

THESIS

BEEF CATTLE MATERNAL AND TERMINAL ECONOMIC SELECTION INDICES

Submitted by

Xi Zeng

Department of Animal Sciences

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2013

Master's Committee:

Advisor: Enns, Richard Mark

Thomas, Milton G.
Dalsted, Norman L.

ABSTRACT

BEEF CATTLE MATERNAL AND TERMINAL ECONOMIC SELECTION INDICES

The breeding objective in most livestock operations is to increase profit ability by improving production efficiency. Animals with different purposes are associated with different production systems. The objective of the study is to develop economic selection indices for females and males in three different production systems: maternal, terminal with self-replacement females, and terminal without self-replacement females, based on production characteristics in the intermountain region of the US. Profit equations were constructed to derive economic values under fixed herd size scenario. The parameters used to calculate the cumulative discounted gene expressions (CDGE) and genetic parameters were estimated from 10,007 individual records and 27,165 pedigree records from the Angus herd at the John E. Rouse Beef Improvement Center of Colorado State University. There were 313 sires with an average generation interval of 3.30 years involved in the study, as well as 2,160 dams with an average generation interval of 5.32 years. Sensitivity tests were performed to test the effect of changing production and economic variables on economic selection indices weights. The impacts on selection index for all systems were small with changing production variable. Also, varying economic variables had small effect on selection index of maternal system with correlations among objectives more than 0.80. However, it affects the selection index of two terminal systems a lot with low (-0.05) or even negative (-0.82) correlation between one and another other. The selection responses with considering the cumulative discounted gene expression and based on six economic selection indices were \$259.77, \$957.10, \$93.901, \$361.58, \$71.81 and \$279.30 per generation for females and male in the three production systems, maternal, terminal with self-replacement heifer and terminal without self-replacement heifer, assuming that the selection intensity is one standard deviation. Under all scenarios, selection will lead to increasing profit.

ACKNOWLEDGEMENTS

I would like to express my special thanks to my advisor Dr. Mark Enns, who has the attitude and the substance of genius. His effort on research and teaching should be an example in my future work. Without his guidance and persistent help, this thesis would not been possible.

I would like to thank my committee member Dr. Milton Thomas and Dr. Norman L. Dalsted who is professional in agriculture economics. Also I would like to express my appreciation to Dr. Denny Crews. Their suggestions for study help my thesis to be better.

In addition, thanks would be expressed to Dr. Scott Speidel, who is smart, funny and serious in research and work. He taught me the related technical skill to accomplish the thesis, generously read the manuscript in its entirety and give me many useful suggestions to my study.

Also, I am grateful to Brain Brigham, who helps me gather the data I used in my thesis and help me solve a key problem about economic value in my study. He is talented, friendly and generous for help.

Furthermore, I would like to offer my thanks to my colleagues: Iara Solar Diaz, Emma Huff, Miranda Culbertson. They give me the benefits of their suggestion in discussion of my project with me.

Lastly, I am appreciating the support from my parents, my boyfriend, and my friends. However, I am solely responsibility for any shortcomings made in the thesis.

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
TABLE OF CONTENTS.....	iv
LIST OF TABLES.....	ix
LIST OF FIGURES.....	xi
CHAPTER 1 INTRODUCTION.....	1
CHAPTER 2 LITERATURE REVIEW.....	4
2.1 History of The U.S. Beef Industry.....	4
2.2 Cattle Improvement.....	5
2.2.1 Matting system.....	5
2.2.2 Selection.....	5
2.3 Breeding Objectives.....	6
2.3.1 Breeding and marketing system.....	6
2.3.2 Determine the revenue and cost.....	7
2.3.3 Determination of biology traits influencing income and cost.....	7
2.4 Selection Criteria.....	9
2.4.1 Choice selection criteria.....	9
2.5 Selection Index Theory.....	10
2.5.1 Phenotypic and genetic parameters.....	11
2.5.2 Derive economic weight.....	13
2.6 Selection Response of Index.....	16

2.7 Accuracy of Selection Index	17
2.8 Sensitivity of Selection Index	17
2.8.1 Sensitivity of selection index for different estimates of variances and co-variance	18
2.8.2 Sensitivity of selection index on estimation of economic value	18
2.9 Traits Contributing to Response.....	19
2.10 Alternative Selection Index Approaches.....	20
2.10.1 Restriction index	20
2.10.2 Desired gain index	21
2.11 Usage of Selection Index	21
2.11.1 Beef cattle breeding	21
2.11.2 Swine breeding	22
2.12 Conclusions.....	22
 CHAPTER 3 DEFINITION OF BREEDING OBJECTIVE AND DEVELOPMENT OF PROFIT	
EQUATION	
.....	23
3.1 Introduction.....	23
3.2 Describing the Breeding System.....	23
3.3 Describing the Production and Marketing System.....	23
3.3.1 Reproduction and health plan	24
3.3.2 Replacement and culling policy	24
3.3.3 Feed plan.....	24
3.4 Develop Profit Equation.....	26

3.4.1 Reproduction traits.....	26
3.4.2 Meat quality traits	28
3.4.3 Function traits	29
3.4.4 Developing the profit equation	29
3.5 Results of the Estimated Parameters	40
3.6 Conclusions.....	43
CHAPTER 4 DERIVING ECONOMIC VALUES.....	44
4.1 Introduction.....	44
4.2 Materials and Methods.....	44
4.2.1 Estimating economic value of continuous traits	44
4.2.2 Estimating economic value of category traits	46
4.2.3 Sensitivity of economic value on population means of traits	49
4.3 Results and Discussion.....	49
4.3.1 Genetic parameters.....	49
4.3.2 Economic value.....	51
4.3.3 The rank of traits by economic importance	52
4.3.4 Sensitivity of economic value (EV) on production variable.....	54
4.3.5 The application of economically relevant traits	58
4.4 Conclusions.....	60
CHAPTER 5 CUMULATIVE DISCOUNTED GENE FLOW	61
5.1 Introduction.....	61
5.2 Materials and Methods.....	61

5.2.1 Developing survival and productive matrix.....	62
5.2.2 Terminal males	63
5.2.3 Terminal females	65
5.2.4 Maternal females.....	66
5.2.5 Maternal males.....	68
5.2.6 Sensitivity of discount factor	70
5.3 Results and Discussion.....	70
5.3.1 Cumulative discounted gene expression (CDGEs).....	70
5.3.2 Sensitivity of CDGEs on discount rates	71
5.4 Conclusions.....	73
CHAPTER 6 SELECTION INDEX AND GENETIC GAIN	74
6.1 Introduction.....	74
6.2 Materials and Methods.....	74
6.2.1 Developing aggregate genotype.....	74
6.2.2 Developing selection index.....	74
6.2.3 Constructing genetic (co)Variance matrix	75
6.2.4 Estimation of selection response and genetic gain of traits	77
6.2.5 Effect of alterative feed, heifer and meat price on selection index.....	77
6.3 Results and Discussion.....	77
6.3.1 Economic weights.....	77
6.3.2 Genetic parameters.....	78
6.3.3 Selection indices, selection response and Genetic gain	80

6.3.4 Effect of alterative economic information	83
6.4 Conclusions.....	84
REFERENCES	85

LIST OF TABLES

Table 3.1: Summary of variables within profit equation	27
Table 3.2: Traits influencing cost and revenue in the study	28
Table 3.3: Summary of cow distribution, average live weight (kg) and the average of average daily gain of each cow age group in John E. Rouse Ranch of Colorado State University Beef Improvement Center	38
Table 3.4: Estimated Total Hay intake of each animal category based on energy requirement guidelines of NRC	41
Table 4.1: Summary statistics for records from John E. Rouse Ranch of Colorado State University Beef Improvement Center	46
Table 4.2: Summary of prices per CWT, probability and truncation points before (P,t) and after (P',t') trait change of each meat quality	48
Table 4.3: Summary of cost per calving, truncation points (t) and probability before (P) and after (P') change in calving ease	49
Table 4.4: The phenotypic variance (σ_p^2), heritability (h^2) and standard deviation of additive genetic effect (σ_A) of each economic relevant traits	50
Table 4.5: Marginal economic value and relative economic value of economically relevant traits	51
Table 4.6: Sensitivity of economic values to changes of production variables in maternal system	55
Table 4.7: Sensitivity of economic values to changes of post-weaning average daily gain	56
Table 5.1: Symbols of cumulative discounted gene expression (CDGE) calculated in the study	61
Table 5.2: The components of survival (S) and profitability (P) vector	63
Table 5.3: CDGEs of five categories traits in four categories animals	71

Table 6.1: Traits involved in Aggregate Genotype and Index	75
Table 6.2: Economic weights of 14 traits for three production system by sex based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center	78
Table 6.3: Heritability (on diagonal), genetic standard deviation (below diagonal) and genetic correlation (above diagonal) between traits including traits in breeding objectives and index	79
Table 6.4: Index weights of 11 selection criteria used in six indices based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center.....	81
Table 6.5: Genetic gain per generation for 14 traits of six indices and selection responses per generation of six indices with one standard deviation selection intensity	82
Table 6.6: Correlation among indices of female (above diagonal) and male (below diagonal) derived from different feed, meat, heifer and bull price levels for maternal systems based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center.....	83
Table 6.7: Correlation among index of female (above diagonal) and male (below diagonal) derived from different feed, meat, heifer and bull price levels for terminal systems based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center.....	84

LIST OF FIGURES

Figure 3.1 Production structure of John E. Rouse Beef Improvement Center of Colorado State University	25
Figure 3.2 Nutrition plan of Colorado State University Beef Improvement.....	26
Figure 4.1 Example of calculation of economic value based on normalized category data	47
Figure 5.1 Sensitivity of CDGEs on changing discount rate	72

CHAPTER 1

INTRODUCTION

The US is the largest producer beef as well as consumer in the world. According to the records of Economic Research center of the USDA from 2002 to 2010 (USDA-ERS, 2012), average U.S. beef consumption was 27.27 billion pounds; and average carcass weight of U.S beef production was 26.02 billion pounds. Also, the United States was the world's largest beef exporter with 1.66 billion pounds of beef worth \$2.34 billion. Considering these numbers stated above, the beef industry was and remains to be one of the most important industries in the United States.

The general aim of agriculture producers is to maximize the revenue while minimizing the cost for all segments of the industry (e.g. animal product, technology and finance). In the animal industry, there are many ways to achieve this goal through: nutrition, reproduction, management, and breeding and genetics. The revenue and cost are directly related to the phenotype which is the combination of genotype and environment effects of the animal ($P=G + E$) (Van Vleck, 1993). The genetic improvement can be passed generation to generation. To achieve these goals, we should answer which animal we should choose as the parent of the next generation. Considering the different goals of a herd or an enterprise, selection will be different. So at first, we should ensure the role and the aim of a herd, and then make the mating plan or breeding program according to the goal. Harris et al. (1984) presented a process for developing a breeding program which involves eight different steps: 1. Describe the production system(s) 2. Formulate the objective: both simplified and comprehensive 3. Choose a breeding system and breeds 4. Estimate selection parameters and (discounted) economic values. 5. Design an animal evaluation system. 6. Develop selection criteria 7. Design mating for selected animals 8. Design a system for expansion – dissemination-of genetic superiority. Groen et al. (1997) summarized all these steps in three major steps: 1. Defining the breeding goal: setting up the aggregate genotype and deriving cumulative discounted expressions and economic values. 2. Estimating the breeding value: deciding what traits to be included in the information index, derivation of the regression coefficients to be included in the information index,

estimating the information index value. i.e. the estimated breeding value for each potential breeding animal. 3. Breeding program optimization: optimizing the organization to routinely gather information on potential breeding animals and/or their relatives, and to select and mate breeding animals to breed the next generation.

Traditionally, the EPDs/EBVs are treated as tools to select parents. However, the EPDs/EBVs represent genetic merit in only one trait and producers need to use many traits simultaneously. There are three distinct forms of selection for more than one trait: First, Tandem Selection: Selection for traits in sequence. Second, Selection with Independent Culling Levels: Selection for traits simultaneously where each trait has an acceptable level or “window”. Third, Multiple trait selection index. The selection index is the recommended method for multiple traits selection in farm livestock. In fact, selection for an index which gives proper weight to each trait is more efficient than selection for one trait at a time or for several traits with an independent culling level for each trait, because it can lead to greater increase in profit (Hazel, 1943).

The beef production system in the US can be generally divided into seedstock, and commercial herds which can be divided into terminal with or without replacements herds. In the seedstock, two requirements should be met: 1. Self-replacement to keep the breeding system stable; 2. Selling breeding stock and cull harvest animals for profit. So we are interested in producing offspring that have dual purpose, those producing offspring for reproduction in next generation, and producing offspring which can be used as parents for terminal purposes. Considering the two purposes of the seedstock herd, two types of selection index can be used for selection, the maternal selection indices: making reproductively competent parents; and the terminal selection index: producing terminal parents.

In the livestock industries, economic selection indices are not widely used. When constructing a selection index, information on genetic parameters, phenotypic parameters and economic values are needed. These can be obtained by various methods such as calculating from the phenotypic data or obtaining from previous literature estimates. Estimates of genetic parameters vary little across breed. However, the economic values can be different for different production systems and purposes. The study

of Smith (1983) indicated that large differences in economic weights will affect the efficiency of the selection index considerably. These differences can also result in considerable bias of the estimated genetic gain. The economic value is typically obtained by constructing a “profit equation” and then applying partial differentiation. The profit equation is constructed according to the breeding objectives. Selection criteria were unique to each production system. Furthermore, the economic value will be influenced by gene flow and discounted factors. Thus economic values should be calculated based on current specific herd structures while considering the economic discounted factor and cumulated gene flow influence. Because the selection index is influenced by many factors stated above, the efficiency of an index should also be determined to test whether the index is sufficient to help the producer achieve their goals.

The objectives of the study are:

1. Estimate the economic value of traits in breeding objective for seedstock whose offspring will have either terminal or maternal purposes
2. Calculate the cumulative discounted expression of gene flow using the John E. Rouse ranch of Colorado State University Beef Improvement Center cow age structure.
3. Determine genetic and phenotypic (co) variance structure of economic traits and selection criteria.
4. Use the results above to calculate terminal economic selection index function and maternal economic selection index for beef cattle in the Rocky Mountain Western region of the U.S.
5. Estimate the economic selection response and genetic gain for each trait in breeding objectives.

CHAPTER 2

LITERATURE REVIEW

2.1 History of the U.S. Beef Industry

Since the Spanish first brought cattle to the Americas, the beef industry has played a major role in North America and the United States. There are several breeds in the United States which are normally used for beef resource: Angus, Hereford, Simmental, Shorthorn, etc. Angus were first imported into United State in 1873, since that time, this breed has become one of the most important beef breed in United States, because of its ability to introduce functionality and value into their herds, while cutting operating costs, reducing time and labor requirements, balancing traits, and boosting profits (Association, 2011; 2012). With improvements in communication and commerce between countries, the market for beef is not only local, but also national and international. So in order to improve beef production, several associations have been established: National Cattlemen's Beef Association, American Society of Animal Science, and America Angus Association. Through these associations, the breeders can interchange the production information and collaborate to solve problems. American Angus Association was the first association for Angus which is built in 1886, while National Cattlemen's Beef Association was the first national association in the United States which was established in 1898 (Ball, 2000; Association, 2012). Besides these associations, in 1930's, the Beef Improvement Federation, BIF, was conceived, and it standardized the programs and methodology for objectively evaluating beef cattle (BIF, 2002).

According to the records of livestock marketing information center, from 1983 to 2007, a reduction in inventory has led to more beef production, which agrees with the report of United States Department of Agriculture (USDA) saying despite the continued reduction of the United States cattle herd, beef production in the United States in has actually risen over the past 30 years(Short, 2001). Since 1979, commercial beef production has grown by 22 percent while total cattle inventory fell by 15 percent indicating the higher efficiency of beef industry. This phenomenon can be attributed to the improvement of cattle populations (Short, 2001).

2.2 Cattle Improvement

The overall goal of a beef operation should be to increase net income (the balance between operation cost and operation income), which means breeders should focus on increasing income while minimizing cost (Bullock, 2003). How can we achieve that goal? Genetic improvement is one option widely used in animal industries. In animal breeding, the goal is to improve animal populations and to improve future generations of animals (Dekkers et al., 2004). Two tools are selection and mating.

2.2.1 Mating system

Mating systems are the rules to determine which (selected) males are bred to which (selected) females. There are three reasons for using a mating system: 1. to produce offspring with extreme breeding values; 2. to make use of complementarities; 3. to obtain hybrid vigor (Dekkers et al., 2004). Also, two systems usually used in cattle industry are: 1. straight breeding programs which produce progeny for further finishing and replacement females for herd; 2. crossbreeding programs which capitalize on the existing genetic differences between two or more breeds to produce progeny that have characteristics suitable for a defined market or environment. Generally, purebred animals are the basis of genetic improvement of beef cattle in the United States. For example, purebred animals are a contributor to crossbreeding (Long, 1980; VanRaden and Sanders, 2003). Crossing breeding is used to create offspring with desired performance through heterosis (Gregory and Cundiff, 1980) or for improving performance in low heritable traits. For instance, Long (1980) reviewed that crossbred cattle had better reproductive performance than purebred cattle.

2.2.2 Selection

Selection is the process of choosing which individuals become the parents to make long term genetic change in population (MacNeil et al., 1997). The genetic effect of traits, which is the average additive effects of genes inherited by offspring from both parents is “breeding value”, which is the factor we are concerned with in selection (Mrode and Thompson, 2005). However, true breeding value cannot be known, so estimated breeding values (EBV) calculated from performance data are used as information for

selection. Actually, expected progeny differences (EPD), half of the estimated breeding value (EBV), are widely used to select animals. Expected progeny differences (EPDs) are reported for specific breed on each traits. However, appropriate choice of parents involves evaluation of more than one trait (MacNeil et al., 1997). With the goal of improving multiple traits, selection on index is appropriate. That is why the index is developed. Selection index is a selection tool involving multiple traits simultaneously and accounting for both biological production levels and economics (Parlsh, 2011). In animal science, profitability was the basis for original development of the selection index (MacNeil et al., 1997). Thus, with combining several traits' biological and economical information into one index value, economic selection index becomes the most efficient selection tool for multiple traits.

2.3 Breeding Objectives

The first step in the process of selection for a production system is to define a breeding objective. The breeding objective is a combination of economic weighting factors and genetic information for traits to be improved (Falconer, 1981). To develop breeding objectives, we need to know the management and production system of a herd, the return and cost of the production system, and the economical relevant traits which have influence on the return and cost of the production system.

2.3.1 Breeding and marketing system

A breeding system is how the breed or individuals in the herd are utilized (Newman et al., 1992). Generally, the breeding system can be divided into three categories: general purpose, dam (maternal) line and sire (terminal) line (MacNeil et al., 1994). With this perspective, selection indices based on specific lines will lead to more efficient in selection of parents for specialized sire and dam lines (MacNeil and Newman, 1994). The selection indices should concentrate their weighting on specific traits. For instance, a maternal index is better for selection of reproductive traits, while terminal sire index is better for production traits. In short, when determining selection objectives for herd, the producers must consider the current strength of their breed and customer.

2.3.2 Determine the revenue and cost

In beef industry, revenue mostly comes from finished steers, finished heifers, culled cows and bulls. In animal production, the costs can be divided into variable and fixed categories. The variable costs changed with production level, e.g. feed cost, veterinary and marketing cost, etc. Fixed costs are independent of the herd production, e.g. factory and truck. (Ponzoni and Newman, 1989).

2.3.3 Determination of biology traits influencing income and cost

There are many traits that are related to the breeding objectives but not directly related to profit. The ones involved in Aggregate genotype (breeding objective) are referred as economically relevant traits (ERT). Dekkers et al. (2004) pointed out three criteria for deciding traits should be included in aggregate genotype:

1. The aggregate genotype must include those traits contribute to the breeding objective (profit in our case).
2. Traits that have an indirect impact on the objective do not necessarily belong in the aggregate genotype.
3. Traits that have little or no genetic variation need not to be included.

The most important point is to do not ignore any traits which influence industry production systems. In the beef industry, the traits can be divided into four categories: growth, reproduction, carcass and life traits with each potentially involved in the appropriate objective.

2.3.3.1 Growth traits

In the beef industry, the growth traits can be considered one of the most important traits because they often directly determine revenue. The growth traits commonly recorded in beef industry are: birth weight (BW) , weaning weight (WW), yearly weight, 18 month weight, 24 month weight, and sale weight (Payne, 1970; Davis, 1993).

Average daily gain which can be calculated from weight observation is an important trait correlated with feed intake, and reflects the efficiency of a cattle growth. Feed intake is also one of the most important traits, and it is difficult and costly to collect. Typically in practice, we use the energy

requirements to estimate the feed intake. Guidelines of The National Research Council (NRC) (NRC, 2000) are commonly be used to calculate feed intake. According to the NRC, energy requirements can be divided in to several parts: maintenance gain, pregnancy and lactation. Besides the NRC, other organizations such as Ministry of the Agriculture, Fisheries and Food Food (1990) can be the reference to derive energy requirement for animals, which are similar with NRC calculation equations.

2.3.3.2 Reproduction and longevity traits

The number of the cattle which can be marketed is one of the most important factors influencing revenue. The number of animals available for market largely depends on the reproductive ability of the herd as well as the health and survival of animals. The reproduction traits commonly recorded are: calving ease (CE), calving rate (CR), Age at first calving (AFC) and calving interval (CI). Genetic evaluation are available for some of these traits.

Calving ease EPD are expressed as differences among individuals in the expected proportion of unassisted calvings (Golden et al., 2000), and represent two components of calving ease: direct and maternal. Calving ease direct EPD predict differences among individuals in the calving ease of their progeny. Alternatively, calving ease maternal EPD reflect differences among individuals in the ease with which their daughters bear calves (i.e. calving ease as a trait of the dam); (Dekkers, 1994). Estimates for both traits require collection of calving ease scores, as described earlier, and may utilize calf birth weight data as well.

Age at first calving (AFC) and calving interval (CI) are different among breed, and they can have several records in a cow's life time, e.g.: CI of Hereford different from 293.9d to 556.6d (Rakha et al., 1971). Theoretically, reduction of AFC can lead to more offspring per cow (Nilforooshan and Edriss, 2004), whereas shorter CI indicates the cow has higher fertility and reproductive efficiency (MacGregor and Casey, 1999).

Stayability is defined as the period the cow produces in a herd, which is a longevity trait. Another definition of stayability is the probability a cow will remain in the herd until six years of age given she first calved as a two year old (Brigham et al., 2006). The stability record is binary observation for dams

enough to have had the required number of calves, coded as 1 (success) and 0 (failure). Because the dam needs to be old enough to have complete records, we can find other indicators (Days to calving, Calving interval, etc.) which are correlated with stayability (Golden et al., 2000).

2.3.3.4 Carcass trait

Carcass traits determine the price and amount of salable meat. Common carcass traits recorded: carcass weight, marbling score, fat depth, leanness, and meat quality. The economic values of these traits are dependent on the preference of customer and accordingly to market.

2.4 Selection Criteria

For selection, genetic value of animals are needed, and the phenotypic observation or measurements are required to estimate genetic parameters and values (Falconer, 1981). However, the traits for improvement may not always be measurable therefore a series of measurable characters highly correlated to these traits are chosen as criteria for selection on the immeasurable traits (Hazel, 1943).

