2013a) there is more incentive to maximize the number of cattle sent to market. The world population is expected to reach the 400 million mark by 2050 and with the decline in cattle numbers in the United States, each calf has to produce more pounds of meat. Improving calving difficulty could substantially improve beef cattle efficiency and increase cattle numbers.

Crossbreeding improves beef production efficiency through breed complimentary and heterosis (Cundiff et al., 1993). Using the underlying genetic diversity of breeds breed complimentary, in concert with heterosis, can match genetic potential with the production environment and marketing goals of the producer. Breed complementary is beneficial for calving difficulty, breeds known to have little calving difficulty can be mated to breeds that have more difficulty and produce calves that are born with little difficulty. However, heterosis is usually detrimental for calving difficulty direct as it can cause crossbred calves to have heavier birth weights. There are several different crossing systems that can be implemented and they all have advantages and disadvantages. However, with the invention of Artificial Insemination (AI) and even more recent advances including the availability of sexed semen, some of these crossbreeding systems have become easier for small producers to implement. Use of AI allows for a large number of producers to use elite genetics to decrease calving difficulty as well as improve production. Brinks et al. (1973) showed that the sex of the calf as well as the age of the dam influences calving difficulty. With the use of AI, sexed semen, and the strengths of different breeds producers can tailor a breeding program that minimizes calving difficulty and keeps production at a level that maximizes profit. Calves born to first parity dams tend to have more calving difficulty than calves born to later parity cows. With this knowledge, producers can mate their first parity cows to calving ease bulls and breed later parity cows more growth oriented sires. Sexed semen could be a tool to help minimize calving difficulty as first parity females could be bred to produce predominately heifer calves. However, sexed semen is a new technology, gaining a lot more use since the mid 2000's, that has added cost compared to traditional semen and has been shown to have lower conception rates compared to traditional AI or natural service (Norman et al., 2010).

Increased knowledge of genomic information from Single Nucleotide Polymorphisms (SNP) and advances in computational ability to analyze these data has allowed for genomic predictions that can be incorporated into Estimated Breeding Values (EBV) to increase accuracy (Spangler, 2012). Not every breed association has taken advantage of incorporating genomic information into EBV. Genomic information can be collected early in an animal's life to enhance accuracy, it is a valuable asset to producers who want to use young unproven sires to incorporate new genetics into their herd. The added accuracy from genomically enhanced EBV should improve confidence in the transmitting ability of young sires and help mitigate the risk of using unproven sires. Calving difficulty EBV can be modeled with a linear or threshold model. When incorporating molecular breeding values (MBV) into an EBV that is estimated using a threshold model, the MBV should be trained on the underlying scale (Kachman & Spangler, 2014). Genomic enhanced EBV are here to stay, and as larger resource populations of animals with both phenotypes and genotypes are built (Spangler, 2012), more breed associations will start incorporating genomic predictions into their respective EBV.

There are several different breeds of cattle used throughout the industry, some are used more than others, and every breed association has their own set of EBV. Given the independence of each breed association, it is impossible for producers to fairly compare bulls of different breeds against each other. This is a concern for commercial producers that are considering purchasing bulls of different breeds. Different breeds of cattle have different strengths, as some breeds are known for their maternal qualities were others are known for terminal qualities. The EBV of bulls across breeds might look similar in magnitude but they generally are not, because of differences in genetic trends and breed specific base adjustments. Although adjustment factors currently exist for many growth and carcass traits, they do not exist for calving difficulty (Kuehn and Thallman, 2012). Consequently, the objectives of this study were to estimate genetic parameters and breed differences for calving difficulty and birth weight as a first step towards the development of across-breed adjustment factors for CD.

Literature Review

Across-breed adjustments

Across-breed adjustments for Expected Progeny Difference (EPD) are needed for producers to compare and make selection decisions among sires from different breeds. Different breeds of cattle have prioritized different traits to improve over time, thus each breed has its own unique genetic trend that influences the breed's EPD. In addition to differences in genetic trend, each breed association sets an arbitrary base for each EPD, creating another source of differences between breeds. As of January 1, 2013, Gelbvieh, Red Angus, and Simmental EBV are generated by the American Simmental Association and are on the same base and can be directly compared to each other for growth and carcass traits as long as there are pedigree ties between the three breeds. Notter and Cundiff (1991) developed methods to compare birth weight, weaning weight, and yearling weight EBV from different breed associations. The Germplasm Evaluation program was utilized to estimate breed differences that are utilized in the across breed adjustments. The development of a common base to adjust growth traits, combined with breed association EBV, allows producers to compare sires from different breeds and make informed selection decisions. Over several years, these original methods (Cundiff, 1993) have under gone slight statistical changes to add random sire and dam effects, the use of mixed models to estimate regression coefficients, and to include the estimates of heterosis (Van Vleck et al., 2007). The addition of sire and dam effects helped to reduce the standard error for breed of sire solutions. The regression coefficients were obtained by taking the regression of progeny records from U. S. Meat Animal Research Center (USMARC) on breed association EBV (Van Vleck and Cundiff, 2005). Heterosis estimates were used to adjust progeny records to a base of 100% expected heterozygosity, since the objective was to compare sires of different breeds to produce crossbred calves (Van Vleck et al., 2007).

Currently the U.S. Meat Animal Research Center calculates across breed adjustments factors for 18 breeds for four or more traits including: birth weight, weaning weight, yearling weight, maternal milk, marbling score, ribeye area, and fat thickness. The factors adjust the EPD to an Angus base. However, with the American Gelbvieh Association now included in the American Simmental Association's multi-breed evaluations they have carcass across-breed adjustments. Across-breed adjustments are updated annually because breed differences change over time as different breeds put emphasis on different traits for genetic improvement, due to changes in models, and as GPE continues to collect data (Kuehn and Thallman, 2012). As breeds with smaller populations build progeny records in GPE adjustment factors for those breeds will continue to change. As breed means of EPD for traits change over time it will also change adjustment factors.

The calculation of across-breed adjustments relies on breed solutions from the analysis of records at USMARC GPE and on the average of within-breed EPD from the breed association (Kuehn and Thallman, 2012). The basic calculations are as follows:

$$M_i = USMARC(i)/b + [EPD(i)_{YY} – EPD(i)_{USMARC}]$$

and the breed table factor A_i to add to the EBV of breed i is equal to:

$A_i = (M_i – M_x) – (EPD(i)_{YY} – EPD(x)_{YY})$

where USMARC(i) is the USMARC breed of sire solution (1/2 breed solution) of breed i that is converted to an industry scale (divided by b) and adjusted for genetic trend. The pooled regression coefficient (b) of progeny performance at USMARC regressed on EPD of sire. $EPD(i)_{YY} – EPD(i)_{USMARC}$ is the difference between the average within-breed EPD for breed i to a base year (YY, which is two years before the update) and the weighted average EPD for sires of breed i that have descendants with records at USMARC. The base breed (x) in this case is Angus. $EPD(i)_{YY} – EPD(x)_{YY}$ is the difference between the average within-breed EPD for breed i and the average within-breed EPD for Angus.

Calving Difficulty

Calving difficulty (CD) represents a significant economic cost to beef production, through the loss of calves, death of dams, and extra labor required from the producer or veterinary assistance. Half of all difficult births are associated with the loss of calf and 40 to 60% of calf losses within the first 24 hours of birth are associated with calving difficulty (Meijering, 1984). Selection for reduced calving difficulty (dystocia) can be done to some extent through the use of birth weight (BWT) EBV due to the high positive correlation between birth weight and dystocia (Bennett & Gregory, 2001a; Mujibi et al., 2009). However, by selecting to reduce birth weight a correlated reduction in growth traits like weaning weight (rg=0.67) and yearling weight (rg=0.65) would be expected (Bennett and Gregory, 1996). Calving difficulty EBV directly predicts the genetic potential for animals to produce calves without difficulty and birth weight is typically used as an indicator trait (Mujibi et al., 2009). Although a correlated response in decreased growth would still be expected when selecting on CD EBV, the magnitude of the response would not be expected to be as large as compared to selecting on birth weight EBV. Birth weight is the major indicator of calving difficulty but it is not the only factor that influences dystocia. Calving difficulty is influenced by calf (direct) and dam (maternal) genetic effects as well as other factors like gestation length, age of dam, sex of calf, shape of calf, breed, mating system, pelvic area, and weight of dam (Brinks et al., 1973). Bennett and Gregory (2001a) reported a small negative correlation between direct and maternal effects for calving difficulty, which is slightly antagonistic to simultaneous improvement of both effects. Two year-old females are at greater risk than dams with multiple parities and male calves tend to experience more dystocia than female calves (Brinks et al., 1973). Brinks et al. (1973) showed an increase in calving difficulty with male born calves (10.5%) as compared to female calves (7.1%) as well as a wide range (5 to 13%) of calving difficulty among different lines of sires. A common reason that cows experience calving difficulty is due to having large calves relative to their inlet pelvic dimension.

Breed of sire and dam and age of the dam affect the birth weight and gestation length of calves and thus influence calving difficulty. Smith et al. (1976) reported that male born calves had 1.7 day longer gestation length than female calves. Smith et al. (1976) also reported that Limousin sired calves had the longest gestation length (288.1 days) and that Simmental, Charolais, and South Devon sired calves had similar gestation lengths. Reciprocal crosses of Angus and Hereford and Jersey sired calves had shorter gestation lengths than Limousin, Simmental, Charolais, and South Devon sired calves

(Smith et al., 1976). These effects of different sire breeds indicate the importance of additive genetic variability in gestation length (Smith et al., 1976). Breed of sire also affects the relationship between birth weight of the calf and its gestation length. Calves that are born from longer gestation length cows tend to be heavier at birth. Smith et al. (1976) showed a sire breed by age of dam interaction that has an effect on the amount of calving difficulty experienced with calves born to 2 year old females being more affected by the breed of sire than mature cows. Calves born to 2 year old females and sired by traditionally larger Continental breeds experienced greater calving difficulty than the same 2-year old females bred to British breed sires. Mature cows experience less calving difficulty than 2-year old females and were impacted less by the size of calf.

