Economic values for beef production traits from a herd level bioeconomic model

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Koots, K. R. and Gibson, J. P. 1998. **Economic values for beef production traits from a herd level bioeconomic model**. Can. J. Anim. Sci. **78**: 29–45. A bioeconomic model of an integrated Canadian beef production system was developed to derive economic values for genetic improvement of multiple traits. The breeding objective was assumed to be profit maximization of the integrated enterprise. Sixteen input traits were identified as potentially influencing returns and costs in the system. These were mature size, direct and maternal calving ease (in heifers and cows separately), cow fertility, calf survival, cow survival, peak milk yield, residual post-weaning growth rate, residual feed intake in growing animals, residual feed intake in mature animals, residual slaughter weight and dressing percentage at constant backfat thickness, marbling and lean percentage. Most traits were defined to be functionally independent of each other. Thus, traits related to mature size were redefined as residual traits after accounting for the nonlinear relationships among mature size, growth and feed intake traits following mammalian size scaling rules. The base model, which incorporates average returns and costs under production and marketing systems typical of eastern Canada, is described. Economic values in the base model suggest that calf survival, fertility, residual feed intake, and dressing percentage are of primary economic importance in a purebreeding system. These traits also ranked highly in dam lines and (with the exception of fertility) in sire lines in terminal crossbreeding systems.

Key words: Beef cattle, economic values, bioeconomic model

Koots, K. R. et Gibson, J. P. 1998. **Valeurs économiques des caractères de production de bovins à viande à partir d'un modèle bioéconomique par troupeau**. Can. J. Anim. Sci. **78**: 29–45. Un modèle économique d'un système intégré de production de bovins à viande utilisé au Canada est élaboré pour obtenir les valeurs économiques de l'amélioration génétique de caractères de production multiples. L'objet de la sélection était considéré comme étant la maximisation de la rentabilité d'un atelier intégré. Seize caractères étaient pris en compte pour leur influence éventuelle sur les recettes et sur les coûts de production. Ce sont : la taille à l'âge adulte, les effets directs et les effets maternels sur la facilité de vêlage (évalués séparément pour les génisses et pour les vaches adultes), la fécondité des vaches, le taux de survie des veaux et celui des mères, le rendement laitier de pointe, le taux de croissance résiduelle en post-sevrage, l'ingéré alimentaire résiduel chez les sujets en croissance et chez les sujets adultes, le poids et le rendement à l'abattage résiduels à épaisseur constante de gras de couverture, le persillé et le pourcentage de viande maigre. La plupart des caractères étaient fonctionnellement indépendants l'un de l'autre. Pour cette raison, les caractères établis en fonction de la taille au stade adulte étaient rédéfinis en caractères résiduels après prise en compte des relations non linéaires existant entre les caractères de croissance et d'ingestion alimentaire en fonction de la taille adulte établie selon les règles de graduation de la taille des mammifères. Les auteurs décrivent le modèle de base qui incorpore les recettes et les coûts moyens obtenus dans le régime typique de production et de mise en marché en usage dans l'est du Canada. À partir des valeurs économiques produites par ce modèle de base, il appert que le taux de survie des veaux, la fécondité, l'ingéré alimentaire résiduel et le rendement à l'abattage sont des caractères de première importance économique dans un régime de production en race pure. Ces caractères occupaient également un niveau d'importance élevé chez les lignées maternelles et, sauf pour la fécondité, chez les lignées paternelles utilisées dans les systèmes de production en croisements terminaux.

Mots clés: Bovin à viande, valeurs économiques, modèles bioéconomique

Critical to a successful animal breeding program is the definition of appropriate multiple trait selection goals, yet this often receives little attention. Defining the economic value of genetic improvement of different traits requires an adequate description of the production system. Simple profit equations describing the relationship between genetic change and enterprise profit may be adequate for very simple production systems. More complex systems are better described by computer modelling. With beef cattle, production models have been developed primarily for comparison of breeds and crosses in different environments (Wilton et al. 1974; Bourdon and Brinks 1987; Lamb et al. 1992). These beef production models often have limited value for defining economic values for within-breed improvement. More recently, bioeconomic models have been used to derive economic values for a limited number of traits in particular segments of the production system (e.g. Kolstad 1993; Amer et al. 1994). These ignore the reality that animals must perform in all segments and levels of a production system.

Abbreviations: CEDC, calving ease direct in cows; **CEDH**, calving ease direct in heifers; **CEMC**, calving ease maternal in cows; **CEMH**, calving ease maternal in heifers; **EBRC**, University of Guelph Elora Beef Research Centre; **LY**, lean meat yield; **ME**, metabolizable energy; **MR**, marbling; **RFG**, residual feed intake in growing animals; **RFM**, residual feed intake in mature animals; **RSW**, residual live slaughter weight at 7 mm subcutaneous fat depth; **DP**, dressing percentage at 7 mm subcutaneous fat depth

In constructing bioeconomic models for estimation of economic values, careful attention must be paid to the exact definition of traits and the inter-relationships among them. Previous studies have treated traits as being independent of each other. Since the conversion of economic values to selection index weights assumes linear genetic relationships among traits, no allowance is made for known non-linear relationships among traits. Apart from being an over-simplification of reality, this approach can lead to unrealistic impressions about the potential value of genetic change by attributing substantial economic values to each trait of a highly interdependent set. As an example, Bourdon and Brinks (1987) and MacNeil et al. (1994) considered mature size, birth weight, weaning weight and post-weaning growth rate as independent traits and estimated an economic value for each. Most of the variation in these traits is, however, likely to be driven by non-linear dependencies on mature size. Since selection indexes are linear, the non-linear interdependencies among traits cannot be accounted for in subsequent derivations of selection indexes. These non-linear relationships can be better accounted for by directly incorporating them in the model, which can also lead to a better appreciation of the true value of changing overall size versus changes in other growth traits, expressed as a deviation from the expected growth curve at a given mature size.

The present study develops a model of beef cattle production which is then used to derive economic values for genetically controlled traits in an integrated beef enterprise. Modelling a complete beef production system (as opposed to cow-calf and feedlot segments separately) was necessary to reflect a situation where market signals flow down to those making the breeding decisions. That is, although payment is inevitably based on carcass value, animals must flow through both segments of the industry. Sensitivity of the model to changes in production and marketing assumptions is presented elsewhere (Koots and Gibson 1998).

MATERIALS AND METHODS

Model Overview

The bioeconomic model describes an integrated beef production system. The model is deterministic and assumes no genetic variation between animals within the herd. The following classes of animals are defined; feedlot steers and heifers (from birth to slaughter), replacement heifers, cows (age classes 2 to 10) and breeding bulls. The model is non-integer (fractions of animals are allowed) and the herd size fixed at 50 pregnant females at pregnancy check. A 1-yr production period is modelled, but many activities are simulated on a daily basis. Information on biological relationships among traits are taken from the literature and data from the University of Guelph Elora Beef Research Centre (EBRC) are used to validate the model.

It is assumed that replacement heifers come from within the herd whereas breeding bulls are obtained from outside the herd. The model allows purebreeding (or synthetic) or crossbreeding, where a proportion of the females are mated to maternal sires and the remainder to terminal sires. The herd size is maintained by culling nonpregnant cows after a 60-d breeding season. This is consistent with recommended management practices (e.g. Minish and Fox 1982). Calves are born on 1 March (on average) and weaned in mid-September, at an average age of 205 d. Pasture is available for 183 d (May to November). The cows are fed a diet of corn silage and hay during the winter (182 d). For the calves, access to creep feed (consisting of grain corn and corn silage) is available to supplement milk consumption for the first 61 d (March to May). It is assumed that during the summer, metabolizable energy (ME) requirements of cows and calves are supplied entirely by clover-orchard grass pasture. At weaning, all steers and heifers enter a stocker-grower period where they are fed on pasture for 38 d and then fed corn silage and hay for 53 d. At an average age of 296 d, all steers and any heifers not needed as replacements are put on a finishing diet of grain corn (50%) and corn silage (50%) until they reach an average optimum backfat thickness (7 mm).

Replacement heifers are put on the same feeding regime as cows, and are bred to calve at 2 yr old. Replacement heifers that are not pregnant after a 60-d breeding season (at an average of 570 d old) are culled and are assumed to receive the same market price as heifers finished on a finishing diet. These replacement heifers are older and heavier than heifers that had gone straight into the feedlot.

Revenues come from the sale of feedlot steers and heifers, and from cull replacement heifers, cows and bulls. Costs are incurred by feed (feedlot and cow-calf segments), labour and husbandry, bedding, marketing, veterinarian and medicine, and breeding (purchase of bull).

Genetic Traits

Sixteen independent traits are identified as potentially influencing returns and costs. Traits were chosen 1) if they influence returns or costs in the integrated beef production system, and 2) if they could vary independently of other traits in the breeding objective. The 16 traits are defined below and, where applicable, their effect on other traits is introduced.