2.4.1 Choice selection criteria

In selection index, the selection criteria differ with the breeding objective, but irrespective they must be highly correlated with those traits involved in breeding objectives. Actually, genetic correlation is the bridge connecting breeding objectives and selection criteria. Therefore, the choice of selection criteria should satisfy the following requirements: 1. They must be highly correlated with the economically relevant traits. 2. They should have enough genetic variation. 3. They should be easily measured and observed (Hazel, 1943). For example, slaughter weight can be evaluated using birth weight, average daily gain and weaning weight as criteria for selection. Age at first calving, calving interval and calving rate can reflect reproductive performance (Rewe, 2004) and could be used for selection. We can carefully make a plan to complete the phenotypic records of traits treated as selection criteria. With a more complete data, the more accurate genetic parameter can be predicted and a more rapid genetic improvement rate can be gained.

2.5 Selection Index Theory

Selection index is a technology to maximize genetic improvement in a specified objective (MacNeil et al., 1997). In the breeding and genetics field, Dr. Hazel first scientists introduced the approach to help producers improve more than one trait at the same time. Afterward, the approach was named selection index. Hazel completely expounded this concept in his two articles (Hazel and Lush, 1942; Hazel, 1943). In the first, he describing the conception called total score which is an economic value considering all the relevant traits. The following year, selection index was described in his second article.

Selection index theory involves the knowledge of statistics, genomics, and genetics fields. From a statistic point, we should maximize the correlation between independent (selection index) and dependent variable (breeding objective). For genomics, we should consider the impact of the correlation among genes and the gene linkage influencing more than one trait. For genetics: recognize the relationship between genotype and phenotype (St-Onge, 2000). Hazel combined these to create selection index. He also conclude that index selection has been more effective than independent culling levels or sequential selection, according to the equations used to calculate selection efficiency: $ag^2\frac{1}{p}\sigma$ (sequential), $\sqrt{n}ag^2\frac{1}{p}\sigma$ (index), $ag^2\frac{1}{\sqrt{p}}\sigma$ (culling level), where a was economic weights, g^2 represented heritability, p was selection fraction, z represented normal distribution heights with proportion p and σ was the phenotypic standard deviation (Hazel and Lush, 1942; Hazel et al., 1994).

Hazel defined the concept as aggregate genotype: the sum of the product of the genetic value and the economic value for several traits, Aggregate genotypes are a way to amalgamate information for different traits into a single value that represents the breeding objective. The equation for aggregate genotype (H) is defined as follows:

$$H = a_1G_1 + a_2G_2 + \dots + a_nG_n \quad (2-1)$$

where H is Aggregate genotypes, a represent economic value, G is genetic value and n is the number of traits in the objective. In animal breeding, the breeding values (EBV) are usually used as “ G ” value in the equation. Then the equation becomes:

$$H = a_1EBV_1 + a_2EBV_2 + \dots + a_nEBV_n \quad (2-2)$$

Statistical methods (eg: BLUP and linear mixed model (Henderson, 1975)) and computation tools (eg: SAS (Institute, 1999), R (Ihaka and Gentleman, 1996), Animal Breeder's Tool Kit (Golden et al., 1992)) to calculate the breeding value which is called Estimate Breeding Value (EBV). In Hazel's articles, selection index defined as the sum of product of every traits' record value and coefficient as follows:

$$I = b_1x_1 + b_2x_2 + \dots + b_nx_n \quad (2-3)$$

where, I represents index, b are index weights and x is the information (phenotype, EBV, etc) used for selection. Equation (2-1) includes traits in breeding objective, while Equation (2-3) includes traits in the selection criteria. In the two equations (2-1, 2-3), the traits can be the same, or they can be different depending on available information. However, in most situations, the economically important traits are difficult to record, thus the breeding objectives and selection criteria are not the same (Dekkers et al., 2004).

2.5.1 Phenotypic and genetic parameters

In order to connect the information in index equation and Aggregate genotype, then to derive selection weight, the following statistics are needed (Hazel, 1943):

A. Phenotypic constants

The standard deviation for each of the traits

The phenotypic correlation between each pair of traits

The phenotypic correlations between the performances of relatives

B. Genetic constants

The Heritable fraction of the variance of each trait

The Genetic correlation between each pair of traits

The information is used to construct P and G matrices, respectively, which are used to estimate the weighting coefficient for each source of information in the index. The result of the calculation in matrix form is:

$$b = P^{-1}Gv \quad (2-4)$$

where P is phenotypic co(variance) matrix of selection criteria traits, G is genotypic co(variance) matrix of economic relevant traits and selection criteria, V represents a vector of economic values of traits in breeding objective and b is a vector of selection weights for selection criteria. Using the example in MacNeil's article (MacNeil et al., 1997), in which selection is placed on 5 traits: birth weight (BW), yearling weight (YW), scrotal circumference (SC), net reproduction (NR) and carcass merit (CM), using 3 measures for the traits BW, YW and SC; the P , G , V and b matrix looks like:

$$P = \begin{bmatrix} \sigma^2_{P_{BW}} & \sigma_{P_{BW}.P_{YW}} & \sigma_{P_{BW}.P_{SC}} \\ \sigma_{P_{BW}.P_{YW}} & \sigma^2_{P_{YW}} & \sigma_{P_{YW}.P_{SC}} \\ \sigma_{P_{BW}.P_{SC}} & \sigma_{P_{YW}.P_{SC}} & \sigma^2_{P_{SC}} \end{bmatrix}$$

$$G = \begin{bmatrix} \sigma_{P_{BW}.g_{BW}} & \sigma_{P_{BW}.g_{YW}} & \sigma_{P_{BW}.g_{SC}} & \sigma_{P_{BW}.g_{NR}} & \sigma_{P_{BW}.g_{CM}} \\ \sigma_{P_{YW}.g_{BW}} & \sigma_{P_{YW}.g_{YW}} & \sigma_{P_{YW}.g_{SC}} & \sigma_{P_{YW}.g_{NR}} & \sigma_{P_{YW}.g_{CM}} \\ \sigma_{P_{SC}.g_{BW}} & \sigma_{P_{SC}.g_{YW}} & \sigma_{P_{SC}.g_{SC}} & \sigma_{P_{SC}.g_{NR}} & \sigma_{P_{SC}.g_{CM}} \end{bmatrix}$$

$$V = \begin{bmatrix} EW_{BW} \\ EW_{YW} \\ EW_{SC} \\ EW_{NR} \\ EW_{CM} \end{bmatrix}$$

The method stated above approaches economic selection index based on phenotypic records. However, in some case, estimated breeding values (EBVs) are available, which lead the index to be:

$$I = b_1g_1 + b_2g_2 + \dots + b_ng_n \quad (2-5)$$

If traits in the breeding objectives and selection index are the same, the index weight equals to the economic value. So the multiple-trait selection index can be rewritten as

$$I = H = a_1EBV_1 + a_2EBV_2 + \dots + a_nEBV_n \quad (2-6)$$

If the traits in the breeding objectives and index are not the same, the selection weight can be calculated as described where (Dekkers et al., 2004):

$$b^* = C_I^{-1}C_{IH}V \quad (2-7)$$

where C_I is the genetic variance/covariance matrix among the traits which appear in the index and C_{IH} represents the genetic covariance matrix between traits in the index and traits in the aggregate genotype.

To improve the accuracy of the selection index, a multiple trait model for breeding value estimation is more appropriate as it leverages correlations among these traits. The accuracy of genetic and phenotypic parameters is essential for estimating selection index weights because they directly determine the accuracy of the index.

2.5.2 Derive economic weight

With multiple trait selection, economic weights provides direction to the selection program (MacNeil et al., 1997). Finding the economic weight of each trait is the first step in framing the ideal toward which the breeder is to strive (Hazel and Lush, 1942). Two parts are involved with cumulative gene expression: marginal economic value and cumulative discounted gene expression (CDGEs) (Ponzoni and Newman, 1989). The CDGE are used to adjust economic values, and the economic weight is the product of economic value and CDGE. Thus, in order to obtain economic weight, economic value and CDGE are first required.

2.5.2.1 Estimate economic value

The economic value is defined as the change profit expected for each unit of improvement in one trait while keeping all other traits constant (Hazel, 1943). There are three ways usually used to estimate economic value: First, regression of profit on related traits (Crews Jr et al., 2005). Second, building a profit equation based on the production system and using partial derivatives of the profit equation to get the economic value (Ponzoni and Newman, 1989; van Arendonk, 1991; MacNeil et al., 1994). Third, simulate the production system and combine the economic and biological information to build a bio-economic profit equation and then evaluate the impact of change in each production variable on profitability (Van Arendonk, 1985; Koots and Gibson, 1998; Tess and Kolstad, 2000). The simple profit equation approach may be adequate for simple production system while more complex system can be described by bio-economic model (Kluyts et al., 2004).

2.5.2.2 Building the profit equation

Among these methods, the profit equation is widely used in animal science to derive the relative economic value. Moav and Moav (1966) presented the profit equation to integrate the cost and returns from production to compare the profitability of animals. In animal breeding, the profit equation is a mathematic form of production system and breeding objective. In previous literatures, the profit equation differs greatly across operations as reflected in the traits involved in equation (Hirooka et al., 1998; Amer et al., 2001; Conington et al., 2004; Fernandez-Perea and Alenda Jiménez, 2004). Furthermore, profit equations vary with alternate profit units: e.g. per female, per individual or per unit of produce. Thus, the specific profit perspective must be chosen at the outset of objective development.

Traditionally, the profit equation and selection index are both the linear expressions of traits. However, we cannot deny that, in some situations, the profit equation can be a non-linear expression of those traits (Moav and Hill, 1966). Actually, the more complex equation will result in great accuracy results because it can be used to completely study of the actual relationship among these traits (Dekkers et al., 2004). It seems that we need a non-linear selection index but the economic value coming from non-linear profit equation will not be a constant and will differ with change of the population mean. Actually, when considering all kinds of profit equations (including non-linear), the linear selection index is optimum to achieve the largest gain in selection because it leads to the largest increase in profit (Goddard, 1983). More accurate results can be obtained by selection through a simple linear profit equation (Kluyts et al., 2004) and thus, it is reasonable to use the linear profit equation and selection index in this project.

2.5.2.3 Deriving economic value

When estimate economic values using profit equation, there are two options: First, partial budgeting the estimated economic value is the different between original profit and new profit associated with a unit change in a trait, keeping performance in other traits constant. Second, the partial differentiation method: using partial derivatives of the profit equation with respecting to the trait interest. Rewe (2004) used the partial derivatives of the profit equation as economic weights for within line selection, while Kluyts et al.

(2007) used partial budgeting to derive economic value for Simmental breed.

Records of traits for which economic values are needed can roughly be subdivided into two groups: (1) records of traits on continuous scale (Birth weight, fat depth, hip height, etc. (2) records of traits on an order categorical scale (calving ease, quality grade, etc). In practice, it is easier to estimate the economic value for continuous traits. For category traits, a profit function can be represented as fixed costs or returns for different categories. For example, for quality traits, a profit function is in most cases only approximately known in terms of the threshold below and above a given target for which price differentiating is applied (Kluyts et al., 2007). To overcome the problem, normalizing the grade of these category traits is used. According to the studies of Koots et al. (1994) and Falconer (1981), it indicated that for categorical traits, there is an unobserved underlying normal distribution of genetic and environmental values, and that the phenotypic category is defined by the threshold value applied to this distribution.

2.5.2.4 Cumulative discounted expression

In most situations, genetic superiority is not only expressed in one generation but the following generations of the selected animals as well. There are also delays of the expression of the economic benefits of the genetic improvement (Amer, 1999). Considering factors, such as inflation and sooner or later expression of genetic improvement, adjustment (in terms of discount factor) must be made to calculation of the economic benefits of genetic improvement. Thus, in evaluation of the economic benefits of genetic improvements, we must account for the spread of genetic improvement through a population and a series of time coming from a single selected group of animals. The discounted gene flow method proposed by McClintock and Cunningham (1974) and the cumulative discounted gene flow method stated by Hill (1974) are the ways for us to achieve this goal.

Cumulative discounted gene flow is the number of cumulative discounted gene expressions (CDGE) as a consequence of one mating; “cumulative” refers to an accumulation of expressions over generations or years; and “discounted” implies to the fact that future return is discounted to today’s values by a discounting factor (Jiang et al., 1999). The discounting factor value is related to the interest rate and

inflation rate. The principle of discounted gene flow has historically been used in animal breeding and genetic fields (Ponzoni and Newman, 1989; Amer, 1999; Jiang et al., 1999; Berry et al., 2006). Ponzoni and Newman (1989) indicated that since the discounted gene flow method takes into account both the frequency and the time of expression of traits, it should be the preferred method used in the estimation of economic values for beef cattle. Van Vleck and Everett (1976) used discounted gene-flow principles to evaluate new reproductive technologies which increase selection intensity in dairy cattle. The discounted gene expression genotype in a trait can be briefly define as the accumulation over generations and years of the product of (1) the probability that the matting or insemination results in a offspring; (2) the degree of relationship of the bull and cow to the animals in which his/her genotype is expressed; (3) the number of years separating each such expression from the year in which the insemination was carried out or the cow entered the herd and (4) the number of years after the selection that are taken into account.

2.6 Selection Response of Index

The selection response is the changes in performance of offspring from the matting of choosing superiority animal. However, the selection response we are always interested in is the genetic selection response, which is defined as the genetic improvement in new generation as a consequence of mating selected parents (Rewe, 2004). The selection response (R_H) base on the selection index expressed in matrix notation is:

$$R_H = i \frac{b'Gv}{\sqrt{b'Pb}} \quad (2-8)$$

Where b is the index weights; G is the genetic (co)variance matrix; P is the (co)variance matrix based on information from selection criteria and v is the economic weights vector. If the index is a optimal index, the selection response equation is written as:

$$R_H = i \sqrt{b'Gv} \quad (2-9)$$

From the index, the expected change in the additive genetic value of the i th trait (R_{ai}) in the aggregate genotype due to selection on the index can be calculated , which is defined as:

$$R_{ai} = i \frac{b'G_i}{\sqrt{b'Pb}} \quad (2-10)$$

where G_i is the genetic parameter vector related to the i th trait. For an optimal index:

$$R_{ai} = i \frac{b'G_i}{\sqrt{b'Gv}} \quad (2-11)$$

2.7 Accuracy of Selection Index

The accuracy of the selection index (r_{HI}) is defined as the correlation between the aggregate genotype (H) and the selection index (I), which is calculated as:

$$r_{HI} = \frac{\sigma_{HI}}{\sigma_I \sigma_H} \quad (2-12)$$

where σ_{HI} is the covariance between aggregate genotype (H) and the selection index (I); σ_I is the standard deviation of index; σ_H is the standard deviation of aggregate genotype. In matrix notation, the equation becomes:

$$r_{HI} = \frac{b'Gv}{\sqrt{b'Pb v'Cv}} \quad (2-13)$$

where v is a column vector of economic weights of the n traits in the aggregate genotype, C is an $n \times n$ matrix of genetic covariance among the traits in the aggregate genotype, b , P , G are the same meaning as previous notation. Because we assume the index is to be unbiased, the $b_{HI} = 1$ and $b_{HI} = \sigma_{HI}/\sigma_I^2$, thus $\sigma_{HI} = \sigma_I^2$

$$\sigma_{HI} = b'Gv = \sigma_I^2 = b'Pb \quad (2-14)$$

and therefore

$$r_{HI} = \sqrt{\frac{b'Gv}{v'Cv}} \quad (2-15)$$

2.8 Sensitivity of Selection Index

As described so far, the selection index provides a method to maximize selection response for a given aggregate genotype when a given set of observations are available and is determined by P , G , C and v . In principle, it is assume that the elements of economic value vector and the variance and covariance are known without error. In practice, elements of P , G , C , and v are estimated with error. The prediction errors will affect the efficiency of selection (Sales and Hill, 1976). However, errors are inherent in animal data

and therefore a better approach is to test the sensitivity of the index to the elements of v , P and G .

2.8.1 Sensitivity of selection index to change in variances and covariances

In practice, there are many ways that can be used to estimate the variance and covariance, all of which may result in different results. Therefore, the factors: an index which is insensitive to changes of variance and covariance would be superior. A test of sensitivity would be what proportion of maximum selection response we expect in the aggregate genotype if one set of variances to derive our index coefficients when another set of variance was more appropriate which is denoted as E_{ut} . The calculation equation is expressed as follows:

$$E_{ut} = \frac{b'_u G_t v}{\sqrt{b'_u P_t b_u}} \frac{1}{\sqrt{b'_t G_t v}} \quad (2-16)$$

$$b_u = P_u^{-1} G_u v \quad (2-17)$$

$$b_t = P_t^{-1} G_t v \quad (2-18)$$

where the subscript u describes the results of parameters used; t describes the results of assumed true parameters.

2.8.2 Sensitivity of selection index on estimates of economic value

Similar to the scenario of changes in variance and covariance, the economic value is neither rarely known without error. As discussed previous, there are many methods can be used to estimate economic value. Furthermore, the biological and management model used to estimate economic values are uncertain as are the values of different traits in future production systems and markets. The sensitivity of the selection index to changes in economic value should be tested. If it is sensitive, we should try to find out the best estimates. As the same as the investigations of uncertain variance and covariance, we can carry out analogous investigations for uncertain economic weights which is denoted as E_{ut} and calculated as:

$$E_{ut} = \frac{b'_u G v_u}{\sqrt{b'_u P b_u}} \frac{1}{\sqrt{b'_t G v_t}} \quad (2-19)$$

$$b_u = P^{-1} G v_u \quad (2-20)$$

$$b_t = P^{-1} G v_t \quad (2-21)$$

where the subscript u describes the results of economic values used; t describes the results of assumed true economic values. Besides this approach, correlations can be treat as a approach to assess the sensitivity of selection index on estimates of economic values which was used in previous study of Ponzoni (1986) and Rewe (2004). It is the method adopted in the study to test the sensitivity.

2.9 Traits Contributing to Response

Traditionally, more information leads to more accuracy. However, additional performance of animals takes time and effort consequently incurs costs. Thus, for selection index, it is important to test how much does each observation contributes to response in the aggregate genotype, so that the economic benefits of including that observation in terms of enhanced response can be evaluated against the cost of recording. Then a decision can be made on whether or not to collect that information to include into the index. The contribution of a trait to selection response and be calculated by comparing to the reduced index. The efficiency of a reduced index without observation i (E_i) can be defined as the ratio of economic (aggregate genotype) response for the reduced index (R_{H_i}) to that with the full index (R_H):

$$E_i = \frac{R_{H_i}}{R_H} = \sqrt{\frac{b_i^{*'} G_i^* v^*}{b' G v}} \quad (2-22)$$

$$b_i^* = P_i^{*-1} G_i^* v^* \quad (2-23)$$

where the subscript i indicates that the observation i has been excluded, and “*” describes the developed P , G , v and b matrices are related to the reduced index without observation i .

Besides the traditional calculation form, Cunningham and husdyrav1 (1969) described an alternative method to estimate the efficiency of reduced index without calculating the selection response of the new index. Efficiency of the index ignoring observation i can also be derived from:

$$E_{I_i^*, I} = \sqrt{\frac{\sigma_I^2 - \frac{b_i^2}{W_{ii}}}{\sigma_I^2}} \quad (2-24)$$

where σ_I^2 is the variance of full index; b_i is index weights vector of reduced index ignoring observation i in full index and W_{ii} denotes the inverse of phenotypic matrix ignoring observation i in full index.

The advantage of this method is that it is less calculation. Only the full index variance and index weights should be calculated, no new index has to be derived; information for the computation is available from computations of the original index.

2.10 Alternative Selection Index Approaches

In selection index, the index response is determined by the economic value, the genetic and phenotypic variance and covariance calculated from the available information. Actually, in some case, when construct indexes, the rate of genetic change in one or more traits is predetermined. For instance, we may constrain genetic change in a trait to 0 or one trait may be set to get genetic change at two times the rate of other traits.

2.10.1 Restriction index

Aim is to maximize selection for a given aggregate genotype, subject to the restriction of no genetic change in one or more goal trait was introduced by Kempthorne and Nordskog (1959). MacNeil and Newman (1994) reported on use of the restricted index. According to the study Brascamp (1984) the solution for restriction index is expressed as follows:

$$b = P^{-1}(1 - G_i(G_i'P^{-1}G_i)^{-1}G_i'P^{-1})Gv^* \quad (2-25)$$

where G_i is the genetic parameters related to restricted trait i ; G is genetic variance and covariance matrix of all traits without restriction and v^* denotes the economic value vector with restriction on trait i .

The new equation expressed as:

$$P^*b^* = G^*v^* \quad (2-26)$$

where P^* is phenotypic variance and covariance matrix of selection criteria with restriction, G^* is genetic variance and covariance matrix of traits in breeding objective without restriction and b^* is the index weights associated with restriction on trait i . They can be expressed as follows:

$$\begin{bmatrix} P & G_i \\ G_i & 0 \end{bmatrix} \begin{bmatrix} b \\ \lambda \end{bmatrix} = \begin{bmatrix} G \\ 0 \end{bmatrix} [v^*] \quad (2-27)$$

Then the λ and b^* can be solved as:

$$\lambda = (G_i'P^{-1}G_i)^{-1}G_i'P^{-1}Gv^* \quad (2-28)$$

$$b^* = P^{*-1}G^*v^* \quad (2-29)$$

where P is the phenotypic variance and covariance matrix of selection criteria; λ denoted the LaGrange multipliers.

2.10.2 Desired gains index

An alternative approach to selection index is the desired gains approach (Itoh and Yamanda, 1986). The aim is for the genetic responses of specific traits in the breeding objective to meet a predetermined rate. Pešek and Baker (1969) first suggested a selection index to attain predetermined desired genetic gains which is called desired gains index requiring no relative economic value for each component trait. The equivalent approach:

$$\begin{bmatrix} P & G_i \\ G_i & 0 \end{bmatrix} \begin{bmatrix} b \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ d \end{bmatrix} \quad (2-30)$$

The solution is:

$$b = P^{-1}G_i(G_i'P^{-1}G_i)^{-1}d \quad (2-37)$$

where d is the predetermined gain; P is the phenotypic variance and covariance matrix of selection criteria; λ denoted the LaGrange multipliers; G_i is the genetic parameters related to restricted trait i .

2.11 Usage of the Selection Index

2.11.1 Beef cattle breeding

The selection index has been used for last 20 years in beef cattle industry (MacNeil et al., 1997). The bulls in the industry are selected for a balance between traits affecting reproduction, calf growth and carcass merit. However, it is almost impossible for a bull to perform well in all the roles. So it is sagacious to us to breed bulls for a specific purpose according to their performance to get as much genetic improvement as possible in one direction. In industry, multiple trait indexes using economic weights on measurable traits (e.g. birth weight, gain before and after weaning, scrotal circumference and ultrasound carcass measurements) are used to evaluate and rank bull to select super prior bulls (MacNeil et al., 1997). While, cow indexes focused on birth weight, pre-weaning gain, post-weaning gain, and mature weight are used to cull poor performance cows (MacNeil et al., 1997).

2.11.2 Swine breeding

In the swine industry, the “purebred” grandparent lines are usually used in production and the parents are generally crossbred. So, selection index are used to do within line selection to produce progeny. The use of specialized sire and dam lines, high reproductive rates characteristic of swine, short generation intervals, and intense selection yield rapid genetic improvement and also facilitate near-maximum exploitation of hybrid vigor (MacNeil et al., 1997).