Calves born from difficult births had greater mortality than their contemporaries that were born unassisted. There is variability in mortality of calves born to difficult births among different sire breeds (Smith et al., 1976). Calves born to Charolais sires crossed on Angus and Hereford cows experienced the highest percentage of calf death loss within the first 24 hours (9.6 ±1.3%) but was not significantly different from calves born from Simmental and South Devon sires mated to Angus and Hereford cows (Smith et al., 1976). Breed of sire had different effects on dystocia for early mortality; dystocia had a greater effect on calf mortality from Charolais and Limousin sires (Smith et al. 1976). Calf survival was significantly affected by breed of sire but there was not significant variation among sires of the same breed (Cundiff et al., 1986). However variation in calf survival may also be attributed to environmental causes and be maternal in origin with respect to the maternal environment induced by the dam.

Cundiff et al. (1986) reported heritability estimates for calving difficulty, birth weight, gestation length, and calf survival of 0.421 ± 0.079, 0.793 ± 0.003, 0.775 ± 0.003, and 0.114 ± 0.086, respectively. There were strong positive genetic correlations between birth weight and calving difficulty (0.85 ± 0.04) and strong negative genetic correlations between birth weight and calf survival (-0.75 ± 0.10) and calving difficulty and calf survival (-0.69 ± 0.12) (Cundiff et al., 1986). Reduction in birth weight will reduce dystocia, but is a point at which a small birth weight is not optimal. When birth weight becomes too small then the viability of the calf becomes a concern. On the other hand calves that are too large cause dystocia, which can compromise the viability of calves, thus there is an optimal range of birth weight to limit dystocia and improve calf survivability. In contrast, Burfening et al. (1978) reported that direct selection for calving difficulty will reduce calving difficulty with little correlated reduction in birth weight and 205 day weight, while shorting gestation length. However, directly selecting for reduction in birth weight would not effectively reduce calving difficulty, and would also reduce 205 day weight (Burfening et al., 1978). Bellows et al. (1971) found a significant strong negative correlation between calving difficulty and pelvic width in Angus cows but not in Hereford cows. The Angus cows had lighter body weights compared to the Hereford cows suggesting that cows with lighter body weights tend to have smaller pelvic areas. Cows with smaller pelvic areas experience more calving difficulty than cows with larger pelvic area (Bellows et al., 1971).

Bellows et al. (1971) also investigated the impact of precalving body weight of the dam, total gestation weight gain, fat thickness and condition score of the dam, and gestation length and sex of the calf on birth weight. From these factors, precalving body weight had a significant large positive effect and was ranked the most important factor to either dam or calf on influencing calving difficulty. Dams with heavier precalving body weight had heavier calves at birth through some component of maternal environment but this did not seem to be associated with total gestation weight gain or precalving fat thickness of the dam (Bellows et al., 1971).

The effect of maternal environment on birth weight is not fully understood but there is reason to suggest that partitioning of nutrients between dam and fetus is not the same for large dams as smaller dams. Bennett and Gregory (2001a) reported the maternal heritability for calving difficulty varies among breeds. For calving difficulty maternal Pinzengauer and Braunvieh had the lowest estimates of maternal heritability (0.05 and 0.07, respectively) where Hereford and Gelbvieh had the highest estimates of maternal heritability (0.35 and 0.40, respectively) while estimates for other breeds were around 0.25. Permanent environment variance explained 2, 8, and 17% of the total phenotypic variance for calving difficulty score in Charolais, Limousin, and Maine-Anjou breeds, respectively (Phocas and Laloë, 2004). Regulation of fetus growth is largely effected by the placenta. The placental membrane of ruminants has sites called cotyledons that attach to caruncles on the uterine wall. The cauncular-cotyledonary unit is called a placentome and is the primary area of physiological exchange between mother and offspring (Funston et al., 2010). The efficiency of placental nutrient transport is directly related to uteroplacental blood flow. Research has shown that large increases in transplacental exchange, which supports the exponential increase in fetal growth during the last half of gestation, depends primarily on the dramatic growth of the uteroplacental vascular beds during the first half of pregnancy (Funston et al., 2010). Despite intensive research in the area of placental-fetal interactions there is still not much knowledge on how placental growth, uteroplacental blood flow, and vascularization are regulated. . Corah et al. (1975) reported that heifers fed a high-energy ration 100 days before calving gave birth to heavier calves than heifers offered a low-energy diet. Increasing body condition of heifers before calving has been shown to increase calf birth weight (Larson et al., 2009). Maternal birth weight is not the only factor effecting maternal calving difficulty, it is also affected by the pelvic size of the dam and the dams' ability to relax the pelvis.

Cows experiencing calving difficulty have a decrease in reproductive performance (Cammack et al., 2009). Lester et al. (1973) reported a 14.4% decrease in detection of estrus during a 45 day AI period in cows that required assistance compared to cows that did not require assistance. Conception rate for AI and total season breeding were 53.6 and 69.4% in cows experiencing dystocia compared to 69.2 and 85.3% in those not experiencing dystocia (Lester et al., 1973). Dystocia had a significant effect on non-return rate after first insemination and depended on the degree of difficulty, varying from 5 to 15% when calving was assisted by moderate traction and up to 25 to 45% after caesareans (Meijering, 1984).

Modeling

Beef Improvement Federation (BIF) guidelines recommend calving difficulty be recorded on a one to five scale, where the lowest (1) indicates no assistance required at calving and the highest (5) that considerable assistance or caesarian is needed (BIF, 2010). Evaluations of categorical traits usually require different methods as compared to normally distributed traits. Best linear unbiased prediction (BLUP) is the best approach for predicting random effects if the response variable is continuous, however categorical traits violate many assumptions for linear mixed models and thus BLUP is not an appropriate method (Abdel-Azim and Berger, 1999). The BLUP methodology is a suitable application when the response is quantitative and follows a fixed, mixed, or random linear statistical model (Harville and Mee, 1984). However, calving difficulty scores are discrete and thus not distributed normally and because of this, methods used to analyze continuous data are not appropriate (Varona et al., 1999a). The recording of calving difficulty by producers is done by assigning the difficulty of the birth to one of some number of *M* ordered categories. When modeling calving difficulty it is important to account for the effects of year, season, sex of calf, and the parity of the dam, as the frequency of difficulty is higher in first parity dams compared to older dams. BIF standards for age of dam at birth of calf groupings are females that are 2, 3, 4, 5 to 10, and 11 and older (BIF, 2010). Categorical traits like calving difficulty have been assumed to have an unobserved continuous variable that underlies the categorical traits and a threshold that designates the category (Wright, 1934). When considering a threshold model for calving difficulty data, the linear model for the underlying continuous response variable can be composed to incorporate the effects of year, season, sex, and sire and dam parity. Threshold models are quite flexible, as the distribution of **e** (residual) can be taken as a non-normal distribution. The model can also be expanded to multiple responses by having some components be ordered categorical and others be quantitative (Harville and Mee, 1984). A threshold model has an unobservable underlying variable usually normally distributed and a set of thresholds (Quaas et al. 1988).

The phenotype of the animal on the underlying scale is represented by a linear combination of parameters and random variables (Gianola, 1982). To apply BLUP procedures to ordered categorical data, the categorical response can be translated into a quantitative response by assigning ordered numerical values to the M categories and then proceed as if these discrete quantitative responses follow a mixed linear model. However, some of the assumptions implied in many mixed models, including those of additive effects and homogenous variance, may be less reasonable when applied to discrete responses instead of continuous responses (Harville and Mee, 1984). Linear models assume that the variable of interest is normally distributed and is continuous. With a threshold model the variable of interest is not normally distributed and the variable of interest is assigned to a category. Depending on the number of categories, calving difficulty can either have a multinomial distribution or a binomial distribution.

Calving difficulty has a strong correlation with birth weight, because of this relationship Janss and Foulley (1993) suggest a bivariate analysis for calving difficulty (threshold) that includes birth weight (linear) as a correlated indicator trait, with genetic and residual correlations between the two traits fully accounted for. With a bivariate linear-threshold model, the linear component can increase the accuracy of predicting the categorical trait (Varona et al., 1999b). Due to the categorical nature of calving difficulty recording, population differences in incidence rates, and its correlation with birth weight, calving difficulty has been modeled different ways. Calving difficulty can be modeled as univariate linear, univariate threshold, bivariate linear-linear and bivariate linear-threshold. With a univariate linear animal model both birth weight and calving difficulty are independently modeled as continuous traits Verona et al. (1999b). Alternativly, a univariate threshold animal model can be used for calving difficulty For calving difficulty the underlying distribution was modeled as continuous with the response to calving difficulty distribution modeled as thresholds that define the categories of response (Varona et al., 1999b). The bivariate linear-linear animal model was similar to the univariate linear animal model except birth weight and calving difficulty are assumed to be correlated. The bivariate linear-threshold animal model was similar to the univariate linear-threshold model except the traits were assumed to be correlated (Varona et al., 1999b). Varona et al. (1999b) looked at comparing the success of these four different models in their ability to predict calving difficulty. Based off of mean square error values, Varona et al. (1999b) found that the bivariate linear-threshold animal model did a slightly better job at predicting the genetic merit of calving difficulty than the bivariate linear-linear animal model (0.31 vs 0.33), there was not much difference in the predictive ability between the two different univariate models (0.39 vs 0.40). The largest improvement was seen when replacing a univariate model with a bivariate model. The stabilizing ability of the linear correlated trait may be why the threshold model showed greater advantage bivariate model rather than the univariate. Ramirez-Valverde et al. (2001) also compared the four different models and their ability to predict direct and maternal genetic solutions for calving difficulty and found that a higher accuracy for calving difficulty was observed when the correlated trait birth weight was included in the model. Correlations for direct genetic solutions were 10% higher for the threshold animal model than the linear animal model (0.69 vs 0.63). Similarly, the average correlation from the threshold-linear bivariate animal model was 4% higher than the linear-linear bivariate animal model (0.90 vs 0.86; Ramirez-Valverde et al., 2001). There was also a higher correlation between breeding values for calving difficulty and birth weight when a bivariate model is used rather than a univariate model. Phocas and Laloë (2003) reported a slightly negative correlation between direct and maternal calving difficulty for a univariate threshold model (-0.33) compared to a linear model (-0.31). When looking at maternal effects were included in the model, model rankings were similar to that of direct effects models. However, after parsing the data into a training and prediction set, the magnitude of the correlations between the true and predicted values were lower for the bivariate models when maternal effects were included (Ramirez-Valverde et al., 2001). The lower correlations observed by Ramirez-Valverde et al. (2001) when including maternal effects suggest that maternal effects for calving difficulty may be influenced by birth weight, suggesting that maternal effects for dystocia should be considered even if there is little interest in maternal genetic evaluation in bulls (Manfredi et al., 1991). In an animal model when the number of progeny per sire was increased the correlation coefficient stayed similar between the bivariate models with the threshold-linear model being better than the linear-linear model (0.90 vs 0.87). However the same was not seen in the univariate models. Depending on the number of progeny per sire (accuracy), there appears to be a difference in which univariate model works better. For moderate accuracy sires Ramirez-Valverde et al. (2001) observed that the linear model had a higher correlation between true and predicted values (0.71 vs 0.70) than the threshold model but when high accuracy sires were used the threshold model had a higher correlation (0.81 vs 0.80) than the linear model. There was not a difference in the ranking of the different bivariate and univariate models when a sire-maternal grandsire model was used instead of an animal model. Sire-maternal grandsire bivariate models had higher correlations then univariate models with small differences when using more accurate sires (Ramirez-Valverde et al., 2001).

