Proc. Assoc. Advmt. Anim. Breed. Genet. 23:47-50

EXPERIENCES WITH NON-LINEAR ECONOMIC VALUES IN SELECTION INDEX DESIGN

C.D. Quinton[1], P.R. Amer[1], T.J. Byrne[2], J.A. Archer[1], B. Santos[1], F. Hely[1]

[1]AbacusBio Limited, 442 Moray Place, PO Box 5585, Dunedin 9058, New Zealand
[2]AbacusBio International, Roslin Innovation Centre, Midlothian EH25 9RG, United Kingdom

SUMMARY

In breeding objectives, linear economic values (LEV) are typically applied because they are effective and easy to implement. However, LEVs can be over-simplifications for some traits in diverse populations that span a wide range of economic and biological conditions. We have been helping an increasing number of breeding programs by applying non-linear economic value functions (NLEV). Although NLEV are more complex to implement in breeding objectives, they can provide more specific and robust trait and therefore overall index valuation. We describe experiences applying NLEV for prolificacy, wool quality, dystocia, and maternal ability in sheep and cattle breeding objectives.

INTRODUCTION

Most animal breeding objectives and selection indexes are built as linear functions. For example, a linear selection index that estimates individuals' total merit in units of currency is defined as $I = \Sigma(b_i \times \hat{g}_i)$, where, for each trait *i*, the individual's trait value in units of currency is the trait weighting common to all individuals (b_i, index weight) multiplied by the individual's estimated genetic value for that trait ($\hat{g}_i$, e.g. EBV). The individual's index value *I* is then the sum of all trait values.

However, many traits have non-linear relationships between genetic values and trait values caused by complex market signals or biological limits. A classic example is where carcass sale price ($/kg) has an intermediate optimum relationship with fat cover: below- and above-optimum levels earn reduced prices. Non-linear economic value functions (NLEV) and selection indexes have been discussed in scientific literature (see Martin-Collado *et al*. 2016), but rarely implemented in practice. Commonly, breeding objectives apply a linear economic value (LEV) and index weighting that reflects the population mean genotype; i.e. b_i = partial derivative of a non-linear function at the population mean. When the breeding objective is periodically reviewed, the LEV is updated in accordance with the population mean. This approach is effective for selection and genetic change on a large population scale (e.g., Goddard 1983) and furthermore is simple to configure in genetic evaluation systems, and straightforward to report to users.

A crucial limitation to LEVs as approximations of non-linear value functions is that for diverse populations that span a wide range of economic or biological conditions, LEVs can result in genotypes at the extremes of the distributions being severely over- or under-valued for that trait. This has further implications for multi-trait breeding objectives if it causes individuals to rank highly only because of that trait while being merely average for others. For these reasons, an increasing number of genetic evaluation systems are applying NLEVs in breeding objectives and selection indexes.

NON-LINEAR ECONOMIC VALUE FUNCTIONS

For NLEV, a full function is defined that describes the relationship between individuals' genotype and profitability. The function form may be a simple quadratic or exponential, or more complex combined function. The full range of available genotypes need to be considered to ensure that the function properly values extreme genotypes. Ideally, the function should represent industry conditions, yet be robust and easy to code into genetic evaluation systems.

A primary outcome of implementing NLEV in a selection index is that relative trait weightings within the index depend on the individual's genotype and its location on the function. This is described further in examples below.

