EVALUATION OF ALTERNATIVE SELECTION INDEXES FOR NON-LINEAR PROFIT TRAITS APPROACHING THEIR ECONOMIC OPTIMUM

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SUMMARY

This paper presents a simulation which evaluates the performance of alternative selection index configurations in the context of a breeding program where traits with non-linear economic value are approaching an economic optimum. The simulation described uses a simple population structure that approximately mimics selection in dual purpose flocks in New Zealand, where number of lambs born is believed to be approaching an optimum, while other genetically correlated traits with linear economic values are assumed to not be approaching any economic optimum. A "non-linear below the optimum and then flat" approach to index formulation was found to be at least comparable in efficiency to the approach of regularly updating the linear index with short (15 year) and long (30 year) time frames, especially when the current average value of the "non-linear" trait is at a reasonable distance from the optimum. Use of a non-linear index that is efficient may have other benefits in highly heterogeneous industries (breeds and production environments) such as the New Zealand sheep industry.

INTRODUCTION

Number of lambs born (NLB) is a key trait that has delivered significant economic value from genetic improvement to the New Zealand sheep industry to date. However, its genetic improvement might be reaching an economic optimum above which further increases are not desirable, because of an increase in costs that would decrease the profitability of animals. There is therefore a need to define a selection index which could hold traits such as NLB at their optimum levels, while focusing selection on other traits which are not approaching any economic optimum.

The predominant view among theoretical livestock geneticists, that has not been revised for a number of years, is that when faced with a non-linear profit function for one or more traits, the best approach is to still use linear selection indexes as they are optimal when regularly updated (Goddard 1983; Meuwissen and Goddard 1997; Dekkers and Gibson 1998). However, when the trait average is near the optimum or when profit functions are extremely non-linear, linear selection indexes would be unsatisfactory (Goddard 1983; Dekkers and Gibson 1998). Furthermore, Meuwissen and Goddard (1997) showed that non-linear indexes can approach the response achieved by linear indexes while not requiring any updating. Nevertheless, there are more options which, to our knowledge, have never been tested: for example use of a non-linear index before the optimum and then "flat", i.e. the marginal economic value is assigned a value of zero.

The aim of this study is to the compare the effect of alternative selection index approaches on the genetic change in a trait with non-linear economic value, approaching its economic optimum, and traits with linear economic value. The efficiency of the selection indexes is measured in terms of genetic progress achieved in the population and in economic benefits achieved in the short, medium, and long-term.

METHODS

The model simulates 30 generations of a population of 1000 males and 1000 females. Two genetically correlated (0.07) traits were simulated: one trait with a non-linear economic value (T_{NL}, h^2=0.1) and the other one with a linear economic value (T_L, h^2=0.25). Genotypes for the animals in the base population were simulated from a random normal distribution N (0, $\sqrt{h^2}$). Phenotypes and genotypes of the base population and subsequent generations were simulated using standard approaches as described by Hely *et al.* (2012). In each generation estimated breeding values (eBVs) were calculated by applying alternative selection index functions (described below) to their phenotype. The best 20% of the males born in each year are selected to become sires in the next generation. Conversely, for dams an aging process was simulated. In the base population females were assigned randomly to one of three cohorts (age groups). In each year the oldest dam cohort was culled and replaced by the best females born from the previous year. Dams and sires were randomly mated. One offspring was simulated for each unique parent mating type. Then, the economic performance of the selection approach was calculated by applying the profit functions (described below), to the average population phenotypic value of T_{NL} and T_L. The economic performance is given as discounted profit to express the profit of future generations at present value with a discount rate of 0.07 per year.

Profit functions. Profit functions defined the true economic merit of the individuals and were used to quantify the economic performance of alternative selection approaches at population level. They consisted of a linear function for T_L and a non-linear function (quadratic) for T_{NL}. Two profit functions were defined which differed in the distance of the T_{NL} optimum to the initial population T_{NL} average (T_{NL}=0): (1) a "close to the optimum" profit function that had the optimum at T_{NL}=2, and (2) a "distant to the optimum" function that had the optimum at T_{NL}=4. T_{NL} optimum values where arbitrarily defined so that the optimum values were reached in the time frame considered (30 years) when applying some of the selection index functions evaluated.