An underlying issue relative to the development of across-breed EBV for CD direct and maternal is correctly accommodating the differences in models used by various beef breed associations in the estimation of EBV for these traits. All breeds use a multi-trait model fitting birth weight, but some use a linear-linear model while others use a threshold-linear model. Even within these two broad categories of model specification other differences exist. Some breeds combine categories, thus shrinking the number of potential scores on a linear scale. For breeds that utilize a probit function treating CD as a threshold character, the point at which CD is centered on the underlying scale differs. Also, the mean incidence of difficulty (e.g., 50%, 80%, etc.) at which the back-transformed EBV is calculated from the underlying EBV can be different. To correctly utilize breed differences towards the development of adjustment factors for breeders to use when comparing animals of different breeds for CD direct and maternal this larger issue of scaling must be addressed. Differences due to sire sampling undoubtedly impacts these estimates. For breeds where sampled sires' EBV deviate from their breed's mean EBV of calves born in a reference year (e.g. 2011), estimates should be adjusted for the sampling bias. However, this requires rescaling across breeds. Furthermore, sires that were born several decades ago may have had CD recorded in some breeds, but not in others. Genetic trend will be underestimated in breeds which began recording CD more recently and the disparity in data between breeds could bias estimates of breed differences.

Summary:

The beef industry's ultimate goal is to produce a high quality, healthy meat product that satisfies consumers. Calving difficulty may not seem like a critical component towards meeting this goal, calf survival is a key component that is substantially affected by calving difficulty. The ease of birth leads to the success of creating a quality product for consumers. It is known that calving difficulty has an economic impact on beef production. Calves born unassisted have a higher survival rate, as there tends to be fewer health issues that arise right after birth. Birth weight is the major contributor to calving difficulty but it is not the only factor. Dystocia is also affected by the shape of the calf, gestation length, sex of the calf, age of the dam, breed of calf and dam, and the pelvic area of the dam. Previously, producers have selected to decrease birth weight as a means to decrease dystocia. However, with the strong positive correlation between birth weight and growth traits, putting selection pressure on decreasing birth weight can lead to decreased growth. . The EBV of different cattle breeds are not directly comparable. This limitation becomes an issue when producers are considering the use of sires from different breeds to enhance the genetic potential of their operation. Across breed adjustment factors provide the ability for producers fairly compare the genetic merit of sires of different breeds and select the one that will be the most beneficial for their operation. Across breed adjustment factors have already been developed for growth and carcass traits. Calving difficulty is a complex trait that has an impact on the industry and because of this impact across breed adjustment factors for calving difficulty EBV are necessary. Across breed adjustment factors for calving difficulty are not as straight forward as growth and carcass traits because calving difficulty EBV are calculated more than one way and differences exists in the models us by various breed associations. For the development of across breed EBV for CD we must account for not only the mean effect of each breed but also for differences in models used and resulting scaling differences.

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Genetic Parameter Estimates and Breed Effects for Calving Difficulty and Birth Weight in a Multi-Breed Population.

Abstract

Birth weight (BWT) and calving difficulty (CD) were recorded on 4,579 first parity females from the Germplasm Evaluation (GPE) program at the U.S. Meat Animal Research Center (USMARC). Both traits were analyzed using a bivariate animal model with direct and maternal effects. Model 1 fit calving difficulty scores using the USMARC scoring system where model 2 fit calving difficulty using Z scores located at the midpoint incidence rate of each USMARC score. Breed fraction covariates were included to estimate breed differences. Heritability estimates for BWT direct, CD direct, BWT maternal and CD maternal for model 1 were 0.35 (0.10), 0.29 (0.10), 0.15 (0.08), and 0.14 (0.08), respectively. Heritability estimates for BWT direct, CD direct, and BWT maternal for model 2 were similar to model one. The heritability estimate of CD maternal from model 2 was similar to model 1. Genetic correlation estimates for model 1 were 0.63 (0.17), 0.41 (0.38), -0.44 (0.51), 0.18 (0.36), 0.17 (0.42), and -0.16 (0.29) between BWT direct and CD direct, CD direct and BWT maternal, BWT maternal and CD maternal, BWT direct and CD maternal, CD direct and CD maternal, and between BWT direct and BWT maternal, respectively. Genetic correlation estimates for model 2 were similar to model 1. *Bos Indicus* influenced calves appeared to have the heaviest BWT. Not all breed associations report a calving difficulty direct and maternal EBV. Among the breeds that have CD and calving difficulty maternal EBV, Hereford appeared to experience the least calving difficulty direct and maternal for both models. Braunvieh

and Shorthorn experienced the most calving difficulty direct for both models. Braunvieh, Chiangus, and Red Angus experience the most calving difficulty maternal for both models. There was little re-ranking of animals between the two models. Rank correlations for all animals, high and low accuracy sires were 0.994, 0.995, and 0.993, respectively. Rank correlations between direct effects from both models and maternal effects from both models were 0.99 and 0.99, respectively.

Introduction

Calving Difficulty (Dystocia) is a significant cost to beef production and is most prevalent in first-calf heifers. Dystocia increases the likelihood of calf and dam mortality, postpartum interval, and labor and veterinarian costs (Bennett and Gregory, 2001). Calving difficulty is affected by both direct (calf) and maternal (dam) genotypes. Factors affecting calving difficulty include age of dam, sex of calf, shape and weight of calf, gestation length, breed, sire of calf, pelvic area of dam, and weight of dam (Brinks et al., 1973). Calving difficulty has been shown to have a high and positive correlation with birth weight thus selection to decrease birth weight (BWT) can be used to reduce calving difficulty (Bennett and Gregory, 2001). However, using bulls with low BWT estimated breeding values (EBV) may decrease growth potential in the absence of selection pressure on growth. Calving difficulty (CD) EBV predicts the ability of calves to be born unassisted and typically includes BWT as an indicator trait.

Different breeds allow for the exploitation of heterosis and complementarity to match genetic potential with markets, feed resources, and climates (Cundiff et al., 1998). However, in the current U.S. beef industry, it is generally not possible to directly compare the EBV of animals across breeds without the aid of adjustment factors. Across-breed adjustments were first developed in 1991 by Notter and Cundiff (1991). They were developed so producers could compare sires of different breeds as breed associations EBV have different base years of cows (Van Vleck et al., 2007) thus EBV are not directly comparable. Across-breed adjustment factors have most recently been estimated by Kuehn and Thallman (2014) for birth weight, weaning weight, yearling weight, maternal milk, marbling score, ribeye area, and fat thickness. Unfortunately, across-breed adjustment factors do not exist for CD.

Consequently, the objectives of this study were to estimate genetic parameters and breed differences for calving difficulty and birth weight in the U.S. Meat Animal Research center Germplasm Evaluation program (GPE) as a first step towards the development of across-breed adjustment factors for CD.

Materials and Methods

Animals

All animal procedures were approved by USMARC Animal Care and Use Committee and cattle treated according to FASS guidelines. Pedigree and performance data used in this study originated from the Germplasm Evaluation (GPE) program at the U.S. Meat Animal Research Center (USMARC). The mating plans for cycle 1 (phases 2 and 3) and cycles 2-8 (phase 3 from phase 2 heifers) can be found in tables 1-9 in the appendix, respectively. Data from the continuous evaluation of eighteen breeds in GPE were also included (Kuehn et al., 2008). The 18 breeds involved in the evaluation are Angus, Hereford, Red Angus, Shorthorn, South Devon, Beefmaster, Brangus, Brahman, Santa Gertrudis, Braunvieh, Charolais, Chiangus, Gelbvieh, Limousin, Maine-Anjou, Salers, Simmental, and Tarentaise.

Data were recorded for CD and BWT on 5,795 calves born to first parity females. Animals were removed from the dataset if they were born with an abnormal presentation (12.2%) (e.g., breach), presented with cryptorchidism (0.2%), or born to a founder female or a twin (72.6%). Animals born before 1970 (spring born) (0.6%) or before 2007 (fall born) (14.4%) were excluded from the analysis. These cutoffs represent the start dates of evaluation of GPE progeny. After edits there were a total of 4,579 records. Cows were monitored closely for calving difficulty and were assigned a calving difficulty score as outlined in Table 1. Birth weights were recorded within the first twenty-four hours of calving. Figure 1 shows the mean birth weight for each calving difficulty score. Figure 2 shows that male calves have a heavier mean birth weight per year than female calves and that spring born calves are heavier than fall born calves. Figure 3 shows that male calves have a higher mean calving difficulty score per year than female calves and spring born calves experience more calving difficulty than fall born calves on average.