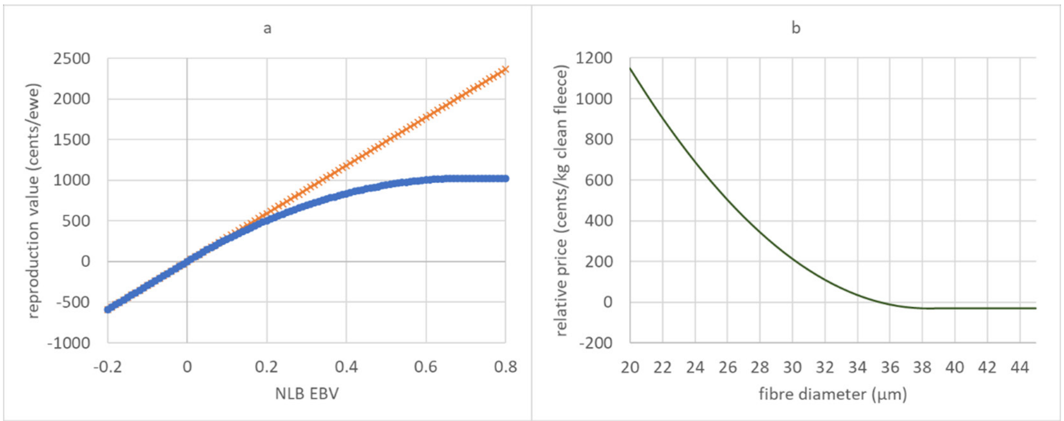

Figure 1. Illustrations of economic value functions. (a) Sheep reproduction value linear (×) and non-linear (●) functions. (b) Wool adult ewe fibre diameter non-linear relationship with relative price

Sheep prolificacy. In 2017, the New Zealand national sheep evaluation system implemented a NLEV for number of lambs born per litter (NLB) in the NZMW maternal index (https://www.sil.co.nz/files/151191893412.pdf) which includes reproduction, growth, survival, and wool sub-indexes. Previously, the index applied a LEV for NLB which was based on the national population mean. Although the population mean is below optimum, there is a wide diversity of prolificacy genotypes in the evaluation so that many individuals have substantially above-optimum genotypes. These individuals were over-valued for reproduction under the linear system, with the outcome that many high-prolificacy rams would achieve top index ranking due to their NLB EBV while having only average EBVs for other index traits such as growth.

A NLEV was developed to better value high prolificacy genetics (preliminary function described by Quinton *et al*. 2017). The function (Figure 1a) is composed of 3 parts: at low prolificacy individuals' value (cents) increases linearly up to the population mean NLB EBV; from mean to optimum NLB, value increases in quadratic fashion with diminishing gains; then above the optimum, a flat "capped" value is imposed so all genotypes receive the same value. Therefore, average rams' reproduction values remained similar, but very high prolificacy rams' values were capped and therefore full NZMW index ranking differences amongst these became due to their genotypes for other traits. Thus, NLB has less influence on the full index value at high prolificacy levels.

This non-linear then flat function has been demonstrated to be the most efficient approach to value an intermediate optimum trait in a multi-trait selection index, when the population mean is below and close to optimum (Martin-Collado *et al*. 2016). From a full index perspective, this approach is predicted to mitigate the risk of highly prolific genetics badly overshooting optimum NLB, while improving selection response in other traits.

Wool fibre diameter. The NZMW index also includes a wool sub-index, which currently values fleece weights, but a recent industry survey revealed substantial interest in valuing crossbred wool quality traits including fibre diameter. A NZ wool sale price analysis (unpublished) quantified the well-known non-linear relationship of fibre diameter with price (c/kg). At stronger micron range (35µm+), micron has little effect on price. However, at finer microns (33-35μm), some price premiums are awarded. The premiums become greater as fleeces move to the mid-micron and finer ranges. Because of these differing relationships, a single LEV for fibre diameter is not suited for the diversity of wool in NZ. The conventional approach of calculating separate LEVs and therefore separate breeding objectives for categories of sheep based on typical fibre diameter ranges has drawbacks: multiple ranking systems are confusing to users who will be considering ram purchases across a wide fibre diameter range; and also incorrectly values individuals that are at the borders of these categories.

A NLEV for fibre diameter (Figure 1b) has been proposed featuring high values for finer micron, with a quadratic curve of decreasing values over medium and stronger microns (<38μm). The lowest (base) wool price occurs. At ≥38μm, all are assigned the base price. This approach is suited to the greater price premiums (c/kg fleece) awarded to mid-micron and finer wool types, compared to crossbred and strong wool types. Therefore, the same function can be used to value fibre diameter in all NZ crossbred and mid-micron breeds and separate breeding objectives are not required for each type.

Dystocia. Dystocia is typically a categorically observed phenotype with an underlying normal distribution of birthing ease genotypes that results in proportions of a population falling into observed categories. With an economic value defined as the change in profit per unit change in population EBV, then a non-linear relationship between profit (costs) and genotype emerges as the population mean shifts. Distinct category costs (e.g. labour, veterinary, and potential replacement costs) may also contribute to non-linearity.

A survey of Irish beef and dairy farmers (Martin-Collado *et al*. 2017) and a recent American Angus industry survey (unpublished) showed that farmers are prepared to tolerate a small amount of dystocia, but as herd dystocia levels rise this trait is considered to be increasingly problematic. The American Angus trait preference survey also revealed that farmers' opinions of the relative importance of calving ease within the full breeding objective depends on their herd's current levels.