Selection index functions. The selection index functions always gave T_L a constant linear weighting. The weighting approach for T_{NL} defined the four alternative selection index functions evaluated:

Linear index. The T_{NL} component is linear, with the linear slope value calculated as the partial derivative of the profit function at the initial population mean.

Linear index updated periodically (LUP index). The T_{NL} component is linear but the slope of the linear function is updated (each 3 or 5 years) to match the slope of the T_{NL} non-linear profit function being used.

Non-linear index. The T_{NL} component is non-linear and is identical to the corresponding T_{NL} profit function being used.

Non-linear then flat index (NLTF index). Before the optimum, the T_{NL} component is non-linear and is identical to the corresponding T_{NL} profit function being used. After the optimum the marginal economic value takes a value of zero. Thus, animals with eBVs below the optimum are penalised, while animals with eBVs at or above the optimum are not penalised.

RESULTS AND DISCUSSION

Table 1 presents the economic performance of the alternative selection indexes evaluated with the two profit functions for selecting for T_L and T_{NL}. Figure 1 shows the evolution of the population average T_L and T_{NL} phenotypic values and of the discounted profit when the profit function is set so that the T_{NL} optimum was distant from the initial population value.

Linear selection indexes are initially the fastest way to increase average T_{NL} and reach the optimum but since they continue selecting above the optimum they ultimately become counterproductive. This selection pressure on T_{NL} reduces the selection space for T_L which is therefore not heavily selected for.

LUP indexes are more efficient than Linear indexes since while they still achieve a fast improvement of T_{NL} before the optimum, once the population average reaches the optimum they stop selecting for T_{NL}. However, since the same index is applied to all the individuals in the population, once the population average reaches the optimum, individuals below the optimum are not penalised which results in a loss of some selection potential for T_{NL}.

Non-linear selection indexes decrease the rate of response as the population gets close to the optimum and negatively select those individual above the T_{NL} optimum. Therefore, the non-linear selection indexes do not allow the population to surpass the optimum. Animals at either extreme from the optimum are not considered as selection candidates, even though with relatively balanced selection of animals at both extremes, the population mean would not move away from the optimum. These effectively excluded candidates are not considered for selection on T_L and therefore the potential selection on T_L is not fully realized. The selection pressure on the non-linear trait, when close to the optimum, is not very intense so the rate at which the non-linear index approaches the optimum is slower than linear selection indexes.

A **NLTF index** achieves a selection speed before the optimum intermediate to the linear selection indexes and the pure non-linear indexes, leaving more selection space to the T_L than linear selection indexes. After the optimum the NLTF keeps on penalizing for T_{NL} all those animals below the optimum, while those animals above the optimum are not negatively selected for T_{NL}, allowing them to be selected for T_L.

Table 1. Cumulative discounted profit achieved by applying alternative selection indexes

Trait with non-linear profit function	Period (years)	Selection indexes				
		Linear	Linear 3-year update	Linear 5-year update	Non-linear	Non-linear then flat
Close to optimum	1-10	12.4	14.9	14.2	10.1	**15.8**
	1-15	16.2	26.6	24.9	18.4	**27.4**
	1-20	13.4	**38.1**	35.1	26.4	26.4
	1-25	4.6	**48.4**	44.1	33.5	44.7
	1-30	-8.5	**57.2**	51.7	39.4	50.5
Distant from optimum	1-10	16.6	17.0	17.0	14.8	**18.1**
	1-15	28.1	30.6	30.4	26.8	**32.7**
	1-20	36.4	43.5	43.1	38.2	**46.2**
	1-25	41.1	55.1	54.5	48.2	**57.8**
	1-30	42.3	64.9	64.3	56.5	**67.3**

CONCLUSION

NLTF selection indexes are the most optimal indexes to select for traits with non-linear economic values in the short and mid-term when the average population is relatively close to the optimum (Table 1). After that period it becomes less profitable than the updated linear selection indexes because the negative profit, due to the T_{NL} average population value being far above the optimum, is not offset by the better selection for T_L. However, when the optimum profit is set to be relatively distant from the current T_{NL} average population value, the NLTF selection index is the most profitable of all the indexes assessed for the time span evaluated. There could well be other advantages of the NLTF selection approach. For example, a single index of this makeup could be applied across a wide diaspora of breeds and flocks differing in their current level of merit for the non-linear trait. In the New Zealand sheep context, breeder flocks with low average genetic merit for NLB would have a high weighting applied to NLB, while those with average merit at or beyond the economic optimum would not. However, there are also some challenges for the implementation of an index with a NLTF selection function. The simple multiplication of eBVs by known economic weights, to produce a selection index, is lost for the non-linear trait when NLTF selection approach is applied. This has the potential to create a communication and extension challenge for index users. Consideration will also need to be given to the base value for the non-linear index.