Statistical analysis

Two bivariate animal models were fit including CD and BWT. Model 1 included calving difficulty using the USMARC scoring system. Model 2 included CD transformed from the USMARC scores to the corresponding Z scores from the standard normal distribution (Table 1) based on incidence rate of the USMARC scores. The midpoint value of the incident rate between each USMARC score was used to assign Z scores. A threshold-linear model where calving difficulty was treated as a threshold trait and birth weight as linear was not utilized because an animal model with both direct and maternal effects did not reach convergence. Both models included fixed effects for sex, breed (fitted as covariates), contemporary group (concatenation of year and season of birth and location of birth at USMARC), and covariates for direct and maternal heterosis. Random effects included direct and maternal effects, and a residual. The covariates for heterosis direct and maternal were allocated as the regression on expected breed heterozygosity fraction. For heterosis calculation, AI sires and commercial cows of the same breed were considered the same breed, Red Angus was assumed the same as Angus, and composite breeds were considered according to their nominal breed composition. Composite breeds consisted of MARC II (¼ Angus, ¼ Hereford, ¼ Simmental, and ¼ Gelbvieh), MARC III (¼ Angus, ¼ Hereford, ¼ Red Poll, and ¼ Pinzgauer), Brangus (⅜Brahman and ⅝Angus) Santa Gertrudis (⅜Brahman and ⅝Shothorn), Beefmaster (½ Brahman, ¼ Angus, and ¼ Shorthorn), Chiangus(½ Chianina and ½ Angus), and ½ Red Angus ½ Simmental cross cows. Breed fractions were determined based on pedigree information; each animal was assigned half of its sire breed and half of its dam breed. Breed fractions were assigned for each individual and assigned as covariates for breed effects. Founder animals were AI sires or dams with unknown sire parentage. Founder animals were assigned to their respective breeds and used to assign breed fractions throughout the pedigree.

REML estimates of variance components and fixed effects were estimated using ASReml version 3.0 (ASReml User Guide Release 3.0*,* 2009). Birth weight and calving difficulty breed differences were deviated from Angus. Birth weight breed differences were adjusted to current (2012) breed mean EBV by accounting for the sampled AI sires by adding the sampling effect of sires to estimated breed effects. The sampling effect of sires was accounted for by estimating the weighted (using average relationship to phenotyped progeny) average EBV of AI sires that had descendants with records, deviated from the mean EBV of their respective breed for calves born in 2012 following:

$$(\mathrm{EBV(i)YY} - \mathrm{EBV(i)USMARC})$$

Where $\mathrm{EBV(i)}_{YY} - \mathrm{EBV(i)}_{USMARC}$ is the difference between the average within-breed EBV for breed i to a base year (YY) of 2012 and the weighted average EBV for sires of breed i that have descendants with records at USMARC.

Calving difficulty breed differences were standardized by the following:

$$\frac{BreedSoln}{\sigma_a}$$

Where *BreedSoln* were the estimated breed effects from the current analysis and sigma was the additive genetic standard deviation. The standardized estimated breed effects were then corrected for sampling of AI sires. Sampling of AI sires were standardized by the following:

$$\frac{(\mathrm{EBV(i)YY} - \mathrm{EBV(i)USMARC}) \times (-1)}{\sigma_{r(i)}}$$

Beef cattle breeds in the U.S. report EBV for calving ease, not calving difficulty. To convert breed association calving ease EBV to calving difficulty EBV the weighted calving ease EBV for AI sires were multiplied by -1. The residual standard deviation ($\sigma_{r(i)}$) was obtained by fitting a simple linear model with the fixed effect of year to account for sampling bias that could occur by year principally due to base differences that occurred overtime in CD evaluations by breed. Sire sampling adjustments were standardized to account for the different models that breed associations use. Breed effect estimates were standardize to allow sire sampling adjustments to be made.

Results and Discussion

Genetic parameters

Estimates of variance components for BWT and CD for models 1 and 2 are presented in Tables 2 and 3, respectively. Direct and maternal variance estimates for BWT were similar for both models. Model 1 had larger CD direct variance estimates (0.5 vs. 0.25) than model 2 as well as larger CD maternal variance estimates (0.12 vs. 0.05). Model 1 also had larger covariance and residual estimates between CD direct and BW maternal, BW direct and CD maternal, and CD direct and maternal. Estimates of direct and maternal heritability for BWT and CD and their correlations for models 1 and 2 are presented in Tables 4 and 5, respectively. Heritability estimates for direct and maternal BWT and CD were similar for both models. Mujibi and Crews (2009) reported higher direct heritability estimates and similar maternal heritability estimates for BWT and Bennett and Gregory (2001) reported higher heritability for direct and maternal heritability for CD in 2-yr old females.

Direct and maternal variances and correlations between direct and maternal for BWT are similar to those obtained by Mujibi and Crews (2009). Bennett and Gregory (2001) reported higher correlations between CD and BWT direct than reported in the present study. The positive correlation between BWT direct and CD direct suggest that as birth weight increases calving difficulty score also increases. Bennett and Gregory (2001) reported similar strength in correlation between BWT direct and CD maternal (-0.16) but differed in direction compared to model 1 (0.18) and model 2 (0.11). Bennett and Gregory (2001) reported a stronger negative correlation between direct CD and maternal CD (-0.26) as opposed to the estimates from model 1 (0.17) and model 2 (0.10). The positive correlation between CD direct and CD maternal suggests that as direct CD difficulty increases maternal CD will also increase although literature would suggest that as CD direct increases maternal CD will decrease. It should be noted that the correlations presented here are associated with large standard errors and are not significantly different from zero. Bennett and Gregory (2001) reported a moderate positive correlation between CD maternal and BWT maternal (0.34) compared to the moderate negative correlation estimated in model 1 (-0.44) and model 2 (-0.42). The negative maternal CD and maternal BWT correlation estimated in both models suggest that as maternal CD increases maternal BWT decrease. Females that have less calving difficulty will also have lighter calves. Bennett and Gregory (1996) reported an estimate of similar strength but differed in direction between BWT direct and BWT maternal for composite breeds (MARC II and MARC III; 0.14) and weaker correlations for the purebred that make up the composites (0.08) compared to the estimate 0.16 from both models in the current study.

The rank correlations between EBV from model 1 and model 2 were 0.994, 0.995, and 0.993 between all animals, high accuracy sires, and low accuracy sires, respectively. These correlations imply that re-ranking of animals between the two models is minimal. Rank correlations between direct and maternal breed effects were 0.99 and 0.99, implying that there was minimal re-ranking of breeds between the two models.

Breed effects for birth weight:

EBV adjusted breed effects for BWT are presented in Table 6 and were the same for both models. The breed solutions for BWT presented here majorly differ from those previously reported by Kuehn and Thallman (2014). There are several likely reasons for this discrepancy. Kuehn and Thallman (2014) used mature cow data as well as the heifer data from this study for a total of over 30,000 birth weight records. The breeds with the largest changes between the studies included those in which over half of the phenotypes in the present study were generated from continuous GPE where heifers were bred back to their breed of sire via artificial insemination, potentially creating partial confounding between direct and maternal breed effects.

Among the British breeds, Shorthorn calves were estimated to have the heaviest birth weights whereas Red Angus calves were estimated to have the lightest birth weights. Among the *Bos Indicus* influenced breeds, Brahman were estimated to have the heaviest birth weights and Brangus calves were estimated to have the lightest birth weights. Among the Continental breeds, Charolais calves were estimated to have the heaviest birth weights and Salers and Tarentaise calves were estimated to have the lightest birth weights. Cundiff et al. (1986) reported that high growth rate breeds (Simmental, Maine-Anjou, Brahman and Charolais) had heavier birth weights where low growth rate breeds (Hereford, Angus, and South Devon) had lighter birth weights.

Estimates of breed effects show similar results except for Hereford, Simmental, and Maine-Anjou where estimates suggest that Hereford have larger birth weights than Simmental and Maine-Anjou in contrast to Cundiff et al. (1986) who reported that Hereford had lower birth weights. These differences reflect the changes in selection that have occurred within breed over time.

Breed effects for calving difficulty

Breed effects for CD direct and maternal are presented in Tables 7 and 8 for model 1 and 2, respectively. Breeds without estimates reflect breed associations that do not have CD and calving difficulty maternal (CDM) EBV. For both models, Shorthorn was estimated to have the greatest amount of calving difficulty direct with model 1 having the higher breed effect estimate (3.72) than model 2 (3.59) where Red Angus was estimated to have the greatest amount of calving difficulty maternal with model 2 having the higher breed effect estimate (2.43) than model 1 (2.29). Hereford experienced the least difficulty at calving both direct with model 2 having the lower breed estimate (-1.06) than model 1 (-1.01) and maternal with model 2 having the lower breed estimate (-1.42) than model 1 (-1.34) among the British breeds for both models. Within the continental breeds for both models Braunvieh experienced the most calving difficulty direct with model 1 having a higher breed estimate (7.50) than model 2 (7.36) and maternal with model 2 having a larger breed estimate (5.27) than model 1 (5.25). For both models Tarentaise experience the least calving difficulty direct with model 1 having a lower breed effect (-0.78) than model 1 (-0.67). For both models Salers experience the least calving difficulty maternal with model 1 having a lower breed effect estimate (-0.90) than model 2 (-0.79). Tarentaise maternal breed effects were based on only 36 dams that were 50% Tarentaise, thus creating estimability problems. Cundiff et al. (1986) reported that high growth rate breeds (Simmental, Maine-Anjou, and Charolais) experience more calving difficulty direct than low growth rate breeds (Hereford and Angus) the estimates of breed effects show similar results Simmental. Reynolds et al. (1990) reported that dams breed to large size sire breed experience more calving difficulty then dams breed to medium size sire breeds. Figures 4 and 5 plot model 1 vs 2 breed solutions for direct and maternal calving difficulty, respectively. This plot shows that the breed solutions move in the same direction in both models.

Challenges for developing across-breed EBV adjustments for calving difficulty

An underlying issue relative to the development of across-breed EBV for CD direct and maternal is correctly accommodating the differences in models used by various beef breed associations in the estimation of EBV for these traits. All breeds use a multi-trait model fitting BWT, but some use a linear-linear model while others use a threshold-linear model. Even within these two broad categories of model specification other differences exist. Some breeds combine categories, thus shrinking the number of potential scores on a linear scale. For breeds that utilize a probit function treating CD as a threshold character, the point at which CD is centered on the underlying scale differs. Also, the mean incidence of difficulty (e.g., 50%, 80%, etc.) at which the back-transformed EBV is calculated from the underlying EBV can be different. To correctly estimate breed differences towards the development of adjustment factors for breeders to use when comparing animals of different breeds for CD direct and maternal this larger issue of scaling must be addressed. Differences due to sire sampling undoubtedly impact these estimates. For breeds where sampled sires' EBV deviate from their breed's mean, EBV of calves born in a reference year (e.g. 2011), estimates should be adjusted for the sampling bias. However, this requires rescaling. Furthermore, sires that were born several decades ago may have had CD recorded in some breeds, but not in others. Genetic trend will be underestimated in breeds which began recording CD more recently and the disparity in data between breeds could bias estimates of breed differences.