2.12 Conclusions

When constructing a selection index, we should correctly design the breeding objectives so that we use economically important traits and selection criteria. Secondly, we should use as much information as possible to obtain the genetic parameters and genetic correlations among selection criteria and economic related traits. Generally, the restricted maximum likelihood (REML) method is widely used as an unbiased method to calculate the genetic parameters and correlations. Thirdly, the relative economic value’s influence on the efficiency of selection index varies with the production and marketing system. Discounted gene flow method should be involved in estimating the relative economic value (Ponzoni and Newman, 1989). In sum, when constructing a selecting index, we should be clear and define the errors in genetic parameters and economic weights that may lead to losses in efficiency in selection.

CHAPTER 3

DEFINITION OF BREEDING OBJECTIVE AND DEVELOPMENT OF PROFIT EQUATION

3.1 Introduction:

The combination of genetic, nutritional, biological, management, marketing environment and economic factors contribute to the complexity of beef production systems. Thus, simulating a production system while considering as many of these factors as possible is an efficient way to estimate the economic weights for traits related to the return and cost of a herd. Actually, the profit equation is a mathematical expression of the production system, and an essential part of developing a profit equation is to determine the breeding objective. The procedure developed by Ponzoni and Newman (1989) was used to define the breeding objective in this study. The chapter describes the economically relevant traits and their interrelationship involved in the profit equation. Also the breeding, production and marketing systems of the specific John E. Rouse ranch Colorado State University Beef Improvement Center (CSU BIC) are described in the chapter.

3.2 Describing the Breeding System

The breeding system is the way in which the animal is used in beef industry. Generally, the role of an animal can be general purpose, maternal or terminal purpose. In this study, the economic values were estimated for maternal purpose animals (offspring used as parents in future production) and terminal purpose animals (offspring used to slaughter).

3.3 Describing the Production and Marketing System

The production and marketing system includes the production size, the age composition of the herd, replacement policy, feed plan, health care, ages and prices of animals at marketing and slaughter (Newman et al., 1992). The study is based on three production and marketing systems: 1. Maternal system (Rouse system): sale heifers at 18 months; sale yearling bulls at 12 months; slaughter steers at 15 months; with a female and male self-replacement plan; 2. Terminal system without self-replacement (simulation based on CSU-BIC system): all replacement cattle are from outside herd; slaughtered all offspring at 15

months; 3. Terminal system with female self-replacement (simulation based on Rouse system): with female self-replacement policy; slaughtered all offspring except replacement heifer at 15 month. The production structure of the maternal system (Rouse ranch production and marketing system) is presented in Figure 1.

3.3.1 Reproduction and health plan

Based on the Colorado State University Beef Improve Center (CSU-BIC) herd, the calving date was set as March to April, with the average weaning age of 186 day calculated from the data of CSU-BIC. Natural mating was assumed for all the three systems. Based on the calculation from pedigree data of CSU-BIC, the bull to cow ratio was approximately to 1:50, and used accordingly as the cow to bull ration to build profit equation. Also, bulls were used for 2 years on average.

All the three systems had a health care plan, which included vaccination of all animals in the herd and castrating of steers for slaughter. The cost of the health care was considered a fixed value for each animal in building profit equation.

3.3.2 Replacement and culling policy

The replacement and culling policy used in the study was based on the 10,007 individual records and 27,165 pedigree records from the Angus herd at the John E. Rouse Beef Improvement Center of Colorado State University. The data contained the records of calves and cows from 1986 to 2011. The population size (N), age composition of the herd (cow age from 1 to 16) and fixed effects (sex, age of dam, and calving year) were assumed the same for all the three system in the study. The herd size was assumed constant overtime for all system. The sex ratio for offspring in the system was assumed as 1:1.

3.3.3 Feed plan

All of the three production systems were assumed to have the same feed plan. The feed plan had been generally divided into two parts: grazing and hay. The grazing period was in the season which has plenty and high quality grass, from 1st May to 15th December every year. Figure 3.2 showed the feed plan of CSU-BIC. The major feed was assumed to be hay outside the grazing period.

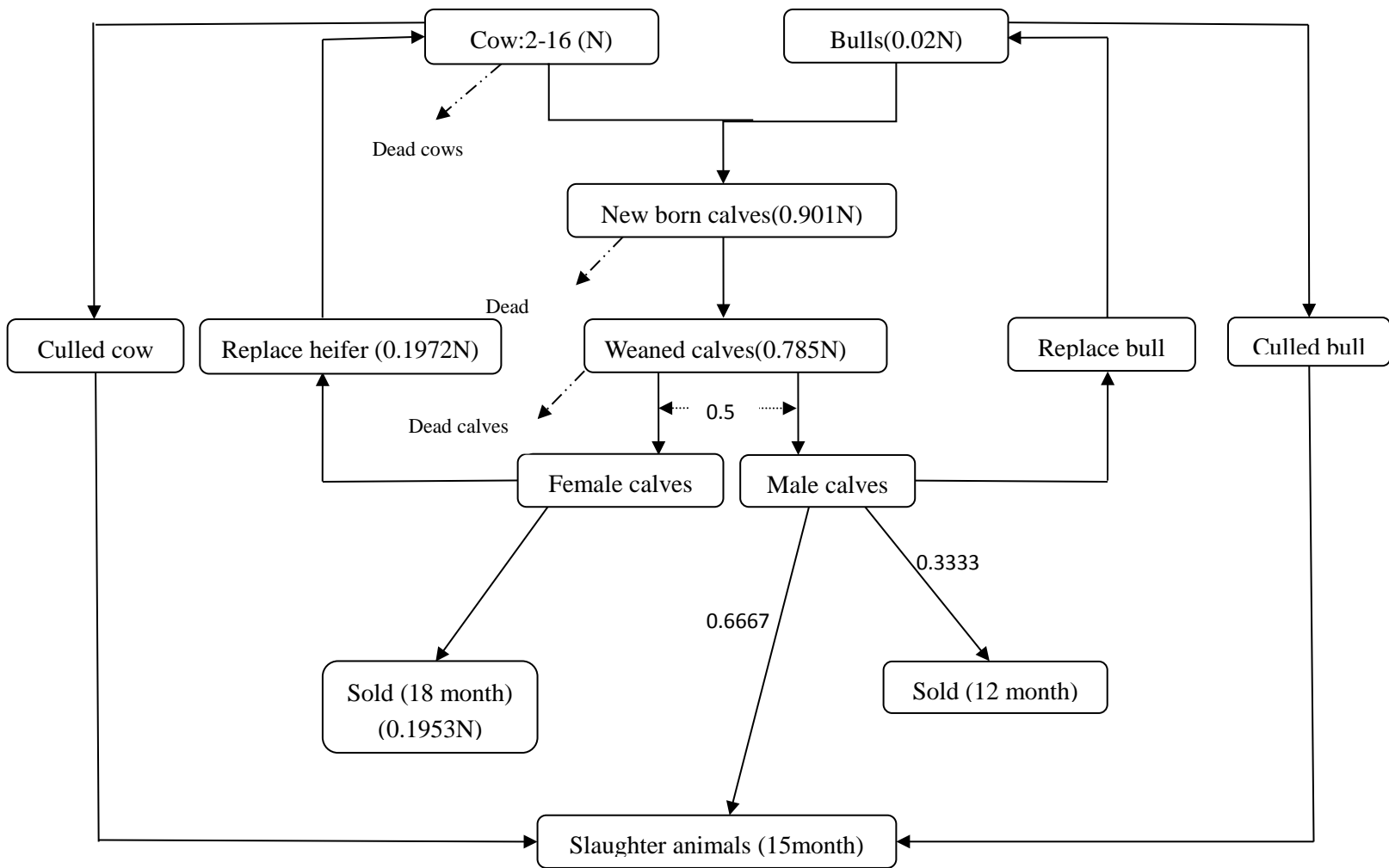


Figure 3.1 Production structure of John E. Rouse Beef Improvement Center of Colorado State University

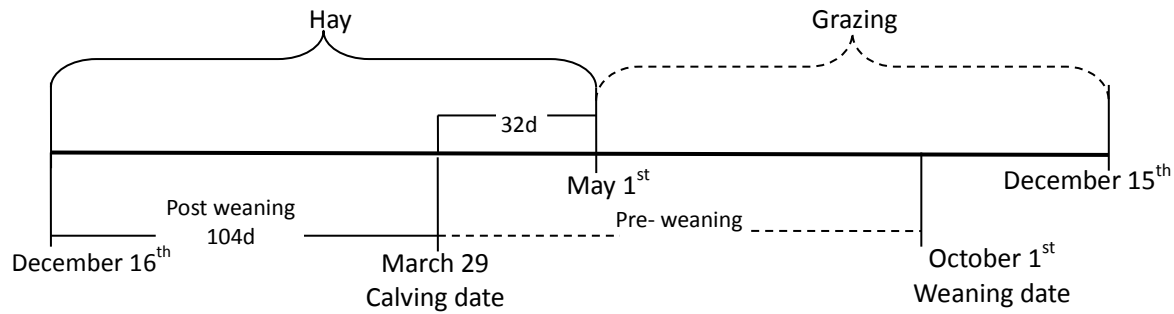


Figure 3.2. Feed plan of Colorado State University Beef Improve Center

In the study, it was assumed that there was no additional feed to feedlot animals or bulls. The fix feed cost for grazing was \$25/cow pair per month, and the average price for hay was assumed to be 260.5/ton calculated from the USDA market report from December 2011 to April, 2012 (USDA-AMS, 2011). The hay was only variable feed factor affecting the cost of a herd. Table 3.1 shows the variables and their values needed to build the profit equation.

3.4 Develop Profit Equation

In the profit equation, all economically relevant traits of interest were included, so that the economic value could be derived. In beef industry, higher carcass quality and higher net calf crop are two of the most important factors leading to higher biological and economic efficiency (Rewe, 2004). Actually, there are a lot of traits contribute to the two function, which can divided into three category: production, quality and function traits. Table 3.2 lists the traits influencing the revenue and cost of the herd considering that they are related to steps of the production system.

3.4.1 Production traits

The production traits included those influencing the growth and final weight of calves. In this study, these traits were birth weight (BW), weaning weight including additive weaning weight effect (WW) and maternal weaning weight effect which is the milk yield (MY), pre-weaning average daily gain, (preADG), pos-weaning average daily gain (postADG), because they are related to feed intake cost of slaughter

Table 3.1. Summary of variables involved profit equation^a

Symbol	Variable	Value
NCW	Number of calves weaned	0.785
CoSR(%)	Cow survival rate per year	99.000
CoWR(%)	Cow weaning rate per year	79.290
CR(%)	Calving rate	90.100
SR(%)	Pre-weaning Calf Survival rate	88.000
PSR(%)	Post-weaning Calf Survival rate	99.620
NsC	Number of weaning steers for slaughter	0.262
RR _b (%)	Bull replacement rate	25.000
RR _c (%)	Cow replacement rate	19.270
CCR(%)	Culling cow rate	18.270
BW(kg)	Average Birth weight	36.589
WW(kg)	Average Weaning weight	179.410
preADG(kg/d)	Pre-weaning average daily gain	0.767
mposADG(kg/d)	Male post weaning average daily gain	1.366
fposADG(kg/d)	Female post weaning average daily gain	0.763
NE _{ma} (Mcal/kg)	Average maintenance Net energy of hey	1.215
NE _{ga} (Mcal/kg)	Average growth net energy of Alfalfa hey	0.648
CoWT(kg)	Mature cow weight	541.560
P _f (\$/Ton)	Price of feed	0.260
P _m (\$/kg)	Carcass price	3.143
P _c (\$/kg)	Culled cow price	1.587
rhc(\$/head)	Replacement heifer cost	1,200
Rbc(\$/head)	Replacement bull cost	1,585
MY(kg)	Milk yield per year	1,037.009
FI _c (kg)	Cow feed intake (hey)	1706.03
CM(\$/head)	Marketing cost	10.000
CDcost(\$/calving)	Calving difficult cost	5.700
GC(\$/pair)	Fixed graze cost	25.000
Lab(\$)	Labor salary	115,771.000
Other(\$)	Other fixed cost (Transportation and facilities)	166,761.000

^a The values were estimated from CSU BIC records and the equations used to calculate feed intake are from Nutrient requirements of beef cattle (NRC, 2000).

Table 3.2 Traits influencing cost and revenue in the study

Profit components	Class of herd	Relevant Traits ^a
Cost		
Feeding	Slaughter animals	CoSR, CR, SR, BW, WW, preADG, posADG, PSR
	Sale yearly bulls	CoSR, CR, SR, BW, WW, preADG, posADG, PSR
	Sale heifer	CoSR, CR, SR, BW, WW, preADG, posADG, PSR, CCR
	Replacement heifer	CoSR, CCR, WW, preADG, posADG, PSR
	Cows	CoSR, CCR, CoWT,
Health	Slaughter animals	CoSR, CR, SR, PSR, CCR, CE
	Sale yearly bulls	CoSR, CR, SR, PSR, CCR, CE
	Sale heifer	CoSR, CR, SR, PSR, CCR, CE
	Replacement heifer	CoSR, CCR, PSR, CE
	Cows	CoSR
Marketing	Slaughter animals	CoSR, CR, SR, PSR
	Sale yearly bulls	CoSR, CR, SR, PSR
	Sale heifer	CoSR, CR, SR, CCR, PSR
	Cows	CCR
Revenue		
	Slaughter animals	CoSR, CR, SR, PSR, WW, posADG, USDAgrade, DP
	Sale yearly bulls	CoSR, CR, SR, PSR
	Sale heifers	CoSR, CR, SR, CCR, PSR
	Culled cows	CCR, CoWT

^aCoSR: Cow survival rate per year; CR: Cow calving rate per year; SR: Calf survival rate before weaning; BW: Birth weight; WW: Weaning weight; preADG: pre weaning average daily gain; postADG: Post weaning average; PSR: Calf post weaning survival rate; CCR: Cow culling rate; CoWT: Cow weight ; CE: Calving ease; USDAgrade: USDA meat quality grade; DP: Dressing percentage

animals (FI_s), sold heifer (FI_h), sold bulls (FI_b), replacement heifer (FI_{rh}), cow (FI_c) and hot carcass weight (HCW). In the study, feed intake was calculated according to the net energy required for maintenance and growth, and the hot carcass weight was determined by the weaning weight, post weaning average daily gain and the dressing percentage (DP) because of lacking of these data. Also the dressing percentage was set to be constant as 0.62 (MacNeil et al., 2005).

3.4.2 Meat quality traits

Meat quality traits are those traits indicative of the quality of the beef produced, sub sequentially influencing the price of the meat. In fact, the selection for quality traits should depend on the customer demand. These meat quality traits included marbling score, fat depth, ribeye area and shear force. However, the main factor to determine the price of the beef is the USDA quality grade (USDA-AMS, 2011-2012), so in the study, the economic value was only estimated for USDA quality grade.

3.4.3 Function traits

Function traits are those related to cow survival, reproduction and calf survival. They include the cow survival rate (CoSR), cow weaning rate (CoWR) which was determined by cow calving rate (CR) and calf survival rate before weaning (SR), calving interval (CI), cow replacement rate (RRc) which was determined by cow survival rate and cow culling rate of the herd (CCR) and post weaning calf survival rate (PSR).

3.4.4 Developing the profit equation

Generally the profit equation for the herd per year as a function of economic relevant traits can be expressed as (Rewe, 2004):

$$P = \sum_{i=1}^m [n_i(R_i - C_i)X_i] - F$$

where P represent the total profit, m is the number of categories of animals in a herd, n is the number of animals for a trait in the i th class of animal (divided by function), R and C represent the revenue and cost per unit for trait X and F are the fixed costs including transportation.

The profit equation developed in the study was based on per cow per year. Usually, when constructing the whole profit equation, animals in a herd were classified into several categories to develop the profit equation separately, and then merge them together, so that the process can be clear and simple (Ponzoni and Newman, 1989; Koots and Gibson, 1998).

Since the numbers of mature bulls is much less than cows and they have little influence on total revenue and cost of an industry herd, the revenue and cost come from mature bulls were ignored in the present study. The first step to construct profit equation was determined by the number of animals at weaning because it is important in deriving the number of calves at each stages of the life cycle, e.g. the number of steers which can be slaughtered. As discussed above, the number of calves weaned can be expressed as:

$$NCW = N * CoSR * CoWR \quad (3-1)$$

Where NCW was number of calves at weaning; CoSR denoted cow survival rate per year; CoWR was calf weaning rate per year, and

$$\text{CoWR} = \text{CR} * \text{SR} \quad (3-2)$$

where CR was cow calving rate per year calculated as the number of new born calves divided by total number of breeding cows ; SR was calf survival rate before weaning.

3.4.4.1 Profit equation for maternal system

In the system, the animal had been divided into six categories: slaughter calves (P_s), sold heifers (P_h), sold yearling bulls (P_{yb}), self-replacement heifers (P_{rc}), and cows (P_c), and F denote the total fixed cost:

$$P = P_s + P_h + P_{yb} + P_{rc} + P_c - F \quad (3-3)$$

3.4.4.1.1 Profit equation of slaughter animals

According to the production structure of the maternal system, all females were kept in herd for sale as replacement heifers and about two thirds (66.67%) of the male calves were raised for slaughtering while others were kept as bulls for sale at a year old. Then, the number of steers attending slaughter (NsC) was:

$$NsC = 0.5 * NCW * 0.6667 \quad (3-4)$$

where NCW was number of calves at weaning. The revenue of the slaughter animals (Rs) can be expressed as:

$$Rs = NsC * PSR * HCW * P_m \quad (3-5)$$

P_m was the price of meat which was depended on quality grade. Based on the weaning weight, post-weaning average daily gain and the limited records of hot carcass data, HCW was described as (MacNeil et al., 2005):

$$HCW = (ww + \text{postADG} * 271) * DP \quad (3-6)$$

postADG denoted post weaning average daily gain; DP is dressing percentage; 271 was the days between weaning age and slaughter age (age 457 day - age 186 day). The feed cost was considered in two parts in the study, the pre weaning feed intake cost ($CsFW$) and the post weaning feed intake cost ($CsFPW$):

$$CsFW = NsC * FIs * Pf \quad (3-7)$$

$$CsFPW = N_s C * PSR * FI_{sp} * P_f \quad (3-8)$$

where P_f was hay price assumed as 260.5 per ton according to the Colorado weekly hay report from December 2011 to April, 2012 (USDA-AMS, 2011); FI_s represented the feed intake per slaughter animal before weaning; FI_{sp} was the post weaning feed intake per slaughter animal. Furthermore the feed intake was calculated by dividing the net energy needed for maintenance (NE_m) and growth (NE_g) for each animal using maintenance energy (NE_{ma}) and growth energy (NE_{ga}) contained in feeds. The equation used to calculate net energy requirements was developed according to the mathematical function and adjustment factors for Angus cattle in the Nutrient Requirements of Beef Cattle: Seventh Revised Edition of National Research Council (NRC, 2000), where the breed effect parameter for Angus was 1, lactation effect for calves was 1, temperature was assumed to be fixed at 20 centigrade based on the report of NRC, and body condition score was set at 4.66 which is the calculated average score of calves of CSU-BIC. Fitting these parameters into the original equation of NRC, the net energy equations for maintenance and growth can be expressed as:

$$NE_{mi} = 0.0734 LW_i^{0.75} \quad (3-9)$$

and

$$NE_{gi} = 0.0506 LW_i^{0.75} * ADG^{1.097} \quad (3-10)$$

where NE_{mi} was the energy needed by the animal to maintain life on the i th day after birth; NE_{gi} represent the energy needed by animal for growth on the i th day after birth. When calculate pre-weaning feed intake, the ADG is pre-weaning average daily gain, and the live weight on day i (LW_i) can be calculated as:

$$LW_i = BW + preADG * i \quad (3-11)$$

where BW represents birth weight, i is number of days after birth; $preADG$ represent pre-weaning average daily gain. Then the whole feed consumed by animal in pre-weaning period can be calculated as:

$$FIS = \frac{\sum_{i=1}^{32} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{32} NE_{gi}}{NE_{ga}} \quad (3-12)$$

Because the grazing feed cost was fixed at \$25/pair in the study, the only variable feed cost considered

was hay. According to the feed plan of CSU BIC showed in figure 3.2, the first 32 days in pre-weaning period were hay, so the 32 days was considered in feed equation.

When calculating the post-weaning feed intake for slaughter animals, the ADG was the post-weaning average daily gain. The slaughter age was fixed at 15 months based on the production system of CSU-BIC, and the live weight was calculated as:

$$LW_i = WW + postADG * i \quad (3-13)$$

where i was the number of days after weaning. However, based on the feeding plan, the animals grazed in the first 75 days in post-weaning period, and 136 (next grazing time-weaning age -75) days were considered feeding hay, so live weight for post-weaning slaughter animals were adjusted as:

$$LW_i = WW + postADG * (i + 75) \quad (3-14)$$

Then the feed consumed in post-weaning period by calves for slaughter (FIsp) was calculated as (with the changing of ADG):

$$FIsp = \frac{\sum_{i=1}^{136} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{136} NE_{gi}}{NE_{ga}} \quad (3-15)$$

Besides the feed cost, the health cost for pre-weaning (CsHW) and post-weaning (CsHPW) animals including veterinary and medicine cost was also considered as variable cost because they were depend on the number of animals:

$$CsHW = NsC * (vet + medicine) + CDcost_s \quad (3-16)$$

and

$$CsHPW = NsC * PSR * (Vet + Medicine) \quad (3-17)$$

where the calving difficulty cost (CDcost) was calculated as:

$$CDcost = CR * RRc * CDhcost + (1 - RRc) * CR * CDccost \quad (3-18)$$

where CDhcost represented the calving difficulty cost for heifer, CDccost was the calving cost for mature cow, CR was calving rate and RRc represented cow replacement rate. Based on the price information collected from previous literature (Dekkers, 1994) and the calving ease score records from CSU BIC, the average calving difficulty cost for the first calving heifer (CDhcost) was calculated as

$$CDhcost = \sum_{j=1}^5 C_j p_j = \$5.6802 \quad (3-19)$$

where C_j was calving difficulty cost for j th calving ease category, and p_j is the percentage of heifers with calving difficulty in j th calving ease category. The calving difficult cost for cow (CDccost) was calculated similarly. Thus the cost for heifer was assumed to represent the whole caving difficulty cost, so:

$$CDcost = CR * RRc * 5.6802 \quad (3-20)$$

where:

$$RRc = 1 - CoSR + CCR \quad (3-21)$$

CCR was cow culling rate per year. The sum of the calving difficulty cost in each part was the total calving difficulty cost of the system expressed as equation (3-20). Thus, when economic values were calculated, it can be used to represent the total calving difficulty cost. In the livestock industries, another variable cost is the marketing cost (CM) for animals. Since when compared to other factors (Feed, meat price and number of animal available to trend), it is of less influence on profit of a herd, the marketing price (M) for all kind of animals was assumed the same as \$10 per animal according to previous literature (PSU, 2001):

$$CM = N_s C * PSR * M \quad (3-22)$$

3.4.4.1.2 Profit equation for yearling bulls on sale

Although there should be replacement bulls in the herd, the number was too small to affect the profit, so the replacement of bull was not considered in profit equation in the study. Thus, the number of yearling bulls attending sale (NbC) based on the marketing plan (one third of the male calves for sale) was:

$$NbC = 0.5 * NCW * 0.3333 \quad (3-23)$$

The revenue of the yearling bulls (Rb) can be expressed as:

$$Rb = NbC * PSR * Pb \quad (3-24)$$

$$Pb = -1356.635 + 6.01 * (WW + mpostADG * 179)$$

where WW was weaning weight, $mpostADG$ represent male's post weaning average daily gain, 179 was

the day between weaning and yearling, -1356.635 and 6.01 were linear regression parameters when yearling weights was regressed on the bull prices. The linear relationship between the price and mature weight was estimated from the historical bull sale records (1999-2000) of CSU BIC.

