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IMPACT OF INDUSTRY STRUCTURE, INTENSITY OF PRODUCTION and RESOURCE CONSTRAINTS ON RESEARCH BREEDING OBJECTIVES

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Summary

The importance of the structure of the beef industry with respect to crossbreeding programs and division into cow-calf and feedlot segments; intensity of production with respect to market standards, feeds and labour; and resource constraints with respect to feed, labour, land and capital; are discussed and quantified where possible. The use of discounted gene flow provides estimates of relative expression rates which differ with crossbreeding programs and relative sizes of populations of purebred and commercial cattle. The importance of feedback from feedlot to cow-calf to purebred operation is emphasized, for both discounted expression rates and modelling approaches. The composition and quality of beef marketed, the influence of energy availability for cow herds and energy density of feedlot diets, and the level of management are discussed as important components of modelling beef production. The impact of resource constraints is discussed and an example is presented which shows the changes in selection decisions caused by changes in constraints. The situations under which selection decisions using linear programming would equal those from the use of a single equation to estimate breeding value for total merit are identified, as are some of those in which selections would differ. The implications of these differences in establishing breeding objectives are discussed.

Introduction

Breeding objectives for the genetic improvement of beef cattle have been difficult to establish because of interactions with a range of factors which may broadly be classified as environmental. One of these factors is the structure of the industry, by which is meant the segmentation of the industry typically into purebred and commercial herds with the latter in turn divided typically into cow-calf and feedlot operations, and the crossbreeding arrangements in the industry. Another set of factors relate to the programs for producing beef. These include marketing considerations, or market standards, in particular the extent to which composition and quality of beef are important to consumers; the quality of feed available for cow-calf and feedlot operations; and the level of management and labour that is available. A third factor resulting in possible changes in rankings of animals is the set of resource constraints or limitations under which the beef production program is operating. Limits in capital, feed, labour and land may all be of importance.

Considerable work has been done with systems analysis to determine optimum crossbreeding programs, as reviewed by Cartwright (1982). Similarly, much work has been done on the examination of the impact of changes in various traits from a modelling approach (Cartwright, 1982) and from an expense per unit product equation approach (Dickerson, 1982). However, less work has been done on methods of establishing breeding objectives and selection procedures. A need for further developments in animal breeding theory to handle the effects of changes in traits of individual animals within a complex production program has been pointed out by Doren et al. (1985).

The purposes of this paper are to:

1. describe the effects of industry structure, intensity of production and resource constraints,

2. quantify these effects where possible,

3. illustrate a method for selecting animals considering these factors, and

4. discuss research and development required in possible use of this method.

Industry Structure

1. Structure of Cross-Breeding Programs

The role that breeds or lines play in cross-breeding programs has a major effect on the breeding objectives and decisions for those breeds or lines. Cartwright (1970) and Foulley (1976), for example, have described the changes in criteria for breeds that would be used as terminal sires compared to those that would be used in rotational programs. The impact of crossing program on selection criteria can be quantified by the use of discounted gene flow (Wilton and Danell, 1981) or by extensions of linear programming models such as those by Cartwright et al. (1975) and Wilton and Morris (1976). The greater emphasis on market traits relative to female production traits in terminal programs than in rotational programs can be calculated for specific situations including such factors as replacement rates, mortality rates, sire usage rates and population sizes (Table 1). In rotational crosses market traits had a slightly lower discounted expression rate than female production traits in the Wilton and Danell (1981) study. In comparison, market traits had more than 3 times the expression rate of female production traits when the commercial population was 3.5 times as large as the terminal sire population and over 10 times the expression rate when the commercial population was 14 times as large as the terminal sire population.

The use of a systems approach would require modelling of the crossbred and purebred populations required to generate those crossbreds. A closed, self-contained herd approach or an approach of using purchased replacement females or males or both could be used. The approach of using purchased replacements would be fairly complex because it would require the simultaneous modelling of several farms. The feedback from commercial to purebred producers with respect to the relative importance of the various traits would have to be known (parallel information would have to be known in discounted gene flow in accumulating expressions). A multiple year model would be most appropriate to account for the use of breeding stock over time and population. Replacement rates would be important in determining the timing of expression rates through the various populations. In addition, the transition from existing populations to more nearly optimum arrangements of the total population would have to be considered.