MATURE SIZE (A). Mature body weight was chosen to represent a single measure of body size. Here, mature body weight is defined as the asymptote of the curve of body weight versus age (Taylor 1989) and is 50% higher for bulls than cows (Taylor and Murray 1987). Mature size determines baseline growth rate, feed requirements and slaughter weight of all classes of stock. Variation in growth and feed intake around these predictions is allowed by defining residual growth and feed intake traits.

CALVING EASE DIRECT IN HEIFERS, CALVING EASE MATERNAL IN HEIFERS, CALVING EASE DIRECT IN COWS, CALVING EASE MATERNAL IN COWS. Calving ease is assumed to be a continuous trait on the genetic scale, but scored phenotypically in five categories as a threshold trait (U = unassisted, E = easy pull, H = hard pull, M = malpresentation and S = surgical). Calving difficulty, here defined as all births not in category U, incurs the direct costs of labour and sometimes veterinary treatment, as well as indirect costs associated

with reduced cow fertility and reduced calf survival. Mortality (within 96 h) of calves experiencing difficult calving is increased more than fourfold over calves not experiencing a difficult calving, based on Ontario field data (Anderson 1989), in agreement with the 3.7 to 5-fold range found in the literature (Laster and Gregory 1973; Smith et al. 1976; Rahnefeld et al. 1990). In the model, mortality after 96 h is assumed to be unaffected by calving difficulty (Patterson et al. 1987).

Survival rate of cows is not affected by difficult calving directly (Rahnefeld et al. 1990). Subsequent reduced fertility, however, would increase voluntary culling at time of pregnancy checking. Fertility is reduced 15% in those cows experiencing difficult calving (Laster et al. 1973). Based on the review by Meijering (1984), milk yield is not affected by difficult calving.

Both birth weight and dam weight are proportional to mature weight (A) and do not affect calving ease in purebreeding systems (Meijering 1984). In the model for crossbreeding systems, calving ease is affected by calf birth weight and dam weight in heifers, and by calf birth weight alone in later parities (see later).

FERTILITY (FR). Fertility is defined as the probability of conception (after a 60-d breeding season) at constant calving ease. It is assumed that the management of the herd maintains the number of pregnant cows in the fall at a constant, N, so fertility affects number of heifers and cows bred, culling rate and calving date. Fertility in heifers is set to a constant proportion (0.9) of fertility in cows (Rogers et al. 1985; Fiss and Wilton 1989; Koch et al. 1994). Replacement heifers are assumed to receive adequate nutrition to reach a sufficient size such that 90% of them will exhibit estrus by 15 mo old (the age at which heifers are bred to produce their first calf at 2 yr old) as commonly recommended (Bellows and Short 1994). Costs and returns are affected by increasing fertility as follows:

1) Increased returns and costs result from earlier calving dates leading to an increased calf weight at weaning of 0.25 kg per 1% increase in fertility (C. Smith, personal communication). Progeny then reach slaughter weight in fewer days.

2) Fewer cull cows are marketed (at heavier weight but low price) and more heifers marketed (at lower weight and higher price).

3) Increased number of mature cows, which have lower calving difficulty and a 10% advantage over heifers in weaning weight of their calves (e.g. Woldehawariat et al. 1977), which is accounted for by higher milk yields in mature cows.

The additional benefit arising from the increased opportunity for selection resulting from a lower involuntary replacement rate is not included in the model. In practice, genetic progress in fertility will likely be small, so increased opportunity for selection will be limited.

CALF SURVIVAL (S1). Calf survival is defined as the proportion of calves surviving from birth to weaning, at constant calving ease.

COW SURVIVAL (S3). Cow survival is defined as the proportion of cows surviving the yearly cycle, at constant calving ease and fertility (involuntary culling).

PEAK MILK YIELD (PM). Because the production system modelled is an integrated one, pre-weaning growth will affect the energy requirements for maintenance and post weaning gain (including compensatory growth) as summarized by Fox et al. (1988). Milk yield influences cow and calf feed requirements and is included to account for costs of gain in the calf through milk from the dam (on pasture) versus cost of gain in the feedlot (on a relatively expensive diet).

RESIDUAL POST WEANING GROWTH RATE (RG). Residual post weaning growth rate is defined as growth rate at a constant mature size for a given feeding regime. It influences the number of days required to reach market weight, which incurs a management cost per day, plus maintenance feed costs. Variation in RG at constant mature size implies variation in shape of growth curves.

RESIDUAL FEED INTAKE IN GROWING ANIMALS, RESIDUAL FEED INTAKE IN MATURE ANIMALS. Residual feed intake is defined as deviation in feed intake from the predicted requirements for growth and maintenance as driven by mature size and residual growth rate. Although residual feed intake in growing cattle has received only limited attention (Koch et al. 1963; Korver et al. 1991) it has intuitive appeal as a measure of feed efficiency. Feed efficiency, measured as a ratio, has problems inherent with selection on ratio measures (Koch et al. 1963). Although Kennedy et al. (1993) showed that residual feed intake provides no additional information over and above its components, for the purposes of modelling, residual feed intake provides a way of attaching a value to variation in feed intake that is genetically and phenotypically independent of production.

RESIDUAL LIVE SLAUGHTER WEIGHT AT 7 MM SUBCUTANEOUS FAT DEPTH, DRESSING PERCENTAGE AT 7 MM SUBCUTANEOUS FAT DEPTH. Residual live slaughter weight is defined as the deviation in slaughter weight from that predicted by mature size (A). The observed slaughter weight and the dressing percentage at a constant backfat, combine to determine carcass weight. Carcass value is determined from carcass weight at 7 mm backfat, which is in the middle of the 4 to 10 mm range required for A1 grade in Canada. In 1992, measures of carcass quality based on marbling and carcass yield predicted from lean yield were introduced to match the grading system used in the United States (Anonymous 1992). Future payment schemes may incorporate this information into carcass prices, and this is investigated by defining additional traits marbling and lean meat yield.

MARBLING. Although there is no premium paid in Canada for any carcass quality trait, A1 and A2 carcasses must have at least “trace” marbling. Only 1% of carcasses will not meet this minimum for A1 and A2 grades (Anonymous 1992). However, only 20% of Canadian A1 and A2 carcasses

would have the "small" marbling required to meet USDA quality grades of Prime or Choice (Black and Pikering 1992; Taylor 1994).

In most applications of the model, marbling was assigned no value. But, to determine the potential economic value for marbling, Koots and Gibson (1998) apply a penalty to all carcasses falling below "small".

LEAN MEAT YIELD (LY). Lean meat yield is assessed in Canada's grading system from backfat thickness and longissimus muscle area. Currently there is no premium, but A1 and A2 grades must have more than 53% lean meat yield. More than 95% of carcasses would meet this minimum (Jones et al. 1987). To meet USDA choice in the boxed beef trade, a carcass yield grade of at least 3, corresponding to cutability of over 47.8% trimmed retail cuts (Minish and Fox 1982), would be required (Anonymous 1993). Again this minimum would easily be met by Canadian grade A1 and A2 carcasses. Therefore, in the base situation, lean yield was assigned no value. But in Koots and Gibson (1998), the potential economic value of lean meat yield is determined by setting the carcass price to levels that reflect a payment scheme for weight of lean meat only.

Profit Function

Profit per year is defined as net returns to labour and management for the constant herd size of 50 females pregnant in the fall. To simplify presentation, profit is split into that derived from each class of livestock

$$P = P_s + P_h + P_c + P_r + P_b - K$$

where P_s, P_h, P_c, P_r, P_b are returns over variable costs for steers, heifers, cows, replacement heifers and bulls, and K is fixed costs of the enterprise. The profit for each class is defined as follows:

$$P_s = (.5N\ ES\ S_1' S_2)\left(R_{CWs} - \frac{C_{ced}}{S_1' S_2} - \frac{(1+S_1')\,C_{f1}}{2\ S_1' S_2} - \frac{(1+S_2)(C_{f2}+C_{f3}+C_{hg})}{2\ S_2}\right),$$

$$P_h = (.5N\ ES\ S_1' S_2 - RR\ N)[FR_h\left(R_{CWh} - \frac{C_{ced}}{S_1' S_2} - \frac{(1+S_1')\,C_{f1}}{2\ S_1' S_2} - \frac{(1+S_2)(C_{f2}+C_{f3}+C_{hg})}{2\ S_2}\right) +$$

$$(1-FR_h)\left(R_{CWh} - \frac{C_{ced}}{S_1' S_2} - \frac{(1+S_1')\,C_{f1}}{2 S_1' S_2} - \frac{(1+S_2)(C_{f8}+C_{f3}+C_{hg})}{2\ S_2}\right)],$$