Implementation of existing across-breed EBV has been through a table of additive adjustment factors. The scaling differences between breeds makes this approach problematic for CD. An updated delivery model (perhaps web-based) would be required to effectively implement across-breed EBV for CD. It would also allow substantial improvements to the system for other traits.

Conclusion:

Both BWT and CD direct are moderately heritable allowing for genetic selection to improve calving difficulty but are lowly heritable for maternal effects. Birth weight explained 41% of calving difficulty variation in model 1 and 40% of calving difficulty variation in model 2. Selecting to improve calving difficulty direct will have little effect on calving difficulty maternal. Selecting to improve calving difficulty direct will moderately increase maternal birth weights. Selecting to improve calving difficulty maternal will moderately decrease maternal birth weights. Selection on birth weight direct will have little effect on calving difficulty maternal and birth weight maternal. . Calving difficulty direct breed effects ranged from -1.06 to 7.36 for model 1 and ranged from -1.01 to 7.50 for model 2. Calving difficulty maternal breed effects ranged from -1.42 to 5.27 for model 1 and from -1.34 to 5.27 for model 2. Hereford, Simmental, Gelbvieh, and Tarentaise would be the most likely to reduce calving difficulty direct, where Braunvieh, Shorthorn, Salers, and Limousin would be the least likely to reduce calving difficulty direct. Hereford, Salers, and Tarentaise would be the most likely to reduce calving difficulty maternal, where Braunvieh, Red Angus, and Chiangus would be the least likely to reduce calving difficulty maternal. Results show that the diverse biological types of cattle have different effects on both BWT and CD. There is not a clear pattern that one biological type is better or worse for reducing calving difficulty (direct or maternal). There are British and Continental breeds that rank among the best for reducing calving difficulty direct and maternal and there are breeds that rank the worst. *Bos Indicus* influenced breeds rank in the middle relative to their ability to reduce calving difficulty direct and maternal. These differences can be used to match breeds to complement needs of production systems. Between the two different models there was very little reranking of animals or among high and low accuracy sires. There were small differences in breed effects estimated among the two models for CD. Issues to be resolved to develop an across-breed adjustment for calving difficulty direct and maternal includes accounting for different models used by breed association. Some breed association use a linear model and some use a threshold model. Among breed associations that use linear models there can be differences between the number of categories that are used and the incidence rates for each category. Among breed associations using a threshold model there are differences in the incidence rates, where centering occurred on the underlying scale, and the number of categories used. Scaling factors need to be developed to account for these differences. This work will serve as the foundation for the estimation of across-breed EBV for calving difficulty in the U.S.

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Table 1. Description of calving difficulty score

USMARC Score[a]	Z score[b]	Difficulty Level	Incidence rate	Mid point value
1	-0.33	No assistance given	74%	37.0
2	0.68	Little difficulty, assisted by hand	2.3%	75.1
3	0.81	Little difficulty, assisted by calf jack	5.7%	79.2
4	1.18	Slight difficulty, assisted by calf jack	12%	88.0
5	1.62	Moderate difficulty, assisted by calf jack	1.5%	94.8
6	1.86	Major difficulty, assisted by calf jack	2.7%	96.9
7	2.35	Caesarean birth	1.8%	99.1

[a]USMARC calving difficulty scores
[b]Z score based on the midpoint incidence rate

Table 2: Residual, direct, and maternal (co)variance estimates for birth weight and calving difficulty (MARC scale[a])

Trait[bc]	**BWT_r, kg**	**CD_r**	**BWT_d, kg**	**CD_d**	**BWT_m, kg**	**CD_m**
BWT_r, kg	10.65 (1.56)					
CD_r	0.78 (0.35)	0.93 (0.14)				
BWT_d, kg			6.94 (1.93)			
CD_d			1.17 (0.43)	0.50 (0.17)		
BWT_m, kg			-0.73 (1.52)	0.50 (0.39)	3.01 (1.59)	
CD_m			0.23 (0.44)	0.06 (0.13)	-0.38 (0.34)	0.25 (0.14)

[a]Calving difficulty reported on USMARC scale 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, 6= major difficulty, and 7= caesarean.

[b] Birth weight residual (BWT_r), calving difficulty residual (CD_r), birth weight direct (BWT_d), calving difficulty direct (CD_d), birth weight maternal (BWT_m), and calving difficulty maternal (CD_m)

[c]Variances and their standard errors are on the diagonal and covariance are on the off diagonal.

Table 3: Residual, direct, and maternal (co)variance estimates for birth weight and calving difficulty (standardized score[a])

Trait[bc]	**BWT_r, kg**	**CD_r**	**BWT_d, kg**	**CD_d**	**BWT_m, kg**	**CD_m**
BWT_r, kg	10.68 (1.55)					
CD_r	0.37 (0.17)	0.23 (0.03)				
BWT_d, kg			6.91 (1.93)			
CD_d			0.58 (0.21)	0.12 (0.04)		
BWT_m, kg			-0.75 (1.52)	0.26 (0.19)	3.03 (1.59)	
CD_m			0.07 (0.21)	0.01 (0.03)	-0.17 (0.17)	0.05 (0.03)

[a]Calving difficulty reported as Z scores based on midpoint of the continuous incidences rate
[b] Birth weight residual (BWT_r), calving difficulty residual (CD_r), birth weight direct (BWT_d), calving difficulty direct (CD_d), birth weight maternal (BWT_m), and calving difficulty maternal (CD_m)
[c]Variances and their standard errors are on the diagonal and covariance are on the off diagonal.

Table 4: Direct, and maternal correlation estimates for birth weight and calving difficulty (MARC scale[a])

Trait[bc]	**BWT_d, kg**	**CD_d**	**BWT_m, kg**	**CD_m**
BWT_d, kg	0.35 (0.10)			
CD_d	0.63 (0.17)	0.29 (0.10)		
BWT_m, kg	-0.16 (0.29)	0.41 (0.38)	0.15 (0.08)	
CD_m	0.18 (0.36)	0.17 (0.42)	-0.44 (0.51)	0.14 (0.08)

[a]Calving difficulty reported on USMARC scale 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, 6= major difficulty, and 7= caesarean.

[b] Birth weight residual ($BWT_{r,}$) calving difficulty residual (CD_r) birth weight direct (BWT_d), calving difficulty direct (CD_d), birth weight maternal (BWT_m), and calving difficulty maternal (CD_m)

[c]Heritabilty and their standard errors are on the diagonal and covariance are on the off diagonal.

Table 5: Direct, and maternal correlations estimates for birth weight and calving difficulty (standardized scores[a])

Trait[bc]	BWT_d, kg	CD_d	BWT_m, kg	CD_m
BWT_d, kg	0.34 (0.10)			
CD_d	0.64 (0.17)	0.29 (0.10)		
BWT_m, kg	-0.16 (0.29)	0.43 (0.38)	0.15 (0.08)	
CD_m	0.11 (0.37)	0.10 (0.42)	-0.42 (0.53)	0.13 (0.08)

[a]Calving difficulty reported as Z scores based on midpoint of the continuous incidence rate
[b] Birth weight residual (BWT_r), calving difficulty residual (CD_r), birth weight direct (BWT_d), calving difficulty direct (CD_d), birth weight maternal (BWT_m), and calving difficulty maternal (CD_m)
[c]Heritability and their standard errors are on the diagonal and correlations are on the off diagonal.

Table 6: Birth weight breed effects[a]

Breed	Ave. Base EBV		Breed Soln[d]	BY 2012 Breed Difference[e]
	Breed 2012[b] (1)	USMARC Bulls[c] (2)	at USMARC (vs Angus) (3)	(4)
Angus	3.4	3.0	0	0.0 (0)
Hereford	7.0	4.1	0.62	3.10 (1.27)
Red Angus	-2.4	-4.9	-2.71	-0.60 (1.89)
Shorthorn	4.4	1.7	3.77	6.10(2.13)
South Devon	5.2	4.4	1.49	1.90 (2.03)
Beefmaster	0.6	1.6	1.42	0.10 (3.34)
Brahman	3.4	1.1	6.17	8.10 (2.68)
Brangus	1.6	0.9	-3.13	-2.90 (4.24)
Santa Gertrudis	0.4	0.7	6.53	5.80 (2.71)
Braunvieh	5.6	7.2	4.91	2.90 (2.42)
Charolais	1.0	-0.8	2.99	4.40 (1.32)
Chiangus	7.4	5.7	0.61	1.90 (2.66)
Gelbvieh	1.6	2.9	-0.75	-2.40 (1.83)
Limousin	3.4	2.0	1.95	3.00 (1.28)
Maine-Anjou	3.4	3.7	-3.11	-3.80 (2.63)
Salers	3.2	3.3	-5.17	-5.70 (2.45)
Simmental	4.4	6.1	3.10	1.00 (1.41)
Tarentaise	3.8	3.5	-4.72	-4.90 (4.71)

[a]Breed effect estimates and standard errors adjusted for sire sampling
[b]The average within-breed EBV for each breed for birth year 2012
[c]The weighted average EBV of bulls for each breed having descendants with records at USMARC
[d]Estimated breed effects solutions from analysis of USMARC data with Angus set as the base
[e]Estimated breed effects corrected for sire sampling for birth year 2012 as calculated by:
(4)= (3) + [(1) – (2)]

Table 7 Calving difficulty score direct breed effects[a]

