Attaching Economic Figures to Production Traits

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Introduction[1]

The National Beef Quality Audit (NBQA, 1992) estimated that the average loss due to quality "defects" in beef carcasses was $279.82 per head for every steer and heifer slaughtered in 1991. This amounts to a loss in value of about 25%, or nearly $3 billion for the U.S. beef industry. The sheer size of this number was enough to generate considerable interest in the quality characteristics of beef and its by-products among industry members. The fact that the study was sponsored by the National Cattlemen's Association (NCA) only lent to its credibility.

For many producers, the NBQA seems to provide the panacea they have traditionally sought —a single answer that solves the multifaceted problems they face. There is evidence that some producers (and researchers) may be changing their priorities in an effort to remedy beef quality defects and thereby capture the perceived economic benefit.

It is this reaction that prompts the greatest concern regarding the NBQA results. If the NBQA results are misinterpreted or lead to overreaction, producers could be diverting their attention from other characteristics and production considerations that may be equally or more (economically) important. As a result, they may be undertaking changes that are detrimental to their own operations and the beef industry at large.

In this paper we attempt to bring some balance to the debate as it specifically applies to beef cattle breeders (including both seed-stock and commercial producers) and the economically important characteristics of beef. For this purpose we have organized this paper into four basic sections: (1) a review of the principles of multi-trait selection; (2) an empirical example or application that includes estimates of the relative profit maximizing weights that should be devoted to different characteristics by either an industry (all-encompassing) representative firm, or a commercial cow-calf producer marketing weaned calves in a manner typical of the currently prevailing industry structure; (3) comparison of these results to those obtained in the NBQA; and (4) an overall summary. The paper concludes with a brief discussion of the broader implications of this study for future directions in the beef industry.

Multi-trait Selection and the Economic Value of Beef Characteristics

Animal breeders have long recognized the inherent deficiencies of the "single characteristic" model of genetics in animal production. Over fifty years ago, Hazel (1943) observed that, in practice, commercial breeders are concerned with many characteristics. However, their efforts to achieve simultaneous changes in multiple characteristics are often hampered by differences in the heritability of the characteristics and the genetic correlations that exist between the characteristics. To relieve these problems, Hazel (1943) suggested the use of a multi-trait selection index in which the index value of an individual animal (I) would be equal to the weighted sum of its (m) observed characteristics expressed as deviations from the population mean,

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$$I = b_1 P_1 + b_2 P_2 + \ldots + b_i P_i + \ldots + b_m P_m = \sum_{i=1}^{m} b_i P_i$$

where b_i is the weight (or emphasis) and P_i is the observed (phenotypic) value of the *i*th characteristic.

To be effective as a breeding tool, the animal's aggregate breeding value (*H*), defined as

$$H = a_1 G_1 + a_2 G_2 + \ldots + a_i G_i + \ldots + a_m G_m = \sum_{i=1}^{m} a_i G_i$$

where G_i is the breeding value of the *i*th characteristic in the animal (expressed as a deviation from the mean) and a_i is the weighting of the characteristic in an aggregate breeding value, should be reflected by the index[2]. Hence, the index weights (the b_is) should be selected so that the correlation between the index value (*I*) and the aggregate breeding value (*H*) of an animal is maximized.

There are no universally correct values for the a_i. The proper choice will depend upon the objective of the breeder. However, it is clear that their choice will dramatically effect the weights used in the index. For example, if all the a_is except one are zero, the multi-trait index produces results that are equivalent (other than a scale effect) to single trait selection. Furthermore, if all the a_is are equal the resulting multi-trait index will maximize the aggregate genetic change in the population by weighting each characteristic by its heritability. This result can be most easily demonstrated by assuming that the characteristics are uncorrelated, either phenotypically or genetically. Under this condition, the index weight of the *i*th characteristic is

$$b_i = \left(\frac{\sigma^2_{G_i}}{\sigma^2_{P_i}} \right) a_i = h_i^2 a_i$$

and the index value (*I*) of an animal is

$$I = \sum_{i=1}^{m} h_i^2 a_i P_i = a \sum_{i=1}^{m} h_i^2 P_i$$

where the a_is are each equal to the constant, *a*.

Neither of these options is especially satisfying. However, Hazel (1943, pp. 477) suggests an alternative:

> *"It is logical to weight the gain for each trait by the relative economic value of the trait ..."*,

where the relative economic value of a trait[3]

> *"... depends upon the amount by which profit may be expected to increase for each unit improvement in the trait."*

This definition of the a_is is reasonable and intuitively appealing for commercial producers. It has the effect of reducing selection to a single trait—*"net economic merit"*—based on an index of characteristics when each characteristic (and thus the index itself) is measured in economic units (dollars). As such, this index explicitly recognizes that commercial producers must make a profit from their

[2]For the reader unfamiliar with these breeding terms, the breeding value can be defined in more familiar terms as twice the EPD (expected progeny difference) of the characteristic.

[3]Hazel (1943) defines the a_is as relative economic values, meaning that each characteristic's value is expressed as a multiple of a single (selected) characteristic whose value is equal to one. However, this condition is not necessary for the construction of a selection index, which can be equally well developed using actual economic values.

operations to survive and that no amount of genetic change will benefit the producer who goes bankrupt and ceases production. Furthermore, this index definition is equally appropriate for purebred or seed-stock producers who must sell their product (breeding stock) to commercial producers to remain in business. That is, commercial producers will not rationally buy breeding stock which they do not expect to enhance their profitability.

Despite this reasonable definition of the a_is as economic values, relatively little progress in multi-trait, index-based selection has been made in the U.S. beef industry in the half-century since Hazel (1943) proposed its use. A portion of this deficiency can be attributed to the difficulties inherent in estimating the economic values of characteristics. In fact, it wasn't until the late 1970s, over 30 years after Hazel's (1943) initial article, that economists began to more fully develop the theoretical basis for economic values of genetic characteristics (see, for example, Ladd and Gibson (1978), Melton and Ladd (1979), and Melton et al (1979)). From these efforts, methodologies required to correctly estimate the economic values of characteristics have been developed.

Net Profit and Economic Values

Net profit is most frequently defined as the difference between total revenue and total cost.

$$Profit = Total\,Revenue - Total\,Cost$$
$$Price \times Output - Average\,Cost \times Outpu$$

Net profit will therefore change, if changing a characteristic affects either the producer's (or industry's) revenue or cost. Mathematically, this results in a generalized expression for the economic value of the ith characteristic to a producer based on the economic theory of the profit maximizing firm (for greater detail see Melton et al, 1994b). That is, the economic value of a characteristic is

$$= Output\left(\frac{Change\ in\ price}{Change\ in\ characteristic}\right) + Price\left(\frac{Change\ in\ output}{Change\ in\ characteristic}\right)$$

where *output* is the level of homogeneous product (beef) marketed at an average *price*.

The first term of a_i is the effect of the genetic change on the sales price of the product, whether it is animal or meat. It reflects the price premium (discount) from some base or average price received by the producer because of superior (inferior) quality in the product. Hence, it may be viewed as the qualitative price effect of genetic change.

The second term is the effect of the genetic change on production costs. More specifically, it represents the effect of a genetic technological change measured in terms of the value of additional (reduced) product that would be possible with the same level of input use following the genetic change. It is equivalent to the cost savings that could be realized from a marginal genetic technological change evaluated at the original level of output. Economist refer to this term as the *"Marginal Value Product* (*MVP*)*"* of the *i*th genetic input. Because the cost of achieving a marginal genetic change in a single characteristic is typically very small, this term alone can frequently be interpreted as the economic value of a "production" characteristic (i.e., feed conversion efficiency) that has negligible effects on market price (Melton et al, 1994b).

Modifications and Extensions

This derivation of economic values has numerous implications. However, four points warrant special attention and elaboration.