$$P_c = (1-RR)N\ S_3'\ ((1-FR_c)\ R_{CWc} - ES\ C_{cem} - C_{f4} - C_{f5}$$
$$- ES\ C_{f6} - .5(1+S_1')ES\ C_{f7} - C_{hm}) +$$

$$.5\,(1-RR)\ N(1-S_3')\ (R_{CWc} - ES\ C_{cem} - C_{f4} - C_{f5} - ES\ C_{f}$$
$$- .5(1+S_1')\ ES\ C_{f7} - C_{hm}),$$

$$P_r = RR\ N\ S_3'[((1-FR_c)\ R_{CWh}) -$$
$$\left(\frac{C_{ced}}{S_1' S_2} + \frac{(1+S_1')\,C_{f1}}{2\ S_1' S_2} + \frac{(1+S_2)(C_{f8}+C_{hg})}{2\ S_2}\right) -$$

$$(C_{f5} + C_{f9} + ES\,(C_{cem} + C_{f10}) + .5\,(1+S_1')\ ES\ C_{f11} + C_{hm})] \cdot$$

$$.5\ RR\ N(1-S_3')\ (R_{CWh} -$$
$$2\left(\frac{C_{ced}}{S_1' S_2} + \frac{(1+S_1')\,C_{f1}}{2 S_1' S_2} + \frac{(1+S_2)(C_{f8}+C_{hg})}{2\ S_2}\right) -$$

$$(C_{f5} + C_{f9} + ES\,(C_{cem} + C_{f10}) + .5\,(1+S_1')\ ES\ C_{f11} + C_{hm})],$$

$$P_b = ((N/FR)/25)\,[0.5\ R_{CWb} - C_{hm} - C_{f12} - 0.5\ C_{t=0}]$$

where components are defined as follows: N = the number of pregnant cows in the fall; and ES = embryo survival rate post-pregnancy check, which is set at 98%, based on the survey by Rogers et al. (1985) and the review by Koch et al. (1994). Because the nutrient requirements for gestation are small for the majority of a pregnancy, cows carrying embryos that do not survive were assumed to have no additional feed requirement for gestation.

FR_h, FR_c = mean fertility (probability of conception) of heifers and cows.

FR = weighted mean fertility in the herd.

S_1' = average calf survival from birth to weaning in the appropriate class of animal, which is a function of the input trait S1, the proportion of heifers in the breeding herd, the level of calving ease and the amount of crossbreeding. Calves not surviving to weaning were assumed to have died randomly during the preweaning period and incur 50% of the usual feed costs, but 100% of costs associated with calving difficulty. The dams of non-surviving calves are assumed to carry 50% of the feed costs associated with lactation.

S_2 = calf survival from weaning to slaughter, assumed fixed (non-genetic), is set to 1.0 in the base. The heifers and steers that do not survive between weaning and slaughter, incur 0.5 of the usual feed and husbandry costs.

S_3' = average cow survival per year for cows 2 to 9 yr old. Pregnant cows less than 10 yr old have 0.98 probability of survival per annum in the base situation and all cows at age 10 are culled. Of non-surviving cows, 50% are assumed to have salvage value. Non-surviving cows are assumed to incur 50% of the annual cow cost.

RR = replacement rate, defined as the proportion of pregnant cows in age class 1 (i.e., pregnant heifers), and estimated

as $1 - (FR \times S_3')$, where FR and S_3' are the expected values for the herd over 1 yr, not the observed values at pregnancy checking. The overall cow survival, S_3', includes the culling of all 10-yr old cows, and thereby differs from the input trait S3. Replacement rate, as estimated above, ensures a constant number of pregnant females and is dependent on the number of cows leaving the herd due to reproductive failure (cows culled if not pregnant after a 60-d breeding season), age (cows culled at 10 yr old), or sickness or death. The age distribution of the cow herd at equilibrium is determined using a Markov chain as described in Azzam et al. (1990). RR was determined iteratively, because it is affected by FR and S_1', which are themselves affected by average calving ease, and calving ease is in turn affected by proportion of replacement heifers in the herd. Three iterations were generally required to estimate RR to three decimal places.

C_{ced}, C_{cem} = costs associated with level of calving ease incurred by the calf and dam respectively (labour and veterinary).

C_{hg}, C_{hm} = husbandry costs (veterinary, straw and miscellaneous) in growing and mature animals, respectively. Husbandry costs are the product of non-feed variable costs ($\$ d^{-1}$) multiplied by days in feedlot (as a function of growth rate, expected liveweight @ 7 mm backfat thickness, and residual slaughter weight) for young growing animals and $ per animal per yr for mature cows and bulls.

$C_{f1} \ldots, C_{f12}$ = cost of feed used to meet energy requirements for the following classes.

1 = non-milk energy requirements preweaning for growth and maintenance,
2 = energy requirement during stocker-grower and feedlot phases for growth and maintenance,
3 = residual energy intake in growing animals,
4 = energy requirement of cows for growth and maintenance,
5 = residual energy intake in mature animals,
6 = energy requirement of cows for gestation,
7 = energy requirement of cows for lactation,
8 = energy requirement of replacement heifers for growth and maintenance from weaning to 18 mo old,
9 = energy requirement of replacement heifers for growth and maintenance from 18 to 30 mo old,
10 = energy requirement of replacement heifers for gestation,
11 = energy requirement of replacement heifers for lactation,
12 = energy requirements of bulls for growth and maintenance.

$C_{t=0}$ = cost of purchasing a bull, which is replaced after 2 yr. Salvage value is computed directly from carcass value at 30 mo old.

R_{CWc}, R_{CWh}, R_{CWc}, R_{CWb} = returns for carcass for each class, which is estimated as $LW_i \times DP_i \times (V_i - C_m)$, where LW is liveweight, DP is dressing percentage at constant finish, V_i is carcass price in $\$ kg^{-1}$ for the *i*th class (steers, heifers, cull cows and cull bulls) after carcass penalty, which is a function of liveweight and dressing percentage, and C_m is marketing costs in $\$ kg^{-1}$ carcass for feedlot animals, cull cows and cull bulls, which include check offs, commissions and trucking fees.

Detailed Description of the Model

LACTATION. Lactation is estimated on a daily basis using an inverse parabolic exponential model (Jenkins and Ferrell 1982, 1984) as $Milk_t = t/(ae^{pt})$, where $Milk_t$ is milk yield in kilograms on day *t*, *t* is day of lactation, *p* is 1/(days to peak lactation), and *a* is (days to peak lactation)/($e \times$ PM). Peak lactation yields (PM) are taken to be 0.78, 0.88, 0.96, 100 and 0.98 of the assumed value for cows in lactations 1, 2, 3, 4 to 8, and 9, respectively (Lamb et al. 1992).

GROWTH. Birth weight of steers is set to 0.0667 of mature weight (A) based on Hereford cattle data at the Elora Beef Research Centre (Fiss and Wilton 1993; Koots, unpublished data). This same value was used in the Texas A&M Cattle Production Systems (Sanders and Cartwright 1979), but is slightly higher than the range of 0.05 to 0.0625 found by Taylor (1989) across mammalian species. Birth weight of heifers is 3% lower than for steers (Woldehawariat et al. 1977).

Weaning weight of steers is predicted from PM and mature weight (A), adapted from Fox et al. (1988) as

$$WW = 87.7 + 0.202\ A + 6.04\ PM \quad (1)$$

Weaning weight for heifers is set to 0.94 of that for steers (Woldehawariat et al. 1977). Weaning weight is subsequently adjusted for fertility to account for earlier born calves being heavier at a constant weaning date.

Initial feedlot weight (IW) is the expected weight of animals at 296 d old, assuming a 91-d stocker–grower period following weaning (see below for description of growth).

Slaughter weight is the sum of that predicted based on mature weight and sex, plus residual slaughter weight as an input trait, and is at a fixed degree of maturity corresponding to optimum fat level. Marketing animals at a fat constant end point is consistent with Canada's grading system, which discounts carcasses outside the range of 4 to 10 mm backfat thickness. This level of backfat thickness corresponds to an average overall fat content of 26% of carcass weight (J. Buchanan-Smith, personal communication), occurring at degree of maturity of 0.78 (Preston 1991). Slaughter weight of steers in the model is thus taken to be 0.78A. Linear growth to slaughter was assumed, consistent with previous beef models (Wilton et al. 1974; Sanders and Cartwright 1979). Heifers are slaughtered at 0.85 of steer weight, in the mid-range of previous reports (Fox et al. 1988; Boggs and Merkel 1990; and Amer et al. 1994).