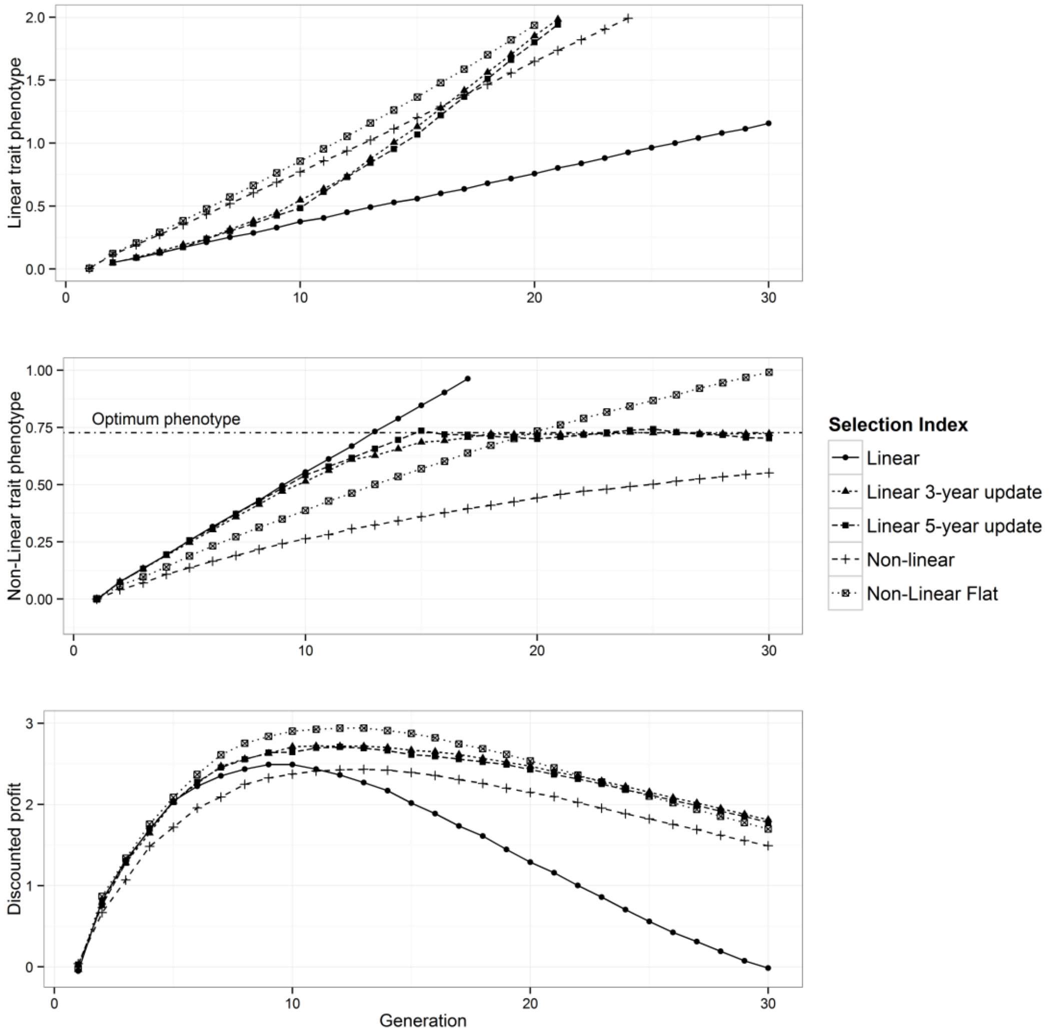

Figure 1. Evolution of average population phenotypic value of the traits with non-linear and linear economic value when selected on the alternative selection indexes. Case of profit function with distant optimum for the non-linear trait.

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