First, the reader should realize that the economic value of a characteristic is not a universal constant. Not only do prices differ, so do markets. People of different age, education, ethnicity, or socio-economic status have different preferences regarding product quality; i.e., *"One man's trash may be another man's treasure."* Thus, in some markets the price effect of a qualitative genetic change may be small or even negative, while in other markets it may be large. Furthermore, producers are endowed with a resource bundle, including both genetics and variable or fixed inputs, that is approximately unique. The profit effect of a genetic technological change may differ dramatically from one producer to another depending upon the level and mix of resources that can be applied to capitalizing on the genetic change. For example, a producer with surplus feed would realize much less economic benefit from improved feed efficiency than one who is feed deficit. Economic values are thus most appropriate to individuals and are themselves individualized values.

Second, these economic values are appropriate to a firm or an individual producer—not to an aggregate industry. At an industry level, the price of beef will fall as the market quantity increases. Furthermore, most estimates are that the price decline is proportionately greater than the beef quantity increase and, as a result, industry total revenue will also decline. A broad-based genetic technological improvement (more beef at the same cost or a lower cost for the same level of beef production) would expand the aggregate beef supply and thereby reduce beef price. Hence, the economic value of the genetic technological change for the industry would be less than that for a comparable change by a single firm or producer.

Third, these economic values are most appropriate for the short-run in which small, one-time genetic changes are made. More complex genetic changes occur over time and these effects are not considered in the above derivation. For example, if a producer selects replacement heifers for increased weaning weight in their progeny, the effects of that selection decision will not be realized for approximately two years—when the first calves of those heifers are weaned. Because producers would prefer to have the benefit today, there is an additional cost associated with this two-year delay that reduces its value to the producer (McArthur and Del Bosque Gonzalez, 1990). This reduced value can be taken account of by discounting the a_is to reflect the time that transpires between the selection decision for a genetic improvement and the characteristic's expression of that improvement on a characteristic by characteristic basis.

In addition, the effects of many genetic changes are dynamic in nature. That is, the effects of a single decision may be felt in more than one future period. For example, in the case of selecting heifers for improved weaning weight the results of that decision may not be felt for two years, but then will recur in each subsequent year remaining in the heifer's productive life. Furthermore, if the progeny of the selected heifer remain in the herd, then the effects of genetic change also carry into the indefinite future, but at half the level in each subsequent generation.

Finally, the economic value of a characteristic often changes as the genetic level (mean) of the population changes, even if all other variables are constant. Specifically, the terms that reflect changes in price or output due to changes in characteristic level are not typically constants (i.e., they are functions of G_i as well as prices for products and inputs). Furthermore, the underlying relationships between characteristics, variable inputs, and product levels or prices implied by these two apparently simple terms are often extremely complex and difficult to estimate. As such, the economic value of the ith characteristic will often depend on its level, and thus it will be different at each (population mean) level of the characteristic. Accordingly, the index should be re-computed for each change in the mean that occurs over time. This fact leads to what many animal breeders have come to term a *"non-linear"* selection index (Smith et al., 1986). However, because the purpose of genetic change is a change in the mean of the population, it is not necessary (nor generally appropriate) to derive index values that differ in their economic values for each genetically different individual.

Applications of Multi-trait Selection to Weight Beef Characteristics

The fundamentals of multi-trait selection provide an adequate initial basis for valuing and weighting (genetic and otherwise) different characteristics or categories of characteristics. However, the application of these principles is dramatically complicated by the structure of the U.S. beef industry and the multiplicity of characteristics that potentially affect its economic well-being. Furthermore, in some instances the economic value of a genetic change in a characteristic (a_i) must be tempered or revised to reflect the value (or cost) of any alternative that will achieve the same change[4]. These complications are illustrated in the following sections as we apply the principles of multi-trait selection and economic evaluation of characteristics to provide some pragmatic guidance in valuing and weighting alternative beef characteristics.

Base Solution: The Integrated Firm

To more fully illustrate the derivation of economic values and weights for beef characteristics, we first consider a base solution appropriate to a firm representative of the overall U.S. beef industry. That is, we assume a single-producer firm that integrates all aspects of beef production, processing, and marketing from birth to final consumer (retail product) and markets closely trimmed (1/4 inch fat) retail beef. In this manner, we assure that any cost saving or value enhancing changes in characteristics can be directly related to their effect on producers' profits. As a result, we are able to initially avoid any economic distortions that may potentially arise from either market or industry structure.

The choice of characteristics to be valued is more difficult. Each different observation of an animal may be viewed as measuring a characteristic. However, if one is to take this view literally the number of possible characteristics approaches infinity and quickly becomes so large as to be practically meaningless. For example, the weight of an animal at 200 days of age is typically not the same as its weight at 210 days of age. Hence, the two might be viewed as different characteristics, although as a practical matter they are more likely to be different observations of the same (underlying) genetic characteristic.

For purposes of this paper a more workable alternative is suggested by the physiology of beef production, processing, and marketing. Specifically, we can conveniently think of the overall beef production–consumption process as being divided into three overlapping phases, as follows:

- the reproduction phase, characterized by the breeding, conception, birth and early nurturing of an animal;
- the production phase in which the composition and mass of the animal is altered by its growth and weight gain; and
- the consumption phase, characterized by the slaughter and consumption or other use of the animal's (disassembled) constituent parts (products).

A reasonably complete representation of the overall process can then be obtained by selecting a limited number of characteristics from each phase that are believed to be (1) economically important in that phase, and (2) not highly correlated with one

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[4]These revisions relate to the economic concepts of profit maximization and opportunity cost (Stigler, 1966). That is, if a characteristic can be changed by either of two methods, the profit maximizing firm will rationally choose to change it by the method with the greatest profit (net value) potential.

another, especially within a phase[5]. The characteristics selected for this study meet these criteria (Table 1). One can argue with the 16 characteristics selected, the phase to which they are specified to apply, or the infinite number of characteristics excluded. For example, some might prefer to see USDA Yield Grade (USDA-YG) included. As a practical matter, however, USDA-YG is an index that approximates or estimates retail product percent, which is included. Similarly, marbling score conveys much of the information embodied in USDA Quality Grade. In short, these characteristics and classifications appear to represent a reasonable starting point for a broad-based analysis of the U.S. beef industry, while providing a workable total number of characteristics with approximately equal representation from each phase of beef production.

The economic values of these characteristics are estimated for a representative West Texas fully integrated firm using average long-term price ratios typical of 1980–84 (Table 2). The economic values of the first 13 characteristics are estimated using data from the Germ Plasm Evaluation trials conducted at the U.S. Meat Animal Research Center, Clay Center, Nebraska (for a summary of the values used see Melton et al, 1994a). However, these data do not include measurements of beef characteristics associated with consumer preference (e.g., flavor, juiciness, or tenderness). Furthermore, the literature of animal science includes few examples of these data and none that display the degree of underlying economic sophistication that would be necessary to correctly estimate economic values. Hence, the first 13 characteristics are valued on the basis of average carcass prices, adjusted for carcass yield and quality grade price differences.

The economic values of the remaining three characteristics associated with consumer judgments of meat quality are estimated for retail meat from a pilot project study conducted for the National Pork Producer's Council as part of the National Pork Quality Audit (Melton, 1994 and Melton, Huffman and Shogren, 1995). Although based on pork trials, it is reasonable to believe that these values are also applicable to beef when adjusted for differences in average beef versus pork prices. This is based on the assumption that consumer preferences for meat quality characteristics are consistent, regardless of meat source. That is, they do not prefer tough meat whether it is beef or pork. Because of this method of derivation, the results must be separated between average production effects (per head in the herd) for the first 13 characteristics and average market price effects (per kg of retail meat sales times an average of 206.2 kg of retail product per head) for the remaining three characteristics.

The interpretation of these results (Table 2) is relatively straight-forward. The coefficient (a_i) is the single year effect on per head profits for the industry representative producer of increasing the mean level of the characteristic by one unit. The t-values reflect statistical confidence in the coefficient estimate where t-values less than 2.0 in absolute value indicate that we can not be statistically sure, with 90% confidence, that the effect is not zero. For example, the coefficient value for gestation length indicates that increasing gestation length by one day (on average) will negatively affect profits by $8.17 per head, but that effect is not significantly different from zero in a statistical sense (t value=-.96).