Breed	Ave Base EBV		Residual Standard Deviation[f] (3)	Breed Soln at USMARC (vs Ang)[g]		BY 2012 Breed Difference[h]	
	Breed 2012[d] (1)	USMARC Bulls[e] (2)		Model 1[b] (4)	Model 2[c] (5)	Model 1[b] (6)	Model 2[c] (7)
Angus	-10.0	-4.1	5.8	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Hereford	-1.6	8.1	4.3	0.15 (0.37)	0.06 (0.18)	-1.01(0.37)	-1.06(0.18)
Red Angus	-8.0	-10.5	8.0	0.41 (0.54)	0.12 (0.26)	1.91 (0.54)	1.68 (0.26)
Shorthorn	2.6	-0.4	5.6	1.53 (0.62)	0.71 (0.30)	3.72 (0.62)	3.59 (0.30)
South Devon							
Beefmaster							
Brahman							
Brangus	-10.2	-9.8	3.1	0.02 (1.25)	-0.04 (0.60)	0.92 (1.25)	0.77 (0.60)
Santa Gertrudis							
Braunvieh	0.4	-10.5	2.5	1.44 (0.71)	0.66 (0.34)	7.50 (0.71)	7.36 (0.34)
Charolais	-6.0	-3.9	6.1	1.29 (0.38)	0.59 (0.18)	2.50 (0.38)	2.37 (0.18)
Chiangus	-11.0	-14.4	5.8	0.67 (0.77)	0.27 (0.38)	2.55 (0.77)	2.38 (0.38)
Gelbvieh	-19.4	-14.2	5.4	0.43 (0.53)	0.17 (0.26)	0.68 (0.53)	0.55 (0.26)
Limousin	-18	-18.8	7.4	1.17 (0.37)	0.52 (0.18)	2.79 (0.37)	2.64 (0.18)
Maine-Anjou	-18.4	-13.7	4.7	0.87 (0.77)	0.40 (0.37)	1.25 (0.77)	1.20 (0.37)
Salers	-0.6	-0.9	1.3	1.16 (0.65)	0.51 (0.32)	2.89 (0.65)	2.72 (0.32)
Simmental	-18.6	-10.5	5.9	0.96 (0.41)	0.41 (0.20)	0.99 (0.41)	0.81 (0.20)
Tarentaise	2.4	-1.3	4.8	-1.81 (1.44)	-0.85 (0.68)	-0.78 (1.44)	-0.67 (0.68)

[a]Breed effect estimates and standard errors adjusted for sire sampling. Breeds without solutions reflect breeds without EBV recorded in their association

[b]Calving difficulty reported on USMARC scale 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, and 6= major difficulty.
[c]Calving difficulty reported as Z scores based on midpoint of the incidence rate
[d]The average within-breed EBV for each breed for birth year 2012
[e]The weighted average EBV of bulls for each breed having descendants with records at USMARC
[f]The residual standard deviation was obtained by fitting a simple linear model with the fixed effect of year to account for sampling bias that could occur by year in EBV
[g]Estimated breed effects solution from analysis of USMARC data with Angus set as the base
[h]Estimated breed effects corrected for sire sampling for birth year 2012
Calculations:
(6)= $\{(4)/STD_{a1} + \{[(1) - (2)]/(3)\}\} - \{[(1) - (2)]/(3)\}_{Angus}$ where STD_{a1} is the direct additive genetic standard deviation from model 1
(7)= $\{(5)/STD_{a2} + \{[(1) - (2)]/(3)\}\} - \{[(1) - (2)]/(3)\}_{Angus}$ where STD_{a2} is the direct additive genetic standard deviation from model 2

Table 8 Calving difficulty score maternal breed effects[a]

Breed	Ave Base EBV		Residual Standard Deviation[f] (3)	Breed Soln at USMARC (vs Ang)[h]		BY 2012 Breed Difference[h]	
	Breed 2012[d] (1)	USMARC Bulls[e] (2)		Model 1[b] (4)	Model 2[c] (5)	Model 1[b] (6)	Model 2[c] (7)
Angus	-16.0	-7.5	4.8	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Hereford	-2.2	9.8	3.1	0.34 (0.27)	0.17 (0.13)	-1.42 (0.27)	-1.34 (0.13)
Red Angus	-10.0	-15.6	8.0	-0.08 (0.46)	0.01 (0.22)	2.29 (0.46)	2.43 (0.22)
Shorthorn	2.8	1.6	6.1	-1.28 (0.57	-0.62 (0.27)	-0.59 (0.57)	-0.80 (0.27)
South Devon							
Beefmaster							
Brahman							
Brangus	-14.2	-14.1	1.0	-0.17 (0.87)	-0.08 (0.41)	1.30 (0.87)	1.23 (0.41)
Santa Gertrudis							
Braunvieh	1.2	-10.0	2.2	-0.85 (0.68)	-0.39 (0.32)	5.27 (0.68)	5.25 (0.32)
Charolais	-7.4	-3.9	4.9	-0.71 (0.33)	-0.33 (0.16)	-0.35 (0.33)	-0.43 (0.16)
Chiangus	4.4	-7.6	5.3	-0.43 (0.87)	-0.15 (0.42)	3.19 (0.87)	3.36 (0.42)
Gelbvieh	-13.6	-8.3	5.0	0.28 (0.41)	0.14 (0.20)	1.30 (0.41)	1.36 (0.20)
Limousin	-9.0	-6.9	7.2	-0.63 (0.33)	-0.29 (0.16)	0.22 (0.33)	0.17 (0.16)
Maine-Anjou	-7.0	-1.7	4.3	-0.39 (0.66)	-0.17 (0.31)	-0.24 (0.66)	-0.23 (0.31)
Salers	-0.8	-0.7	1.5	-1.24 (0.65)	-0.58 (0.57)	-0.78 (0.65)	-0.90 (0.57)
Simmental	-21.2	-13.0	6.3	-0.45 (0.41)	-0.21 (0.34)	-0.42 (0.41)	-0.45 (0.34)
Tarentaise	-1.2	17.2	5.5	0.00 (0.00)	0.00 (0.00)	-1.55 (0.00)	-1.55(0.00)

[a]Breed effect estimates and standard errors adjusted for sire sampling. Breeds without solutions reflect breeds without EBV recorded in their association

[b]Calving difficulty reported on USMARC scale 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, and 6= major difficulty.

[c]Calving difficulty reported as Z scores based on midpoint of the incidents rate

[d]The average within-breed EBV for each breed for birth year 2012
[e]The weighted average EBV of bulls for each breed having descendants with records at USMARC
[f]The residual standard deviation was obtained by fitting a simple linear model with the fixed effect of year to account for sampling bias that could occur by year in EBV
[g]Estimated breed effects solution from analysis of USMARC data for birth year 2012
[h]Estimated breed effects corrected for sire sampling
Calculations:
(6)= $\{(4)/STD_{m1} + \{[(1) – (2)]/(3)\}\} – \{[(1) – (2)]/(3)\}_{Angus}$ where STD_{m1} is the maternal additive genetic standard deviation from model 1
(7)= $\{(5)/STD_{m2} + \{[(1) – (2)]/(3)\}\} – \{[(1) – (2)]/(3)\}_{Angus}$ where STD_{m2} is the maternal additive genetic standard deviation from model 2