Cow weight (W_t) at age *t* days is determined by Brody's (1945) growth equation:

$$W_t = A(1 - Be^{-kt})$$

where k is the maturing rate parameter, and B is the time scale parameter. Initial estimates of A = 589 ± 4 kg and k = 0.0027 ± 0.0001 were obtained from 218 weight measurements on 103 Hereford cows collected at the University of Guelph Elora Beef Research Centre between 1980 and 1988 (a subset of data from Fiss and Wilton [1992]). The value

for B was estimated as the difference between A and the mean birth weight expressed as a proportion of A (i.e., B = (589 – 37.9)/589 = 0.936), because at t = 0, W_t = birth weight. This B value of 0.936 is similar to the range of 0.921 to 0.933 obtained for Angus cross cows by Montano-Burmudez and Nielsen (1990), whereas our estimate of k here lies outside their range of 0.0019 to 0.0022. The larger k value of 0.0027 obtained from Hereford cows at EBRC may be due to the feeding regime, which resulted in high body condition scores for these cows. Thus a k value of 0.0022 is used in the model.

ENERGY REQUIREMENTS. The net energy (NE) requirements for maintenance, growth, lactation and gestation of steers, heifers, cows and bulls are calculated as in NRC (1984), with a 15% increase in maintenance during the 205 d lactation (Ferrell and Jenkins 1985), and a 10% increase in overall energy requirement for stock on pasture (NRC 1984). Growth of cows is assumed linear between each age class. Bulls are purchased at 15 mo at 130% of steer weight (Boggs and Merkel 1990) and sold at 30 mo at 0.8595 A_{bulls} (Sanders and Cartwright 1979). Growth of bulls is assumed linear between 15 and 24 mo and between 24 and 30 mo.

Growth of young stock is assumed to be linear within the three growing periods, preweaning (birth to 205 d), grower (206 to 296 d), and feedlot (297 d to slaughter weight).

Rate of gain to weaning is obtained from the predictions of weaning weight at 205 d and birth weight. Energy requirements are first met by milk available on that day with the balance coming from a calf diet. Milk provided by the dam is assumed to be 12% DM with a ME content of 5.29 Mcal per kg DM (NRC 1988), and efficiency of ME utilization by calves was 0.828 and 0.70 for maintenance and growth (ARC 1980).

Growth rate in the feedlot phase is estimated from the equations of Fox et al. (1988):

$$FFM = NE_{mr}/NE_{ma}$$

$$DMI = W^{0.75}(0.1493NE_{ma} - 0.046NE_{ma}^{2} - 0.0196)(ADJ)$$

$$NEFP = (DMI - FFM)(NE_{ga})$$

$$WE = W(ADJ)$$

$$G = 13.91NEFP^{0.9116}WE^{-0.6837}$$

where FFM is feed required for maintenance (kg DM), NE_{mr} is Mcal of net energy required for maintenance, NE_{ma} is Mcal of net energy available for maintenance per kg dietary DM, DMI is DM intake (kg d^{-1}), W is the mean weight over the feedlot phase as determined from initial weight and slaughter weight, which are functions of mature size, consistent with mammalian size scaling rules, ADJ is used to adjust all steers and heifers to a common weight for use in a single equation for medium frame size steers (Fox et al. 1988), NEFP is Mcal of net energy in feed available for production, NE_{ga} is Mcal of net energy available for gain per kilogram dietary DM, and WE is equivalent weight.

MATING SYSTEMS. A terminal crossbreeding system using specialized sire and dam lines is modelled in addition to a purebreeding system. With crossbreeding, assuming a 50% sex ratio, the proportion of pregnant females required to produce replacement heifers is $2RR/(S_1'S_2)$, and these cows (including all the heifers) are bred to maternal line sires, while the remaining cows are bred to terminal sires. All crossbred calves and maternal breed male calves are fed for slaughter, and all maternal breed female calves are kept as replacements. In addition to the additive genetic contribution of both parents, performance of crossbred cattle included the heterosis values for each trait, taken from a survey of the literature (Koots 1994).

PREDICTING CALVING EASE WHEN CROSSBREEDING. When sire and dam genotypes differ, calving difficulty can be affected by foetal pelvis interactions (Meijering 1984). The most important factors affecting calving difficulty are birth weight (Laster et al. 1973; Smith et al. 1976) and age of dam (Smith et al. 1976). Consistent with Bourdon and Brinks (1987) mean calving ease score (as a score of 1 to 100) for crossbred herds is predicted using equations derived from EBRC data, after transforming calving ease to 100, 50, 30 and 0 for unassisted, easy pull, hard pull and surgical intervention, respectively (Tong et al. 1976), giving

First parity	CE = 74.8 – 2.2BW + 0.124DAMWT
Second parity	CE = 163.7 – 1.986BW
Third and later parity	CE = 134.2 – 1.11BW

where DAMWT is weight of the dam. These equations had coefficients of determination ranging from 0.10 to 0.23, slightly lower than the maximum values of 0.30 found in the review by Rahnefeld et al. (1990).

Given the calving ease score, the percentage of unassisted calvings, as well as the incidence of each of the remaining categories (E, H, S or M), is obtained assuming a threshold model with an underlying normal distribution and the baseline frequency distribution found in Ontario field data (Table 1). The maximum incidence of unassisted calvings is set at 97.5%, which allows for a 2.5% incidence of malpresentation, while the minimum was set at 50%. Incidence of malpresentation (backwards and breach presentations) was 5.0% in the EBRC data (Koots, unpublished data), 2.2% (Patterson et al. 1987) and 1.3% from a survey of beef herds in Ontario field data (Anderson 1989). The high incidence in the EBRC herd is likely a result of the more detailed recording in a research facility.

Base Model

MEANS, SD AND HERITABILITIES OF INPUT TRAITS. Means, SD and heritabilities assumed for each of the 16 input traits are presented in Table 2, taken from a variety of literature sources. All categorical traits are assumed to conform to a threshold model with a normal distribution on an underlying scale. The means are used to describe the base model and s.d. are used in defining changes involved in estimating economic values.

Table 1. Costs and incidences of calving ease categories

Category		Incidence[z]	Cost[y]	Description
U	Unassisted	88.7	0.00	
E	Easy Pull	8.3	6.67	2 persons for 0.33 h @ \$10 h^{-1}
H	Hard Pull	2.3	20.00	2 persons for 1 h @ \$10 h^{-1}
M	Malpresent.	0.4	78.00	1 Vet for 1 h @ \$60 h^{-1} + \$18 $call^{-1}$
S	Surgical	0.3	218.00	C-section @ \$200 + \$18 $call^{-1}$

[z]Beef Herd Improvement Program (1990).
[y]Source: C. Watson (EBRC), B. Matthew (Ontario Veterinary College, University of Guelph).

Table 2. Means, phenotypic standard deviations, and heritabilities of input traits in the base model

Trait	Mean: Dam line[z]	Mean: Sire line	SD	Heritability[y]
Mature size (kg)	589	700	59	0.50
Calving ease, cows (% unassisted)	94	67[x]	1[w]	0.13
Calving ease, heifers (% unassisted)	75	50[x]	1[w]	0.10
Cow fertility				
After unassist. birth(%)	90	–	1[w]	0.17[v]
After assisted birth (%)	76.5	–	1[w]	0.17[v]
Calf survival				
After unassist. birth(%)	96	96	1[w]	0.10[v]
After assisted births (%)	82	82	1[w]	0.10[v]
Cow survival (%)	98	–	1[w]	0.04[v]
Peak milk yield (kg d^{-1})	9.5	–	1.10	0.13
Residual post-weaning gain (kg d^{-1})	0	0	0.07	0.16
Residual feed, growing (Mcal d^{-1})	0	0	1.75	0.17
Residual feed, mature (Mcal d^{-1})	0	0	1.75	0.17
Residual slaughter wt (kg)	0	0	23	0.28
Dressing percentage @ 7 mm backfat	59	60	2.0	0.38
Marbling score	2	2	0.60	0.65
Lean yield percentage	63	63	3.0	0.63

[z]Means assumed in purebreeding systems were equal to dam line values.
[y]Mostly from Koots et al. (1994a,b) except for the following: The heritability assumed for peak milk yield is that obtained for maternal weaning weight. Cow survival heritability is based on Dekkers and Jairath (1994). Heritability of residual feed intake (RFG and RFM) was taken to be .17, which is half the value for feed intake (Koots et al. 1994a) because literature estimates of residual intake heritability (Koch et al. 1963; Korver et al. 1991) are generally half the value obtained for feed intake within the same studies. Heritability estimates for residual post-weaning gain (RG) and residual slaughter weight (RSW) were assumed to be half the weighted values obtained for post-weaning gain and slaughter weight in Koots et al. (1994a).
[x]Percentage of unassisted calvings in crossbred progeny, calculated as described in model description. Note that the mean calving ease in the herd would be 81 and 63 for cows and heifers because a proportion of herd matings are purebred matings.
[w]Traits operating under a threshold model were assumed to have a mean of zero and SD of 1 on the underlying scale.
[v]Heritabilities for binary traits are expressed on the underlying normal scale.