It is important to note that only one of the coefficients (economic values) is statistically significant. This finding may indicate that despite our efforts to select relatively independent

[5]The degree of correlation between characteristics should be judged in the context of their multi-trait correlations as opposed to the simple correlation between any pair of characteristics. For example, weaning weight may not be highly correlated with birth weight, but it is nearly perfectly correlated with a linear combination of birth weight and pre-weaning rate of growth (pre-weaning average daily weight gain).

characteristics, a high degree of linear correlation remains between at least some of the characteristics. This would be expected if the actual number of genetic (production) characteristics is considerably smaller than the 13 selected. If so, many of these characteristics would actually represent alternate observations or measurements of the same underlying characteristic. Hence they are correlated.

To explore this possibility only those characteristics that improve (reduce) the Mean Square Error (MSE) of the model are estimated and all others are assumed to be zero (Table 3).

The number of characteristics is reduced considerably by this method[6]. Of the original 13 production characteristics, only four (now statistically significant) characteristics are required to predict profit effects with minimum error variance (Table 3, top panel). These include characteristics that can be broadly categorized as reflecting (1) the total size or number of cells (weaning weight), the rate of growth or size change (average daily gain), (3) the composition of growth (marbling score), and (4) the metabolic efficiency of growth (feed conversion). Despite eliminating 9 of 13 characteristics, the R^2 value is reduced only slightly (from .62 to .57).

Negative economic values for average daily gain and marbling score with positive values for weaning weight and feed conversion efficiency tend to emphasize the high cost of U.S. grain-fed beef. Specifically, a high rate of weight gain requires more feed to achieve that potential. Similarly, more feed is required for fat deposition than lean. However, either improved feed efficiency or greater weaning weight can reduce post-weaning feed requirements. The economic values shown in Table 3 reflect the cost (or cost savings) of feed embodied in a genetic change, especially in post-weaning production.

The number of consumer characteristics, as reflected in market price, is also reduced slightly by eliminating tenderness from the minimum MSE model (Table 3, bottom panel). The t-values of the remaining characteristics improve as a result, but the drop in the R^2 value (from .2683 to .2682) is negligible. Despite its statistical non-significance in explaining the purchase price, the interest in tenderness among members of the beef industry (Morgan, 1992) warrants its continued inclusion in this study. Hence, we reject the minimum MSE results (Table 3) in favor the model of economic values that includes tenderness (Table 2).

The reader may initially be surprised by the relatively low economic values attributable to meat characteristics, especially tenderness. Equally disconcerting to some may be the low R^2 of these models, indicating that only about one-fourth of the variance in price can be explained by a combination of meat tenderness, flavor, and juiciness. These findings seem to contradict prior research which found that tenderness is an especially important consideration to meat consumers (Morgan et al, 1991; Savell et al, 1987 and 1989 and Morgan, 1992). However, when put in perspective, there may not be a contradiction at all (e.g., see Appendix 1).

Prior research regarding consumer meat preferences has largely been both hypothetical (no transaction occurs) and descriptive in nature. That is, consumers have been asked to judge a piece of meat against an unspecified standard on an ambiguous scale (Savell et al, 1987 and 1989; Morgan et al, 1991). They have not been asked to

[6]If a set of independent variables is highly correlated, fewer than the total number may be required to adequately explain the variance in a dependent variable. One method of evaluating this is the Mean Square Error (MSE) of the regression model. Highly correlated dependent variables may reduce the Sum of Squares Error (SSE), but they also reduce the degrees of freedom for error (dfe) such that MSE rises (i.e., MSE=SSE/dfe). The statistical model with the best predictive ability is the one with the least error variance, as estimated by the MSE. Hence, it is that model which includes only the set of dependent variables (from amongst all possible) that result in a reduction in the MSE (to a minimum).

bid on and purchase a piece of meat (evaluate it on a common dollar scale) after having tasted a sample and being allowed to evaluate its eating characteristics. A considerable body of theory and empirical research in economics suggests that the latter method is strongly preferred to the descriptive and hypothetical method, which tends to yield inflated and largely unreliable answers. However, to relate the two methods, one to the other, the NPPC study also asked consumers to evaluate the product in subjective terms -- reflecting how they judge the overall acceptability of the meat. This measure, which we refer to as *"eatability,"* corresponds to the consumer evaluations used in many prior studies and in which meat is "ranked" according to relative consumer acceptability.

The effects of each characteristic on meat eatability are shown in Table 4, along with the effects of eatability on meat price.

These results explain much of the apparent inconsistency between this and prior studies. Tenderness and flavor are major determinants of consumer acceptability (eatability) of meat products; each accounts for about 40% of consumer preferences and is highly significant. Furthermore, the three characteristics chosen for this study jointly explain nearly 85% of the variability in consumer preferences. However, overall eatability explains only about one-fourth of the variance in consumer price, a result comparable to those shown in Tables 2 and 3. Hence, we may conclude that consumer judgments regarding meat acceptability (or non-acceptability) do not directly translate into differences in either the price or quantity of meat purchased and that these important relationships can not be properly examined except in the context of market price-quantity (or demand) relationships.

Such a finding supports the belief that meat quality characteristics such as tenderness are important components of overall meat acceptability. However, they contribute relatively little to explaining how consumer meat preferences (and acceptability) are eventually expressed in the market. Instead, meat quality is only one consideration in the consumer purchase decision -- with respect to either bid prices or quantity purchases. The nature and magnitude of the other factors considered by consumers, their price-quantity effects, and the nature of their interactions with product quality can not be specified for beef at this time. They may, however, reasonably include such elements as the prices of substitutes, ease of preparation, and various socioeconomic concerns (e.g., see Melton, Huffman and Shogren, 1995). Additional study of the type currently underway by NPPC will be required in the future to address these complex economic issues impacting beef consumption.

The estimated economic values are adjusted for time over a total of 6 generations assuming (1) a discount rate of 5%, (2) a two year lag between selection and production, and (3) a total economic life of 10 years. Furthermore, it is assumed that reproduction traits are expressed within two years of selection while production and consumption traits require upwards of three years.

The genetic and phenotypic covariances used for this study are shown in Appendix 2. Correlations between consumer judgments and product characteristics are not readily available. The NPPC study (Melton, 1994 and Melton, Huffman, and Shogren, 1995) provides some indication, however, by recording consumer judgments of quality along with professional judgments of loin-eye size and marbling. These correlations, reflecting size and marbling score, are included in the genetic-phenotypic covariances. Furthermore, consumer quality judgments, such as tenderness, tend to be more variable than quantitative measurements, such as shear force, because they include both the observations and subjective perceptions of consumers. As a result, they have relatively low heritabilities as compared to most objectively measured carcass characteristics.

These variances-covariances, coupled with the estimated (time-adjusted) economic values (Table 5) allow the index weights of the characteristics (the b_is) to be estimated according to equation (3), as shown in Table 5. These values provide an indication of the weight that should be appropriately applied to each characteristic both in raw terms (per unit of the characteristic) as well as standardized (per standard deviation). In this context the reader should be aware that a characteristic with a zero economic value still contributes to the selection index. Although it may have no effect on profit, because of its correlation with characteristics that do contribute to profit it may have a non-zero weight in the selection index. Hence, even though only 7 characteristics have non-zero economic weights, all 16 contribute to the selection index.

These values, per unit, are the amounts by which phenotypic expressions of the characteristics should be weighted to maximize the net profit of an industry representative firm. As such, they are an indication of the relative importance of each characteristic when its economic (profit) contribution, heritability, and relationship (phenotypic and genetic correlation) with other characteristics are taken account of. (Per standard deviation weights are presented only so that the weights can be compared, one characteristic to another, irrespective of either the units or mean of the characteristics.)