The equation (3-9) and equation (3-10) were also used to calculate the energy requirement for calves in this category. However, based on the feed plan, production and marketing system of CSU BIC (showed in figure3.1 and figure3.2), the yearling bulls stayed in herd for 12 months, so there were 32 days feeding hay in pre weaning period while there are 104 days feeding hay after 75 days' grazing in the post weaning period. Thus, the feed intake of sale bulls before weaning (Flb) and after weaning ($Flbp$) were calculated as:

$$Flb = \frac{\sum_{i=1}^{32} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{32} NE_{gi}}{NE_{ga}} \quad (3-25)$$

and

$$Flbp = \frac{\sum_{i=1}^{104} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{104} NE_{gi}}{NE_{ga}} \quad (3-26)$$

Then the variable feed cost for yearly bulls in pre-weaning (CbFW) and post-weaning (CbFPW) periods for sale bulls were:

$$CbFW = NbC * Fls * P_f \quad (3-27)$$

and

$$CbFPW = NbC * PSR * Flbp * P_f \quad (3-28)$$

The pre-weaning healthy (CbHW) and post-weaning (CbHPW) cost for sale bulls were expressed as:

$$CbHW = NbC * (Vet + medicine) + CDcost_b \quad (3-29)$$

$$CbHPW = NbC * PSR * (Vet + medicine) \quad (3-30)$$

The marketing cost (CbM) for sale bulls was calculated as:

$$CbM = NybW * PSR * M \quad (3-31)$$

3.4.4.1.3 Profit equation for sale heifers

In the production system, all the female calves, except the ones used as for replacements, were sold at 18 months old based on the production system of CSU-BIC:

$$NhC = 0.5 * NCW - (CCR + (1 - CoSR)) \quad (3-32)$$

where NhC denotes the number of heifer for sale. The revenue of these female animals (Rh) was expressed as:

$$Rh = NhC * PSR * rhc \quad (3-33)$$

The heifer price (rhc) was set as \$1200 per head in the study, which came from the records of CSU BIC. The hay feeding periods for the sale heifer are the same with the slaughter animal category. Then, equation (3-9) and equation 3-10) can be used to calculate net energy requirements of maintenance and growth for in pre-weaning and post-weaning period of this category. The post average daily was defined as the ADG after weaning and before yearling, so the post weaning feed intake of this category animal was calculated separately by before and after yearling because of different ADG:

$$LW_i = WW + postADG * (i + 75) \quad (3-34)$$

which was live weight used for calculating feed intake of pre-yearling (104 day)

$$LW_i = WW + postADG * 179 + postyADG * i \quad (3-35)$$

which was live weight of post yearling (32 day). postyADG represent the post yearling average daily gain for heifer. Then the post weaning feed intake for sale heifer (*FIhp*) was calculated as:

$$FIhp = \frac{\sum_{i=1}^{104} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{104} NE_{gi}}{NE_{ga}} + \frac{\sum_{i=1}^{32} NE_{mi}}{NE_{ma}} + \frac{\sum_{i=1}^{32} NE_{gi}}{NE_{ga}} \quad (3-36)$$

Also, the heifers were considered pregnant before selling, so net energy requirement for pregnancy (NEpre) should be included to calculate the total feed intake cost. However, according to the feed plan, the number of pregnancy days in the period was when the animal was grazing, so the pregnancy feed cost is a part of fixed feed cost which did not needed to include in profit equation to estimate economic values. Thus, the pre-weaning (ChFW) and post-weaning feed (ChFPW) intake cost were calculated as:

$$ChFW = NhC * FIh * Pf \quad (3-37)$$

$$\text{ChFPW} = \text{NhC} * \text{PSR} * \text{FIhp} * \text{P}_f \quad (3-38)$$

where FIh represents the feed intake of sale heifer which was calculated as the same as pre-weaning feed intake of sale bulls. Similarly, the pre-weaning (ChHW), post-weaning (ChHPW) and marketing cost for sale heifer (ChM) were expressed as:

$$\text{ChHW} = \text{NhC} * (\text{vet} + \text{medicine}) + \text{CDcost}_h \quad (3-39)$$

$$\text{ChM} = \text{NhC} * \text{M} \quad (3-40)$$

3.4.4.1.4 Profit equation of replacement heifer

The number of replacement heifer (Nrhc) equals the number of culling cows plus the number of dead cows each year:

$$\text{Nrhc} = \text{N} * (1 - \text{CoSR} + \text{CCR}) \quad (3-41)$$

In the study, the replacement heifer was supposed to be fed for two years until they calve to enter the cow category. The pre-weaning feed intake (FIrh) was the same with other calves and the cost (CrhFW) was:

$$\text{CrhFW} = \text{Nrhc} * \text{FIrh} * \text{P}_f \quad (3-42)$$

while because the heifers were considered stay in herd for two years until they become cows, the post-weaning feed intake was calculated for two parts' hay feeding after weaning, firstly, Day 76 to Day 211 with post-weaning average daily gain; secondly, Day 441 to Day 544 with post yearling average daily gain based on the feed plan of CSU BIC every year. The calculation of part one of post weaning feed intake was the same as the sold heifers. However, for the second part, based on the feed plan, the live weight should be calculated as:

$$\text{LW}_i = \text{WW} + \text{postADG} * 179 + \text{postyADG} * 261 + \text{postyADG} * i \quad (3-43)$$

Where i is the number of days after age 440; Then the feed intake estimate was:

$$\text{FIrh}_2 = \frac{\sum_{i=1}^{104} \text{NE}_{mi}}{\text{NE}_{ma}} + \frac{\sum_{i=1}^{104} \text{NE}_{gi}}{\text{NE}_{ga}} \quad (3-44)$$

The pregnancy energy requirement which was considered another energy category for maintenance should be considered in the category. The length of pregnancy was assumed to be fixed 274 days which was the mean value of the data from Rouse ranch from 1986 to 2011. According to the feed plan, in the

first 170 days of pregnancy, animals were grazing, and the hay was only consumed by animals in the later 104 days. Thus, the variable feed intake for pregnancy for replacement heifer (F_{Irhp}) were expressed as:

$$F_{Irhp} = \frac{\sum_{i=171}^{274} NE_{pre_i}}{NE_{ma}} \quad (3-45)$$

where the net energy requirements for replacement heifer (NE_{pre}) were calculated according to the NRC guidelines with considering the characteristics of Angus cattle as:

$$NE_{pre} = 37.6988 * \left(\frac{0.576}{0.13} \right) * (0.05855 - 0.0000996 * t) * e^{((0.03233 - 0.0000275 * t) * t)} * \left(\frac{1}{1000} \right) \quad (3-46)$$

Then the total feed intake post weaning of replacement heifer was:

$$F_{Irhp} = F_{Irhp1} + F_{Irhp2} + F_{Ipre} \quad (3-47)$$

and the post-weaning feed intake cost for the category was:

$$CrhFPW = N_{rh}C * F_{Irhp} * P_f \quad (3-48)$$

The pre-weaning (Cr_hHW) and post-weaning (Cr_hHPW) and marketing cost (Cr_hM) for replacement heifer were expressed as:

$$CrhHW = N_{h}C * (vet + medicine) + CDcost_{rh} \quad (3-49)$$

$$CrhM = N_{h}C * M \quad (3-50)$$

3.4.4.1.5 Profit equation of cows:

It is assumed that death of cows occurred at the beginning of every year, so the number of cows (N_c) involved in the study was:

$$N_c = CoSR \quad (3-51)$$

The revenue of cows (R_c) were all from the sale of culled cows, which was:

$$R_c = CCR * CoWT * P_c \quad (3-52)$$

where the cow weight (CoWT) was the average cow weight of the CSU BIC from 1986 to 1999. The culling cow price (P_c) was the average price of culling cow in every month from March, 2011 to March, 2012 according to the Marketing reports of USDA, which is \$70 per CWT. According to the pre-analysis

LSMEAN results on mature weight of cows in the herd, the cows were separated into 6 parts by age: 2, 3, 4, 5, 6-11 and 12 years old. Because the culling age was fixed to be 12 years old, other older cows were treated as 12 years old in the study. Table 3.3 showed the mature weight data summary. Also it was assumed that there was average daily gain for each cow age except 12 years old animals so that the feed intake could be estimated more accurately.

Table 3.3. Summary of cow distribution, average live weight (kg) and the average of average daily gain of each cow age group in John E. Rouse Ranch of Colorado State University Beef Improvement Center

Age Group	P ^a	LW ^b	ADG ^c
2	0.193	468.507	0.120
3	0.147	512.450	0.096
4	0.127	547.400	0.069
5	0.206	572.490	0.057
6-11	0.290	593.230	-
12	0.036	536.595	-

^a P= proportion of cow in age group i in the herd

^b LW= the average cow weight of age group i

^c ADG= Average daily gain of cow from age i to age i+1

The parameters used in developing net energy equations were the same with calves' but the average body condition score was 5.1569 calculated from mature cow data of CSU BIC from 1986 to 1999 and lactation effect was 1.2 when cows were lactating. The energy requirements for each age group were calculated as based on the equations of NRC guidelines:

$$NE_{m_{ij}} = 0.0903(CoWT_{ij} + ADG_j * i)^{0.75} \quad (3-53)$$

$$NE_{g_{ij}} = 0.0506(CoWT_{ij} + ADG_j)^{0.75} * ADG_j^{1.097} \quad (3-54)$$

where i represented the day animal feed which was 1 to 365 day; j is the age group which was 1 to 6. The hay feed date was day 1 to day 32 and day 262 to day 365 based on the feed plan. Then, the feed intake for cow to maintenance (FI_{c1}) and growth (FI_{c2}) was calculated as:

$$FI_{c1} = \frac{\sum_{j=1}^7 \sum_{i=1}^{32} 0.0903(CoWT_{ij} + ADG_j * i)^{0.75} * p_i + \sum_{j=1}^7 \sum_{i=262}^{365} 0.0903(CoWT_{ij} + ADG_j * (i+261))^{0.75} * p_i}{NE_{ma}} \quad (3-55)$$

and

$$FI_c2 = \frac{\sum_{j=1}^7 \sum_{i=1}^{32} 0.0506(CoWT_{ij} + ADG_j)^{0.75} * ADG_j^{1.097} * p_i + \sum_{j=1}^7 \sum_{i=262}^{365} 0.0506(CoWT_{ij} + ADG_j * (i+261))^{0.75} * ADG_j^{1.097} * p_i}{NE_{ma}} \quad (3-56)$$

where the p_i is the proportion of animals in group i in all cows, and cow weight in the equation was treated as the same trait with the culling cow weight. Additionally the pregnancy feed intake for cow can be calculated using equation (3-44). Besides considering the pregnancy requirement, feed intake for lactation was calculated for cows after calving. The energy requirement for lactation was calculated based on the equations in NRC guidelines as:

$$Yn_w = w / (a * e^{k*w}) \quad (3-57)$$

$$a = \frac{1}{PKYD * k * e} \quad (3-58)$$

$$k = \frac{1}{T} \quad (3-59)$$

$$Yn_{sum} = \sum_1^{30} Yn_w * 7 \quad (3-60)$$

$$NE_{lac} = [(0.092 * 4.03) + (8.31 * 0.049) - 0.0569] * Yn_{sum} \quad (3-61)$$

The parameters used to calculate net energy requirement were from the guidelines of NRC, where w was the week of lactation, Yn_w was daily milk yield at week w of lactation (kg/d), T was the week of peak lactation which was set as 8.5, $PKYD$ is the peak milk yield of Angus which was 8.0 kg/day, e was the base of the natural logarithms which is 2.71828, Yn_{sum} is the total milk yield of the year, and NE_{lac} was the net energy needed to lactation, so the feed intake requirement for lactation of cow (FI_{clac}) was expressed as:

$$FI_{clac} = \frac{NE_{lac}}{NE_{ma}} \quad (3-62)$$

Then feed intake for cow (FI_c) was:

$$FI_c = FI_{c1} + FI_{c2} + FI_{pre} + FI_{clac} \quad (3-63)$$

Thus the total feed intake cost (CcF) was:

$$CcF = CoSR * FI_c * P_f \quad (3-64)$$

All animals in the herd were assumed to get veterinarian, care and treatment with the same cost, and only the culled cows marked, with the assumption that the marketing cost for all animal were the same, cows'

health (CcH) and marketing cost (CcM) were:

$$CcM = CoSR * (Vet + Medicine) \quad (3-65)$$

$$CcM = CCR * M \quad (3-66)$$

3.4.4.2 Profit equation for terminal system with cow self-replacement

The animals in the system can be divided into four parts: male and female calves for harvest, heifers for replacement and cows:

$$P = P_s + P_{rh} + P_c - C_{fix} \quad (3-67)$$

The profit equations for the three animal categories were calculated using the same equations stated above. However, the numbers of slaughter animals were different for alternative production systems. In this system, all the calves, except the replacement heifers were slaughtered, and were expressed as (all the abbreviations have been defined previously):

$$NsC = (NCW - N * (1 - CoSR + CCR)) \quad (3-68)$$

3.4.4.3 Profit equation for terminal system without cow self-replacement

In the system, there were two categories: slaughter calves and cows:

$$P = P_s + P_c - C_{fix} \quad (3-69)$$

All the calves were assumed to be slaughtered at 15 months old of age. Similarly, the profit equations for both the animal categories can be calculated use previous equations of slaughter animal and cow. The number of animals for slaughter in the system was:

$$NsC = NCW \quad (3-70)$$

3.5 Results and Discussion

One of the important parts to complete a profit equation is to estimate the dry matter feed intake for each category. Table 3.4 shows the results of dry matter feed intake for 5 categories of animals using the equations from NRC (2000).

Table 3.4. Estimated Total Hay intake of each animal category based on energy requirements guidelines of NRC

Animal Category	Days of feed	Hay (kg)
Slaughter calves	168	2075.908
Yearling bull	136	1532.508
Sale heifer	168	1110.708
Replacement heifer	272	2235.108
Cow	136	1706.035

Since the feed intake of all animals in the study was calculated based on the average weaning weight or cow weight and post weaning average daily gain according to the energy requirements guidelines of NRC, there was no way to create feed efficiency or residual feed intake data which were considered as important economic traits in other studies (Herd et al., 2003; Crews Jr et al., 2005). Actually, these traits would influence the profit more directly, if there would be some actual feed intake in the future study, they should be include in the breeding objectives. Also, when calculating the cost of feed intake, only the net energy requirements were considered in the study, but the protein, fat and vitamins are all necessary nutrition for life which should be added into the function to improve the profit model. The energy contained in feed was based on the feed table of NRC energy requirement guidelines. If the real energy concentration for the feed used in herd can be obtained, the model would be more reliable. According to relative research, the selection on feed intake were not only placed on the traits stated above, also some traits on molecular level, e.g. the concentration of serum Insulin-Like Growth Factor I (IGF-1) in blood, which was determined having relationship with growth, body size, food conversation, milk production and carcass (Davis et al., 1995). Thus, the trait can be treated as selection criteria for feed intake in an earlier age of animal with more accuracy. Parallel with physiology and genomic knowledge, more indirectly and accuracy selection criteria can be developed in the future. Because the selection can be done earlier in life, the selection cost may decline whereas the economical response might increase. Thus, it is sagacious to put more efforts on molecular level and genomic selection. In this study, the hot carcass

weight was calculated using weaning weight, post weaning average daily gain and dressing percentage which was set as 0.62 based on information from MacNeil et al. (2005).

Another part of the selection index was to use information to get the EPDs for economic relevant traits, if there was no information of the economic relevant trait, there are two ways to navigate this problem: 1. Calculate the phenotypic information of the interested trait with other traits information 2. Estimate the EBVs/EPDs of the trait using correlated traits' information. Usually there was limited or no information of carcass trait, so using weaning weight and post-weaning average daily gain which are rich in data are a good way to mitigate this problem. MacNeil et al. (2005) estimated hot carcass weight using the method. However, if the correct relationship between the economic relevant trait and criteria is available, directly calculating the EPDs using selection should be a better method which would also simplify the profit equation.

When constructing the profit equation for maternal system, the heifers and yearling bulls on sale were simply assumed for having a fixed price. Actually, the prices of these animals depended on the genetic performance of themselves, especially in selling yearling bulls. Because of lacking of data with trait performance and corresponding price, there was no way to estimate the relationship between the price and related traits. If the dataset can be created in the future, multivariate regression can be used to estimate the economic value of these function traits in the part which will improvement the overall economic value. One of the important things was that only the trait truly influence the price can be treated as function traits which can be tested in regression. Also, when considering the health cost, a fixed cost was set besides the calving difficulty cost and there were no other traits considered as economic relevant traits influencing the health cost. Actually there should be some trait affecting the cost, for instance, the disease related traits. In macroscopic view, there was few information that can be used as selection criteria of disease resistance. However, if the selection is placed on the level of genes, it is possible to collect information which will be the selection criteria, for example the performance of quantitative trait loci (QTL), single genes, or closely-linked loci.

3.6 Conclusions

Building a profit equation is a process of explaining the production system and determining which economic relevant traits should be involved in the equations. These traits are the ones we desire to improve. It is found that the profit equations varied with different breeding objectives, so three groups of economic values were estimated. Since the economic selection index should be developed and dependent on a special production and marketing system, it can be only used to rank animals with indices calculated using the same system. Different system would have different profit equation, and then different economic value for the same traits. Thus, if there is no common base for calculation, animals in different systems cannot be compared using economic value or economic selection index.

CHAPTER 4

DERIVING ECONOMIC VALUES

4.1 Introduction

Economic values reflect the economic importance of traits in a given production system. For traits in breeding objectives, economic values weight traits of interest and apply relative selection emphasis ($H = a_1 G_1 + a_2 G_2 + \dots + a_n G_n$). Therefore, the economic value can determine the direction and size of genetic change. There are two methods that can be used to derive economic value. These methods include partial differentiation of a profit equation (Hill, 1974; Ponzoni and Newman, 1989; Fernandez-Perea and Alenda Jiménez, 2004; Forabosco et al., 2005) and partial budget (Koots and Gibson, 1998; Albera et al., 2004; MacNeil et al., 2005). The population means are necessary for both the two methods to estimate economic values. The chapter presents the estimation of economic value and the influence of population means of these traits on economic values.

4.2 Materials and Methods

4.2.1 Estimating economic value of continuous traits

The estimation of economic values was based on the profit equations presented in Chapter 3. Partial differentiation is a method to derive the equation with respect to one of multiple variables, with the others held constant. Partial differentiation of the profit equation with respect to each trait treating others as constant with the value of their population means was used in the study to estimate the economic value for trait in continuous scale. Three types of systems were used in the study to develop profit equations in the study. The economic values were calculated for three systems presented in Chapter 3. The economic value for continuous scale traits was expressed as (Ponzoni and Newman, 1989):

$$EV = \frac{\partial P}{\partial BV_i} \quad (4-1)$$

Besides the economic value, another factor influencing selection is the genetic variance of the trait. Then the relative economic value obtained by multiplying the additive genetic effect standard deviation of each trait can be used to compare the economic importance of traits.

The phenotypic records out of the range from the point which were three standard deviations more than population means to that three standard deviation less than population means were treated as outliers, and eliminated from the data. The summary of the data is shown in Table 4.1. In the study, only the data of BW, WW, calving ease, cow culling rate, pre-weaning calf survival, cow weight, pre-weaning and post-weaning average daily gain were available to estimate the genetic parameters. The parameters for cow survival rate (CoSR), calving rate (CR), post weaning calf survival rate (PSR), which cannot be estimated in the study were from previous literatures estimates (Brascamp, 1984; MacNeil and Newman, 1994).

The heritability for each trait were estimated using the univariate linear animal model in ASReml software (Gilmour et al., 2009), because we want to obtain the genetic variation of every traits. The univariate model was defined as:

$$y = X\beta + Zu + e \quad (4-2)$$

with assumption that:

$$\text{var}(u) = A\sigma_a^2 \quad \text{and} \quad \text{var}(e) = I\sigma_e^2$$

where y is observations, X is the coefficient matrix of fixed effect which include sex, birth year age of dam and weaning age (included in model of WW); β was parameters vector for fixed effect; Z is the coefficient matrix for random effect which include animal and dam (include in model of WW and CE); A was the numerator relationship matrix (Wright, 1922); u was a vector of random effects which is additive genetic effect; σ_a^2 is additive genetic effect variance and σ_e^2 is residual variance. Then the heritability (h^2) were calculated as:.

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2} \quad (4-3)$$

Table 4.1. Summary statistics for records from John E. Rouse Ranch of Colorado State University Beef Improvement Center

Trait ^a	No.	Min	Mean	Max	Variance
BW(kg)	9958	3.629	36.589	57.153	25.356
WW(kg)	7931	33.575	179.408	317.814	771.634
SR (%)	9971	0.000	0.896	1.000	0.093
preADG(kg)	7930	0.005	0.767	1.501	0.021
postADG(kg)	4451	0.170	0.956	2.397	0.142
CEh (%)	1447	1.000	1.436	5.000	0.740
CCR(%)	5611	0.001	0.400	1.000	0.119
CoWT(kg)	4708	350.173	541.558	823.724	5288.628
SC(cm)	472	0.18	29.749	40.500	55.396

^aBW:birth weight; WW:weaning weight; SR:pre-weaning survival rate; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; CEh:calving ease for heifer; CCR:cow culling rate; CoWT: cow weight; SC: scrotal circumference

4.2.2 Estimating economic value of category traits

There were some traits which cannot be simply expressed in the profit equation, but they influence the monetary value of the slaughter animal. In this study, there were two economic values which were calculated through this method: USDA quality grade and calving ease. The categorical traits are not measured on continuous scale but on category scale, and they can influence the profit by ordered categories. Normally, the economic value of traits is independent of the population mean of the trait. However, because the category traits have an optimum range, so there should be a relationship between population mean and economic value (Kluyts et al., 2007). In order to estimate the economic value of category data, it is assumed that there was an unobserved normal distribution of the category records (Falconer, 1981; Koots et al., 1994; Wolfová et al., 1995). Then the distribution can be used to calculate the average profit change (economic value) after one percentage increasing of animals involved in optimal range. The population mean can be estimated from the category. According to the data, the proportion of animals in each category can be determined. Then the truncation value to divide the distribution can be determined. With one percent increase of animal in optimum category, there will be a new truncation value which led to change of proportion of animals in other categories. Figure 4.1 shows a example of the changing. There will be differences in revenues or cost between original and after change situation, which are the economic value for these traits.