With purebreeding, the percentage of unassisted calvings is assumed to be 94% in cows and 75% in heifers, based on a survey of Ontario field data (Martin et al. 1989), and consistent with reports of Laster et al. (1973) and Rahnefeld et al. (1990). Although direct evidence for beef cattle is lacking, distributions of calving ease categories in Canadian dairy cattle (e.g., Cue 1990) suggest that heifers have similar distributions to, but higher incidences than cows, and this is assumed in the model.

Conception rate in heifers and in cows, after a 60-d breeding season, are assumed to be 0.81 and 0.90, respectively, taken from a survey of Ontario beef herds (Rogers et al. 1985). These are similar to the 0.80 and 0.86 obtained for heifers and cows at the EBRC (Fiss and Wilton 1989) and 0.76 and 0.89 obtained in the review by Koch et al. (1994).

Calf survival rate in Ontario field data (Martin et al. 1989) has been estimated to be 96% for calves born unassisted, and 83% for those assisted. This results in a mean survival of 93% given a mean incidence of calving difficulty of 10% (assuming a 20% cow replacement rate). This is similar to mean calf survival rates of 90.1 to 94.9% reported in several populations (Laster and Gregory 1973; Smith et al. 1976; Patterson et al. 1987; Koch et al. 1994).

Survival of cows with unassisted births was taken to be 98%, based on a survey of well-managed beef herds in Colorado (Wittum et al. 1990).

A peak milk yield of 9.5 kg d^{-1} at 42 d and a fat percentage of 4% is assumed in the base situation, following the mean values for this breed given in Fiss and Wilton (1989) and Eq. 1 above. The SD of PM is assumed to be 1.1, based on a CV of 12%, which was obtained for maternal weaning weight in Koots et al. (1994a,b).

The base value of 589 kg for mature size (A) was obtained by fitting Brody's growth curve to Hereford cows at EBRC.

Parameters for residual traits (RG, RFG, RFM and RSW) cannot be measured directly but can be estimated from component traits. The means for residual traits are set to zero in

the base situation, and SD are derived as simple functions of component traits. The SD of RG was arbitrarily assumed to be 0.07 kg d^{-1} and is about half the literature average SD of postweaning growth rate (Koots et al. 1994a,b).

The phenotypic SD of residual feed intake (RF) was estimated using EBRC data to be 1.75 Mcal d^{-1} and is somewhat higher than the 1.17 Mcal d^{-1} reported by Korver et al. (1991).

Residual slaughter weight is assumed arbitrarily to have a mean of zero and a SD equal to half of that for absolute slaughter weight.

Base values for lean percentage are 63 and 62% for steers and heifers, respectively (Jones et al. 1987). Marbling is scored in the three categories A, AA, AAA in Canada (Black and Pickering 1992) and in nine categories in the United States (Taylor 1994). Assuming an average marbling score of 2 (quality grade AA) and a SD of 0.6 results in 80% of the carcasses falling below the minimum amount of marbling required for choice grade (no marbling penalty) which is consistent with the proportions of A1 and A2 carcasses in Canada falling below this threshold (Anonymous 1992).

COSTS OF PRODUCTION DATA. Typical Ontario prices and costs are used in the base model and are detailed in Koots (1994). An important source of production costs information was the Ontario Farm Management Analysis Project reports (OMAF 1980–1991). Annual average product prices and input costs were collected over a 10-yr period (1981 to 1990) and were adjusted to 1990 dollars using appropriate price indices (Koots 1994), and are summarized in Table 3.

Husbandry costs included the costs of straw for bedding, veterinary costs, and miscellaneous (Table 3) and were charged annually on a per-cow basis in the cow-calf segment, but on a daily charge per animal in the feedlot segment. Marketing costs included check-offs, commissions and shipping fees.

Feed costs include the costs of pasture to meet the daily energy requirements of all livestock for half the year, and the costs of mixed feedstuffs (creep feed, cow winter diet and feedlot diet) used to meet the energy requirements of animals for the remainder of the year.

Pasture costs were estimated to be \$0.01658 $Mcal^{-1}$ of ME, based on trials at the Elora Beef Research Centre (Clark 1989) and costs from the Ontario Ministry of Agriculture and Food (OMAF 1980–1991). This is consistent with other estimates in the literature, such as that obtained by Lamb et al. (1992) who calculated the cost of fescue pasture in North Carolina at US\$.014 $Mcal^{-1}$ of ME.

Costs of mixed feedstuffs are based on purchased feed costs. Cows are assumed to consume a winter diet where 50% of their ME requirements (NRC 1984) are met by corn silage, and 50% by alfalfa hay (resulting in a cost of \$0.0351 $Mcal^{-1}$ of ME). Feedlot steers and heifers met their ME energy requirements from a diet consisting of 50% corn silage and 50% corn grain (resulting in a cost of \$0.0382 $Mcal^{-1}$ of ME).

The feed costs determined from NRC (1984) requirements were generally one third less than those observed in surveys of costs of production (e.g. OMAF 1980–1991; Ontario Cattleman's Association 1986–1990; Anderson et al. 1987; Little et al. 1987; Fisher 1989a,b). This inconsistency may be due 1) to errors in NRC equations, 2) to environmental influences such as temperature, disease and activity, and 3) to wasted feed. Predicted feed costs of all feedstuffs are therefore increased 50% to resemble more closely the observed costs of feeding animals in practice.

Table 3. Ten-year averages for prices and costs (in 1990 dollars)

	Costs	
	Cow-calf (\$ cow^{-1} yr^{-1})	Feedlot (\$ kg^{-1} finished animal)
Husbandry		
Straw (bedding)	10.66	0.02938
Veterinary	19.76	0.03288
Miscellaneous	14.47	0.01443
Total husbandry[z]	44.89	0.07669
Marketing	9.83	0.06478
Feed costs	(\$ $(1000\ kg)^{-1}$)	(\$ $Mcal^{-1}$ of ME)
Grain corn	116.40	0.0421
Corn silage	22.32	0.0344
Hay	60.50	0.0358
Tillable pasture	131.95[y]	0.0166
Creep/feedlot		0.0383
Cow winter diet		0.0351
	Prices	
Animals marketed	(\$ kg^{-1} liveweight)	
Steer	1.97	
Heifer	1.90	
Replacement heifer	1.90	
Cull cow	1.28	
Cull bull	1.55	

[z]Husbandry costs for feedlot animals are then expressed as \$0.155 d^{-1} given that the average liveweight of animals in the OMAF surveys was 510.9 kg after an average of 253 d on feed.
[y]\$ $hectare^{-1}$.

Fixed costs do not affect economic values in the short term and are therefore ignored in the economic values derived in the base situation. Fixed costs will be included when investigating longer term horizons and rescaling options in a companion paper (Koots and Gibson 1998).

Economic surveys of Ontario cow-calf enterprises have yielded fixed costs ranging from \$94 to \$220 per cow per year, whereas surveys of feedlots have shown fixed costs ranging from \$19 to \$118 per animal (Fisher 1987a,b; Little et al. 1987; Anderson et al. 1987; OMAF 1980–1991). The highest values were from OMAF (1980–1991) which, being the most complete analyses available, we adopted here.

Breeding is by natural mating (with a bull to cow ratio of 1:25), which accounts for up to 93% of herds in Ontario (Rogers et al. 1985). Bulls are purchased from outside the herd and are replaced every 2 yr. About 50% of the purchase price of yearling bulls is due to their weight (Northcutt et al. 1993). With an average yearling bull price of \$3000 (Canadian Cattleman's Association 1993), and a \$2 kg^{-1} price of young bulls, the purchase price is therefore determined as:

$$C_{t=0} = 1500 + (2 \times 1.3 \times W_{steers})$$

Table 4. Proportion of cows in different age classes in commercial herds

	Age class (yr)								
	2	3	4	5	6	7	8	9	10
Base model[z]	0.200	0.153	0.134	0.117	0.102	0.089	0.078	0.068	0.060
	0.213	0.160	0.136	0.117	0.100	0.085	0.073	0.062	0.053
BHIP[y]	0.210	0.154	0.131	0.505	–	–	–	–	–
Montana[x]	0.212	0.171	0.145	0.122	0.101	0.084	0.070	0.056	0.040

[z]First row is for purebreeding system, second row is for terminal crossbreeding system.
[y]118,166 calvings in Ontario between 1986 and 1991, with age classes 5 and over grouped together.
[x]From Greer et al. (1980), see text for details.

where W_{steers} is the average weight of steers at this age and 1.3 adjusts this weight to a bull basis (Boggs and Merkel 1990). The husbandry (bedding, vet services and medicine, miscellaneous) and marketing costs associated with the bulls are assumed to be the same as those for cows.