Negative weights imply that selection should be against the characteristic or, alternatively, that selection should reduce the mean of the characteristic. Hence, the profit maximizing industry representative firm would select to reduce gestation length. However, such a firm would also select against such characteristics as birth weight, weaning weight, and slaughter weight, as well as many carcass characteristics (marbling score, tenderness, and flavor). The negative selection pressures implied by these results are the direct consequence of (1) the low (or negative) economic weights attributable to these characteristics and/or (2) the negative (positive) correlation between these characteristics and characteristics exhibiting positive (negative) economic values.

Positive selection emphasis should be given to maternal characteristics (i.e., weaning rate, lactation ability, and rate of maturity) and those typically thought of as indicative of production efficiency (i.e., feed efficiency, average daily gain, and retail product percent). Slaughter weight should receive the greatest emphasis (12,846 per standard deviation) and feed conversion the least (134 per standard deviation) when emphasis is defined as the relative attention devoted to selecting for (positive weights) or against (negative weights) a characteristic.

Industry and Structural Effects

Results for the representative industry firm should not be taken as the results for the industry in aggregate. The demand curve for beef, relating the quantity of beef demanded to its price, is downward sloped. That is, a lower price is required to market a larger quantity. The representative firm is assumed to have a fixed (constant) average beef price. When extended to the industry the result of genetic technological improvement is (1) a cost savings or (2) increased output (beef). Both cause beef market supplies to increase and price to decline.

Economists frequently examine market price-quantity relationships in the context of what is termed the price elasticity of demand, defined as the percentage change in quantity for a percentage change in price.

Melton and Huffman (1993) have recently estimated the price elasticity of beef demand in a full expenditure model to be -.309. Thus, a 1% increase in aggregate beef production might be expected to result in a 3.24% decline in average beef price.

Assuming a constant herd size and culling age, the maximum genetic response per generation is fully defined by the heritability of the characteristic (or an index of multiple characteristics) and its phenotypic variance. Based on the results obtained for the representative industry firm and assuming all genetic progress translates directly into expanded supplies, the rate of expansion per generation could be as high as 12%. Hence, average beef prices (in real dollars) might be expected to decline by about 40% per generation.

With those beef price declines, the economic values of characteristics will also fall. Although relative values, defined as the ratio of one economic value to another, may not necessarily change, in the example for the industry representative firm the values of the seven characteristics with non-zero values will be smaller. Hence, they will be closer in value to those that have zero values and relative economic values will change. Additional research, beyond the scope of this paper, is required to quantify the aggregate effects of genetic change on the industry in either absolute or relative terms.

Although the broader industry implications are important, more relevant to today's commercial producer is the prevailing structure of the industry. Our representative firm was assumed to be engaged in all phases of the industry culminating with retail sales to the final consumer. In fact, the prevailing industry structure is one of highly specialized, often competitive sectors. That is, few cow-calf producers own their cattle post-weaning and few live-animal producers slaughter, package, wholesale, or retail their beef. As a result, most commercial cow-calf producers (who make the genetic decisions) can be compensated for those decisions that influence post-weaning performance or consumer quality only through differential prices received at weaning.

Although physical differences (weight, lot size, sex, etc.) affect price, Schroeder et al (1991) found the price differentials attributable to breed to be small. This finding supports what many already believe:

> *"The current beef market, at least at the weaned calf level, is dominated by "average price purchasing" in which genetic post-weaning or consumption superiority (or inferiority) is not adequately reflected by price premiums (discounts)."*

To address these issues the economic values of the characteristics are re-estimated for a producer identical to the first except that calves are sold at weaning for a prevailing market price (per unit weight) that differs only by calf weight and sex (Table 6). Hence, no price adjustment is made for USDA-YG or other qualitative carcass measures that can not be observed at weaning.

Comparing these results to those obtained for the industry representative firm (Tables 2 and 3) one immediately sees the greater value to cow-calf producers of maternal and reproductive characteristics. Furthermore, consumer judgments of quality such as tenderness, flavor, and juiciness have no value to the commercial cow-calf producer who (1) does not typically know what these values are and (2) is not compensated for them. It is also interesting to note that although the producer selling weaned calves is not differentially compensated for superior carcass quality (retail product percent or marbling), these characteristics have positive economic values. However, the economic value of retail product, for instance, is only 20% of its value to the industry representative firm who derives a direct benefit from increased yield. Finally, a significantly greater portion of the variance in profits of a cow-calf producer can be explained by genetics than is possible for an industry representative firm (as judged by the R^2 values). This finding may be partially attributed to the fact that the industry representative firm is highly idealized (it does not actually exist). In other words, we can better describe something that actually exists (the current structure) than something we imagine (an aggregate, integrated industry). Other characteristics, factors, or interactions that are not considered in this study may significantly impact industry profits and their exclusion reduces the R^2 values for the industry representative firm. However, all of these results are to be expected given the prevailing industry structure.

Despite the contrast between these results, it is interesting to note that the minimum MSE models for both include a limited number of characteristics including those reflecting (1) size, (2) growth, (3) efficiency, and (4) composition. This finding lends further support to our hypothesis that the actual number of identifiably distinct genetic characteristics of economic importance may be rather small.

The time-adjusted economic values and selection weights for our representative commercial cow-calf producer are summarized in Table 7. The greatest economic value to commercial cow-calf producers is increased weaning rate (3,796). Without a calf to sell no other characteristic has much meaning. This translates directly into a high characteristic weight (8,178) that is lessened, relative to many other characteristics, by the small standard deviation of weaning rate in the sample data (792). However, it remains one of the prime considerations in genetic selection by a commercial cow-calf producer. In fact, if one examines the selection weights, the importance of pre-weaning and maternal characteristics is clear -- so much so that most post-weaning production and consumption characteristics actually have a negative weight in the cow-calf producer's program of genetic selection.

These results are in direct contradiction to the results obtained for the industry representative firm (see Table 5), in which many post-weaning and consumption characteristics carried positive selection weights. For example, the cow-calf producer, facing fixed prices, attaches a negative weight (-50) to retail product yield whereas the industry representative firm attaches a high positive weight (+8000) to this characteristic. Thus, if the industry desires improved USDA-YGs, differential pricing to cow-calf producers (both plus and minus) are a necessity and those differentials must be substantial. (Marbling does not display nearly as dramatic a change due to industry structure.

Relative selection emphasis can be defined as the portion of overall selection attention devoted to a characteristic or set of characteristics. To compute this value we assume that negative and positive selection are equally important, but in opposite directions. The relative selection emphasis for a characteristic is then the standardized weight (per standard deviation) applied to a characteristic by a profit maximizing firm divided by the sum of these standardized weights for all characteristics, independent of sign. As such, relative selection emphasis reflects not only the economic value of the characteristic, but also its heritability, its genetic and phenotypic covariance with other characteristics, the economic value of these correlated characteristics, and the variability of the characteristic itself (which can be used to achieve genetic change).

Relative selection emphasis in each of the three defined phases of the industry and for overlapping characteristics, as defined in Table 1, are shown in Table 8 for both the industry representative firm and the cow-calf producer.

Elements on the main diagonal of each panel in this table reflect the emphasis that should be applied to all characteristics that solely impact that phase. Off-diagonal values are for characteristics designated to have joint effects in more than one phase.

When only single phase characteristics are considered, the greatest emphasis should be on characteristics classified as affecting reproduction (20.3% for the industry and 30.8% for the cow-calf firm). Characteristics affecting only the production phase tend to warrant limited attention (.4% for the industry and 2.38% for cow-calf). However, these characteristics have large interaction effects for both the reproduction and consumption phases, as indicated the overlapping characteristics. When these overlapping characteristics are considered consumption characteristics, which also warrant limited attention in their own right (6.86% for the industry and 9.42% for the cow-calf), become more important. Furthermore, the effects of overlapping consumption characteristics are more important to the overall industry (51.3% with production and 14.72% with reproduction) than to the commercial cow-calf producer representative of today's industry structure (25.75% with production and 15.05% with reproduction). As a result, the adjusted overall emphasis by a industry representative firm is nearly equal among the three phases (30.89% for reproduction, 29.24% for production, and 39.87% for consumption), whereas the proper emphasis by a cow-calf producer representative of the current structure is strongly biased toward the reproduction phase (46.62% versus 23.56% for production and 29.82% for consumption).