Figure 1: Mean birth weight by difficulty score

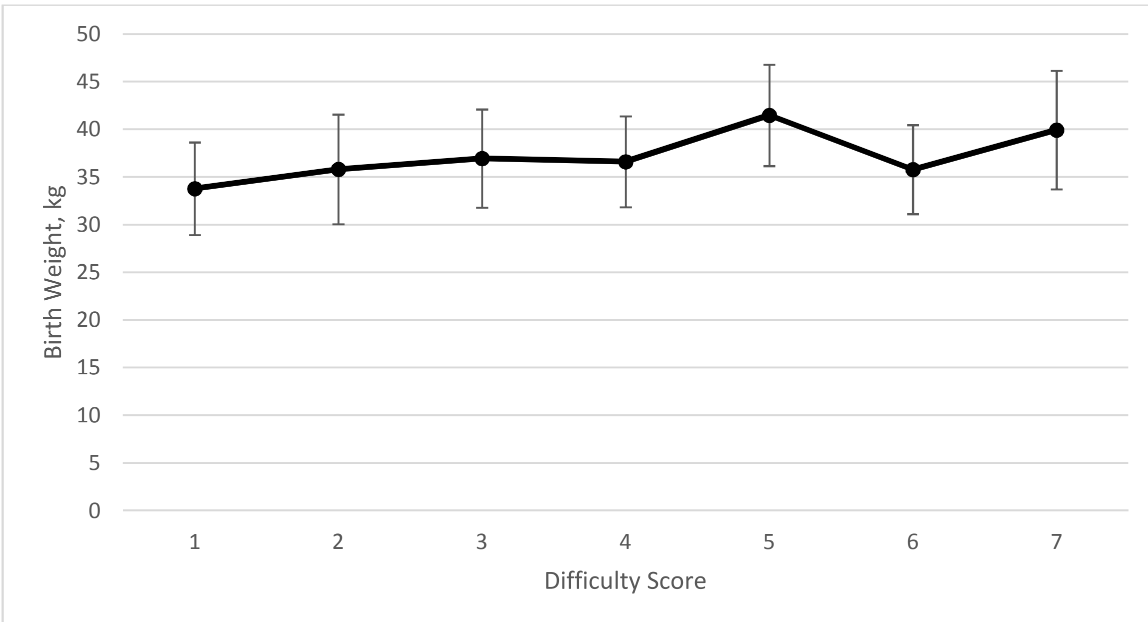


Figure 2: Mean birth weight by year and season of birth and sex of calf

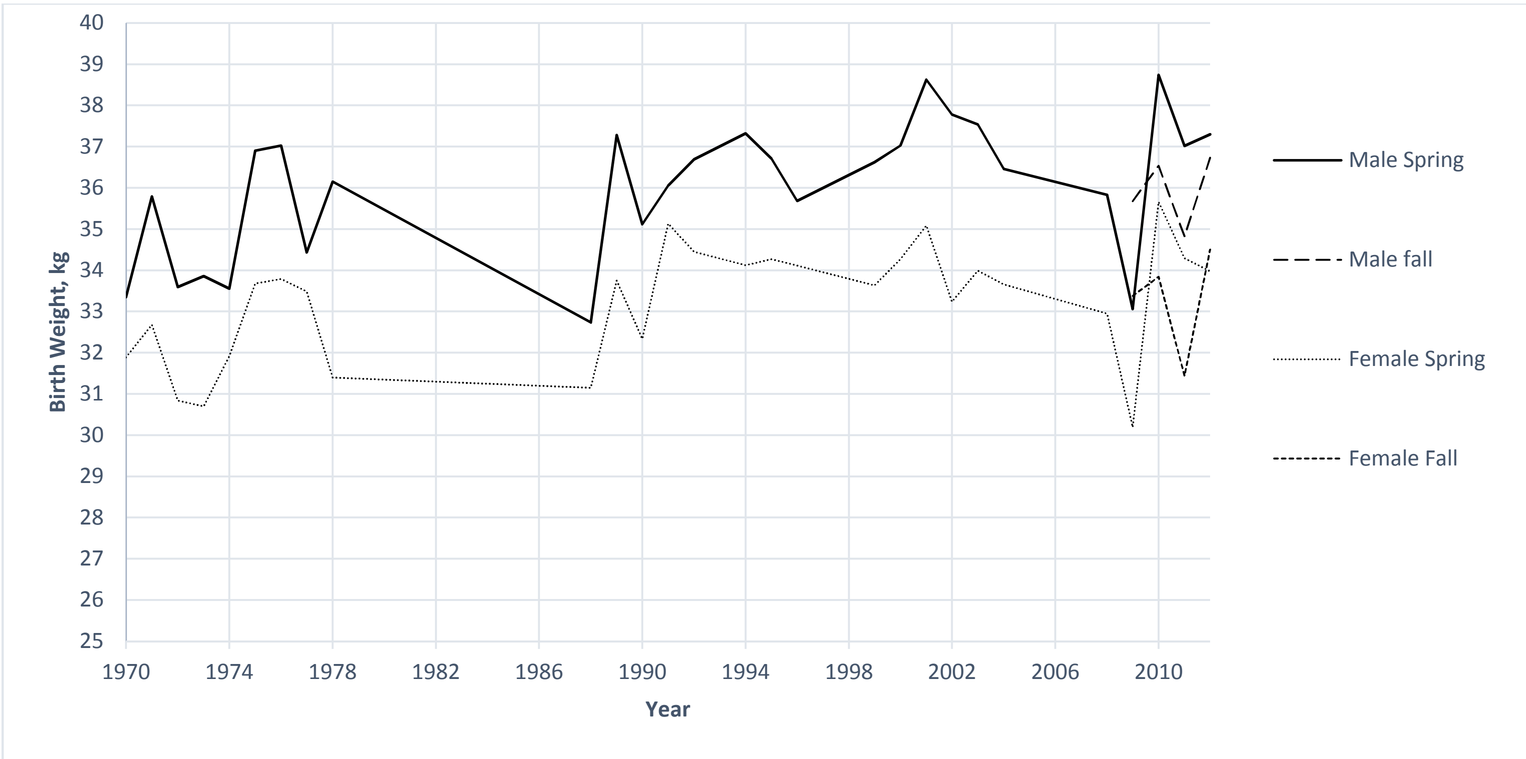
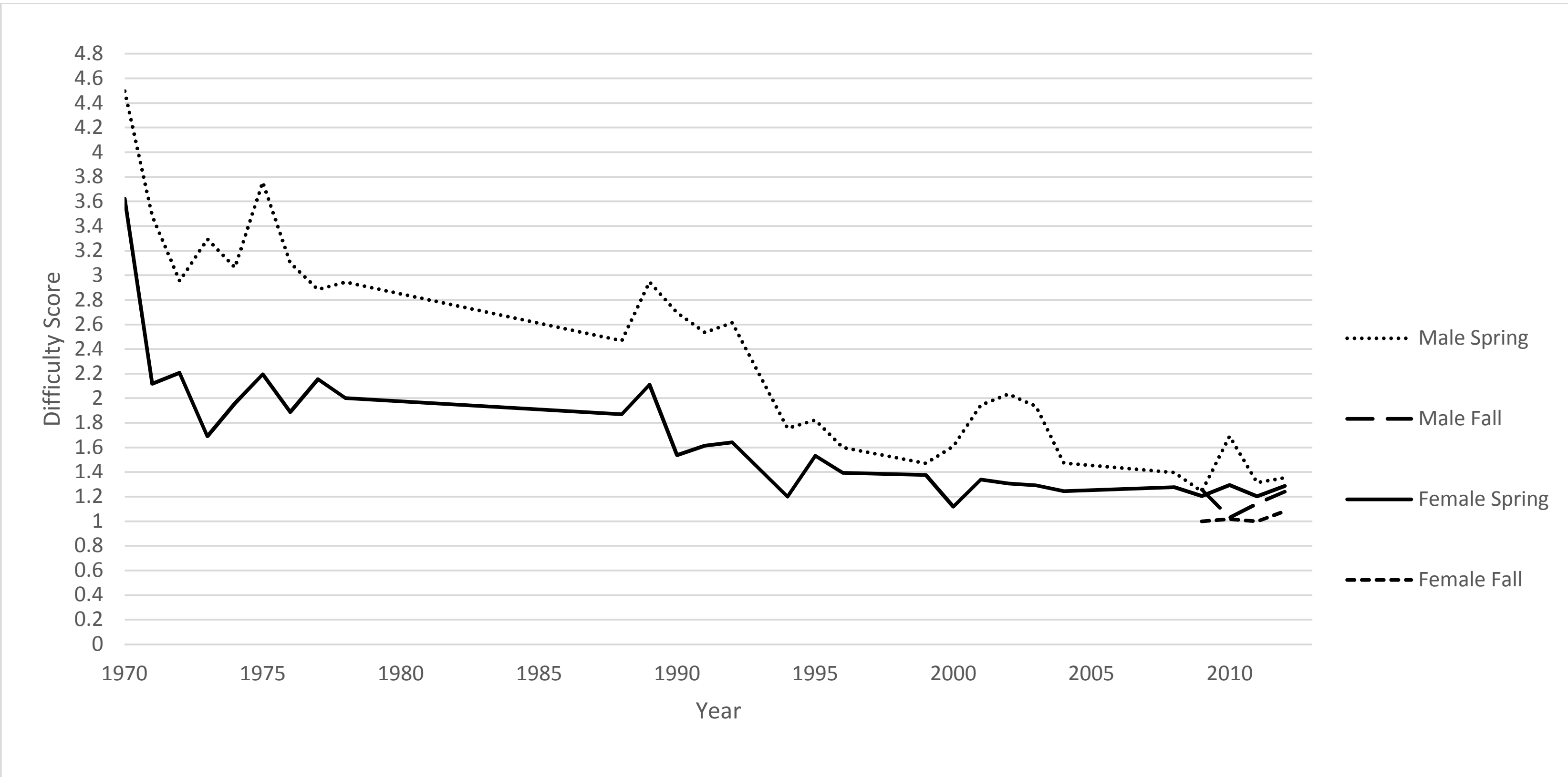
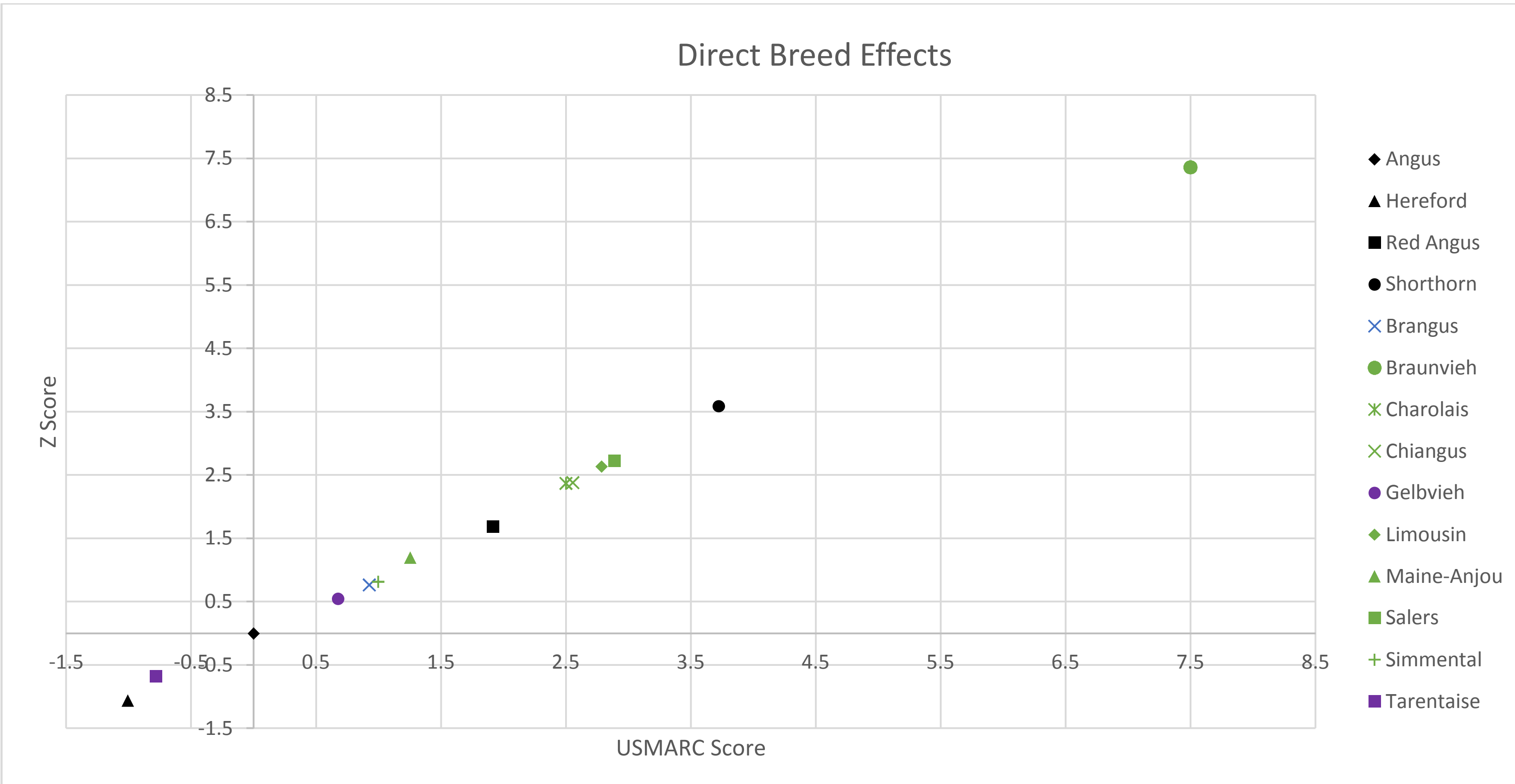

Birth Weight, kg
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010
Year
Male Spring
Male fall
Female Spring
Female Fall

Figure 3: Mean difficulty score by year, season, and sex[a]



[a]Difficulty score is based on USMARC scores 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, and 6= major difficulty.