Table 1. Ratio of total discounted expressions relative to direct male traits for male probands in rotational and terminal sire line programs[1]

Type of trait	Rotational	Terminal sire line[2] 1:35	1:14
Market offspring	0.50	0.43	0.41
Female traits over all productive years	0.56	0.13	0.04

[1] Adapted from Wilton and Danell (1981), Tables 3 and 5 with discount rate of 2% and a 25 year horizon.
[2] Terminal sire line nucleus : commercial population size.

The structure of the cattle breeding industry (both commercial and purebred) influences breeding objectives depending on the types of crossbreeding programs in place and the number of specific F1 females being serviced by a terminal line or breed. The changes in objectives would be quantified by the changes in models of total merit that would result from including discounted expression rates or by working with more comprehensive models.

2. Cow-Calf and Feedlot Segmentation

One of the important aspects of discounted gene flow is the accumulation of numbers of expressions of traits over time and populations. Clearly, the accumulated expressions of traits must be relevant at the level of the decision-maker in the initial nucleus population. This may not be true if the pricing mechanism from one segment of the population to another does not reflect genetic differences in animals. Currently in many beef production situations the pricing mechanism from the feedlot to the cow-calf segment appears to incompletely reflect potential differences in breeds and to completely ignore potential differences from sire to sire within breeds. An additional gap may exist in the feedback mechanism from the cow-calf producer to the nucleus (usually purebred) breeder as just described. Determination of expression rates should be based on the degree of feedback that exists, while efforts should also be made to assure that feedback is as accurate as possible. Genetic change in contribution to total merit could be seriously reduced if variable levels of feedback led to a range of expression rates of traits and hence an unclear breeding objective.

A closely related area is that of genetic correlations between traits expressed in the cow herd and those expressed in the feedlot. Economically antagonistic correlations such as between growth rate in the feedlot and mature weight of cow make it essential to know the relative rates of expressions of these traits.

Intensity of Production

Changes in breeding objectives with varying intensities of production reflect a form of genotype by environment interaction. Genotype includes breeds, the use of breeds in crossing programs and animals within breeds.

Environments includes factors such as market standards (degree of emphasis on composition and quality), *nutrition (both for cow-calf and feedlot* segments) and labour (primarily in the cow-calf phase).

1. Market Standards

Major differences exist in various areas of the world in the extent to which quality of beef is emphasized and, in fact, in the definition of quality. Quality will be defined here as degree of consumer acceptability, determined largely by flavour and tenderness. Quality standards involving flavour are often considered to be closely associated with composition of the product, in particular the fat component. The other major compositional aspect, lean yield relative to bone, enters the discussion on market standards through the extent to which prices of retail cuts and the efficiency on the part of the retailer in preparing those cuts vary with degree of muscling.

Some examples will illustrate the impact of market standards on breeding objectives. There is, for example, a market for highly marbled beef in Japan. This has led to studies on fat depots and lipid and fatty acid composition of subcutaneous fat (Yoshimura and Namikawa, 1983). Progeny testing programs, in which marbling is measured and evaluations of marbling receive considerable attention *in selection, have also been* established.

Considerable research has been conducted in North America to establish the extent to which flavour is influenced by percentage of fat in the carcass (Smith et al., 1983). Minimum amounts of subcutaneous fat (4mm) *have been established in Canada for animals to be classified in the A* quality grade. Smith et al. (1983) summarized work on the association of subcutaneous fat with flavour desirability ratings, indicating an approximate level of 5mm would be sufficient for good ratings for steak. For other markets in many parts of the world, low levels of fatness are considered desirable. Similarly the role of fatness in flavour is different for hamburger and restructured products than for prime cuts.

Closely inter-connected with level of fatness is market weight. This inter-relationship and the differences in breeds for either weights at a constant degree of finish or composition at a constant weight have been well described by Koch et al. (1976, 1979, 1982). In situations in which at least a minimum degree of finish is required (as in Canada), there can be an additional requirement relating to market weight. Carcasses below an acceptable weight are penalized because of labour inefficiencies. Carcasses above an acceptable weight are also penalized, due to either handling problems or size of retail cut problems. Changes in prices associated with carcass weights can obviously vary from country to country and from market to market within countries.

In the area of muscle to bone ratios, specialized markets in France and Belgium for example, are such that price advantages exist for highly muscled animals. There has, as yet, been little quantification of the values of muscle to bone ratios in the market place, which would be required for feedback to the producer.