Long-run Implications

Many will concede that the economic value of improved tenderness is currently small, but will argue that such characteristics are important enough to consumer satisfaction that, if not improved, they will cause beef's long-run market share and price to fall. Of course in the long-run, if long enough, anything is possible. However, by some estimates beef tenderness problems have been with us since the widespread adoption of "boxed-beef" nearly a quarter-century ago. As yet, its effects on beef market share and price have not been dramatic. For example, in a study of over 30 years of price and cost data Melton and Huffman (1993) found that most of the decline in beef's market share can be directly attributed to other factors, most notably including relative price changes between beef and other goods (including dairy, pork and poultry). Many of these price changes are associated with changes in the relative cost of production. The more beef is standardized, the more it is viewed as a commodity rather than a product. Hence, the more responsive it is to the prices of substitutes and the less qualitative differences contribute to value.

These results strongly suggest that beef producers need not be altruistic to preserve their industry. The long-term survival and prosperity of the industry depends on its economic viability, which is better served by improving its competitiveness, profitability, and economic efficiency than by (unduly) focusing on characteristics that customers may want, but for which they are unwilling or unable to pay.

Summary

The results presented in this paper are more complicated than the "rule-of-thumb" weighting proposed by Trenkle and Willham (1977). For many, their complexity may be overpowering. However, in the information age of high-speed personal computing we must accept that complex calculations are no longer beyond the reach of individual producers if the proper software is available. Thus one need not be intimidated by the complexity of the results or the computations required to obtain them. It is much more important that their broader implications be understood.

First, this paper has demonstrated that the economic values of characteristics, though complicated to estimate, can be derived and used in the construction of a selection index. However, the paper has also shown that economic values are individualized values that depend not only the industry structure, but on the individual producer and his (or her) endowment of resources, prices, the production environment, and the genetic level of the herd. Hence, completely different animals (or selection weights) may be required to maximize the profits of two different producers.

This caveat aside, this paper has also shown (through analyses of representative firms) that the number of economically important genetic characteristics (genotypes) may be much smaller than the number of measurements (phenotypes). In other words, the traditional model of animal breeding that requires a one-to-one correspondence of phenotype and genotype may be inappropriate for commercial application. Additional research is required to investigate this phenomena more fully and, if necessary, to develop alternative statistical and economic models of genetic action.

Results of the representative firm analysis highlight the differences that exist between firms, including those due to industry structure. A firm representing the overall beef industry controls production (and product) from conception to consumption. As a result, the net economic benefits of any genetic decision accrue directly to the firm -- without structural or market distortion. Under these idealized conditions, negative economic values result from increased post-weaning rate of gain and marbling score, reflecting the high share of total cost occurring in post weaning fed beef production. Positive economic values are associated with improved weaning weight, feed efficiency, tenderness, flavor, and juiciness, although tenderness has a very small and statistically insignificant economic value. When translated into selection weights (the b_is of a selection index) the greatest relative selection emphasis for an industry representative firm should be on pre-weaning characteristics (i.e., 20% on weaning rate, birth weight, gestation length, lactation ability, etc.). Post-weaning and consumer characteristics should receive much less attention (.4% and 7%, respectively). However, overlapping characteristics that affect more than one phase of production cause the order of emphasis to change and more nearly equalize (adjusted overall emphasis of 31%, 29%, and 40%, respectively).

Although these results provide some useful insights, the assumptions of an industry representative firm are so idealized as to be essentially meaningless to an individual producer. Almost no producers involved in breeding decisions are also directly engaged in the post-weaning production and consumption phases of the industry. Furthermore, there is limited potential for this to occur in the foreseeable future unless it is by virtue of "top-down" vertical integration following the model of U.S. poultry production. An alternative, reflecting this fact and the prevailing industry structure, is examined by assuming a commercial cow-calf producer that market weaned calves as most in the U.S. do. As such, these results reflect the differences between a producer compensated for the value and quality (yield grade differences, etc.) of his (or her) product and those that market in the traditional manner in which final or intermediate quality is not fully recognized.

The economic values and relative selection weights of characteristics are dramatically different for this firm than for the industry. Pre-weaning or reproductive characteristics (weaning rate, lactation ability, and weaning weight) become much more important, with weaning rate having the largest single economic impact ($3,796 for a one percent increase in weaning rate). Production and consumption characteristics (post-weaning rate of gain, retail product percent, marbling score, and consumption characteristics) are not only less important, but in many instances the direction of the emphasis is reversed -- from a positive weight by the industry to a negative weight by the individual cow-calf producer. For example, post-weaning average daily gain has a selection weight (b_i per unit) of 728 for the industry firm, but -2091 for the cow-calf producer. Similarly, the weight for retail product percent (per standard deviation) changes from 8057 to -50.

The emphasis in selection for a cow-calf producer is skewed toward pre-weaning characteristics, with an overall weight of nearly 50% (47% compared to 24% for production and 30% for consumption). These results confirm what many already know: "What may be good for the industry may not be good for individual producers who must bear its cost." For the industry to achieve the genetic changes that are in its long-run overall best interest, the cow-calf producer <u>must</u> <u>be</u> <u>differentially</u> <u>compensated</u> for the efforts and cost required. Current structures do not achieve this. Recent strategic alliance programs have attempted to address this issue, but only in a very limited (and somewhat idealized) fashion. Considerably more research and effort will be required in the future to address these issue in the context of the broader beef industry.

Results of this study also highlight potential flaws in the National Beef Quality Audit (1992) and its interpretation. The relatively small values and selection weights associated with consumption characteristics, and especially those reflecting consumer judgments of quality, seem to contradict the National Beef Quality Audit's (1992) finding of an average loss of $279.82 per head attributed to "quality defects."

Many have erroneously interpreted this amount, representing nearly 25% of total slaughter value, to be the amount of profits foregone by the industry because of carcass quality. In point of fact, the losses estimated in the National Beef Quality Audit (1992) do not correspond to profits. Instead, they are more nearly indicative of foregone revenues. That is, they do not take account of the costs that would be incurred by the industry to capture these additional revenues and thereby arrive at an estimate of the net profit to potentially be lost or gained in the industry. In other words, if the (opportunity) cost of an action taken to increase revenues exceeds the revenues to be gained, the producer and the industry will be worse off.

Furthermore, the estimate of $279.82 per head in lost revenue (revenue foregone) may also be biased, if for no other reason than its implicit assumption of fixed (industry) market prices at 1991 prevailing levels. For example, one can assume, at the extreme, that the capture of this additional $279.82 in revenue, would be achieved by the industry marketing additional beef. The quantity of beef supplied would then increase by about 25%. However, introductory economics tells us that prices decline when quantities increase. For beef, as with most agricultural commodities, we should expect the price decline (as a percentage) to exceed the quantity increase. In fact, some estimates are that the price reduction (in real dollars) that would be required to absorb this additional per capita quantity might be three times as great on a percentage basis (i.e., 1991 prices for slaughter steers would be about $.20 per pound). When these price-quantity changes are recognized and taken account of, the "remedy" of beef quality "defects" identified by the National Beef Quality Audit might actually be expected to cause industry total revenues to fall. Without corresponding reductions in cost, industry profits would become (almost universally) so negative that what happened to the industry in 1973-75 would look insignificant.

Further evidence in support of the values proposed in this study is provided for the consumer characteristic of tenderness, which has lately garnered specific attention among members of the industry. This evidence takes two forms: (1) an analysis of the differences between consumer acceptability and willingness to pay (price) and (2) an analysis of some of the "non-genetic" alternatives that could be employed by packers or meat wholesalers-retailers to remedy tenderness problems.