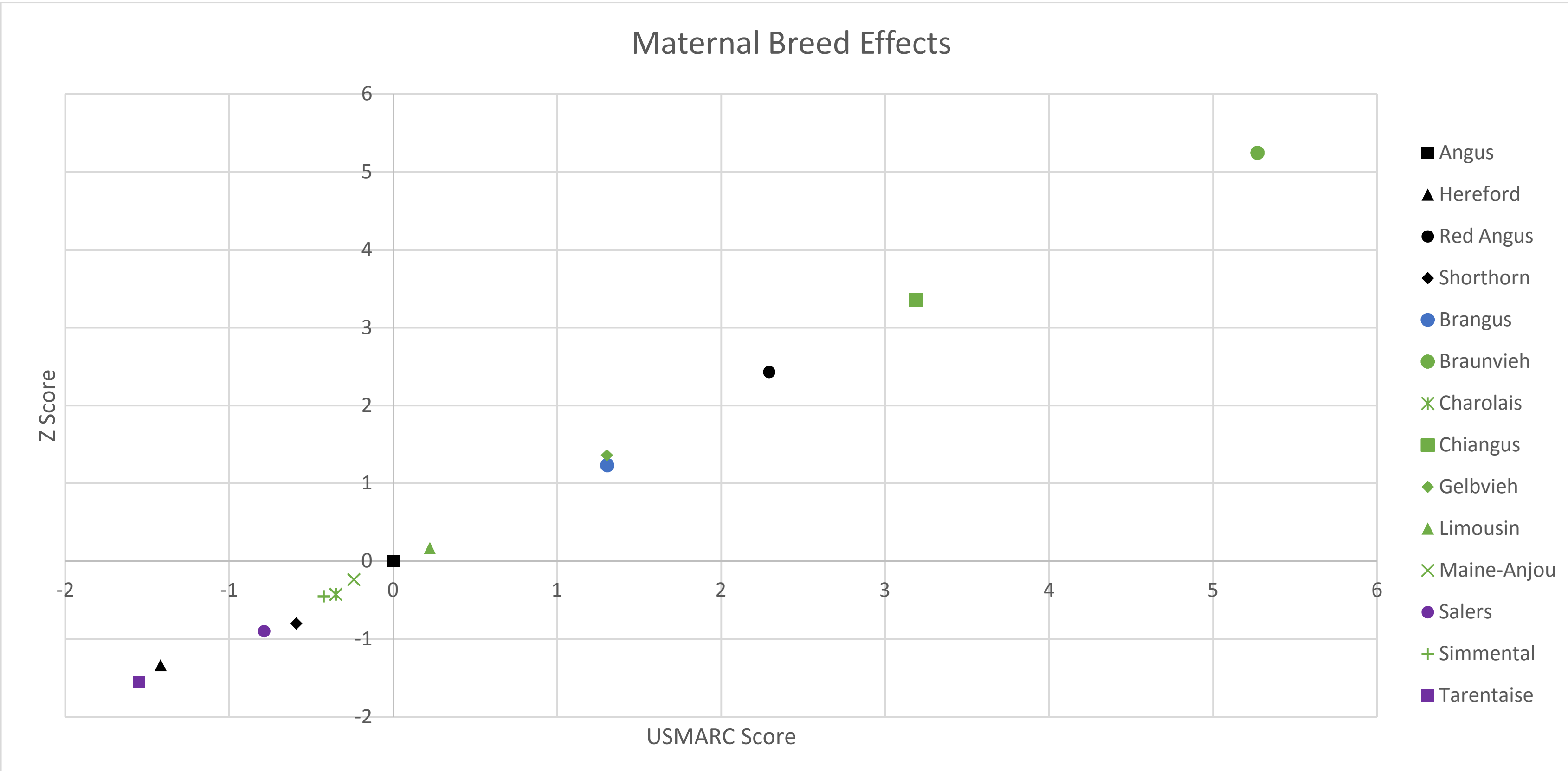
Figure 4: Breed effects from model 1[a] and model 2[b] for calving difficulty direct effect



[a]Model 1 calving difficulty were recorded as USMARC score: 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use of calf jack, 4 = slight difficulty, 5= moderate difficulty, and 6= major difficulty.

[b]Model 2 calving difficulty were recorded as z scores as midpoints of the continuous incidence rate

Figure 5: Plot of EBV for model 1[a] by model 2[b] for calving difficulty maternal effect



[a]Model 1 calving difficulty were recorded as USMARC score: 1 = unassisted, 2 = little difficulty hand assistance , 3 = little difficulty use

of calf jack, 4 = slight difficulty, 5= moderate difficulty, and 6= major difficulty.
[b]Model 2 calving difficulty were recorded as z scores as midpoints of the continuous incident rate

APPENDICES

Appendix 1. Mating plans for cycle 1 to produce phase 2 calves Germplasm Evaluation[a].

Breed of Dam	Sire Breed					
	Hereford	Angus	South Devon	Limousin	Simmental	Charolais
Hereford	X	X	X	X	X	X
Angus	X	X	X	X	X	X

[a]Females of each breed group distributed equally among cells market "X" for each calf crop. Each group of heifers breed by AI as yearlings to produce on calf crop 2-year-olds by these breeds.

Appendix 2. Mating plans for cycle 1 to produce phase 3 calves Germplasm Evaluation.

Dams composition[ab]	Sire Breed			
	Hereford	Angus	Brahman	South Devon
HxH		X		
AxA	X			
AxH			X	X
HxA			X	X
SDxH		X	X	X
SDxA	X		X	X
LxH		X	X	X
LxA	X		X	X
SxH		X	X	X
SxA	X		X	X
CxH		X	X	X
CxA	X		X	X

[a]breed codes H-Hereford, A-Angus, C-Charolais, SD-South Devon, L-Limousin, and S-Simmental

[b]Females of each breed group distributed equally among cells market "X" for each calf crop. Each group of heifers breed by AI as yearlings to produce on calf crop 2-year-olds by these breeds.

Appendix 3. Mating plans for cycle 2 phase 3 of the Germplasm Evaluation

Breed of Dam[ab]	Sire Breed			
	Hereford	Angus	Brangus	Santa Gertrudis
Hereford (H)		X	X	X
Angus (A)	X		X	X
Red Poll (R)	X	X		
AxH & Reciprocal			X	X
HxR & Reciprocal		X	X	X
AxR & Reciprocal	X		X	X
GxH		X	X	X
GxA	X		X	X
MxH		X	X	X
MxA	X		X	X
CxH		X	X	X
CxA	X		X	X

[a]Breed codes H-Hereford, A-Angus, C-Chianina, G-Gelbvieh, and M-Maine-Anjou.
[b]Females of each breed group distributed equally among cells market “X” for each calf crop.

Appendix 4. Mating plans for cycle 3 phase 3 of the Germplasm Evaluation

Breed of Dam[ab]	Sire Breeds	
	Red Poll	Simmental
AxH	X	X
HxA	X	X
TxH	X	X
TxA	X	X
BxH	X	X
BxA	X	X

[a]Breed codes H-Hereford, A-Angus, T-Tarentaise and B-Brahman
[b]Females of each breed group distributed equally among cells market "X" for each calf crop.

Appendix 5. Mating plans for cycle 4 phase 3 of the Germplasm Evaluation

Breed of Dams[a]	Sire Breeds	
	Red Poll	Simmental
Angus	X	X
Hereford	X	X
Hereford x Angus	X	X
Angus x Hereford	X	X
Shorthorn x Angus	X	X
Shorthorn x Hereford	X	X
Salers x Angus	X	X
Salers x Hereford	X	X
Charolais x Angus	X	X
Charolais x Hereford	X	X
Gelbvieh x Angus	X	X
Gelbvieh x Hereford	X	X

[a]Females of each breed group distributed equally among cells market "X" for each calf crop.

Appendix 6. Mating plans for cycle 5 phase 3 of the Germplasm Evaluation

Breed of Dams[a]	Sire Breeds	
	Red Poll	Charolais
Hereford x Angus	X	X
Hereford x MARC III	X	X
Angus x Hereford	X	X
Angus x MARC III	X	X
Brahman x Angus	X	X
Brahman x Hereford	X	X
Brahman x MARC III	X	X

[a]Females of each breed group distributed equally among cells market “X” for each calf crop.

Appendix 7. Mating plans for cycle 6 phase 3 of the Germplasm Evaluation

Breed of Dams[a]	Sire Breeds	
	MARC III	Charolais
Hereford x Angus	X	X
Hereford x MARC III	X	X
Angus x Hereford	X	X
Angus x MARC III	X	X

[a]Females of each breed group distributed equally among cells market “X” for each calf crop.

Appendix 8. Mating plans for cycle 7 phase 3 of the Germplasm Evaluation

Breed of Dam[ab]	Breed of Sire							
	MARC III	H x A	A x H	R x H	S x H or S x A	G x H or G x A	L x H or L x A	C x H or C x A
Hereford	X	X	X	X	X	X	X	X
H x A	X	X	X	X	X	X	X	X
H x MARC III	X	X	X	X	X	X	X	X
Angus	X	X	X	X	X	X	X	X
A x H	X	X	X	X	X	X	X	X
A x MARC III	X	X	X	X	X	X	X	X
R x A	X	X	X	X	X	X	X	X
R x H	X	X	X	X	X	X	X	X
R x MARC III	X	X	X	X	X	X	X	X
S x A	X	X	X	X	X	X	X	X
S x H	X	X	X	X	X	X	X	X
S x MARC III	X	X	X	X	X	X	X	X
G x A	X	X	X	X	X	X	X	X
G x H	X	X	X	X	X	X	X	X
G x MARC III	X	X	X	X	X	X	X	X
L x A	X	X	X	X	X	X	X	X
L x H	X	X	X	X	X	X	X	X
L x MARC III	X	X	X	X	X	X	X	X
C x H	X	X	X	X	X	X	X	X
C x A	X	X	X	X	X	X	X	X
C x MARC III	X	X	X	X	X	X	X	X

[a]Breed codes H-Hereford, A-Angus, C-Chianina, G-Gelbvieh, and M-Maine-Anjou
[b]Females of each breed group distributed equally among cells market "X" for each calf crop.

Appendix 9. Mating plans for cycle 8 phase 3 of the Germplasm Evaluation

Breed of Dam[a]	Sire Breeds	
	MARC III	Charolais
Hereford x Angus	X	X
Hereford x MARC III	X	X
Angus x MARC III	X	X
Brangus x Angus	X	X
Brangus x MARC III	X	X
Beefmaster x Angus	X	X
Beefmaster x MARC III	X	X

[a]Females of each breed group distributed equally among cells market “X” for each calf crop.