CARCASS PENALTIES. Since slaughter animals are assumed to be individually marketed at optimum backfat, no prediction of carcass grade is required in the model. Dressing percentage for cull cows and bulls is set at 53 and 56%, respectively (Minish and Fox 1982), and the base value for dressing percentage of young market animals is 59%. Fan (1988) found that at the same backfat thickness, heifers and steers do not differ in dressing percentage, and only small differences existed for marbling.

The penalties for slaughter animals at Ontario packers are –0.09, –0.045, 0, –0.045, –0.09, –0.18 and –0.22 kg^{-1}, for carcass weights of <227, 227 to 250, 251 to 341, 342 to 364, 365 to 409, 410 to 455, and >455 kg (Peter Hatsis, personal communication). The average carcass price is estimated using a threshold model to estimate the proportion of carcasses in each price category, given the mean and variance of slaughter weight and assuming a normal distribution. Average carcass prices are then expressed on a liveweight basis by multiplying by the appropriate dressing proportion.

Economic values for marbling and lean percentage are assumed to be zero in the base situation, which reflects the current marketing system for beef carcasses in Ontario. Their potential economic values under different marketing schemes are investigated in Koots and Gibson (1998).

The direct costs of calving difficulty are summarised in Table 1. Indirect costs associated with calving difficulty (all CE categories other than U) include a subsequent reduction in fertility by 15% and an increase in calf mortality of 4.5-fold. At a given average level of calving ease, the proportion of calvings falling into each calving ease category is calculated assuming a normal distribution on the underlying scale and thresholds for expression determined by the incidences given in Table 1.

Economic Values

Economic values are derived for each input trait using the base level parameters described above for two mating systems: 1) purebreeding, and 2) separate dam and sire lines in a terminal crossbreeding system. Economic values are derived by estimating the change in profit resulting from a small change in a given trait while holding all other traits constant. Each trait is altered an amount equivalent to 0.05 phenotypic SD. Threshold traits, CEDC, CEDH, CEMC, CEMH, FR, S1, and S3, are increased 0.05 SD on the underlying normal scale. Changing the mean on the underlying scale, causes changes in proportions falling into different categories and hence economic change. This approach to estimating economic values of categorical traits is similar to that used by Munoz-Luna et al. (1988) in a profit equation context. Because the relationship between expression on the underlying and the observed scales is nonlinear, an increase of 0.05 SD usually caused less change than a decrease of 0.05 SD, but differences are small over this relatively small change in level of expression.

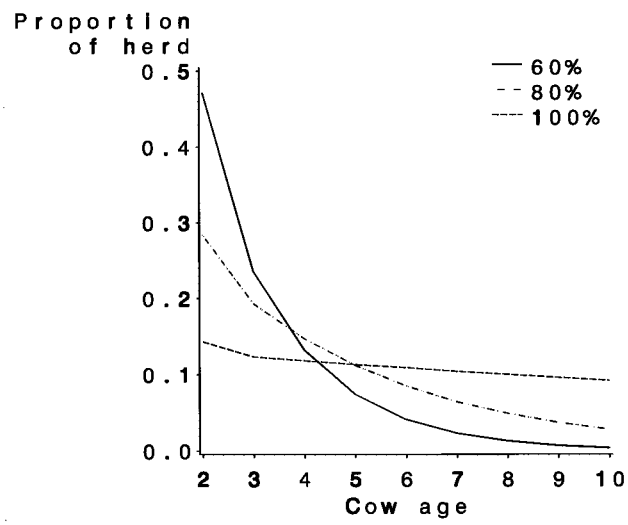

Fig. 1. Effect of conception rate in a 60-d mating period on cow age distribution (with culling of non-pregnant cows).

RESULTS AND DISCUSSION

MODEL TESTING. In general, the performance of animals generated by the model is consistent with experimental results reported in the literature and with performance data available from EBRC or the Beef Herd Improvement Program (BHIP), as shown in Koots (1994). As an example, the predicted distribution of cows in each age class agrees with the age distribution found in Ontario field data (Koots, unpublished BHIP data, representing 118,166 calvings over the period 1986 to 1991) and in 34 yr of data collected at the

Table 5. Summary of returns and costs in a purebreeding system[z]

			Repl. heifers			
	Steer	Heifer	Culled	Calving	Cow	Bull
Numbers of animals						
Number at calving	24.5	24.5		10.0	40.0	2.3
Number at weaning	23.2	23.2		10.0	40.0	2.3
Number died				0.2	0.8	
Number marketed	23.2	11.0	2.2	2.0	10.0	1.2
Avg. wt (kg)	459	391	405	478	574	759
Dressing %	59	59	59	53	53	56
Returns						
Carcass price ($ kg^{-1})	3.34	3.22	3.22	2.42	2.42	2.75
After penalty ($ kg^{-1})	3.33	3.17	3.21	2.41	2.41	2.59
Carcass value ($ animal^{-1})	902	730	758	611	732	1102
Costs ($ animal^{-1})						
Husbandry	32.14	31.28	58.98[y]	44.09	44.89	44.89
Marketing	29.76	25.30	26.14	30.89	37.09	49.19
Profit ($)	13,390	5,775		–5,625	–7,854	–2,511
	Ps	Ph		Pr	Pc	Pb
	Ps + Ph + Pc + Pr + Pb = 3,175			K = 15,348		

[z]Predicted average performance of animals in a purebreeding system are given in Appendix Tables 1 to 4.
[y]Husbandry costs of replacement heifers is higher due to an extra feeding period of 91 d.

Table 6. Summary of costs and returns for a crossbreeding system[z]

	Purebred		Crossbred		Repl. heifer			Bull	
	Steer	Heifer	Steer	Heifer	Culled	Calving	Cow	A=589	A=700
Numbers of animals									
Number at calving	11.3	11.3	13.2	13.2		10.7	39.3	1.09	1.27
Number at weaning	10.7	10.7	12.4	12.4		10.7	39.3	1.09	1.27
Number died						0.2	0.8		
Number marketed	10.7	0	12.4	12.4	2.5	2.9	10.7	.55	.63
Avg. wt (kg)	459	391	518	440	405	478	572	759	902
Dressing %	59	59	59.5	59.5	59	53	53	56	56
Returns									
Carcass price	3.34	3.22	3.34	3.22	3.22	242	2.42	2.75	2.75
After penalty ($ kg^{-1})	3.33	3.14	3.30	3.17	3.19	2.41	2.41	2.59	2.53
Carcass value ($ animal^{-1})	902	730	1027	838	758	611	730	1102	1279
Costs ($ animal^{-1})									
Husbandry	32.23	31.39	34.99	33.61	58.98	44.89	44.89	44.89	44.89
Marketing	29.76	25.30	33.55	28.51	26.20	30.89	37.04	49.19	58.46
Profit ($)	6,156	0	8,104		6,028	–5,978	–7,529	–1,183	–1,483
Subtotals			14,259	6,028	–5,978	–7,529	–2,667		
			Ps	Ph	Pr	Pc	Pb		
	Ps + Ph + Pc + Pr + Pb = 4,114				K = 15,348				

[z]Predicted average performance of animals in a crossbreeding system are given in Appendix Tables 5 to 8.

Livestock and Range Research Station in Montana (Greer et al. 1980) as shown in Table 4. The effect of fertility on cow age distribution is shown in Fig. 1. Herd production and profit predictions are presented for a purebreeding system in Table 5 and for terminal crossbreeding in Table 6. To generate each of these tables, the base input traits from Table 2 and costs and returns from Table 3 were used.

ECONOMIC VALUES. Economic values for a purebreeding system as well as for separate sire and dam lines in a terminal crossbreeding system are presented in Table 7 for the base set of parameters given in Tables 2 and 3. These economic values are expressed in dollars per genetic s.d. per cow, which gives the best indication of the relative potential for economic change in each of the traits through genetic selection.

Table 7. Estimated economic values for input traits for the base situation under 1) a purebreeding or rotational crossing system, 2) a dam line and 3) a sire line

Trait		Economic value[z]		
		Purebreeding	Dam line	Sire line
A	Mature size (kg)	3.62	–1.33	3.24
CEDC	Calving ease, cows - d (% U)	3.81	6.49	4.56
CEMC	Calving ease, cows - m (% U)	3.81	10.98	.00
CEDH	Calving ease, heifers - d (% U)	2.77	2.91	1.44
CEMH	Calving ease, heifers - m (% U)	2.77	4.33	.00
FR	Cow fertility (%)	14.72	18.56	.00
S1	Calf survival (%)	17.53	18.11	9.43
S3	Cow survival (%)	3.72	4.24	.00
PM	Peak milk yield (kg d^{-1})	.45	.46	.00
RG	Residual post-weaning gain (kg d^{-1})	2.14	1.68	.70
RFG	Residual intake, growing (Mcal d^{-1})	–13.21	–9.74	–4.65
RFM	Residual intake, mature (Mcal d^{-1})	–12.41	–12.20	.00
RSW	Residual slaughter wt (kg)	4.42	2.68	1.13
DP	Dressing percentage	13.58	9.08	4.86
MR[y]	Marbling score	0.00	0.00	0.00
LY[y]	Lean meat yield (%)	0.00	0.00	0.00

[z]\$ σ_g^{-1} cow^{-1}.
[y]economic values for situations with payment on MR and LY are presented in Koots and Gibson (1998).
U = unassisted, d = direct; m = maternal.