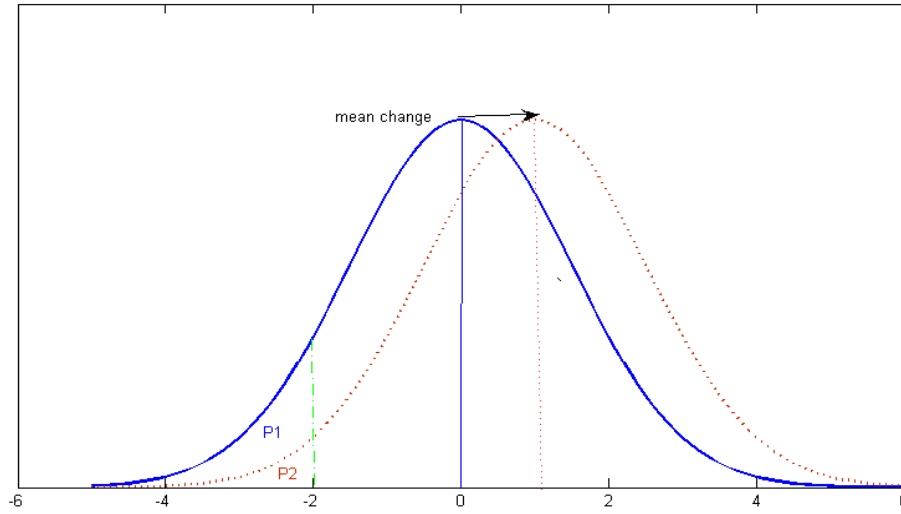


Figure 4.1. Example of calculation of economic value based on normalized category data

4.2.2.1 Estimating economic value for USDA grade

USDA has 9 categories for meat quality (BIF, 2002), however, only three category had been adopted in recording data of some years. In order to unify the data, it was assumed that there were only three categories for USDA meat quality grade. Also let “1” represents prime, “2” represents choice, “3” represents select. The original animal proportion in each category, and the related price were calculated based on 725 slaughtering records. The truncation number, probability of animals of original and after increasing 1% in prime category, and the price per cwt carcass weight within each category are shown in Table.4.2. The truncation numbers are the same for old ($N \sim (2.219, 0.740)$) and new ($N \sim (2.118, 0.740)$) distribution which were determined by the CSU-BIC data. The new proportions of each categories were calculated in R (Ihaka and Gentleman, 1996) based on the distribution of original data and truncation number. The average price of all the three categories was considered the meat price in the profit equation, so with the carcass weight estimated in the profit equation, the economic value can be calculated:

$$EV_{USDAgrade} = \Delta P \times \text{carcass weight} \quad (4-4)$$

where $EV_{USDAgrade}$ denote the economic value of USDA quality grade; ΔP is the average price change

before and after increasing 1% in prime category.

Table 4.2. Summary of prices per CWT, probability and truncation points before (P, t) and after (P', t') trait change of each meat quality

Category	Price	P ^a	T	P' ^b
Prime	145.637	0.013	< 1.333	0.232
Choice	144.506	0.754	1.333-2.645	0.808
Standard	134.840	0.233	> 2.645	0.169

^aproportions of each traits categories related to the distribution $N\sim(2.219, 0.445)$

^bproportions of each traits categories related to the distribution $N\sim(2.118, 0.445)$

4.2.2.2 Estimation of economic value for calving ease score

The probabilities of calving difficulty for first calving heifer and cows differ so much that they cannot be treated as the same trait. However, because there are a tiny proportion of cows ($P=9.697e-04$) experiencing dystocia have calving problem originally in the herd, the probability to improve calving ease was very small based on the limited genetic variation. Thus, the economic value for cows' calving ease was too small to be considered in the study compared to economic value of dystocia in heifers. Thus, only the economic value of heifer's calving ease score was estimated in the study. The calving score system used in the study had five categories: 1 – No difficulty, no assistance; 2 – Minor difficulty, some assistance; 3 – Major difficulty, usually mechanical assistance; 4 – Caesarian section or other surgery; 5 – Abnormal presentation according to the Beef Improvement Federal Guidelines 9th edition (BIF, 2002). The unobserved normal distribution was determined as $[X \sim N(\mu, \sigma^2)]$ (Johnson and Wichern, 1992) of the calving difficulty. Table 4.3 shows the truncation number, probability of animals before and after increasing 1% and the cost within each calving ease category. The values in the table were calculated through the same way as USDA meat price. The truncation numbers were the same for old ($N\sim(1.436, 0.740)$) and new ($N\sim(1.415, 0.740)$) distribution which were determined by the CSU BIC data. The cost used in the paper was based on the study of Dekkers (1994).

4.2.3 Sensitivity of economic value on population means of traits

Another analysis in the study was to test the influence of the changing mean values of some economic relevant traits (BW, WW, preADG, posADG, CoWT) on the economic values with while other variables are constants. The changes were conducted using $\pm 10\%$ of the original value which is the mean of each trait in CSU BIC data. The economic values will change with the changing of these values.

Table 4.3. Summary of cost in dollar/calving, truncation points (t) and probability before (P) and after (P') change in calving ease

Category	Cost	P	T	P'
1	0.000	0.684	< 1.791	0.694
2	3.000	0.216	1.791-2.387	0.212
3	47.600	0.089	2.387-3.131	0.084
4	255.000	0.001	3.131-3.167	0.001
5	47.600	0.010	> 3.167	0.009

^aproportions of each traits categories related to the distribution $N\sim(1.436, 0.740)$

^bproportions of each traits categories related to the distribution $N\sim(1.415, 0.740)$

4.3 Results and Discussion

4.3.1 Genetic parameters

The phenotypic variance, heritability and additive genetic standard deviation of the economic relevant traits obtained from the dataset and previous literatures are presented in Table 4.4. The heritability of BW, estimated in the study is 0.53 (0.02) which was a little larger than 0.48 and 0.40 of the result of Crews Jr (2005) and Nelsen and Kress (1979). Compared to the heritability of weaning weight presented in MacNeil and Newman (1994) and Fan et al. (1995) which are 0.26 and 0.16, the heritability is a little smaller which is 0.10 (0.02). This fact may contribute to lacking of more information or different adjustment procedure. MacNeil and Newman (1994) showed that the heritability of pre-weaning average daily gain was 0.30 which is similar to the result (0.39 (0.03)) obtained in the study. However, the heritability in this study for post-weaning average daily gain is 0.11 (0.03) which was much smaller than 0.34 and 0.23 presented by MacNeil and Newman (1994) and Rewe (2004). While the heritability obtained by Wolfová et al. (2011) was similar to the one in the study which is 0.18. The difference may be

Table 4.4. The phenotypic variance (σ_P^2), heritability (h^2) and standard deviation of additive genetic effect (σ_A) of each economic relevant traits

Trait ^b	σ_P^2	h^2	σ_A
BW (kg)	25.356	0.528	3.657
WW (kg)	771.634	0.095	8.566
preADG (kg)	0.021	0.387	0.091
postADG (kg)	0.142	0.108	0.124
SR (%)	934.000	0.020	4.289
MY (%)	771.634	0.290	14.959
CoWT (kg)	5288.628	0.557	54.255
CE (%)	0.001	0.045	0.741
CoSR ^a (%)	99.002	0.030	1.723
CR ^a (%)	0.223	0.180	0.200
PSR ^a (%)	99.002	0.030	1.723
USDAgrade (%)	0.350	0.530	0.255
CCR (%)	1179.923	0.045	7.303
DP (%)	5.760	0.490	1.680

^a The parameters were from previous literatures (Rewe et al., 2007 (Rewe, 2004); Callis et al., 2010 (Callis, 2010); MacNeil et al. (1994) (MacNeil and Newman, 1994))

^b BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage.

caused by different breeds, different method or different models. In this study, the genetic parameter for MY was expressed as the maternal effect of weaning weight and the heritability was 0.29 (0.02) which was similar to previous literature (MacNeil and Newman, 1994). The heritability of mature cow weight calculated in the study (0.56 (0.02)) was reasonable which is similar with previous literatures: MacNeil et al. (1982): 0.54; Dib et al. (2010): 0.48. The heritability for fertility traits like CCR (0.05 (0.02)) and SR (0.02 (0.01)) calculated in the study were both small, which is a characteristic of reproduction traits. There was few studies on CCR, while the previous studies showed difference among heritability of SR: 0.226 \pm 0.018 in Cervantes et al. (2010) and 0.039 to 0.142 in Goyache et al. (2003). The later one is similar with that obtained in present study. The low heritability means that there is limited genetic variation in the population for this trait. Selection to improve these traits should require high data density to be effective. The higher heritability of cow culling rate and calving rate of cow indicates that there is more opportunity to improve the traits based on genetic selection. The standard deviation of additive genetic effects for each trait presented in Table 4.4 indicates how much they can be improved because

they refer to the variation of traits.

4.3.2 Economic value

Table 4.5 shows the estimated economic value derived from the profit equation build in Chapter 3 based the three systems and the relative economic value which was the results of the economic value multiplying the additive genetic standard deviation. According to the result, the economic values for CoSR, WW, SR, CR, PSR, USDAgrade, CE, postADG and DP were positive, which means a unit increase in these traits leads to increases of return or decreasing cost in the three production system, while the economic values for CCR, BW, MY, CoWT and preADG were negative which means one unit genetic increasing in these traits lead to decrease of return or increased in cost of the three production systems. Absolute values of these economic values represent the economic importance for selection, the signs indicated the direction of selection when applied to the industry.

Table 4.5. Marginal economic value and relative economic value of economically relevantly traits on three production systems

Traits ^c	Partial differentiation			Per σ_A		
	Maternal	Terminal 1 ^a	Terminal 2 ^b	Maternal	Terminal 1 ^a	Terminal 2 ^b
CoSR(%)	16.408	11.496	10.419	28.28	19.81	17.96
WW(kg)	0.550	0.710	0.317	4.71	6.08	2.71
BW(kg)	-0.221	-0.221	-0.221	-0.81	-0.81	-0.81
SR(%)	7.165	4.569	4.569	30.74	19.60	19.60
CR(%)	7.021	4.462	4.451	0.141	0.894	0.892
PSR(%)	4.698	4.248	2.103	8.10	7.32	3.62
CCR(%)	-6.327	-3.555	-2.645	-48.33	-27.15	-20.21
CoWT(kg)	-0.157	-0.157	-0.157	-8.53	-8.53	-8.53
MY(kg)	-0.072	-0.072	-0.072	-1.08	-1.08	-1.08
USDAgrade(%)	2.154	6.461	4.838	0.55	1.65	1.23
CE (%)	0.567	0.567	0.567	0.42	0.42	0.42
preADG(kg)	-13.703	-13.703	-13.703	-1.24	-1.24	-1.24
postADG(kg)	42.562	87.573	22.741	5.27	10.84	2.82
DP(%)	4.550	13.648	10.298	7.64	22.93	17.30

^a Terminal production system without replacement

^b Terminal production system with replacement

^c BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage.

Economic values were based on the same genetic variance that was calculated by partial differentiation, but the possible change ranges vary for different traits. Thus, the relative economic value can reflect the general economic importance of each trait. The most economically important trait in the study for all the three production system were SR, CCR and CoSR since the product of genetic standard deviation and economic value for them was high. Because the adapted genetic variation of CR was low based on previous studies (Martinez-Velazquez et al., 2003; Yilmaz et al., 2004; Callis, 2010), CR appeared to be of a lower relative economic important in the study. However, calving rate was defined as the number of calving cows over all cows in the herd, which partially determined the revenue of the herd. Moreover, fertility traits had higher economic weights which indicated that more emphasis should be placed on the selection of fertility traits. In the terminal system, the weaning weight and post-weaning average daily gain were more important than in maternal system. This is due to the fact that they are highly related to slaughter weight revenue, and because the slaughter revenue was calculated as:

$$R_s = N_s * (-1356.635 + 6.01 * (WW + \text{mpostADG} * 179)) \quad (4-5)$$

where R_s is the revenue of slaughtered animals; N_s denotes the number of animal available for slaughter; WW is weaning weight; mpostADG represent male's post weaning average daily gain, and number of cattle available for slaughtering in terminal system was much more than it in maternal system. Thus, in terminal system, attention should also be paid to these production traits. Most of the traits in maternal system had high economic value mainly because it was a high input production system with more animals raised in the system.

4.3.3 The rank of traits by economic importance

Most of literature estimates showed that reproductive related traits had more economic importance in beef production system than other type of traits, e.g. fertility and calf survival have the highest relative economic value among 17 traits in the study of Koot and Gibson (Koots and Gibson, 1998; Fernandez-Perea and Alenda Jiménez, 2004; Kluys et al., 2004; Rewe, 2004), which is similar with the

results of the presented study. However, some of these reports also indicated that the dressing percentage (DP) or post-weaning average daily gain (postADG) was more economical important than reproduction traits, for instance, the economic value for dressing percentage was 2.78, for average daily gain is 1.90 compare with the economic value of fertility traits which was around 1.00 in the study of MacNeil and Newman (MacNeil et al., 1994; Fernandez-Perea and Alenda Jiménez, 2004; Rewe, 2004). In fact, the presented results also showed that dressing percentage and post average daily gain had a higher economic importance compared with weaning weight.

The rank of traits within reproduction category was similar with study of Rewe (2004), MacNeil et al. (1994), Kluyts et al. (2004), and Koots and Gibson (1998), which indicate that the calf survival rate pre-weaning and cow survival rate had the highest economic importance. In the study, the calving ease (CE), milk production (MY), birth weight (BW) and pre-weaning average daily gain (preADG) were less important which was similar with the results from previous literatures (Koots and Gibson, 1998; Kluyts et al., 2004; Wolfová et al., 2011). Also birth weight was one of the least economic important traits according to the results in the presented study. Wolfová et al. (2011) also showed the less economic importance of birth weight, but the economic value for birth weight was negative in that study which means that the genetic increase of the birth weight would lead to decreased the profit. Also, MacNeil et al. (2005) reported a negative economic value for birth weight which was still of less importance compare to other traits such as fertility traits, weaning weight (WW) and cow mature weight (CoWT) in these systems. The economic value of Pre-weaning ADG is seldom calculated in studies, but the presented study found a small relative economic value (-1.24), which resembled the results of Fernandez (Fernandez-Perea and Alenda Jiménez, 2004). The relative economic value of weaning weight varies in previous studies and the rank of it was also much different. Kluyts et al. (2007) and reported high relative economic value (25.57) of weaning weight, which was the third largest relative economic value, whereas Fernandez-Perea and Alenda Jiménez (2004) found a small relative economic value (3.5%), which was the second smallest in the study. In this study, the relative economic value for weaning weight is small and positive in maternal system and terminal system.

Contributing to the diversity of slaughter revenue of the three systems, the relative economic value for weaning weight were different. The relative economic value of cow mature weight was moderate because it was in the middle rank of relative economic value in the study which was similar with the study of MacNeil et al. (1994) which reported a economic value -0.11. Fernandez-Perea and Alenda Jiménez (2004) showed a much higher economic importance of mature weight with 56% of economic importance which rank first in his study. Furthermore, in the presented study concludes that the relative economic value for meat quality (USDAgrade) was moderate with median value which resembles MacNeil et al. (1994) result indicating the economic value of percent high quality grade is 0.18. The existing difference of rank of economically relevant traits was reasonable, because factors onstructing the economic value cannot be the same for different herds. These factors include the breeding objective, production system, marketing system, economic environment and management policy. That was why the economic value of one herd can be only used to ranking the animals in the particular herd. Even if for breed associations, they have published different type of index served as reference. The sensitive study can also verify the variability of economic value.

4.3.4 Sensitivity of economic value (EV) on production variable

The sensitivity tests of economic value on production variables were completed for all the three production system considered in the study. According to the results of sensitivity test, the economic value changes were similar in these three systems on production variable except the post-weaning ADG, so only the results of sensitive test on maternal system and the results of only change post –weaning average daily gain on all the three systems are presented in Table 4.6 and Table 4.7. Although the 10% change in production variable had limited effect on economic value, the sensitivity test can show the changing trends of economic values on variety of production variable. Also, based on the results, the alternative of production variables would not lead to significantly changing of economic important rank of traits.

The change in birth weight (BW) had a small negative effect on economic value of CoSR (changed from 16.417 to 16.400), CR (changed from 7.030 to 7.012), SR (changed from 7.175 to 7.156), and preADG (changed from -13.195 to -14.206). Also the profit equation of BW is non-linear according to

Table 4.6. Sensitivity of economic values to changes of production variables in maternal system

Traits ^a	Base	BW		WW		preADG		postADG		CoWT	
		-10%	+10%	-10%	+10%	-10%	+10%	-10%	+10%	-10%	+10%
CoSR(%)	16.408	16.417	16.400	16.365	16.452	16.419	16.398	16.301	16.627	16.645	16.185
WW(kg)	0.550			0.540	0.560			0.586	0.528		
BW(kg)	-0.221	-0.225	-0.217			-0.210	-0.231				
SR(%)	7.165	7.175	7.156	7.196	7.137	7.176	7.153	7.266	7.180		
CR(%)	7.021	7.030	7.012	7.047	6.997	7.032	7.008	7.119	7.035		
PSR(%)	4.698			4.701	4.697			4.756	4.343		
CCR(%)	-6.327			-6.257	-6.397			-6.130	-6.533	-7.188	-5.468
CoWT(kg)	-0.157									-0.168	-0.147
MY(kg)	-0.773										
USDAgrade(%)	2.154			2.084	2.224			2.008	2.300		
CE(%)	0.567										
preADG(kg)	-13.703	13.195	14.206			13.244	14.156				
postADG(kg)	42.561			47.804	37.333			53.663	35.796		
DP(%)	4.550			4.403	4.697			4.242	4.858		

^a BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage.

Table 4.7. Sensitivity of economic values to changes of post-weaning average daily gain

Traits ^c	Maternal			Terminal 1 ^a			Terminal 2 ^b		
	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%
CoSR(%)	16.408	16.301	16.627	11.496	11.362	11.607	10.419	9.872	10.918
WW(kg)	0.550	0.586	0.528	0.710	0.758	0.663	0.317	0.357	0.276
BW(kg)	-0.221			-0.221			-0.221		
SR(%)	7.165	7.266	7.180	4.569	4.417	4.694	4.569	4.417	4.694
CR(%)	7.021	7.119	7.035	4.462	4.315	4.584	4.451	4.303	4.573
PSR(%)	4.698	4.756	4.343	4.248	4.114	4.358	2.103	2.049	2.138
CCR(%)	-6.327	-6.130	-6.533	-3.555	-3.555	-3.555	-2.645	-2.233	-3.034
CoWT(kg)	-0.157			-0.157			-0.157		
MY(kg)	-0.773			-0.773			-0.773		
USDAgrade(%)	2.154	2.008	2.300	6.461	6.024	6.899	4.838	4.511	5.166
CE(%)	0.567			0.567	0.000	0.000	0.000	0.000	0.000
preADG(kg)	-13.703			-13.703			-13.703		
postADG(kg)	42.562	53.663	35.796	87.573	104.620	70.690	22.741	37.320	8.308
DP(%)	4.550	4.242	4.858	13.648	12.724	14.572	10.298	9.601	10.995

^a Terminal production system without replacement

^b Terminal production system with replacement

^c BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage.

Chapter 3, so the economic value of itself is based on its own population mean. The increase in mean value of BW leads to an increase in its economic value. Because WW is positively related to the profit of the slaughter animal according to the profit equation presented in chapter 3, the positive relationship between WW and economic value of CoSR, SR, PSR can be explained. Also, the improvement of DP and USDAgrade will increase the revenue from slaughter animals, which has positive relationship with WW, so the economic value of DP and USADgrade increased with the raising of WW. Whereas, the CCR's increasing will lead to much more feeding cost for replacement heifer, which is based on the WW: higher WW lead to higher feed cost. As the same as BW, the economic value of WW was related to its own mean value based on the profit equation developed in Chapter 3, so the EV rise with increasing the means. Similarly, the pre-weaning ADG is related to pre-weaning feed intake cost, so it influence economic value of other pre-weaning feed cost relevant traits (CoSR, CR, SR, BW) and itself. Since CoWT was only related to the culling cow revenue and cow feed cost in the profit equation, only the CCR's, CoSR's and its own economic values were affected by the change of mean value. Furthermore, since there was no replacement in one of the terminal system, the EV of CCR was not affected by the variables except CoWT.

According to the results, the trend of EVs of some traits was not consistent on the varying post-weaning ADG in different system. Its increase in mean resulted in the reduction of EVs for CR, SR and PSR in the maternal system, while increasing of those EVs in the terminal system. Post-weaning ADG is related to the revenue of slaughter animals, selling bulls and post-weaning feed costs. Because the portion of animals available for slaughter and sale were smaller in the maternal system than in the terminal system, the influence of postADG on feed cost was greater than slaughter animal revenue in maternal system. This relationship leads to the decrease in EV of CR,SR and PSR with increasing the population mean of postADG. However, in the terminal system, the change in postADG had a positive effect on the profit of the system, which means the increases in postADG caused the increase in EV of those traits. Otherwise, CoSR, WW, CCR, USDAgrade, DP and postADG have the same trends for the three systems based on the changing of postADG value. The improvement of CoSR causes the reduction

in replacement cost and increases in slaughter and sale revenues. Higher post-ADG results in higher costs and revenues, so there was higher EV of CoSR. Also, the increase costs associated with increasing in post-weaning ADG will lead to higher replacement animal costs, so the EV of CCR will decrease. The postADG positive related to hot carcass weight caused increase in EVs of DP and USDAgrade. According to the equation used to calculate feed intake, WW and posADG were involved in a non-linear equation to determine the post-weaning feed intake of calves. The non-linear relationship determined that increasing in both of them resulted in the decrease in economic value of them.

4.3.5 The application of economically relevant traits

To develop economic selection indices, prediction of additive genetic units are needed in addition to economic values. However, usually there are no records of some of these traits, so it is impossible to get the genetic information of them directly. Traits with available records were used to indirectly predict the additive genetic effect of those estimated economic relevant traits. In the study, WW, CE and CoWT, were normally recorded, and can be directly selected using different kinds of information (individual, offspring, half sibs). In beef industry, because the milk yield record is not available, maternal effect of weaning weight is used to indicate the genetic effect of milk production.

Although the pre-weaning ADG and post-weaning ADG were not measured directly, they can be calculated with measurements of BW, WW, YW and days between each of them. Then the additive genetic effect can also be calculated directly which was done in the study.

Although the calf's survival rate was not usually recorded in herds, if the death record or complete weaning record were available it is easy to assess survival rate by recording 1 to survival individual and "0" to death ones before weaning. These data can be used to calculate the genetic parameters for calf survival (Goyache et al., 2003). Studies indicated that there was a high genetic correlation between calf survival before weaning and calving ease (Cundiff et al., 1986; Cubas et al., 1991; Cervantes et al., 2010), so it is reasonable to select for calf survival using calving ease.

The situation for cow culling rate is similar to that of calf survival rate. The reason for culling can be divided into two categories: involuntary culling and voluntary culling. The former reason was mainly due

to health problems and accident (missing or killed by other animal), whereas the later was related to the production ability of the cow. The other description of the culling risk is the longevity of the cow, which can be indicated by stayability recorded by herds. Also Forabosco et al. (2004) showed that muscularity traits and age at first calving had important effect on culling risk. Furthermore, a research (Rick Rasb, 2011) pointed out that unsound udders and teats were related to reducing productive life and inferior calf performance. Poor udder and teat conformation is a major reason why cows are culled from the breeding herd. Thus selection on these traits will be another pathway to reduce culling rate which can be assessed in future study.

In the study, calving rate, which was calculated as the number of born over the total number of cows in breeding, had included the pregnancy rate of the cow. The calving rate was related to the fertility of cows and sires. Toelle and Robison (1985) showed that genetic correlation between the yearling scrotal circumference and the pregnancy rate of heifer was 0.26 with half-sib data and 0.93 using sire-daughter data. Morris and Cullen (1994) found the genetic relationship between SC and pregnancy rate for beef cattle, but the value was 0.53 between SC and heifer pregnancy and 0.34 between SC and lifetime pregnancy rate. Therefore scrotal circumference can be used as an indicator trait to select for calving rate as defined in this study.