The study shows that meat tenderness, flavor, and juiciness explain about 85% of the variance in consumer judgments of meat acceptability. Furthermore, a 1% increase in tenderness increases the overall acceptability of the meat by .4%. This finding is in general agreement with other studies that have found tenderness to be a major factor influencing consumer acceptability of meat. However, this study also demonstrates that consumer judgments regarding meat acceptability do not explain the majority of price differences. In fact, neither acceptability nor a combination of tenderness, flavor, and juiciness explained over about 28% of the variance in meat price. Other factors, such as prices of substitutes and complements, income, or socio-economic concerns must account for much of the difference in meat price and these can not be remedied nor changed by the beef producer. The low correspondence (correlation) between meat quality characteristics and price support the contention of this paper that such characteristics should not receive large weights in the breeding program of a profit maximizing firm or industry.

Additionally, alternatives to breeding exist as means to remedy beef tenderness problems. These include both mechanical and biochemical means at virtually every stage of production, although only increased aging and aging with calcium chloride injections at the packer level are considered in this study. These results suggest that the industry average cost of remedying tenderness problems (in the estimated 15% of the carcass exhibiting these problems) would be \$.90 to \$1.35 per head. However, the National Beef Quality Audit (1992) suggests that the value of remedy is (the majority of) \$2.89 per head. If the revenues foregone by a profit maximizing industry, or a firm in that industry, due to tenderness problems were actually \$2.89 per head, it is rational for that firm to expend \$.90 to \$1.35 per head to remedy it because a net benefit (profit) of \$1.55 to \$2.00 per year would result. The smaller value attributed to consumer-based characteristics in this paper is actually more consistent with observed actions of packers.

In many ways this study raises more questions than answers. However, in a larger sense that may be its greatest contribution to the industry. It recognizes that the U.S. beef industry is not one-dimensional and, as a result, there is no single-characteristic panacea to the problems confronting the industry. The problems, like the industry itself, are multi-dimensional. The *"correct"* solution requires a balance that can not be achieved by a quick-fix nor by remedies that fail to (correctly) recognize the inherent economic consequences -- not only for the industry, but for individual producers who must bear the cost and whose profits and survival rests on these decisions.[7]

Implications

The beef industry is struggling to define its current and future priorities. As the industry looks to the future, we judge the following to be some of the more important implications of this study:

+ The number of economically important genetic characteristics (genotypes) in beef cattle is probably <u>much</u> <u>smaller</u> than the number of characteristics measured (phenotypes). More rapid genetic progress, with greater profit potential, would be possible if these genotypes were more fully defined and the number of phenotypic measurements were reduced to include those that best predict the unobserved genotypes.
+ Economic values of characteristics are individualized; they depend on the resources, prices, management, genetic levels and the environment prevailing for an individual firm. Just as there is nearly infinite variety in the producers that comprise the U.S. beef industry, there is a wide range of economic values. Hence, what is best for one, is likely not to be best for all -- nor perhaps even for one other. Methods of deriving individualized economic values, including more complete consideration of genetic by environmental interactions, will increase the industry's profitable genetic progress and reduce the dependence of its members on "single-answer" solutions that really fit no one.
+ The beef industry is far from a single entity. It is more nearly a collection of competitive "sub-industries" that happen to deal in a common commodity -- the beef animal. As such, changes that benefit one sub-industry may be at the expense of another. Economic values that fail to recognize these fundamental structural and market differences are more likely to trans-

[7]Total Quality Management (TQM), which motivated much of the recent attention on beef quality, is but one component of a solution, as evidenced by the fact that many of the firms cited for excellence in the pioneering essay on TQM by Peters (1982) are currently "down-sizing," in financial distress, or bankrupt.

fer costs and benefits between sub-industries (i.e., from packer to feeder or cow-calf producer) than to the enhance the total. This fact contributes to the marked differences in economic values and selection weights found for the industry representative firm and the commercial cow-calf producer used as examples in this paper. If the cow-calf producer is to make genetic changes that enhance post-weaning performance or carcass characteristics, he (she) must receive differential (quality based) prices for weaned calves -- something that does not occur under the current industry structure. Methods that recognize the contribution of each sub-industry and individual firm, such as value-added marketing, must be developed if each member of the industry is to be fairly compensated for its contribution to revenue and the cost it bears.

+ Greater total production (and market share) is not, in itself, the answer to the beef industry's problems. With greater production, average beef prices will fall by proportionately more than output expands, as the current market illustrates. As a result, total revenue to the beef industry will decline and, unless cost is reduced by proportionately more, industry profit will also fall. The industry must, therefore, sharpen its focus on promoting profitable change -- accepting in the process that the greatest possible level of production (or market share) may not be the most profitable.

+ Consumer preferences are certainly important in any market, but only to the extent that those preferences are translated into price differences. Such qualitative meat characteristics as tenderness, flavor, and juiciness are key determinants of aggregate consumer acceptability, but not of price. The industry must focus on those characteristics that result in real value for the producer, as indicated by cost and/or price differences. In this respect the industry must realize that beef is increasingly viewed as a "commodity" rather than a "product." Efforts to "standardize" beef will accentuate its commodity image and make it even more difficult to translate qualitative differences between animals or carcasses into real price differences. Assuming, as this research indicates, that qualitative differences will persist, consideration should be given to developing quality differentiated markets (such as in Japan and other areas of the world) that will effectively accommodate (and capitalize on) beef as a qualitatively varied product capable of satisfying the real and varied quality demands of consumers.

+ Economic values are intended to guide the industry (and its individual members) in very practical issues related to profitability and survival. That does not mean that the underlying economics must be either naive or simplistic, nor that economic considerations (and problems) warrant less scientific sophistication than those of a breeding, nutritional, or physiologic nature. Hence, the industry should not be satisfied with over-simplified or partial answers and should concentrate on bringing greater economic sophistication to bear.

Some readers may find other aspects of this paper more significant or to have greater implications for future priorities in the beef industry. However, it is felt that these six points provide a diverse base on which to build an enhanced understanding, without attempting to be all encompassing.

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Table 1. Characteristic means.

Characteristic	G_i Mean	Phase		
		Reproduction	Production	Consumption
Gestation Length (days)	286.88	x		
Weaning Rate (percent)	0.83	x		
Birth Weight (kg)	40.02	x		
Lactation Ability (Milk Production)	3.55	x		
Rate of Maturity (Growth)	1.73	x		
Weaning Weight (kg)	190.37	x	x	
Feed Conversion Efficiency (Mcal/kg)	0.12	x	x	
Mature Cow Weight (kg)	518.35	x		x
Post-Weaning Rate of Gain (kg/d)	1.05		x	
Slaughter Weight (kg)	517.14		x	x
Carcass Weight (kg)	294.57		x	x
Retail Product (percent)	0.70		x	x
Marbling Score (10 = sl-)	9.80		x	x
Tenderness Score (0-100)	45.23			x
Flavor Score (0-100)	47.75			x
Juiciness Score (0-100)	44.56			x

Table 2. Estimated Economic Values for an Integrated Beef Firm.

Characteristic	\$ Value (a_i)	t-value
Production Effects (per Head Economic Values)		**R^2=.6192**
Gestation Length (days)	-8.17	-0.96
Weaning Rate	220.36	0.82
Birth Weight (kg)	-4.59	-0.58
Lactation Ability (Milk Production)	24.72	1.05
Rate of Maturity	-213.55	-0.94
Weaning Weight (kg)	2.67	0.94
Feed Conversion Efficiency (kg/Mcal)	4474.65	1.71
Mature Cow Weight (kg)	-0.23	-0.23
Post-Weaning Rate of Gain (kg/d)	-200.69	-0.81
Slaughter Weight (kg)	-0.98	-1.87
Carcass Weight (kg)	0.18	0.25
Retail Product	1998.44	1.75
Marbling Score (10=sl-)	-9.84	-0.71
Market Price Effects		**R^2=.2683**
Tenderness Score (0-100)	0.43	0.24
Flavor Score (0-100)	7.71	4.05
Juiciness Score (0-100)	3.15	1.79

Table 3. Minimum MSE Estimated Economic Values.