The economic values presented in Table 7 vary across systems primarily due to the different numbers of expression in the two mating systems modelled. In the terminal crossbreeding system, for example, CEMC, CEMH, FR, S3, PM and RFM have a zero economic value in the sire line because these traits are only expressed in cows at the commercial level. In the present model no effect of these traits on costs and returns in the pure sire-line herd is accounted for, but this can be accommodated by adjusting the price of breeding bulls for differences in maternal costs. In the base situation, the price of bulls is only adjusted for liveweight.

The economic values shown in Table 7 can generally be explained by examining the costs and returns derived by the model, summarized in Tables 5 and 6 for purebreeding and terminal crossbreeding systems. For example, increasing mature size by 0.05 SD in the purebreeding system results in slightly more returns to the enterprise ($56), due to heavier market weights of steers and heifers, than increased costs ($43), due to feeding the larger cows in the herd.

The economic value for mature size in the purebreeding system, \$3.62 per σ_g, can be shown to be consistent with the values of \$–1.33 and \$3.24 per σ_g obtained in the dam and sire lines used in a terminal crossing system. The increase in profit of $56 for 36.4 market animals in the purebred system (Table 5) indicates that improvement is worth about $1.54 per animal. In the dam line of a crossbreeding system, increasing mature weight causes decreased cow returns of –$43 (as in the purebreeding system), as well as 25.6 expressions of market animals (assuming that about half of the herd was bred to a terminal sire), yielding total net returns of $25.6 \times 1.54 - 43 = -\$3.58$. This gives an approximate economic value for mature size of $(-3.58/50) \times 20 \times h^2 = -\$1.43$ per σ_g, which is similar to the value obtained from the model (\$–1.33 per σ_g). Similar checks of consistency of results can be undertaken for the remaining traits, and only calving ease traits, fertility, and cow and calf survival do not conform to this pattern.

The higher economic value of calving ease traits in the crossbreeding system is due to the lower incidence of unassisted calving in the crossbreeding system compared to the purebreeding system (0.81 versus 0.94 for cows, and 0.63 versus 0.75 for heifers) and the higher costs of calving ease at this level.

The economic values for fertility and cow survival are higher in the crossbred system than would be expected based on the values in the purebreeding system and frequency of expressions alone. This arises because the crossbreeding system is 25% more profitable than the purebred system and therefore any change that results in more market animals has a larger impact on the crossbreeding system.

The economic value of calf survival is also higher in the crossbreeding system than would be expected based on the value obtained in the purebred system. This is due to the higher incidence of calving difficulty in the crossbred system. When the effect of calving difficulty on calf survival was removed from the model, the economic value for calf survival was \$42 per σ_g in the purebred line and \$24 and \$13 per σ_g in the dam line and the sire line of the crossbred system, as would be expected from differences in the expected frequency of expressions.

Overall, calf survival (S1), Cow fertility (FR), residual feed intake traits (RFG, RFM) and dressing percentage (DP) are of prime importance in the base purebreeding system. Calf survival (S1) here, has a slightly different definition than it would in most studies providing heritability estimates (Koots et al. 1994a). In the present study, S1 is defined as calf survival from unassisted calvings. It was assumed that heritability of calf survival here, was similar to estimates in the literature where survival of all calvings in a given population generally make up the data.

Under a terminal crossbreeding system, S1, RFG, RFM and DP again showed the most potential for economic change from genetic selection, but these traits ranked differently in importance for the two breed roles. Calving ease is

an important trait in both systems when one considers all of its expressions (CEDH, CEMH, CEDC, CEMC). The value of each of these calving ease traits differ from each other, which justifies obtaining partial economic values for each.

With the exception of peak milk yield, all traits have a non-trivial economic value and simplifying the aggregate genotype by eliminating traits is not recommended. Peak milk yield was the least important trait economically, suggesting that the cost of gain in nursing calves (biologically inefficient, but based on inexpensive pasture), is similar to that of post-weaning (when feed is more expensive, but does not have to be processed through the dam). Weaning weight, as an indicator trait for milk yield, is the most frequently recorded trait in beef cattle populations (Koots et al. 1994a) and it is likely substantial selection in beef cattle populations has been practiced for increased weaning weights at the expense of improvement of economically more important traits.

Previous estimates of economic values for beef production traits do not include values for residual intake traits, which were here found to be two of the most important traits economically. Also, previous economic values often fail to account for all costs incurred in producing beef, usually being based on either cow-calf production (Kolstad 1993) or a feedlot enterprise (Amer et al. 1994).

MacNeil et al. (1994) estimated economic values for an integrated system in Western Canada, but a simpler model was used than here. Economic values for four of the same traits as evaluated here (cow weight, female fertility, calf survival and dressing percentage), were presented for specialized dam and sire lines as well as for a general purpose population using commercial data. Taking a general purpose population as an example (M2 in Table 3 of MacNeil et al. [1994]), the economic value reported for cow weight was \$–0.33 kg^{-1} versus \$0.09 kg^{-1} here. These estimates are not directly comparable because mature size here includes the economic effects of component traits such as weaning weight, and postweaning gain. MacNeil et al. (1994) derived separate (and positive) values for these component traits. The economic value for dressing percentage agree well in the two studies (\$11.17 per % versus \$11.02 per %). The economic value for cow fertility was \$3.73 per % in MacNeil et al. (1994) versus \$2.10 per % obtained here. The higher value for cow fertility in MacNeil et al. (1994) seems to be due to differences in the herd structures modelled. In MacNeil et al. (1994) an increase in fertility results in a greater proportion of the cows calving and this results in more market animals sold. In the present model, an increase in cow fertility changes the age structure of the herd, not the number of animals marketed, because the herd size is kept constant at 50 pregnant females, which is a more realistic representation of industry structure. The reason for the difference between the economic value for survival here, \$6.72 per %, versus the \$3.45 per % reported in MacNeil et al. (1994) is less obvious, but is also likely due to differences in the structure of the model. In the present model, calf survival, cow fertility and calving ease affect each other, and subsequently the replacement rate and age structure of the herd. The model of MacNeil et al. (1994) appears to ignore these interactions.

Amer et al. (1994) reported economic value for average daily gain, feed intake, dressing percentage and fat depth for feedlot enterprises in Canada. In the present model, the economic value for mature size includes changes in profit due to component traits, such as average daily gain and feed intake. The across breed average economic value of dressing percentage in Amer et al. (1994) was \$8.40 per steer per 1% of the mean, which corresponds to \$9.44 per animal per 1% of the mean in the terminal line here (taking the economic value \$2.34 per 1% of the mean pregnant cow bred, with 12.4 expressions of the sire genotype in the base crossbred herd (Table 6) with 50 cows). Thus, these two models give similar results despite the model of Amer et al. (1994) being of only the feedlot portion of the production system. Amer et al. (1994) only considered costs associated with feedlot traits and allowed animals to be marketed at differing backfat thickness. It was argued that the optimum end point depended on the genotype (early versus later maturing). In the base model here all feedlot animals are slaughtered at 7 mm backfat. Sensitivity of economic values to changes in management from the base model, such as marketing at earlier or later end points is investigated in Koots and Gibson (1998). It is worth noting here that in our model with slaughter at constant backfat, variation in residual slaughter weight is driven by variation in backfat deposition rates after accounting for mature size.

Bourdon and Brinks (1987) reported economic values for an integrated range beef production system using a revised version of the Texas A&M Cattle Production Systems (Sanders and Cartwright 1979). Again, direct comparisons of economic values are difficult given the different production systems and different definition of breeding objectives. But Bourdon and Brinks (1987) speculated that traits affecting survivability will have important effects on overall economic efficiency, based on the importance of birth weight in their model. Here, calf survival was found to have the highest economic value, supporting Bourdon and Brinks (1987).

Generally, previous models of beef production have focused on estimation of economic values for components of overall growth, such as growth rate to a constant age. The identification of the driving role of mature size here leads to a more complete accounting of the costs and values of the components of growth. This leads to the result that many traits are of greater economic importance than growth components such as mature size and residual growth rate. Although optimum selection indexes have not been constructed here, it seems clear that current recording and selection practices for beef cattle are generally far from optimum.