Because of limited cow survival data, we cannot study it. However, according to this study, it had a high relative economic value (28.28) making, it reasonable for us to do future study. One of the main reasons for mortality of cows in the herd is health, so selection on disease resistance traits could lead to lower cow mortality rate in a herd. The presented study was involved Angus cattle at high altitude and high altitude disease (HAD) was indicated as an primary reason leading to mortality in calves and cows (Jensen et al., 1976). Currently, the best indicator of HAD susceptibility is pulmonary arterial pressure (PAP) test (Ahola et al., 2006). Shirley et al. (2008), found that the Heritability of PAP direct was 0.34 \pm 0.05 for Angus cattle, indicating that it is possible to select for low PAP score in a herd. Thus the PAP score could be used as a tool to select for higher survival rate for both cows and calves. Furthermore, Cervantes et al. (2010) suggested that a positive relationship existed between calving ease and the death of

cow, so calving ease may be an indicator for selection for high cow survival rate. Identifying the genetic relationship between PAP score and cow survival rate and that between calving ease and cow survival rate should be done in future studies. However, the birth weight of calves and pelvic area of cows can be the indicator to selecting CE, so another option may be use birth weight and pelvic to select for cow survival rate.

Dressing percentage is an economically relevant trait, since it is highly genetic related to hot carcass weight. Also, Pariacote et al. (1998) showed that there is a moderate genetic correlation between DP and fat thickness. Since fat thickness can be obtained by ultrasound test in earlier age of cattle, it is can be used to selection for dressing percentage when the animal is alive.

4.4 Conclusions

Selection of several traits at the same time is an efficient way to achieve the goals of most of the production system at the same time. There are lots of traits recorded on an individual, yet only a handful of them can influence revenue and cost. Therefore, identifying essential traits and estimating their economic value which will be used to weigh these traits in an equation are necessary to select for profitability. In this study, reproductive traits showed larger effect in all the three production systems, indicating that the main task of a production system was to decrease mortality rate of calves and increase the number of calves making revenue. Also, results indicated that economic value for production traits and harvest traits were higher in terminal system than they were in maternal system, which corresponds to the fact that terminal system pay more attention on meat quality, growth and feed efficiency.

CHAPTER 5

CUMULATIVE DISCOUNTED GENE FLOW

5.1 Introduction

In the beef industry, the genetic superiority of an individual is not only expressed in their own generation but in future generations. Because the numbers of offspring vary, have different purpose and have different mating time, the frequency of their gene expression varies for animals. Also, there are delays of gene expression among individuals and offspring for different traits, and therefore adjustment should be made to account for these differences in expression. Thus the objective of this chapter is to calculate cumulative discounted gene expressions (CDGEs) of traits expressed differently in time of four matting systems: maternal male, female and terminal male and female.

5.2 Materials and Methods

The CDGEs for birth, slaughter, annual and end-of-cow-life traits were calculated in terminal and maternal purpose Angus cattle. The traits categories are determined by the frequency and time point a trait is expressed. The CDGEs for each sex were calculated separately. Table 5.1 summarizes the symbolisms of for CDGEs calculated in the presented study. The calculation equations of CDGEs in the study expressed as following were based on the approach outlined by Amer (1999). The parameters used in these equations to calculate the CDGEs were estimated from 10,007 individual records and 27,165 pedigree records from the Angus herd at Colorado State University the John E. Rouse Beef Improvement Center (CSU-BIC). There were 313 sires with an average generation interval of 3.30 years involved in the study, as well as 2,160 dams with an average generation interval of 5.32 years.

Table 5.1. Symbols of cumulative discounted gene expression (CDGE) calculated in the study

Trait category	Maternal		Terminal	
	Female	Male	Female	Male
Annul traits	Xrfa	Xsrda	Xtfa	-
End-cow-life traits	Xrfe	Xsrde	Xtfe	-
Birth traits	Xrfb	Xsrd b	Xtfb	Xtsb
Weaning traits	Xr fw	Xsr dw	Xt fw	Xts w
Slaughter traits	Xrfs	Xsrds	Xtfs	Xtss

5.2.1 Developing survival and productive matrix

In order to calculate the CDGEs, the survival rate of cow and producing ability (the average number of calves born per cow) for each age are necessary parameters. The age group of cows was set as single year group from birth to the possible highest age of a cow in the herd (m). The m was set as 16 years old. Let S be a n by 1 vector, whose components are defined as probabilities of a cow surviving and calving from age group $i-1$ to age group i for $i=1$ to m , calculated as:

$$S(i) = 1 - \frac{N_{c(i)}}{N_{(i-1)}} \quad (5-1)$$

where $N_{c(i)}$ was the number of cows culled from age group $i-1$ to age group i ; $N_{(i-1)}$ was the number of cows in age group $i-1$. The number of replacement heifers was not available, therefore the first non-zero elements was set at 0.97 which was the survival and calving rate from age one to age two. Another vector P is a n by 1 vector, the components of which were the numbers of calves available for slaughter, sale or replacement per cow per calving in age group i . We assumed single birth for this study. Since the mortality of calving and cows were already involved in vector S , the components of P were the pre-weaning survival rate vector of calves calved by cow in age group 1 to m , which was calculated as:

$$p(i) = \frac{N_{cww(i)}}{N_{cb(i)}} \quad (5-2)$$

where $N_{cpre(i)}$ is the number of calves at weaning born by cows in age group i ; $N_{cb(i)}$ is the number of calves at birth born to cow in age group i . First calving age is assumed at 2 years old, so the first element of S and P should be zero, since they are related to age 1. Because the number of cows over 12 years old is small (1.8%), it is assumed that the cow over 12 years old should be culled from the herd. This was then considered the culling policy for the study. So the elements of age group over 12 were all zero in vector S and P . The S and P vector are presented in Table 5.2.

Table 5.2. The components of survival (S) and profitability (P) vector

Age group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S'	0.00	0.97	0.81	0.82	0.94	0.71	0.78	0.85	0.86	0.89	0.85	0.69	0.00	0.00	0.00	0.00
P'	0.00	0.90	0.94	0.96	0.97	0.98	0.98	0.98	0.97	1.00	0.98	0.94	0.00	0.00	0.00	0.00

Because the probability of a cow survival and calving from age 1 to age i will be used to construct expression matrices, let a_i a vector of possibility of cow survival from age 1 to and calving age i , which can be calculated as:

$$a_i = \begin{cases} \prod_{j=2}^i S_j & i = 2 \text{ to } 12 \\ 0 & \text{otherwise} \end{cases} \quad (5-3)$$

where S_i is the component of vector S. In order to calculate the cumulative expression of end-of-cow-life traits, the probability of cow dying or being culled in each age category needs to be calculated. They were the components in vector d which can be calculated as:

$$d_i = \begin{cases} 1 - a_i & \text{for } i = 2 \\ a_{i-1} - a_i & \text{for } i = 3 \text{ to } 11 \\ a_{i-1} & \text{for } i = 12 \\ 0 & \text{for } i < 2 \text{ and } i > 12 \end{cases} \quad (5-4)$$

where a_i is the component of vector a according to base information vectors, the CDGEs for traits of each animal category can then be estimated as following.

5.2.2 Terminal sire

In a terminal sire matting system, selection was assumed to be placed on animals at one year of age and all offspring were assumed to be slaughtered. When CDGEs for terminal sires are calculated, it is convenient to involve the average number of cows calving as mated to the single sire in any one year and is noted by the symbol “ k ” in the study. k was set as 17 in the study estimated from the pedigree data in the study. Also, the average number of calves, denoted by c , survival to make output per cow per calving was defined as:

$$c = a' p(1'a)^{-1} \quad (5-5)$$

where a was a vector of probability of cow survival from age 1 to calving age i ; and p is a vector of number of calves available for slaughter and “1” in the equation was a vector of ones whose order equal to the number of age group. The value of c should be 0.953 calculated from equation (5-5). The average number of years a sire was used in the herd was almost 2 years calculated from CSU-BIC data. Because all the offspring were slaughtered, only one generation’s expression needs to be calculated.

The discounted factor vector denoted by t which had 2 dimensions because the sire would be used for two years in the herd and is defined as:

$$t_j = \left(\frac{1}{1+r} \right)^j \quad (5-6)$$

where r is the economic discounting factor assumed as 0.03 for the base scenario (Dekkers et al., 2004). The equation assumed that the sires were purchased one year before the traits were expressed. The cumulative discounted gene expression for traits at birth (X_{tsb}), weaning (X_{tsw}) and slaughter (X_{tss}) of their offspring can be expressed as, based on the equation developed by Amer (1999):

$$X_{tsb} = \frac{1}{2*pre*pos} 1' * t * \left(\frac{1}{1+r} \right)^{-0.2493} * k * c \quad (5-7)$$

$$X_{tsw} = \frac{1}{2*pos} 1' * t * \left(\frac{1}{1+r} \right)^{0.2603} * k * c \quad (5-8)$$

$$X_{tss} = \frac{1}{2} 1' * t * \left(\frac{1}{1+r} \right) * k * c \quad (5-9)$$

where the factor $1/2$ represents the genetic contribution of a sire’s genetic material to his progeny. The pre is the pre-weaning calf survival rate set as 91.30% calculated from data of CSU BIC by:

$$pre = \frac{N_{cww}}{N_{cb}} \quad (5-10)$$

where N_{cww} denote the numbers of calves at weaning; N_{cb} is the number calves at birth. Also, pre represents the pre-weaning calf survival rate which is 99.62% according to previous study (Baharin and Beilharz, 1977). It was assumed that the birth traits were expressed after 274 day’s pregnancy which was

the mean of available gestation length data of cows in CSU-BIC. Because it is 91 days short of a complete year, $\left(\frac{1}{1+r}\right)^{-0.2493}$ is the adjust factor for discounted factor of birth traits, where

$$\left(\frac{1}{1+r}\right)^{-0.2493} = \left(\frac{1}{1+r}\right)^{0-(91/365)} \quad (5-11)$$

Weaning and slaughter traits were assumed expressed at 186 days which is the average weaning age of CSU-BIC data, and 458 day after calving which is slaughter age of steers in CSU-BIC. They were aged 460 day and 732 day after being purchased. Accordingly, the adjustment factor should be $\left(\frac{1}{1+r}\right)^{0.2603}$ and $\left(\frac{1}{1+r}\right)$ for weaning and slaughter traits, where:

$$\left(\frac{1}{1+r}\right)^{0.2603} = \left(\frac{1}{1+r}\right)^{0+((186+274-365)/365)} \quad (5-12)$$

$$\left(\frac{1}{1+r}\right) = \left(\frac{1}{1+r}\right)^{0+((458+274-365)/365)} \quad (5-13)$$

5.2.3 Terminal Females

Similarly to the terminal sire calculation, all the progeny of the terminal females were harvested. However, there are still some traits related to cows themselves identified as annual traits in the study. The calculation equations are also based on the study of Amer (1999). Let T the discounting factor matrix, which is expressed based on the cow age structure and only the values on diagonal are non-zero, which were calculated as:

$$T_{ii} = \left(\frac{1}{1+r}\right)^{i-1} \quad (5-14)$$

T was a 16 by 16 dimension matrix and $i=1$ to 16. It is assumed that the female enters the herd at one year of age, so T indicated that the expressions of traits that are discounted back to one year old females. The annual traits were expressed by survival cow every year, so the CDGEs (X_{tfa}) are calculated as:

$$X_{tfa} = 1' * T * a \quad (5-15)$$

where “ 1 ” is a vector of ones whose order is 16 by 1; a is a vector of proportion of cow survival from

age 1 to calving age i . On the other side, the CDGEs of culling cow traits of this animal category (X_{tfe}) can be expressed as:

$$X_{tfe} = 1' * T * d \quad (5-16)$$

where d is a vector whose components are the proportion of cow dying or being culled in each age category. According to the productivity and survival ability of cow on each age, the birth (X_{tfb}), weaning (X_{tfw}) and slaughtering (X_{tfs}) traits of terminal females can be calculated as:

$$X_{tfb} = \frac{1}{2 * pre * pos} * p' * T * \left(\frac{1}{1+r} \right)^{-0.2493} * a \quad (5-17)$$

$$X_{tfw} = \frac{1}{2 * pos} * p' * T * \left(\frac{1}{1+r} \right)^{0.2603} * a \quad (5-18)$$

$$X_{tfs} = \frac{1}{2} * p' * T * \left(\frac{1}{1+r} \right) * a \quad (5-19)$$

Where the pre was the pre-weaning calf survival rate; pos represented the post-weaning calf survival rate; p was a vector of number of calves available for making output and “ 1 ” was a vector of ones whose order equal to the number of age group and r is discounting rate.

5.2.4 Maternal females

In this part, the CDGEs of maternal females were calculated, where the maternal system produces its own replacements. The genetic expressions of maternal females are not only realized in one generation but several generations, so the CDGEs need to be calculated according to the length of time in the herd. In this study, the gene expressions after 4 generations were considered zero, so the calculation planning horizon was set as 20 years from the birth of the self-replacing female (Berry et al., 2006). Then let D be a 20 by 20 matrix with columns of survival probabilities of a cow in each year lagged by each row of a new birth year. The elements of matrix D are defined as:

$$D_{ij} = \begin{cases} a_{i-j} & \text{for } i - j > 1 \text{ and } i - j \leq 12 \\ 0 & \text{otherwise} \end{cases} \quad (5-20)$$

Where a is a vector of proportion of cows surviving from age 1 to calving age i ; i and j denote the age

group of the cow. Similarly, let F be an 20 by 20 matrix of the number of calves produced per cow age group, which can be specified as:

$$F_{ij} = \begin{cases} a_{i-j} * p_{i-j} & \text{for } i - j > 1 \text{ and } i - j \leq 12 \\ 0 & \text{otherwise} \end{cases} \quad (5-21)$$

where p is a vector of number of calves available for slaughter, sale or replacement. Since there is a portion of the female's offspring which will be used as replacements, the calves available for harvest will be less in this system. Let E be the matrix with number of animals available for slaughtering per cow in each of the cow age group:

$$E_{ij} = \begin{cases} a_{i-j} * (p_{i-j} - R) & \text{for } i - j > 1 \text{ and } i - j \leq 12 \\ 0 & \text{otherwise} \end{cases} \quad (5-22)$$

Where R represents the number of heifers required as replacements per calving year. In this study, the number was assumed as constant and calculated as:

$$R = \frac{1}{\sum_{i=1}^{12} a_i} \quad (5-23)$$

Similarly the culled cow number matrix (C) was expressed as:

$$C_{ij} = \begin{cases} d_{i-j} & \text{for } i - j > 1 \text{ and } i - j \leq 12 \\ 0 & \text{otherwise} \end{cases} \quad (5-24)$$

The calculation of CDGEs for self-replacement animals was performed for 4 generations. The gene expression of a cow at 1 year of age is assumed to be $g'_1 = [1 \ 0 \ 0 \ \dots \ 0]$, which is a 20 dimension vector. The rows of the vector correspond to the time series of the calculation. Let g_k represent the gene expression in the k^{th} generation specified as:

$$g_k = \frac{1}{2} * r * D * g_{k-1} \quad (5-25)$$

where r is the discounting rate; D denotes a matrix with columns of survival probabilities of a cow lagged by each row of a new birth year. The cumulative generation genetic expressions (g_{sum}) were expressed as:

$$g_{sum} = \sum_{k=1}^4 g_k \quad (5-26)$$

The design matrix and cumulative yearly genetic expressions were used to calculate the cumulative gene expressions of the one year old heifer over 4 generations after her life span. In the study, q was defined as a discounted factors vector of the category of animals with 20 dimensions, whose elements can be specified as:

$$q_i = \left(\frac{1}{1+r} \right)^{i-2} \quad (5-27)$$

which means the expressions in each age group of cows were scaled-back to the one year old cow. Then the CDGEs of annual traits for self-replacing cow (X_{rfa}) can be defined like:

$$X_{rfa} = g'_{sum} * D' * q \quad (5-28)$$

The discounted expression numbers for culled cows was expressed as:

$$X_{rfa} = g'_{sum} * C' * q \quad (5-29)$$

where the C is the culled cow number matrix. Based on the herd dynamics, the CDGEs of birth (X_{rfa}), weaning (X_{rfw}) and slaughter traits (X_{rfs}) of self-replacing females at one year of age should be estimated similarly as the calculation of terminal animals with g_{sum} , as:

$$X_{rfa} = \frac{1}{2 * pre * pos} * g'_{sum} * F' * q * \left(\frac{1}{1+r} \right)^{-0.2493} \quad (5-30)$$

$$X_{rfw} = \frac{1}{2 * pre} * g'_{sum} * F' * q * \left(\frac{1}{1+r} \right)^{0.2603} \quad (5-31)$$

$$X_{rfs} = \frac{1}{2} * g'_{sum} * E' * q * \left(\frac{1}{1+r} \right) \quad (5-32)$$

where the pre is the pre-weaning calf survival rate; pos represents the post-weaning calf survival rate; r is the discount rate.

5.2.5 Maternal males

The sire breeding self-replacing females was named as the maternal sire in the study. His genes were expressed in his daughter and his daughter's offspring. However, not all daughters were used as

replacements heifers. The calculation equations are constructed based on the study of Amer (1999). H was defined as the proportion of females used for replacement. Then the CDGEs of annual (X_{srda}) and end-of-cow (X_{srde}) traits for maternal sires were specified as:

$$X_{srda} = \frac{1}{4} * 1' * z * k * c * h * X_{rfa} \quad (5-33)$$

$$X_{srde} = \frac{1}{4} * 1' * z * k * c * h * X_{rfe} \quad (5-34)$$

where $1/4$ accounts for the relationship between sire and offspring and half of the offspring of the sire are daughters. The value of h is set to 0.4 in the study. Also, “ 1 ” is a vector of ones whose order equal to 20; z is a vector of discounted coefficients whose dimension is 2 by 1; k is the average number of cows mated to a single sire; c denote the average number of calves surviving to market (slaughter, sale or replacement); X_{rfa} is the CDGEs of annual trait for self-replacing cow; X_{rfe} is The discounted expression numbers of culling cow. The expressions of sire should be discounted back to the day the sire was purchased. So the discounted factor vector can be defined as:

$$z_i = \left(\frac{1}{1+r} \right)^{i+1} \quad (5-35)$$

which was constructed based on a purchased sire two years before his daughter reached one year of age. However, the expressions of the birth, weaning and slaughter traits are not only related to the replacing animal but to other offspring of the sire and the expression should be nearly one year earlier than annual and culling traits. Adjustments for herd dynamics can be specified as:

$$X_{srdb} = \frac{1}{2} * 1' * z * k * c * \left(\frac{1}{2} * h * X_{rfb} + \frac{1}{pre*pos} * \left(\frac{1}{1+r} \right)^{-1.2493} \right) \quad (5-36)$$

$$X_{srdw} = \frac{1}{2} * 1' * z * k * c * \left(\frac{1}{2} * h * X_{rfw} + \frac{1}{pos} * \left(\frac{1}{1+r} \right)^{-0.7397} \right) \quad (5-37)$$

$$X_{srds} = \frac{1}{2} * 1' * z * k * c * \left(\frac{1}{2} * h * X_{rfs} + \left(1 - \frac{1}{2} * h \right) \right) \quad (5-38)$$

where the pre is the pre-weaning calf survival rate; pos represents the post-weaning calf survival rate; r is the discount rate; X_{rfb} is the CDGE of birth traits of self-replacing females; X_{rfw} denote the CDGE for weaning traits of self-replacing female and X_{rfs} represents the CDGE for slaughter traits of

self-replacing females.

5.2.6 Sensitivity of discounted factor

Discount rate is representing the change in the value of genetic superiority today versus the future. Thus, in order to make selection decisions based on the economic importance of animals, all of the gene expressions should be scaled back to the specific time period (usually the beginning of investment). Since all equations for calculating CDGEs include the discount rate, its change may lead to variation of cumulative expression. Thus, a test of sensitivity of CDGEs to changing discount rate was conducted. In the test the discounted rate ranged from 0 to 0.2. Furthermore, almost all the variables used in the calculation were estimated from the real herd data, so the sensitive test had only been applied to the discount rate.

5.3 Result and Discussion

5.3.1 Cumulative discounted gene expressions (CDGEs)

The results of cumulative discounted gene expression of traits for different animal categories are shown in Table 5.3. According to the results, , there a large range of CDGEs among these animal categories because the different number of descendants were involved in calculation of different animal category. For instance, the CDGE of birth traits ranges from 2.170 for the terminal female to 22.987 for the maternal male, the larger values representing more expression in turn leading to more emphasis on the related economic value in multiple trait selection. Traits of maternal male have the most expressions, while the terminal females have the least. Usually, the selection is placed separately by sex with a specify purpose, so McArthur et al. (1990) argued that the cumulative expressions of traits for specific category animals are the same for individuals and therefore have no impact on economic selection. However, according to the results, the cumulative expressions of different traits for the same animal category vary considerably, e.g. the CDGEs for maternal male are from 3.778 of culling traits to 26.518 of birth trait. It is therefore necessary to adjust economic value using cumulative expressions so that the overall economic important can be applied to selection.

Table 5.3. CDGEs of five categories traits in four animal categories

Trait category	Maternal		Terminal	
	Male	Female	Male	Female
Annual	19.442	6.932	0	4.285
Culling	3.778	1.347	0	0.851
Birth	26.518	3.536	16.479	2.170
Weaning	22.987	3.065	14.502	1.909
Slaughter	17.643	2.291	14.444	1.902

5.3.2 Sensitivity of CDGEs

The Figure 5.1 shows the changing trend of the CDGEs based on varying discount rates. This indicates that increasing discount was associated with decreasing of CDGEs. The discount rate has little influence on the CDGEs of traits of terminal purpose animals, whereas it has large impact on the CDGEs of maternal animals whose gene is expressed over a long time (i.e. maternal purpose). The reasonable estimate of discount rate would be 3% per annum, which was reported by Bird and Mitchell (1980), and it is the one we choose to use in the study. All trait categories had a negative trend with increasing of discount rate. However, because of the influence of varying discount rate, the impact degrees were not the same for different kind of traits. Furthermore, Amer (1999) indicated that there are other variables which have impact on CDGEs, such as culling policy and planning horizon. Thus, it is necessary to use a discount rate most closely related to the real value and functional variables based on specific population for estimation, so that the economic selection index can be most efficient.