We have helped develop NLEV for dystocia in breeding objectives for American Angus and for an Irish index aimed at selecting beef bulls to mate to dairy cows. In both cases, the NLEV implements a high cost of differentiation at high levels of dystocia, with diminishing marginal benefits as genetic values for dystocia improve. Therefore, bulls with poor dystocia have a larger penalty applied, meaning that fewer of these will appear on leading index lists; conversely, bulls with exceptionally low dystocia (i.e. less than required by most producers) are unlikely to appear on leading lists based on this trait alone.

Maternal ability. In the American Angus beef industry survey mentioned above, respondents judged that the trait weaning weight maternal (WWM, aka maternal ability or "milk") was over-valued at the higher range. Similar to NLB, farmers opinion was that increased WWM is desirable up to a point, but then in environments where feed has high availability to cows or supplements can be provided increased WWM has no further value. In harder environments with low feed availability, over-optimum WWM is considered a liability as high milk cows lose condition and subsequent fertility. For this trait, an intermediate optimum NLEV was built that incorporated survey results of farmers reported lower and upper thresholds of accepted WWM breeding values.

PRACTICAL CONSIDERATIONS FOR IMPLEMENTION

NLEV are more complex than linear EV and therefore do present some challenges for implementation in large-scale breeding objectives.

First, the genetic evaluation program software needs to be adapted to incorporate the NLEV and calculate individual trait values. Most evaluation software code is designed to apply a single linear index weighting coefficient per trait; therefore, experts are required to program NLEV and test index value calculations.

Genetic evaluation systems also must recognize that individual trait values calculated with NLEV are more sensitive to changes in the genetic base definition. A change in the EBV will change any individual's location on the NLEV which may also cause re-ranking.

We have found NLEV most practical if incorporated into modular breeding objective where each trait economic value fully and independently quantifies revenues and costs associated with the trait. E.g. a three-trait index containing a non-linear trait weighting may be described as follows: $I = (b_1 \times \hat{g}_1) + (b_2 \times \hat{g}_2) + f(\hat{g}_3)$, where the individual's trait values for traits 1 and 2 are calculated in the usual linear approach, but where the trait 3 value is calculated according to NLEV. With this modular perspective, NLEV can be substituted for LEV or added on to conventional linear breeding objectives. This modular approach is increasingly useful as breeding programs add new traits (e.g., health and welfare, environmental, novel genomics).

Predicting selection response with NLEV requires different approaches than conventional linear indexes. Most breeding methodologies and software are built around linear breeding objectives and prediction methods use linear regressions, assuming normal distributions. However, NLEVs can skew distributions, especially if values are capped as in the sheep prolificacy function. In these cases, it is preferable to evaluate potential selection intensity and response by analysing real genetic evaluation data sets and calculating trait mean EBVs of selected individuals. For longer-term predictions, stochastic simulations could be employed.

Our experiences with NLEV are that users (breeders, farmers using GE to select animals) are generally very receptive to the concept because the resultant individual animal trait values and rankings tend to better reflect industry realities and their preferences for selection candidates. However, additional education is required for extension services and users who are familiar with reports formatted for simple linear index coefficients. Similarly, for users who are used to pie or bar charts to illustrate relative trait emphases within an index, education is needed to understand how NLEV can shift relative importance of traits.

CONCLUSIONS

Non-linear economic value functions and selection indexes have been well discussed in breeding objective theory, but until recently rarely implemented genetic evaluation systems. Although NLEVs are more complex to apply, these functions are flexible solutions for valuing genetics in diverse populations and our experience is that they are typically very well received by industry stakeholders.

ACKNOWLEDGEMENTS

The authors thank Angus Genetics Inc. and the American Angus Association, Beef+Lamb New Zealand Genetics, and the Irish Cattle Breeding Federation for their contributions.

REFERENCES

Goddard M.E. (1983) *Theor. Appl. Genet.* **64:**339.

Martin-Collado D., Byrne T.J., Visser B., and Amer P.R. (2016) *J. Anim. Breed. Genet.* **133:**476.

Martin-Collado D., Hely F., Byrne T.J., Evans R., Cromie A.R, and Amer P.R. (2017) *Animal* **11:**318

Quinton C., Byrne T., and Amer P. (2017) *Proc. Assoc. Advmt. Anim. Breed. Genet.* **22:**94.