The additional question of the impact of processing techniques on optimum weights and levels of fatness must also be considered. Dikeman (1985) has reviewed such techniques as electrical simulation, delayed chilling, vacuum packaging and prerigor boning (hot boning) and their combined effects. Lower levels of fatness may be required with the appropriate use of these technologies.

Classical approaches to genotype-environment interactions are required to establish breeding objectives. However, the extent to which the market can be divided into parts such that objectives can be established for each part has not yet been examined. Similarly, the extent to which genotypes would rank differently in these parts requires examination.

With a defined part, such as market values determined by minimum levels of finish and with bounds on market weights, approaches of predicting market weights (on a standard feeding program) as described by McWhir and Wilton (1986) may be a useful approach. Such an approach makes it posible to match the market components of breeding objectives with the realities of market pricing, both in weight per animal and in composition. Refinements in breeding objectives and decisions can be made by considering various selection strategies for non-linear models of total merit as discussed by Jansen (1985), for pricings that are non-linear.

2. Feed

Interaction of feed quality, usually expressed through pasture quality (amount and digestibility), with breed on reproductive performance of cows has been found by several researchers. Fredeen et al. (1981), for example, found re-ranking of breed crosses between range and semi-intensive pasture managment environments. General environment by line interactions have been reported for reproductive rates of Hereford cows by Koger et al. (1979). Ferrell and Jenkins (1985) discussed the differences in energy requirements of different cattle types, with a need to synchronize production environment and germ plasm resources being indicated.

The effect of energy density of feed on weights at which suitable finish is attained has been documented by several authors such as Rompala et al. (1984). Interaction of diets with genotypes has been shown by Crouse et al. (1985) and a general interaction of environment with line has been shown for post-weaning traits of Hereford bulls by Pahnish et al. (1985). Evidence of sire by environment interactions has been reported by Bertrand et al. (1985), although environment in this case included more than feed differences.

The combination of influences of feed availability on cow or feedlot performance (including market weights) or both for different breeds and crosses can be handled in a modelling approach. As more information becomes available the modelling can become more precise. However, this increased precision will also result in much larger models especially if taken to the individual sire level.

3. Labour

An interesting question in the area of intensity of production is that of twinning. Twinning may possibly be increased by selection or by embryo transfer (Rowson et al., 1971; Anderson et al., 1979, 1982; Reid et al., 1986). Embryo transfer requires higher levels of management for transfer, calving and early post-natal care, but allows for the use of specialized embryo lines and specialized recipients (Reid et al., 1986).

Resource Constraints

1. Constraint Variables

Limits can exist for several variables of a beef production operation, with land, labour, feed supplies and capital being some of the major ones. In some cases, limits can exist on output per operation. There are usually no limits to beef sales per farm in North America, although quotas exist for several products in Canada. Both output and input limits can change the value assigned to unit changes in output and input variables, and can make single equation systems less than complete representations of total merit.

Linear programming (LP) is one convenient approach to dealing with constraints, and has been used to analyze crossbreeding programs by Wilton et al. (1974), and Wilton and Morris (1976). It has also been used to examine the influence of changes in traits, such as size (Morris and Wilton, 1975) and milk yield of beef cows (Morris et al., 1976). It has not yet been used to include choices of animals within breed, although Sivarajasingam et al. (1984) compared dairy sires on the basis of the objective values resulting from sequential runs of an LP model. Elements of the model concerning expected daughter performance for such traits as milk yield, milk fat percentage and milking speed were changed from run to run to obtain the values of the objective function.

2. LP Relative to Selection Index

The following example is designed to illustrate the technique of using LP to choose amongst beef sires and to compare the selection decisions using LP with those that would be made with selection index (or a parallel function of predicted differences estimated by Best Linear Unbiased Prediction).

In the example, gross margins (G) are calculated as returns less variable costs. Returns come from market weight (M) and variable costs include feed (F) and labour required for calving (L). The objective function is:

$$G = a_1M - a_2F - a_3L$$

in which G, M, F, and L are as defined above,

a_1 = \$2/kg,

a_2 = \$0.10/kg, and

a_3 = \$10/hour.

The program being modelled is for the use of Charolais sires on F1 females in a terminal crossing program. Of course, the model is very incomplete, with such factors as reproductive rates, breeding herd overhead, heterosis and time period ignored. With heterosis ignored, performance levels of progeny of sires are determined by population means for Charolais sires, F1 females and predicted differences for progeny of various Charolais sires. The assumed (entirely arbitrary) values for these variables are shown in Table 2.