Characteristic	**Value (a_i)**	**t-value**
Production Effects (per Head Economic Values)		$R^2 = 0.5655$
Weaning Weight (kg)	0.64	2.60
Feed Conversion Efficiency (kg/Meal)	-2736.07	3.45
Post-Weaning Rate of Gain (kg/d)	-178.84	-3.00
Marbling Score (10 = sl)	-10.87	-2.64
Market Price Effects		$R^2 = 0.2682$
Flavor Score (0-100)	7.94	4.67
Juciness Score (0-100)	3.38	2.15

Table 4. Effects of Meat Characteristics on Consumer Acceptability.

	Effect	t-value
Effects of Meat Characteristics on Eatabiity R^2=.8403		
Tenderness	0.4068	10.00
Flavor	0.4456	9.96
Juiciness	0.1344	3.23
Effects of Eatability on Meat Price R^2=.2835		
Eatability	104.1516	9.42

Table 5. Weights (b_is) per Unit and per Phenotypic Standard Deviation

Characteristic (unit)	G_i Mean	Std. Dev. (Phenotypic)	Weight (b_i)	
			per Unit	per Std. Dev.
Gestation Length (days)	286.88	5.53	-393.37	-2,175.93
Weaning Rate (percent)	0.83	0.0968	18,416.57	1,783.18
Birth Weight (kg)	40.02	9.4805	-189.76	-1,798.98
Lactation Ability (Milk Production)	3.55	2.2533	1,579.28	3,558.63
Rate of Maturity (Growth)	1.73	0.7495	636.63	477.17
Weaning Weight (kg)	190.37	59.7751	-49.24	-2,943.53
Feed Conversion Efficiency (Mcal/kg)	0.12	0.0271	4,945.74	133.99
Mature Cow Weight (kg)	518.35	145.5236	48.73	7,091.51
Post-Weaning Rate of Gain (kg/d)	1.05	0.2615	728.69	190.54
Slaughter Weight (kg)	517.14	181.9611	-70.6	-12,845.98
Carcass Weight (kg)	294.57	33.6963	-4.68	-157.56
Retail Product (percent)	0.70	0.0872	92,409.07	8,056.96
Marbling Score (10 = sl-)	9.80	4.4808	-813.66	-3,645.84
Tenderness Score (0-100)	45.23	24.552	-22.70	-557.25
Flavor Score (0-100)	47.75	21.2719	-33.80	-719.06
Juiciness Score (0-100)	44.56	22.9218	88.41	2,026.53

Table 6. Short-run Economic Values for Commercial Cow-Calf Production

Characteristic (unit)	All Characteristics R^2=.9940		Minimum MSE R^2=.9937	
	Value	t-value	Value	t-value
Gestation Length	-0.7811	-0.78	0.00	
Weaning Rate	392.23	11.60	392.63	17.83
Birth Weight	-0.6158	-0.64	0.00	
Lactation Ability	1.8146	0.57	2.0092	2.08
Rate of Maturity	-17.09	-0.64	0.00	
Weaning Weight	1.5648	4.66	1.346	35.40
Feed Conversion Efficiency	-45.31	-0.13	0.00	
Mature Cow Weight	-0.1037	-0.87	-0.0465	-1.92
Post-Weaning Rate of Gain	-42.31	-1.36	-42.87	-4.74
Slaughter Weight	-0.024	-0.36	0.00	
Carcass Weight	0.0609	0.71	0.00	
Retail Product	211.97	1.51	117.88	2.76
Marbling Score	4.044	2.47	3.453	3.82
Tenderness Score	0.00		0.00	
Flavor Score	0.00		0.00	
Juiciness Score	0.00		0.00	

Table 7. Time Adjusted Economic Values and Selection Weights.

Characteristic (unit)	Economic Values	Weights (b) per Unit	Weights (b) per std Dev
Gestation Length (days)	0	25.9259	143.4092
Weaning Rate (percent)	3,795.91	8,177.81	791.8134
Birth Weight (kg)	0	187.8243	1,780.66
Lactation Ability (Milk Production	19.42	559.5866	1,260.93
Rate of Maturity (Growth)	0	4,148.67	3,109.51
Weaning Weight (kg)	12.58	-61.4568	-3,673.58
Feed Conversion Efficiency (Mcal/kg)	0	5,640.43	152.8066
Mature Cow Weight (kg)	-0.43	23.8059	3,464.32
Post-Weaning Rate of Gain (kg/d)	-251.84	-2,091.06	-546.784
Slaughter Weight (kg)	0	-16.7466	-3,047.23
Carcass Weight (kg)	0	-2.4542	-82.6958
Retail Product (percent)	1,082.47	-569.9191	-49.6901
Marbling Score (10=sl^{-})	31.71	-613.1863	-2,747.56
Tenderness Score (0-100)	0	8.4643	207.8167
Flavor Score (0-100)	0	-41.3673	-879.9608
Juiciness Score (0-100)	0	47.1421	1.080.58

Table 8. Standardized (per std. dev.) Selection Emphasis by Industry Phase.

Phase	Reproduction	Production	Consumption	Overall	Adj. Overall
			Industry Representative Firm		
Reproduction	20.34%	6.39%	14.72%	41.45%	30.89%
Production	6.39%	0.40%	51.30%	58.08%	29.24%
Consumption	14.72%	51.30%	6.86%	72.88%	39.89%
			Commercial Cow-Calf Farm		
Reproduction	30.78%	16.62%	15.05%	62.46%	46.62%
Production	16.62%	2.38%	25.75%	44.75%	23.56%
Consumption	15.05%	25.75%	9.42%	50.22%	29.82%

Appendix 1: Alternatives for Carcass Characteristic Changes

Many readers will be inclined to dispute the relatively low emphasis these results suggest should be applied to qualitative carcass characteristics for either the industry or the cow-calf producer (Table 7, 9 and 10). Some will argue that the "true" economic values of these characteristics are greater than indicated by this study. Others will contend that these values may be correct now, but that qualitative characteristics are more important in the long-run to prevent continued erosion of beef market share and the "destruction" of the beef industry.

However, there are alternatives to genetic change readily available to improve tenderness and other beef quality characteristics if these are economically significant problems. These alternatives would logically be pursued by a profit maximizing industry if the value contributed by their remedy exceeded the cost of remedy. Hence, these alternatives provide an independent basis for judging the validity of the economic values estimated for qualitative characteristics such as tenderness and provide additional insights to the potential long-run effects on the industry.

Current Alternatives to Improve Tenderness

Three of the most commonly mentioned alternatives to improve tenderness, other than genetics, are (1) blade tenderizing, (2) calcium chloride injection, and (3) increased aging time. Blade tenderizing is a mechanical process that also changes product appearance and gross texture. However, calcium chloride injection and increased aging time are both biochemical processes that are closely related (i.e., calcium chloride injection accelerates the aging process to reduce the time required to achieve the same result) and do not significantly alter product appearance. Hence, for purposes of this study we will confine our consideration of alternatives to the latter two, with the greatest emphasis on extending the aging time.

Aging The advent of boxed-beef in the late 1960s significantly shortened both the aging time and effectiveness of beef processing. Beef, once sold as hanging carcasses, is now vacuum packed in plastic (such as Cryovac®) within a short time of slaughter and rushed to retailers for nearly immediate sale. As a result, the time between slaughter and retail sales has been considerably reduced, as has the "dry" aging that would normally accompany a hanging carcass. Thus, boxed-beef could be expected to be less tender than a comparable carcass marketed in the old hanging beef method. This is simply an unfortunate side-effect of an effort on the part of packers to avoid the (moisture) shrink that accompanies a hanging carcass, but one that warrants economic attention as a possible remedy to the problem of beef tenderness.

Melton and Huffman (1993) have estimated that the industry average real cost of capital services (adjusted for inflation to 1980-82 price levels) in beef packing and processing is about $.007 per pound live-weight of beef slaughtered. The physical plant accounts for about one-third of this cost ($10,000 investment per head-day of slaughter/processing capacity equals $.0025 per pound at 1150 pounds per head) and inventory adds an additional $.0005 per pound slaughtered.