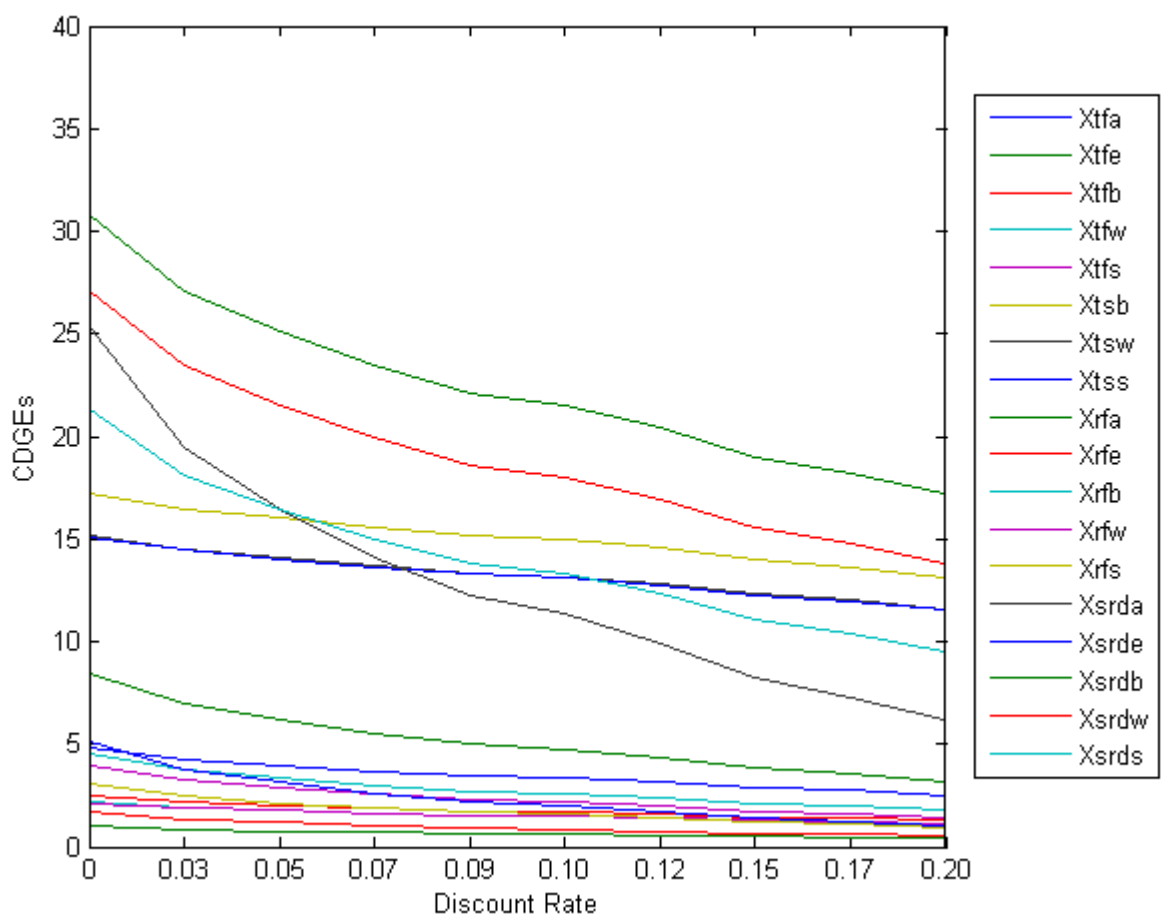


Figure 5.1 Sensitivity of Cumulative Discounted Gene Expressions (CDGEs) on changing discount rate. Xtfa: CDGE for annual traits of terminal females; Xtfe: CDGE for end-of-cow-life traits of terminal females; Xtfb: CDGE for birth traits of terminal females; Xtfw: CDGE for weaning traits of terminal females; Xtfs: CDGE for slaughter traits of terminal females; Xtsb: CDGE for birth traits of terminal males; Xtsw: CDGE for weaning traits of terminal males; Xtss: CDGE for slaughter traits of terminal males; Xrfa: CDGE for annual traits of replacement females; Xrfe: CDGE for end-of-cow-life traits of replacement females; Xrfb: CDGE for birth traits of replacement females; Xrfd: CDGE for weaning traits of replacement females; Xrfs: CDGE for slaughter traits of replacement females; Xsrda: CDGE for annual traits of replacement males; Xsrde: CDGE for end-of-cow-life traits of replacement males; Xsrd: CDGE for birth traits of replacement males; Xsrdw: CDGE for weaning traits of replacement males; Xsrds: CDGE for slaughter traits of replacement males;

5.4 Conclusions

The CDGEs overcome the problems associated with the unequal expression of traits. It is necessary to make adjustments to economic values using cumulative discounted gene expressions so that the relative economic importance of ERTs can be appropriately represented in the resulting selection indices. The method adapted in the study to calculate CDGEs of beef cattle have already been used by Amer (1999) and Berry et al. (2006) for sheep and dairy cattle. The expressions of genetic superiority over generations of animals are shown by the CDGEs. The sensitivity test showed that the CDGEs for most of the traits categories are robust to changes in discount rate within a reasonable range. However, the trend indicates that the CDGEs will be overestimated when ignoring the discount rate. Choosing a suitable discount rate is a more appropriate representation of genetic superiority over generation.

CHAPTER 6

SELECTION INDEX AND GENETIC GAIN

6.1 Introduction

The selection index is the final parameter for combining economic value and genetic effects. In the previous chapters, the economic values (EVs) and cumulative discounted gene expressions (CDGE) had been obtained. These are then integrated to develop the economic weights. With the estimated genetic correlations among traits in the breeding objective as well as the selection criteria, the selection index weights can be obtained. This chapter looks at the development of the selection indices and corresponding response.

6.2 Materials and Methods

6.2.1 Developing Aggregate Genotype

The linear aggregate genotype (H) was used in this study, developed by Hazel (1943). This equation can be specified as:

$$H = a_1G_1 + a_2G_2 + \cdots + a_nG_n \quad (6-1)$$

where the G_i was estimated breeding value (EBV) for traits, and the a_i is the economic weight for each ERTs. In the study, the economic weight can be calculated as:

$$a_i = EV_i * CDGE_i \quad (6-2)$$

where EV_i is the estimated economic value for traits i ; $CDGE_i$ is the cumulative discounted gene expression for trait i . So in present study, the aggregate genotype (H) was expressed as:

$$H = EV_1 * CDGE_1 * EBV_1 + EV_2 * CDGE_2 * EBV_2 + \cdots + EV_n * CDGE_n * EBV_n \quad (6-3)$$

6.2.2 Developing selection index

The general form of selection index is defined as (Hazel, 1943):

$$I = b_1x_1 + b_2x_2 + \cdots + b_nx_n \quad (6-4)$$

where x_i is the information used for selection, which can be phenotypic information, EBVs or EPDs, and b_i is the weighting factor for these records. According to the aggregate genotype equation and the

definition of index, if the traits in index and aggregate genotype are the same and the available information are EBVs, the economic weight in aggregate genotype can be directly used as the selection index coefficients. Table 6.1 shows the traits involved in aggregate genotype and indices in this study. The traits in the selection index are different from the traits in aggregate genotype, because there are no EBVs for some ERTs. Thus, related selection criteria were needed to process selection.

Table 6.1. Traits involved in Aggregate Genotype and Index

Item ^a	Traits ^a
Aggregate Genotype	CoSR, WW, BW, SR, CR, PSR, CCR, CoWT, MY, USDAgrade, CE, preADG, postADG, DP
Index	WW, BW, CoWT, MY, CE, preADG, postADG, STAY, SC, DC, FT

^a BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage; STAY: stayability; SC: scrotal circumference; DC:days to calving; FT: fat thickness.

The information used to calculate index of individuals were EPDs, which is half of EBVs. Thus, the selection index coefficient should be calculated as (Dekkers et al., 2004):

$$b = C_I^{-1} C_{IH} v \quad (6-5)$$

where C_I is the (co)variance matrix between traits in index; C_{IH} is the (co)variance matrix between traits in index and aggregate genotype; v is a vector of economic weights. Then the index can be developed as:

$$I = b_1 * 2 * EPD_1 + b_2 * 2 * EPD_2 + \dots + b_n * 2 * EPD_n \quad (6-6)$$

6.2.3 Constructing the genetic (co)variance matrix

In order to estimate the selection coefficient, the genetic (co)variance matrix (C_{IH}) between traits in breeding objective and selection criteria, and the genetic (co)variance matrix (C_I) among selection criteria were necessary. In this study, the genetic (co)variance estimates were obtained from calculation and previous literature reports. The genetic parameters related to CoSR, CR, PSR, USDAgrade, DP, DC and FT used in the study comes from previous literature. The genetic correlations related to WW, BW, SR,

CCR, CoWT, MY, CE, preADG, postADG and DP were estimated from CSU-BIC data. ASReml (Gilmour et al., 2009) was used to estimate genetic correlation between each pairs of traits using bivariate animal model. The general form of the bivariate model is expressed as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} \quad (6-7)$$

With the assumption that:

$$\text{var} \begin{bmatrix} u_1 \\ u_2 \\ e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} A\sigma_{a_1}^2 & A\sigma_{a_{12}} & 0 & 0 \\ A\sigma_{a_{12}} & A\sigma_{a_2}^2 & 0 & 0 \\ 0 & 0 & I\sigma_{e_1}^2 & I\sigma_{e_{12}} \\ 0 & 0 & I\sigma_{e_{12}} & I\sigma_{e_2}^2 \end{bmatrix}$$

where y_1 and y_2 are observations of two traits, X_1 and X_2 are the coefficient matrix of fixed effect related to two traits observations. The fixed effects included sex, birth year, age of dam and weaning age (included in model of WW); β_1 and β_2 are parameters for fixed effect related to traits 1 and trait 2; Z_1 and Z_2 are two incidence matrices for random effect related to trait 1 and trait 2. The random effects included animal and dam (only included in model of WW and CE). A is the numerator relationship matrix; u_1 and u_2 are two vectors of random effects which is additive genetic effect of trait 1 and trait 2; $\sigma_{a_1}^2$ and $\sigma_{a_2}^2$ is additive genetic effect variance of trait 1 and trait 2; $\sigma_{a_{12}}$ is the additive genetic covariance between trait 1 and trait 2; $\sigma_{e_1}^2$ and $\sigma_{e_2}^2$ are residual variances of trait 1 and trait 2; $\sigma_{e_{12}}$ is the residual covariance between trait 1 and trait 2. Then, together with the genetic variance obtained in chapter 4, the (co)variance of each pair of traits can be achieved with:

$$\sigma_{a_{12}} = r_{a_{12}} * \sqrt{\sigma_{a_1}^2 * \sigma_{a_2}^2} \quad (6-8)$$

where $r_{a_{12}}$ is the additive genetic effect correlation between trait 1 and trait 2.

6.2.4 Estimation of selection response and genetic gain of traits

With selection index weights, the response to selection on the developed index can be estimated using (Van Vleck, 1993):

$$R_H = i \sqrt{b' C_{IH} v} \quad (6-9)$$

where i denotes the selection intensity which is assumed as 1 SD in the study; v is a 14 by 1 vector of economic value because there are 14 traits, C_{IH} is a 11 by 14 genetic (Co)variance matrix with 14 traits in aggregate genotype and 11 traits in index and b is the 11 by 1 selection coefficient vector which is the same as the number of traits in index. The expected changes in the additive genetic value (S_g) of each of the traits in the aggregate genotype due to selection on the index are calculated as (Van Vleck, 1993):

$$S_g = i \frac{b' C_{IH}}{\sqrt{b' C_{IH} v}} \quad (6-10)$$

The selection response and expected additive genetic changes were calculated for all the six indices.

6.2.5 Effect of alternative feed, heifer, bull and meat price on selection index weights

In this study, all the economic information (meat price, heifer price, bull price and feed price) was considered fixed for animals each year. However, the economic values vary with changes in the market, animal breeding and meat quality. Sensitive tests were performed on selection index weights of maternal females by changing of feed price, meat price, heifer price and bull price in the profit equations. The values involved in the study are 0.5 or 1.5 times feed price and meat price, as well as 1.5 times heifer and bull price. The corresponding indices are $I_{pf*0.5}$, $I_{pf*1.5}$, $I_{phc*0.5}$, $I_{phc*1.5}$, $I_{rhc*1.5}$, $I_{rbc*1.5}$. The correlations of these indices were estimated to show effect of changing value on index selection.

6.3 Results and Discussion

6.3.1 Economic weights

The economic weights for each of the 14 traits for three systems by sex (6 indexes) are shown in table 6.2. According to the results, because terminal males have no of annual and end-of-cow-life traits, the weights are zero for these traits. Except for the terminal males, the index weights did not rerank the economic importance of these traits before adjustment, The absolute changed. For example, the difference

in index weights between SR and CR is more than that of economic value. Multiplied by CDGEs will lead to different selection weights of females and males, so it is reasonable to select separately by sex besides selection purposes.

Table 6.2. Economic weights of 14 traits for three production system by sex based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center

Traits ^c	Maternal		Terminal 1 ^a		Terminal 2 ^b	
	Female	Male	Female	Male	Female	Male
CoSR(%)	113.741	319.012	49.260	0.000	44.645	0.000
WW(kg)	1.686	12.645	1.356	10.296	0.604	4.590
BW(kg)	-0.781	-5.855	-0.479	-3.639	-0.479	-3.638
SR(%)	25.337	190.012	9.914	75.291	9.914	75.291
CR(%)	48.669	136.502	19.121	0.000	19.073	0.000
PSR(%)	14.401	107.998	8.111	61.603	4.015	30.492
CCR(%)	-43.859	-123.011	-15.234	0.000	-11.335	0.000
CoWT(kg)	-0.212	-0.594	-0.134	0.000	-0.134	0.000
MY(kg)	-0.500	-1.402	-0.309	0.000	-0.309	0.000
USDAgrade (%)	4.934	38.001	12.289	93.327	5.270	40.024
CE (%)	2.005	15.038	1.231	9.345	1.231	9.345
preADG (kg)	-42.003	-314.995	-26.166	-198.724	-26.166	-198.721
posADG (kg)	97.500	750.914	166.554	1264.897	43.251	328.471
DP(%)	10.422	80.269	25.958	197.135	19.586	148.744

^a Terminal system without replacement

^b Terminal system with replacement

^c BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage

6.3.2 Genetic parameters

The results of genetic correlation and genetic standard deviation were presented in table 6.3. The genetic correlations obtained in the study of WW and BW was 0.24 (0.10) which is similar to that of 0.37 (Gutiérrez et al., 2007). The correlation of maternal WW and WW is -0.28 (0.12) similar with as the results of two studies which are -0.28 and -0.44 (MacNeil and Newman, 1994; Gutiérrez et al., 2007). Also genetic correlation of maternal WW and CE is estimated as -0.11 (0.18) which is in accordance with -0.097 from the results of Gutiérrez et al. (2007). The genetic correlation between WW and postADG is

Table 6.3. Heritability (on diagona), genetic standard deviation (below diagonal) and genetic correlation (above diagonal) between traits including traits in breeding objectives and index

Traits ^a	CoSR	WW	BW	SR	CR	PSR	CCR	CoWT	MY	USDAgrade	CE	preADG	posADG	DP	STAY	SC	DC	FT
CoSR(%)	0.03 1.72	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WW(kg)		0.10 8.57	0.24	0.00	0.00	0.04	0.00	0.00	-0.28	-0.13	0.18	0.43	0.44	0.30	0.00	0.24	0.00	-0.29
BW(kg)			0.53 3.66	-0.24	0.00	0.05	0.06	0.35	-0.04	-0.05	-0.25	0.33	0.44	-0.05	-0.03	0.15	0.00	-0.21
SR(%)				0.11 10.09	0.00	0.00	-0.38	0.00	0.00	0.00	-0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR(%)					0.18 0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	-0.66	0.19
PSR(%)						0.03 1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CCR(%)							0.05 7.64	-0.08	0.00	0.00	-0.03	0.00	0.00	0.00	-0.65	0.00	0.00	0.00
CoWT(kg)								0.56 54.26	0.00	0.00	-0.10	0.04	0.40	0.04	0.06	0.46	-0.05	-0.09
MY(kg)									0.29 14.96	0.00	-0.11	0.17	0.27	0.00	-0.15	-0.63	0.00	0.00
USDAgrade(%)										0.53 0.25	0.00	0.14	0.11	0.31	0.00	0.00	0.00	0.56
CE(%)											0.24 1.80	0.16	0.30	0.00	0.00	0.00	0.00	-0.14
preADG(kg)												0.39 0.09	0.35	-0.08	0.00	-0.65	0.00	0.04
posADG(kg)													0.11 0.12	-0.08	0.00	-0.23	0.00	-0.10
DP(%)														0.49 1.68	0.00	0.00	0.00	0.09
STAY															0.12 0.17	0.00	0.00	0.00
SC(cm)																0.35 0.44	-0.10	0.19
DC (day)																	0.07 8.32	0.00
FT(mm)																		0.35 0.47

^a BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage; STAY: stayability; SC: scrotal circumference; DC:days to calving; FT: fat thickness

0.44 (0.22) in the study and similar to 0.32 reported by MacNeil and Newman (1994), while the estimated genetic correlation between WW and preADG is extremely high (0.99) compared with 0.43 of it (MacNeil and Newman, 1994). This high correlation may be because of that the preADG was calculated based on WW and small variance of BW. Thus, because of the co-linearity between them, the correlation 0.43 from MacNeil and Newman was used in the study. In this study, the genetic correlation between SC and WW is 0.24 (0.52) which is close to 0.36 reported by Boligon (Boligon et al., 2010). The genetic correlation between BW and CoWT or SR, SR and CE are 0.35 (0.05), -0.24 (0.15) and -0.15 (0.18), respectively which are smaller compared with 0.65, -0.49 and -0.35 gained by Cundiff et al. (1986) and (MacNeil and Newman, 1994). However, this difference is not considered large. Genetic correlation between BW and maternal WW is -0.24 (0.12) which is larger than -0.076 from the previous study (Gutiérrez et al., 2007), while the genetic correlation between BW and CE is smaller than its results: -0.25 versus -0.60. The 0.33 (0.11) and 0.44 (0.09) are the estimated genetic correlations of BW and preADG, BW and postADG which are similar to MacNeil's results of 0.34 and 0.51. In the study some previously unreported correlations were estimated. They are CCR related correlations, which corresponding to what we expect. For example, the correlation between CCR and SR was -0.38 (0.07) and between CCR and STAY was -0.65 (0.26), and it is obvious that high CCR corresponding to low SR and STAY. The genetic parameters of inestimable traits (CoSR, CR, PSR, USDAGrade, DP, DC and FT) were taken from previous literature estimates (Swiger et al., 1965; MacNeil and Newman, 1994; Johnston and Bunter, 1996; Pariacote et al., 1998; Splan et al., 1998; Arthur et al., 2001; Martinez-Velazquez et al., 2003; Rewe, 2004; Enns and Nicoll, 2008), which were also presented in table 6.3. The (co)variance matrix C_{IH} and C_I were created from the information in the table.

6.3.3 Selection indices, Selection response and Genetic gain

Table 6.4 shows the index weights for 11 selection criteria. The total selection response from the six indices and the genetic gain of each of the 14 traits based on selection on the six indices are shown in table 6.5. According to the results, all the selection indices will lead to increased profit. Compared with

Table 6.4. Index weights of 11 selection criteria used in six indices based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center

Traits ^c	Maternal		Terminal 1 ^a		Terminal 2 ^b	
	Female	Male	Female	Male	Female	Male
WW(kg)	5.461	28.220	3.138	16.399	2.058	9.767
BW(kg)	-27.112	-184.860	-14.061	-95.443	-12.827	-88.664
CoWT(kg)	0.842	5.431	0.122	0.909	0.141	1.267
MY(kg)	-4.038	-23.577	0.396	-4.910	-0.094	-6.012
CE(%)	17.454	82.152	2.107	-10.772	2.587	-0.677
preADG(kg)	-0.999	158.760	136.220	1136.200	91.005	794.020
posADG(kg)	37.155	1154.400	199.170	1992.400	76.669	952.130
STAY	1238.200	3186.900	432.100	-141.690	314.690	-158.070
SC(cm)	-5.429	-264.030	40.672	187.510	21.155	75.582
DC(day)	-0.502	-1.833	-0.012	1.269	-0.110	0.776
FT(mm)	2.963	-0.167	-3.325	-40.551	-1.561	-29.159

^a Terminal system without replacement

^b Terminal system with replacement

^c BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; MY:milk yield; CoWT: cow weight; CE:calving ease; DP:dressing percentage; STAY: stayability; SC: scrotal circumference; DC:days to calving; FT: fat thickness

other animal categories, the responses in 1 standard deviation of selection on maternal animals are higher than terminal animals. This is because additional gene expressions of maternal animals are exhibited in each descendant and therefore carry forward for multiple years. Most of the traits' gain would lead to an increasing of profit, but the genetic changes of culling cow weight and post weaning survival of calves would lead to less profit and are unfavorable. The reasons for this problem with CoWT are: 1. there are moderate positive genetic relationship between cow weight and weaning weight, and a high positive genetic correlation between cow weight and post-weaning average daily gain. 2. The weaning weight and post-weaning average daily gain had higher economic value. Thus, the improvement of those highly economic important traits will lead to the positive genetic gain in cow weight. Because of the positive genetic relationship between BW and PSR and higher economic value of BW, it is reasonable to obtain a negative gain of PSR to achieve the most selection response. Trait which have a higher economic important or a larger genetic variance, such as CCR, SR, CoWT, MY and weight and post-weaning average daily gain had higher economic value. Thus, the improvement of those highly economic important traits will lead to the positive genetic gain in cow weight. Because of the positive genetic

Table 6.5. Genetic gain per generation for 14 traits of six indices and selection responses per generation of six indices with one standard deviation selection intensity

Item ^c	Maternal		Terminal 1 ^a		Terminal 2 ^b	
	Female	Male	Female	Male	Female	Male
R (\$)	259.770	957.100	93.901	361.580	71.812	279.300
R _c (\$)	99.014	193.220	51.505	91.316	39.739	70.966
CoSR(%)	0.014	0.025	0.019	0.034	0.023	0.041
WW(kg)	1.538	2.205	3.127	5.928	2.112	3.832
BW(kg)	-1.164	-1.924	-1.102	-1.316	-1.751	-2.506
SR(%)	1.120	1.967	1.405	2.286	1.701	2.841
CR(%)	0.002	-0.006	0.012	0.009	0.010	0.003
PSR(%)	-0.021	-0.044	-0.028	-0.058	-0.040	-0.081
CCR(%)	-4.412	-3.416	-4.266	-0.185	-4.154	-0.205
CoWT(kg)	4.365	4.433	6.478	10.260	1.753	3.658
MY(kg)	-5.889	-5.874	-2.133	-2.394	-3.093	-3.804
USDAgrade(%)	0.000	0.001	-0.004	-0.007	-0.001	-0.001
CE(%)	0.473	0.789	0.584	0.976	0.593	0.972
preADG(kg)	-0.005	-0.004	-0.002	-0.002	-0.005	-0.007
posADG(kg)	-0.003	0.011	0.031	0.072	0.003	0.020
DP(%)	0.133	0.181	0.136	0.137	0.150	0.161

^a Terminal system without replacement

^b Terminal system with replacement

^c R:selection response with considering cumulative discounted gene expression (CDGE); R_c:selection response without considering cumulative discounted gene expression (CDGE);BW:birth weight; WW:weaning weight; preADG:pre-weaning average daily gain; postADG:post-weaning average daily gain; SR:pre-weaning calf survival rate; MY:milk yield; CoWT: cow weight; CE:calving ease; CoSR:cow survival rate per year; CR:cow survival rate per year; PSR: post-weaning calf survival rate; USDAgrade: USDA meat quality grade; CCR:cow culling rate; DP:dressing percentage.

relationship between BW and PSR and higher economic value of BW, it is reasonable to obtain a negative gain of PSR to achieve the most selection response. Trait which have a higher economic important or a larger genetic variance, such as CCR, SR, CoWT, MY and WW, would have a higher genetic gain. In this study, CoWT had the largest genetic gain, because its genetic variance was much large than other traits. This fact indicates that the selection emphasis will be placed on traits with high economic value and large genetic variance. Additionally, compared with maternal system, the genetic gain of production traits were larger than they are in maternal system, for instance, the genetic gain for weaning weight in maternal system was 2.205, while it is 5.928. Even though the differences are small, they indicate that there is more emphasis placed on production traits in terminal system. This finding was in accordance with the fact that the growth traits are more important for terminal males.