Table 2. Assumed values for performance levels for modelling and selecting Charolais sires

	Market weight (kg)	Feed intake (kg)	Calving labour (hours)
Charolais average	600	3120	1.0
F1 average	500	3000	0.5
Sire predicted differences (*PD's*)			
a	+15	+60	+0.5
b	+50	+200	+1.5
c	-20	-80	-1.0
d	-10	-60	-0.5
Absolute performance of progeny			
a	565	3120	2.0[1]
b	600	3260	3.0
c	530	2980	0.5
d	540	3000	1.0

[1] Calculated as F1 average (basic cow requirement) plus Charolais average ± sire effect (total sire contribution)

The resource contraints were set initially at 50 spaces for animals, 150,000 kg of feed available and 75 hours of labour available (all again as examples only).

The steps in using LP are then:

1. Identify the decision-maker (the producer choosing the sire).
2. Define the objective (to maximize G subject to resource constraints in this case).
3. Define the model for production (simplified in this case to a description of the performance levels for outputs and inputs of the progeny of four sires and the resource constraints).
4. Carry out the analysis (in this case the following LP analysis):

$$
\begin{aligned}
\text{Maximize}\quad & 2M - 0.1F - 10L + 0a + 0b + 0c + 0d \\
\text{Subject to}\quad & \\
& a + b + c + d \leq 50 \\
& F \leq 150{,}000 \\
& L \leq 75 \\
& M - 565a - 600b - 530c - 540d = 0 \\
& F - 3120a - 3260b - 2980c - 3000d = 0 \\
& L - 2a - 3b - 0.5c - 1d = 0
\end{aligned}
$$

5. Use the sires in the appropriate numbers that maximize the objective function.

The results of this small example illustrate the influence of resource constraints on the choice of sires (Figs. 1 & 2). Small percentage changes in feed available resulted in major differences in numbers of progeny per sire that would result in maximum values of the objective function. As more feed was made available more progeny from sire b (the sire with highest PD's for all traits) were used. These were complemented by decreasing numbers of progeny of sire d and increasing numbers of progeny of sire c. The changes in constraint levels for feed were based on the point of change information generated in the previous analysis, beginning with the 150,000 kg feed constraint. When the labour constraint was changed, maximum objective functions involved using only progeny of sire b, regardless of feed constraint (Fig. 2).

The reasons for the changes from sire d to c in Fig. 1 are not obvious from the predicted differences in Table 2. There appears to be a critical balance between the labour and feed constraints, with a utilization of as many progeny of b as possible with the labour constraint of 75 hours. The situation is clear when the labour constraint is removed. Sire b with the highest output (positive over feed costs) used totally up to the number of animals that can be fed (up to the maximum of 50).

The changes in the values of the objective functions were relatively small over the three feed constraint levels in both Fig. 1 and 2. When labour was limited to 75 hours the value of the objective increased from 38,590 to 39,520 to 39,590 for the increases in feed availability. When labour limitations were increased to 150 hours, the value of the objective function increased to 38,830, 39,870 and 42,200 for the three increasing levels of feed constraints. The impact of the feed resource constraint was thus more important when labour was not limiting (labour having been a slack activity for all levels of feed contraints used).

The sire chosen when labour was not constrained was the same as would be selected using substitution of predicted differences into a linear function, parallel to substitution of estimated breeding values into models of total merit (Henderson, 1963). In this approach the model of merit for the example used would be:

$$T = 2g_M - 0.1g_F - 10g_L$$

Fig 1 Optimal number of progeny per sire, space constraint 50, labour constraint 75