APPLICATION OF ECONOMIC VALUES. The traits considered here would form the aggregate genotype when constructing a selection index. Economic values, presented in Table 7, could be used for selection indices for intensive beef production systems such as those found in Eastern Canada, but also many European countries. Genetic correlations would be required between the 14 traits in the aggregate genotype and traits chosen for the index. Unfortunately, estimates for several of the residual traits are not yet available in the literature. Alternatively, if genetic evaluations for traits in the

aggregate genotype were available, these could be combined directly with economic values (Wilton, 1982). Presently, genetic evaluations are not available for any of the traits in the aggregate genotype. Computing genetic evaluations for some residual traits, however, is possible under current recording programs because the component traits are often recorded. Residual feed intake in growing animals, for example, could be determined from measurements of growth, liveweight and feed intake. These traits are already being recorded in some bull test stations in Ontario (J. Wilton, personal communication). Other residual traits could similarly be determined from component traits.

CONCLUSIONS

The approach to bioeconomic modelling of integrated beef production developed here provides useful insights in to which biological traits are of economic importance in genetic improvement and why they are important. Under intensive production, such as those found in Eastern Canada and many European countries, calf survival, fertility, calving ease, residual feed intake and dressing percentage are of principal importance, which is markedly different to what is generally being emphasised in beef cattle breeding today. In general, most of the 16 traits examined here have non-trivial economic values and must be considered when developing recording programs and selection criteria.

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Appendix Table 1. Predicted average performance of cows in a purebreeding system[z]

		Heifer	Cows	Mean
Calving ease (%U)		75	94	
cost ($)		6.23	0.86	
Fertility		0.780	0.892	0.868
Calf survival		0.925	0.952	0.946
Prop. bred to Terminal sire		n/a		
Avg. peak milk yield (kg d^{-1})		7.4	8.8	
Cow age distribution:	Age class		Prop	Wt
	2		0.200	478.7
	3		0.153	539.6
	4		0.134	566.9
	5		0.117	579.1
	6		0.102	584.6
	7		0.089	587.0
	8		0.078	588.1
	9		0.068	588.6
	10		0.060	588.8
Avg. cow age (not incl heifers)			4.6 yr	
Avg. cow wt (not incl heifers)			573.5 kg	
Avg. wt gain (3 to 10 yr olds)			19.1 kg $annum^{-1}$	
Energy requirements:			Mcal	$
Avg. req for maint	pasture		2,936	48.68
	winter		2,800	147.25
Avg. req for gain	pasture		176	2.91
	winter		184	9.96
Avg. req gestation	pasture		33	0.55
	winter		451	23.73
Avg. req lactation	pasture		1,054	17.48
	winter		696	36.61
Sub totals	pasture		4,150	68.80
	winter		4,091	215.11
Total			8,241	283.9

[z]Base values for input traits are from Table 2 and costs and returns are from Table 3.

Appendix Table 3. Predicted average performance of breeding bulls in a purebreeding system

Number of breeding bulls		2.3	
Avg. bull cost (purchase)		$2,694.49	
Avg. bull wt @ 1 yr (kg)		597.2	
Avg. bull wt @ 2 yr (kg)		708.6	
Avg. bull wt @ 30 mo (sold) (kg)		759.4	
bull req		Mcal	$
	pasture	4,174	69.21
	winter	4,118	216.53
	pasture	4,576	75.86
	Total for 18 mo	12,868	361.60
	Avg. per yr	8,579	241.07

Appendix Table 4. Predicted average performance of calves in a purebreeding system

	steer		heifer	
BW (kg)	39.3		38.1	
WW (kg)	261.6		246.0	
ADG1 (kg d^{-1})	0.56		0.36	
IW (kg)	312.4		278.3	
ADG2 (kg d^{-1})	1.26		1.01	
DOF (d)	116.7		111.2	
SWT (kg)	459.4		390.5	
Source	Mcal	$	Mcal	$
Milk	852	n/c	738	n/c
Creep	310	17.81	333	19.11
Pasture	1,503	24.93	1,578	26.17
Grower	1,432	53.18	1,193	44.22
Feedlot	2,862	164.18	2,398	137.58
Total	6,108	260.10	5,502	227.08

Appendix Table 2. Predicted average performance of replacement heifers in a purebreeding system

		Maintenance & gain		Gestation		Lactation	
Age		Mcal	$	Mcal	$	Mcal	$
birth	milk	738	n/a				
	creep	333	19.11				
	pasture	1,578	26.17				
	grower	1,193	44.22				
	winter	2,477	137.58				
15 mo	pasture	3,525	58.45	33	0.55		
	winter	3,513	184.76	451	23.73	589	30.97
	pasture	2,793	46.31			892	14.79
30 mo	Subtotal	16,150	516.60	484	24.28	1481	45.76
Total		18,115	$586.64				

Appendix Table 5. Predicted average performance of cows in a crossbreeding system[z]

Cows bred to:		Purebred sire (A = 589 kg)			Terminal sire (A = 700 kg)		
		Heifer	Cow	Mean	Heifer	Cow	Mean
Calving ease (%U)		75	94		50	67.4	
cost ($)		6.23	0.86		20.41	9.55	
Fertility		0.780	0.892	0.867	0.763	0.873	0.849
Calf survival		0.925	0.952	0.946	0.917	0.942	0.936
Prop. bred to terminal sire							0.54
Avg peak milk yield (kg d^{-1})		7.4	8.8				
Cow age distribution	Age class	Proportion	Wt				
	2	0.213	478.7				
	3	0.160	539.6				
	4	0.136	566.9				
	5	0.117	579.1				
	6	0.100	584.6				
	7	0.085	587.0				
	8	0.073	588.1				
	9	0.062	588.6				
	10	0.053	588.8				
Avg. cow age (not incl heifers)		4.5 yr					
Avg. cow wt (not incl heifers)		572.8 kg					
Avg. wt gain (3 to 10 yr olds)		20.0 kg $annum^{-1}$					
Energy requirements:		Mcal	$				
Avg. req for maint	pasture	2,933	48.63				
	winter	2,798	147.11				
Avg. req for gain	pasture	85	3.06				
	winter	194	10.19				
Avg. req gestation	pasture	35	0.59				
	winter	482	25.36				
Avg. req lactation	pasture	1,051	17.43				
	winter	694	36.49				
Sub totals	pasture	4,152	68.85				
	winter	4,123	216.85				
Total		8,276	285.69				

[z]Base values for input traits are from Table 2 and costs and returns are from Table 3.

Appendix Table 6. Predicted average performance of replacement heifers in a crossbreeding system

		Maintenance & gain		Gestation		Lactation	
Age		Mcal	$	Mcal	$	Mcal	$
birth	milk	738	n/a				
	creep	333	19.11				
	pasture	1,578	26.17				
	grower	1,193	44.22				
	winter	2,477	137.58				
15 mo	pasture	3,525	58.45	33	0.55		
	winter	3,513	184.76	451	23.73	589	30.97
	pasture	2,793	46.31			892	14.79
30 mo	Subtotal	16,150	516.60	484	24.28	1481	45.76
Total		18,115	$586.64				

Appendix Table 7. Predicted average performance of breeding bulls in a crossbreeding system

	(A = 589 kg)		(A = 700 kg)	
Number of bulls	1.09		1.27	
Avg. bull purchase price	$2,694.49		$2,919.60	
Avg. bull wt @ 1 yr	597.2 kg		709.8 kg	
Avg. bull wt @ 2 yr	708.6 kg		842.1 kg	
Avg. bull wt @ 30 mo	759.4 kg		902.5 kg	
Bull requirements	Mcal	$	Mcal	$
Pasture	4,174	69.21	4,978	82.54
Winter	4,117	216.53	4,928	259.12
Pasture	4,576	75.86	5,439	90.18
Total 18mo	12,867	361.60	15,345	431.83
Avg. per yr	8,578	241.07	10,230	287.89

Appendix Table 8. Predicted average performance of calves in a crossbreeding system

	Purebred				Crossbred			
	Steer	Heifer			Steer	Heifer		
BW (kg)	39.3	38.1			44.3	42.9		
WW (kg)	261.4	245.8			285.7	268.6		
ADG1 (kg d^{-1})	0.56	0.36			0.67	0.48		
IW (kg)	311.6	277.5			337.7	302.6		
ADG2 (kg d^{-1})	1.26	1.01			1.33	1.09		
DOF (d)	117.4	112.0			135.2	126.3		
SWT (kg)	459.4	390.5			517.8	440.1		
Source	Mcal	$	Mcal	$	Mcal	$	Mcal	$
Milk	849	n/c	735	n/c	849	n/c	714	n/c
Creep	309	17.75	331	19.03	398	22.18	426	24.45
Pasture	1,498	24.83	1,572	26.05	1,764	29.25	1,857	30.80
Grower	1,430	53.08	1,191	44.13	1,540	56.42	1,297	48.10
Feedlot	2,874	164.87	2,411	138.34	3,714	213.04	3,099	177.77
Total	6,111	260.53	5,505	227.56	7,416	2321.51	6,679	281.11