Under current standards, this capital cost is adequate to hold beef in the plant for 3-5 days (from slaughter to shipping). If current processing methods are to be revised to increase the aging (and tenderness) of beef carcasses, additional capital costs will be incurred. Assume that the cost of cooler space accounts for 85% of the facility capital cost. To age hanging carcasses for an additional 14 days means that the cooler space will have to be increased approximately three-fold, as will the inventory. Hence, the cost of this means to remedy tenderness problems would be approximately $.008 per pound of live-weight slaughtered, or about $9 per head slaughtered[1]. Because this is not being done, we can be reasonably sure that the value of tenderness is less than $9 per head, and thus, it contributes less than $.02 to a pound of retail beef. Furthermore, if as has been reported tenderness is only a problem in about 15% of all carcasses and only these are aged, the average cost would be only $1.35 per carcass.

These results are consistent with those obtained previously, indicating low economic values for tenderness and thus, that these characteristic warrants very limited genetic emphasis by animal breeders. Specifically, the average cost per head to the industry for aging to remedy problem carcasses of $1.35 can be compared to the $.433 per head average economic value of tenderness (Table 2); both are small relative to other characteristics and value is less than cost, implying a (profit) loss will result from its remedy.

Aging plus Calcium Chloride Injections

Each additional day of aging is estimated to cost approximately $.66 per head if all animals are treated or about $.10 per head if only the 15% with tenderness problems are aged. Calcium chloride injections of the carcass have been proposed as an alternate means of increasing tenderness without the protracted aging process. For example, estimates are that calcium chloride injections improve tenderness, as measured by shear force, by 30 to 40%. By assuming a linear relationship, we can hypothesize that a program of calcium chloride injections would produce comparably tender beef in 30-40% less time; a savings of about 5 days from our prior alternative of aging only. Hence, a comparable calcium chloride injection treatment would cost about $6 per head if all animals are treated or $.90 per head if only the problem 15% are treated (added aging time) plus the cost of the injection treatment itself.

Morgan (1992, pp 186) argues that the treatment is "inexpensive", but no published data could be found to support this contention. However, if the cost is $3 per carcass or less it is a cost effective alternative[2]. The total cost of remedying tenderness problems by this alternative would thus be $6 to $9 per head if all animals are treated or an average of $.90 to $1.35 per head if only the 15% problem carcasses are treated.

These costs, especially for treating only problem carcasses, appear more cost effective for the industry than the breeding alternative. They also reaffirm the relatively low economic values that should be attached to tenderness in either breeding or management. Specifically, if the industry average cost of remedy is approximately $1.35 per head, then its value can not be greater than this amount or packers would already be aging beef to capture the profit difference associated with improved tenderness. This fact suggests that the "estimated average industry loss" of $2.89 per carcass due to palatability, "especially tenderness" (as reported in the National Beef Quality Audit, pp. 236), may seriously overstate the true value. If so, the real economic loss to the industry will accrue not from a tenderness problem, but from economically unjustified efforts to remedy it.

Appendix 2. Genetic and Phenotypic Variances, Covariances and Heritabilities.

Characteristic	Variance	1	2	3	4	5	6	7
	Variance	24.48	0.0009	37.7493	1.0155	0.1517	857.53	0.0002
		Heritability (On Diagonal), Genetic (Above), and Phenotypic (Below) Covariances[1]						
1 Gestation Length	30.5975	**0.80**	-0.0303	6.0796	0	0.3854	57.95	-0.0273
2 Weaning Rate	0.0094	0.2138	**0.10**	-0.0564	0.0123	-0.0024	0.3587	0
3 Birth Weight	89.88	-17.9638	-0.2514	**0.42**	-0.9287	-0.3829	97.157	-0.0051
4 Lactation Ability	5.0775	2.3275	0.0858	-11.0838	**0.20**	0.1962	3.5412	0
5 Rate of Maturity	0.5618	0.6727	0.0278	-4.2312	1.0444	**0.27**	3.3074	0.0005
6 Weaning Weight	3,573.06	127.90	3.1953	67.72	36.0925	23.0636	**0.24**	0.1739
7 Feed Efficiency	0.0007	-0.0637	-0.0005	-0.0353	-0.0105	0.0087	-0.0251	**0.26**
8 Cow Weight	21,177.11	31.725	-0.3505	1,123.65	-168.365	-62.6513	2,829.33	-0.8574
9 Rate of Gain	0.0684	-0.7148	-0.0036	1.8404	-0.1848	-0.0754	0.9578	0.002
10 Slaughter Weight	33,109.86	396.41	3.4203	959.67	-76.22	-59.29	3,707.90	-2.5932
11 Carcass Weight	1,135.44	-1.8561	-0.0256	20.2097	-2.6133	-1.5686	-4.2575	-0.0038
12 Retail Product	0.0076	0.2283	0.0005	0.4198	-0.0555	-0.0238	1.5494	-0.0011
13 Marbling Score	20.0775	-16.59	-0.1103	-13.3088	1.8775	1.0104	-114.01	0.0724
14 Tenderness Score	602.803	0	0	0	0	0	-41.1817	1.926
15 Flavor Score	452.4924	0	0	0	0	0	-23.0056	1.6687
16 Juiciness Score	525.4074	0	0	0	0	0	4.3327	1.1987

[1] Between one-fourth and one-half of the covariances were unable in the literature and were, therefore, estimated by the author with the assistance of R. L. Willham.

Characteristic	8	9	10	11	12	13	14	15	16
Variance	11,647.41	0.0239	13,243.94	510.9474	0.0042	9.0349	138.6447	113.1231	105.0815
	Heritability (On Diagonal), Genetic (Above), and Phenotypic (Below) Covariances								
1	0	-0.3061	227.7491	0	0.096	-2.9743	0	0	0
2	-0.033	-0.0005	-0.1762	0	0	0	0	0	0
3	66.3085	0.4847	424.24	48.6083	0.0596	1.2927	0	0	0
4	-16.3135	0	-11.5971	0	0	0	0	0	0
5	29.4224	-0.0271	26.8921	-4.4017	0.0076	0.4683	0	0	0
6	1,422.17	1.4496	2,392.72	66.1933	0.4734	-10.5625	-35.2538	-28.8288	4.6796
7	-0.0745	0.0009	-0.0477	0	0.0004	-0.0042	0	0	0
8	**0.55**	5.8434	7,452.03	1,463.71	1.3957	-48.6594	-151.5798	-123.9545	20.1206
9	24.9335	**0.35**	14.5984	1.3987	0.004	0.1581	0	0	0
10	20,890.78	14.6198	**0.40**	1,560.80	2.9765	-138.3661	-184.7257	-151.0596	24.5204
11	341.2166	0.4914	346.28	**0.45**	0.585	-27.177	-45.3541	-37.0884	6.0203
12	8.456	0.0031	14.65	0.118	**0.55**	-0.0389	0	0	0
13	-383.715	0.0383	-694.3375	-6.893	-0.3343	**0.45**	27.4248	22.6554	23.7982
14	-150.3866	0.2141	-250.7224	-58.0372	0	36.2813	**0.23**	59.9227	78.3556
15	-84.0114	0.1855	-140.0627	-32.4217	0	19.3655	396.3927	**0.25**	50.0502
16	15.822	0.1999	26.3782	6.106	0	30.7946	431.1769	356.0305	**0.20**

1. One might also add to these costs the value of (moisture) shrink that would be "lost" compared to current rapid chill processing. However, for the overall industry this shrink has no value. That is, someone in the industry must bear it. The option of packers increasing their aging timing simply transfers the incidence of shrink from the wholesales-retailer (who bear it now) to the packer-processor.

2. To be cost effective, the calcium chloride injection system would have to cost less than $.66 per carcass for each day of aging avoided. In comparison to direct aging, the calcium chloride treatment will be cost effective only if its cost is less than $3.20 per carcass.