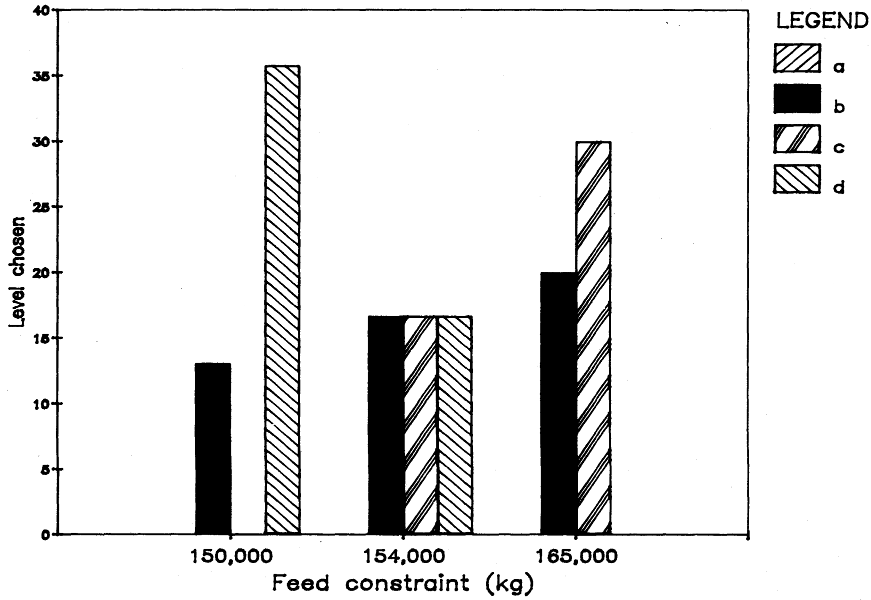
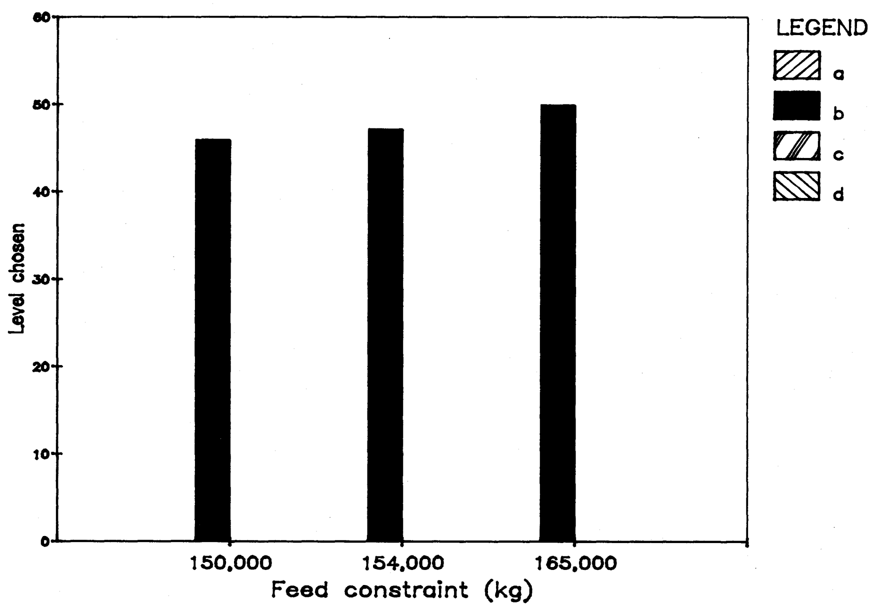


Fig 2 Optimal number of progeny per sire, space constraint 50, labour constraint 150



in which g_M, g_F and g_L are the additive genetic values for market weight, feed intake and labour for calving, respectively.

The estimate of T is

$$\hat{T} = 2\hat{g}_M - 0.1\hat{g}_F - 10\hat{g}_L$$

in which ^ denotes the estimate of the parameter. The values for sires a, b, c and d are $19, $65, $-22 and $-9, respectively. It is interesting to note that the second ranked sire did not enter the solutions in Fig. 1, due to the mix of output and labour requirements that led to the optimum solution.

The example, although greatly simplified, illustrates the effect that resource constraints have in choosing sires. The example shows the ineffectiveness of a single equation in representing the economic value of the use of various sires. A complete model and precise statements concerning resource constraints would be required before one could conclude how critical this difference in sire selection would be in practise.

The approach described deals with sire selection, and additional work is also required to relate sire selection to breeding objectives. Resource constraints have an impact similar to changes in intensity of production in which the model for production was changed. The extent to which production programs could be aggregated so that directional changes in traits of sires would have beneficial economic influences needs to be examined.

Another area of research required is in non-linearity. Jansen (1985) has shown the difficulties of converting non-linear functions of total merit at the phenotypic level to functions at the genotypic level. He also showed differences in the rate at which the population mean for total merit would change depending on the selection criteria used and, to an even greater extent, on selection of mating pairs. The influences of non-linearity depended on the extent to which total merit was in fact non-linear and this area has as yet been relatively unexplored in beef cattle.

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