6.3.4 Effect of alternative economic information

Table 6.6 and Table 6.7 show the correlations of the original index and indices after prices changes in the maternal and terminal production systems. The correlations are high for both male and female indices, indicating that price variation has a relatively small effect on the maternal index weights. Thus, in the maternal system, indices are likely robust to changing economic conditions. However, in the terminal system, while the economic information still has small influence on the index weights of females, they affect the indices of males. According negative correlation coefficient, change of feed and meat prices has changed the rank of the index weights which result in significant changes to the index. Therefore, selection is performed on terminal males using these indices, economic information should be gathered and chosen reasonably, so that a more precise selection decision can be made.

Table 6.6. Correlation among indices of female (above diagonal) and male (below diagonal) derived from different feed, meat, heifer and bull price levels for maternal systems based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center

Index ^a	I _o ^a	I _{pf*0.5}	I _{pf*1.5}	I _{phc*0.5}	I _{phc*1.5}	I _{rhc*1.5}	I _{rbc*1.5}
I _o	1.000	0.936	0.978	0.989	0.988	0.998	1.000
I _{pf*0.5}	0.762	1.000	0.841	0.876	0.978	0.910	0.940
I _{pf*1.5}	0.809	0.237	1.000	0.998	0.935	0.990	0.975
I _{phc*0.5}	0.905	0.417	0.980	1.000	0.956	0.997	0.988
I _{phc*1.5}	0.929	0.611	0.536	0.684	1.000	0.976	0.990
I _{rhc*1.5}	0.978	0.790	0.914	0.974	0.831	1.000	0.997
I _{rbc*1.5}	0.999	0.782	0.782	0.886	0.943	0.967	1.000

^a I_o :The original selection index for maternal females; I_{pf*0.5}: index from 0.5 times feed price in original index with other keeping the same; I_{pf*1.5}: index from 0.5 times feed price; I_{phc*0.5}:index from 0.5 times hot carcass price; I_{phc*1.5}:index from 1.5 times hot carcass price; I_{rhc*1.5}: index from 1.5 times replacement heifer price; I_{rbc*1.5}: index from 0.5 times replacement bull price.

Table 6.7. Correlation among index of female (above diagonal) and male (below diagonal) derived from different feed, meat, heifer and bull price for terminal systems based on information of John E. Rouse Ranch of Colorado State University Beef Improvement Center

Index ^a	I _o	I _{pf*0.5}	I _{pf*1.5}	I _{phc*0.5}	I _{phc*1.5}	I _{rhc*1.5}	I _{rbc*1.5}
I _o	1.000	0.868	0.758	0.598	0.807	0.921	0.999
I _{pf*0.5}	0.915	1.000	0.335	0.126	0.990	0.633	0.868
I _{pf*1.5}	0.193	-0.217	1.000	0.970	0.232	0.918	0.758
I _{phc*0.5}	-0.524	-0.822	0.734	1.000	0.010	0.841	0.598
I _{phc*1.5}	0.934	0.999	-0.168	-0.792	1.000	0.530	0.807
I _{rhc*1.5}	0.989	0.963	0.054	-0.638	0.975	1.000	0.921
I _{rbc*1.5}	0.989	0.963	0.054	-0.638	0.975	1.000	1.000

^a I_o :The original selection index for maternal females; I_{pf*0.5}: index from 0.5 times feed price in original index with other keeping the same; I_{pf*1.5}: index from 0.5 times feed price; I_{phc*0.5}:index from 0.5 times hot carcass price; I_{phc*1.5}:index from 1.5 times hot carcass price; I_{rhc*1.5}: index from 1.5 times replacement heifer price; I_{rbc*1.5}: index from 0.5 times replacement bull price.

6.4 Conclusions

The six selection indexes can be used to make selection decisions, because they will lead to more profit in industry based on the results of selection response. Furthermore, the results indicate that traits studied may not all be included in these selection indexes, because the predicted improvement of genetic would be small, based on these selection indices. Also, the differences in index weights between male and female in maternal and terminal systems indicates that it is necessary to use specific index on specific individual to do selection.

In the presented study, it was assumed that the EBVs or EPDs of traits were available, so estimation of EBVs had not studied. To test the real worth of the study, the best way is to apply the indices in real production systems, and then measure the real improvement of the system based on the application. Also, because of the variability of production and marketing system, the indices should be updated regularly in future.

REFERENCES

- Ahola, J., R. Enns and T. Holt (2006). Examination of potential methods to predict pulmonary arterial pressure score in yearling beef cattle. *Journal of animal science* 84(5): 1259-1264.
- Albera, A., P. Carnier and A. Groen (2004). Definition of a breeding goal for the Piemontese breed: economic and biological values and their sensitivity to production circumstances. *Livestock Production Science* 89(1): 66-77.
- Amer, P. (1999). Economic accounting of numbers of expressions and delays in sheep genetic improvement. *New Zealand Journal of Agricultural Research* 42(3): 325-336.
- Amer, P., G. Simm, M. Keane, M. Diskin and B. Wickham (2001). Breeding objectives for beef cattle in Ireland. *Livestock Production Science* 67(3): 223-239.
- Arthur, P., J. Archer, D. Johnston, R. Herd, E. Richardson and P. Parnell (2001). Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *Journal of animal science* 79(11): 2805-2811.
- Association, A. A. (2011). "Angus Advantage." from <http://www.angus.org/>.
- Association, A. A. (2012). "Angus History." from <http://www.angus.org/Pub/AngHist.aspx>.
- Baharin, K. and R. Beilharz (1977). A survey of reproductive performance in herds of beef cattle from 13 properties in Victoria. *Australian Journal of Experimental Agriculture* 17(85): 181-186.
- Ball, C. (2000). Historical overview of beef production and beef organizations in the United States. *Journal of animal science* 79(E-Suppl 1): 1-8.
- Berry, D., F. Madalena, A. Cromie and P. Amer (2006). Cumulative discounted expressions of dairy and beef traits in cattle production systems. *Livestock Science* 99(2): 159-174.
- BIF, 2002. Guidelines for Uniform Beef Improvement Program, Beef Improvement Federation (BIF) Georgia.
- Bird, P. and G. Mitchell (1980). The choice of discount rate in animal breeding investment appraisal. *Animal Breeding Abstracts*.

- Boligon, A., J. Silva, R. Sesana, J. Sesana, J. Junqueira and L. Albuquerque (2010). Estimation of genetic parameters for body weights, scrotal circumference, and testicular volume measured at different ages in Nellore cattle. *Journal of animal science* 88(4): 1215-1219.
- Brascamp, E. W. (1984). Selection Index with Constraints. *Animal Breeding Abstracts* 52: 10.
- Brigham, B., S. Speidel and R. Enns (2006). Alternative Definitions of Stayability. 2005–2006 Beef Improvement Federation Board of Directors: 75.
- Bullock, B., Anderson, L, Johns, J., Burris, R. (2003). Beef Sire Selection Recommendations. Kentucky Cooperative Extension.
- Callis, B. L. K. (2010). Genetic parameters for calving rate and age at first calving in Hereford heifers, Kansas State University.
- Cervantes, I., J. Gutiérrez, I. Fernández and F. Goyache (2010). Genetic relationships among calving ease, gestation length, and calf survival to weaning in the Asturiana de los Valles beef cattle breed. *Journal of animal science* 88(1): 96-101.
- Conington, J., S. Bishop, A. Waterhouse and G. Simm (2004). A bioeconomic approach to derive economic values for pasture-based sheep genetic improvement programs. *Journal of animal science* 82(5): 1290-1304.
- Crews Jr, D. (2005). Multiple Trait Selection for maternal Productivity: The Hereford Maternal Productivity Index. Agriculture and Agri-Food Canada Research Centre. Lethbridge. Alberta. Canadá.
- Crews Jr, D., G. Carstens and P. Lancaster (2005). Development of a multiple trait selection index for feedlot traits in beef cattle including feed efficiency. Western Section, Animal Society of Animal Science.
- Cubas, A., P. Berger and M. Healey (1991). Genetic parameters for calving ease and survival at birth in Angus field data. *Journal of animal science* 69(10): 3952-3958.
- Cundiff, L., M. MacNeil, K. Gregory and R. Koch (1986). Between-and within-breed genetic analysis of calving traits and survival to weaning in beef cattle. *Journal of animal science* 63(1): 27.

- Cunningham, E. and N. I. I. f. husdyravl (1969). *Animal Breeding Theory: Internordic Licenciati Course in Quantitative Genetics*, Landbruksbokhandelen; Universitetsforlaget.
- Davis, G. (1993). Genetic parameters for tropical beef cattle in Northern Australia: A review. *Crop and Pasture Science* 44(2): 179-198.
- Davis, M., M. Bishop, N. Park and R. Simmen (1995). Divergent selection for blood serum insulin-like growth factor I concentration in beef cattle: I. Nongenetic effects. *Journal of animal science* 73(7): 1927-1932.
- Dekkers, J. (1994). Optimal breeding strategies for calving ease. *Journal of dairy science* 77(11): 3441-3453.
- Dekkers, J., J. Gibson, P. Bijma and J. Van Arendonk (2004). Design and optimisation of animal breeding programmes. Lecture notes. Wageningen.
- Dib, M. G., L. D. Van Vleck and M. L. Spangler (2010). Genetic analysis of mature size in American Angus cattle. *Nebraska Beef Cattle Reports*: 560.
- Enns, R. and G. Nicoll (2008). Genetic change results from selection on an economic breeding objective in beef cattle. *Journal of animal science* 86(12): 33-48.
- Falconer, D. S. (1981). *Introduction to quantitative genetics*, Longman.
- Fan, L., D. Bailey and N. Shannon (1995). Genetic parameter estimation of postweaning gain, feed intake, and feed efficiency for Hereford and Angus bulls fed two different diets. *Journal of animal science* 73(2): 365-372.
- Fernandez-Perea, M. and R. Alenda Jiménez (2004). Economic weights for a selection index in Avileña purebred beef cattle. *Livestock Production Science* 89(2-3): 223-233.
- Food, M. o. A. F. a., 1990. *Tables of nutritive value and chemical composition of feed stuffs*. MAFF, Rewet Research Institute, HMSO, London, UK.
- Forabosco, F., R. Bozzi, P. Boettcher, F. Filippini, P. Bijma and J. Van Arendonk (2005). Relationship between profitability and type traits and derivation of economic values for reproduction and survival traits in Chianina beef cows. *Journal of animal science* 83(9): 2043-2051.

- Forabosco, F., A. Groen, R. Bozzi, J. Van Arendonk, F. Filippini, P. Boettcher and P. Bijma (2004). Phenotypic relationships between longevity, type traits, and production in Chianina beef cattle. *Journal of animal science* 82(6): 1572-1580.
- Gilmour, A., B. Gogel, B. Cullis, R. Thompson, D. Butler, M. Cherry, D. Collins, G. Dutkowski, S. Harding and K. Haskard (2009). ASReml user guide release 3.0. VSN International Ltd., UK. <http://www.vsnl.co.uk> 275.
- Goddard, M. (1983). Selection indices for non-linear profit functions. *TAG Theoretical and Applied Genetics* 64(4): 339-344.
- Golden, B., D. Garrick, S. Newman and R. Enns (2000). Economically relevant traits: A framework for the next generation of EPDs. Proceedings of the 32nd Research Symposium and Annual Meeting of the Beef Improvement Federation.
- Golden, B. L., W. Snelling and C. Mallinckrodt (1992). *Animal Breeder's Tool Kit: User's Guide and Reference Manual*, Colorado State University, Agricultural Experiment Station.
- Goyache, F., J. Gutiérrez, I. Alvarez, I. Fernández, L. Royo and E. Gómez (2003). Genetic analysis of calf survival at different preweaning ages in beef cattle. *Livestock Production Science* 83(1): 13-20.
- Gregory, K. and L. V. Cundiff (1980). Crossbreeding in beef cattle: evaluation of systems. *Journal of animal science* 51(5): 1224-1242.
- Groen, A. F., T. Steine, J. J. Colleau, J. Pedersen, J. Pribyl and N. Reinsch (1997). Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. *Livestock Production Science* 49(1): 1-21.
- Gutiérrez, J., F. Goyache, I. Fernández, I. Alvarez and L. Royo (2007). Genetic relationships among calving ease, calving interval, birth weight, and weaning weight in the Asturiana de los Valles beef cattle breed. *Journal of animal science* 85(1): 69-75.
- Harris, D. L., C. R. Arboleda and T. S. Stewart (1984). *Animal breeding programs: a systematic approach to their design*, Agricultural Research Service, North Central Region, US Department of Agriculture.

- Hazel, L., G. Dickerson and A. Freeman (1994). The selection index—then, now, and for the future. *Journal of dairy science* 77(10): 3236-3251.
- Hazel, L. and J. L. Lush (1942). The efficiency of three methods of selection. *Journal of Heredity* 33(11): 393-399.
- Hazel, L. N. (1943). The genetic basis for constructing selection indexes. *Genetics* 28(6): 476.
- Henderson, C. (1975). Best linear unbiased estimation and prediction under a selection model. *Biometrics*: 423-447.
- Herd, R., J. Archer and P. Arthur (2003). Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. *Journal of animal science* 81(13 suppl 1): E9-E17.
- Hill, W. G. (1974). Prediction and evaluation of response to selection with overlapping generations. *Animal Production* 18(02): 117-139.
- Hirooka, H., A. Groen and J. Hillers (1998). Developing breeding objectives for beef cattle production 2. Biological and economic values of growth and carcass traits in Japan. *Animal Science* 66(03): 623-633.
- Ihaka, R. and R. Gentleman (1996). R: A language for data analysis and graphics. *Journal of computational and graphical statistics*: 299-314.
- Institute, S. (1999). *SAS/STAT User's guide: Version 8*, SAS institute.
- Itoh, Y. and Y. Yamanda (1986). Re-examination of selection index for desired gains. *Genetics Selection Evolution* 18(4): 1-6.
- Jensen, R., R. Pierson, P. Braddy, D. Saari, A. Benitez, D. Horton, L. Lauerman, A. McChesney, A. Alexander and D. Will (1976). Brisket disease in yearling feedlot cattle. *Journal of the American Veterinary Medical Association* 169(5): 515.
- Jiang, X., A. Groen and E. Brascamp (1999). Discounted expressions of traits in broiler breeding programs. *Poultry science* 78(3): 307-316.
- Johnson, R. A. and D. W. Wichern (1992). *Applied multivariate statistical analysis*, Prentice hall

Englewood Cliffs, NJ.

- Johnston, D. J. and K. L. Bunter (1996). Days to calving in Angus cattle: genetic and environmental effects, and covariances with other traits. *Livestock Production Science* 45(1): 13-22.
- Kempthorne, O. and A. W. Nordskog (1959). Restricted selection indices. *Biometrics* 15(1): 10-19.
- Kluyts, J., F. Naser and M. Bradfield (2004). Development of breeding objectives for beef cattle breeding: derivation of economic values: review article. *South African Journal of Animal Science* 33(3): 142-158.
- Kluyts, J., F. Naser and M. Bradfield (2007). Derivation of economic values for the Simmentaler breed in South Africa. *South African Journal of Animal Science* 37(2): 107-121.
- Koots, K. and J. Gibson (1998). Economic values for beef production traits from a herd level bioeconomic model. *Canadian Journal of Animal Science* 78(1): 29-45.
- Koots, K., J. Gibson, C. Smith and J. Wilton (1994). Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. *Animal Breeding Abstracts*.
- Long, C. R. (1980). Crossbreeding for beef production: Experimental results. *Journal of animal science* 51(5): 1197-1223.
- MacGregor, R. and N. Casey (1999). Evaluation of calving interval and calving date as measures of reproductive performance in a beef herd. *Livestock Production Science* 57(2): 181-191.
- MacNeil, M., W. Herring and S. P. GENETI (2005). Economic evaluation of genetic differences among Angus bulls *Amer Soc Anim Sci*
- MacNeil, M. and S. Newman (1994). Selection indices for Canadian beef production using specialized sire and dam lines. *Canadian Journal of Animal Science* 74(3): 419-424.
- MacNeil, M., S. Newman, R. Enns and J. Stewart-Smith (1994). Relative economic values for Canadian beef production using specialized sire and dam lines. *Canadian Journal of Animal Science* 74(3): 411-417.
- MacNeil, M., R. Nugent and W. Snelling (1997). Breeding for profit: an introduction to selection index concepts. *Range Beef Cow Symposium*.

- MacNeil, M. D., L. V. Cundiff, C. Dinkel and R. M. Koch (1982). Genetic correlations of reproductive and maternal traits with growth and carcass traits in beef cattle.
- Martinez-Velazquez, G., K. Gregory, G. Bennett and L. D. Van Vleck (2003). Genetic relationships between scrotal circumference and female reproductive traits. *Journal of animal science* 81(2): 395-401.
- McArthur, A., A. del Bosque Gonzalez and J. Fenwick (1990). Adjustment of annual economic values for time. *Proceedings of the 8th Conference of the Australian Association of Animal Breeding and Genetics*.
- McClintock, A. and E. Cunningham (1974). Selection in dual purpose cattle populations: defining the breeding objective. *Animal Production* 18(03): 237-247.
- Moav, R. and W. Hill (1966). Specialised sire and dam lines. IV. Selection within lines. *Animal Production* 8(03): 375-390.
- Moav, R. and J. Moav (1966). Profit in a broiler enterprise as a function of egg production of parent stocks and growth rate of their progeny. *British Poultry Science* 7(1): 5-15.
- Morris, C. and N. Cullen (1994). A note on genetic correlations between pubertal traits of males or females and lifetime pregnancy rate in beef cattle. *Livestock Production Science* 39(3): 291-297.
- Mrode, R. and R. Thompson (2005). *Linear models for the prediction of animal breeding values*, Cabi.
- Nelsen, T. and D. Kress (1979). Estimates of heritabilities and correlations for production characters of Angus and Hereford calves. *Journal of animal science* 48(2): 286-292.
- Newman, S., C. Morris, R. Baker and G. Nicoll (1992). Genetic improvement of beef cattle in New Zealand: breeding objectives. *Livestock Production Science* 32(2): 111-130.
- Nilforooshan, M. and M. Edriss (2004). Effect of age at first calving on some productive and longevity traits in Iranian Holsteins of the Isfahan Province. *Journal of dairy science* 87(7): 2130-2135.
- NRC, 2000. *Nutrient requirements of beef cattle*. N. R. Council. National Research Council, National Academy Press Washington, DC.
- Pariacote, F., L. Van Vleck and R. Hunsley (1998). Genetic and phenotypic parameters for carcass traits

- of American Shorthorn beef cattle. *Journal of animal science* 76(10): 2584-2588.
- Parlsh, J. A., Rhinehart, J. D., Smith, T. (2011). Expected Progeny Differences and Selection Indices for Beef Cattle Selection. Furtherance of Acts of Congress, Mississippi State University Extension Service.
- Payne, W. J. A. (1970). Cattle production in the tropics. Vol. 1. General introduction and breeds and breeding. Cattle production in the tropics. Vol. 1. General introduction and breeds and breeding.
- Pešek, J. and R. Baker (1969). Desired improvement in relation to selection indices. *Canadian Journal of Plant Science* 49(6): 803-804.
- Ponzoni, R. (1986). A profit equation for the definition of the breeding objective of Australian Merino sheep. *Journal of Animal Breeding and Genetics* 103(1-5): 342-357.
- Ponzoni, R. and S. Newman (1989). Developing breeding objectives for Australian beef cattle production. *Animal Production* 49(01): 35-47.
- PSU, 2001. Beef Cow-calf Production. Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802, Information and Communication Technologies in the College of Agricultural Sciences.
- Rakha, A., G. Igboeli and J. King (1971). Calving interval, gestation and postpartum periods of indigenous central African cattle under a restricted system of breeding. *Journal of animal science* 32(3): 507-509.
- Rewe, T. O. (2004). Development of breeding objectives for production systems utilising the Boran Breed in Kenya. MSc. Egerton University.
- Sales, J. and W. Hill (1976). Effect of sampling errors on efficiency of selection indices 1. Use of information from relatives for single trait improvement. *Animal Production* 22(01): 1-17.
- Shirley, K., D. Beckman and D. Garrick (2008). Inheritance of pulmonary arterial pressure in Angus cattle and its correlation with growth. *Journal of animal science* 86(4): 815-819.
- Short, S. D. (2001). Characteristics and production costs of US cow-calf operations. United States. Dept. of Agriculture. Economic Research Service, US Department of Agriculture.

- Smith, C. (1983). Effects of changes in economic weights on the efficiency of index selection. *Journal of animal science* 56(5): 1057-1064.
- Splan, R. K., L. V. Cundiff and L. D. Van Vleck (1998). Genetic parameters for sex-specific traits in beef cattle. *Journal of animal science* 76(9): 2272-2278.
- St-Onge, A. (2000). Economic values of traits for dairy cattle improvement estimated using field recorded data. Master of Science, McGill University.
- Swiger, L., K. Gregory, L. Sumption, B. Breidenstein and V. Arthaud (1965). Selection indexes for efficiency of beef production. *Journal of animal science* 24(2): 418-424.
- Tess, M. and B. Kolstad (2000). Simulation of cow-calf production systems in a range environment: I. Model development. *Journal of animal science* 78(5): 1159-1169.
- Toelle, V. and O. Robison (1985). Estimates of genetic correlations between testicular measurements and female reproductive traits in cattle. *Journal of animal science* 60(1): 89.
- USDA-AMS. (2011). "Weekly Hay report." from http://www.ams.usda.gov/mnreports/gl_gr310.txt.
- USDA-AMS. (2011-2012). "USDA Beef carcass price equivalent index value." from <http://www.ams.usda.gov/mnreports>.
- USDA-ERS. (2012). "U.S. Beef and Cattle Industry: Background Statistics and Information." from <http://www.ers.usda.gov/news/BSECoverage.htm>.
- Van Arendonk, J. (1985). A model to estimate the performance, revenues and costs of dairy cows under different production and price situations. *Agricultural systems* 16(3): 157-189.
- Van Arendonk, J. A. M. (1991). Use of profit equations to determine relative economic value of dairy cattle herd life and production from field data. *Journal of dairy science* 74(3): 1101-1107.
- Van Vleck, L. D. (1993). *Selection index and introduction to mixed model methods*, CRC Press.
- Van Vleck, L. D. and R. Everett (1976). Genetic value of sexed semen to produce dairy heifers. *Journal of dairy science* 59(10): 1802-1807.
- VanRaden, P. and A. Sanders (2003). Economic merit of crossbred and purebred US dairy cattle. *Journal of dairy science* 86(3): 1036-1044.

- Wolfová, M., J. Wolf and J. Hyánek (1995). Economic weights for beef production traits in the Czech Republic. *Livestock Production Science* 43(1): 63-73.
- Wolfová, M., J. Wolf and M. Milerski (2011). Calculating economic weights for sheep sire breeds used in different breeding systems. *Journal of animal science* 89(6): 1698-1711.
- Wright, S. (1922). Coefficients of inbreeding and relationship. *The American Naturalist* 56(645): 330-338.
- Yilmaz, A., M. Davis and R. Simmen (2004). Estimation of (co) variance components for reproductive traits in Angus beef cattle divergently selected for blood serum IGF-I concentration. *Journal of animal science* 82(8): 2285-2292.