WEIGHTING BREEDING OBJECTIVES

- AN ECONOMIC APPROACH -

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INTRODUCTION

In the last forty years there have been two phases in the development of statistical procedures for selecting animals in breeding schemes.

In the first phase, animal breeding organisations distinguished between the primary objective, secondary objectives, and unimportant objectives. A selection index was designed for the primary objective. A.I. organisations used selection indices for milk production such as the Relative Breeding Value (McArthur 1954). Secondary objectives were included in the selection decision by imposing constraints at lower culling levels. (Holmes and Wilson 1984). Unimportant objectives were ignored. The limitation of this approach is that it does not make explicit the economic importance of secondary objectives.

In the second phase, computers reduced dramatically the cost of data storage and retrieval making it possible to adopt the multi-objective selection index developed for plant breeding by Fairfield Smith (1936). With a multi-objective selection index all records on all traits from all relatives including the individual's records can be used to predict its economic breeding value (Cunningham 1969). A vector of m economic values are required if there are m worthwhile traits for improvement. These are used to derive index weights to apply to each record for each trait in order to maximise the correlation between the selection index and the animal's economic breeding value.

Hazel (1943), who first applied a multi-objective selection index to animals, defined the relative economic value of a trait as

"... the amount by which net profit may be expected to increase for each unit of improvement in that trait".

This definition makes the reasonable assumption that the objective of animal breeding is to increase net profit. A typical procedure for deriving economic values was used by Morris et. al. (1982) which follows this definition. They used partial budgeting to find the addition to net profit which would accrue from a unit increase in each trait for a typical ewe.

Information from market prices of stud stock is an alternative to partial budgeting for deriving economic values. For instance stud stock breeders use prices of stud stock to weight various traits in judging breeding values. Market prices ought to reflect marginal social benefits but unfortunately the stud stock market has some serious imperfections which are mostly due to lack of information at the time of transaction (McArthur (1982)). As recording schemes become more elaborate and estimates of each animal's breeding value for each trait become available at stud stock sales, more confidence will be placed on prices at these sales for estimating economic values.

An indirect method of finding farmer's willingness to pay for various traits has been used by Wickham (1979). By using least squares analysis, he derived relative economic weights for traits-other-than-production from decisions dairy farmers make as to whether to keep or cull their cows.

However both these behavioural approaches use the responses of the current generation of farmers. This is open to the criticism that, from the national point of view, this generation of decision makers may be socially myopic and underestimates long run social benefits which are the promise of animal improvement.

In estimating the addition of profit from a unit increase in a trait, Ladd and Gibson (1977) have used linear programming to derive economic values for backfat, feed efficiency, and average daily gain in pigs. The programme was run using typical prices, average levels for each trait, representative input-output coefficients and technical constraints. Using parametric programming they determined the sensitivity of net profit to a phenotypic standard deviation change in each of the three traits. The reason for using an optimising technique - linear programming in this case - was to measure the net profit from using a better animal when the best decisions are made for exploiting its superior genotype.

A rather different approach has been proposed by Smith, James, Brascamp (1986). Their measure of economic value is the change in profit from a unit change in a trait less the change in profit which would follow from a larger rescaled enterprise with the same change in output but running unimproved animals. This implies that the enterprise was not being run previously at the profit maximising level of output. Their method has some difficulties for general application.

This paper redefines economic value for use in a selection index and proposes a general method of deriving it. The procedure is amplified with an example using a production function to find an economic value. A comparison is made with the Smith-James-Brascamp method of deriving an economic value.

CHANGE IN OPTIMAL NET PROFIT

In this paper it will be assumed that the livestock industry is interested essentially in increasing net profit and that, in the long run, managers tend to be maximisers. In Western countries there is an increasing trend towards a business perspective amongst farmers. An implication is that farmers will alter their managerial decisions to make the most profitable use of improved genetic material. It follows that the impact on net profit of a unit change in a trait includes not only the direct effect of the improvement under the set of decisions used for an unimproved animal but also the effect of the new set of decisions used to exploit the improved animal.

Revising Hazel's definition, this paper defines the economic value of a trait as

"the amount by which net benefit of the optimal policy may be expected to increase for a unit of improvement in that trait".

This definition provides the rationale for Ladd and Gibson's use of an optimising technique for deriving economic values.

Two examples will help explain this definition. Before improvement for disease resistance, a breed of egg-producing birds are replaced yearly. Annual replacement is more profitable than biennial replacement because disease afflicts older birds. After selection for disease resistance, biennial replacement becomes more profitable than annual replacement because replacement costs are spread over two years. Using the above definition for an improved animal, the gain in net profit from selection is the net profit of the improved disease-resistant birds replaced using the optimal biennial policy **minus** the net profit of the unimproved disease-susceptible birds replaced using the optimal annual replacement policy. To measure the gain in net profit under an annual replacement policy both before and after selection is to assume that egg producers will not exploit their improved disease-resistant birds by shifting to the optimal policy of replacement every-other-year.

For a second example, a cow's milk production can be raised by one kilo by selection if she is milked for what was the most profitable number of days. However, if it now pays best to milk such an improved cow for another day raising output by say a further half a kilo, this should be included in the change in profit.

A GENERAL MODEL FOR ECONOMIC VALUES

Following the definition in the last section of economic value of a unit change in a trait, this section describes a very general model for finding them.

Let π_0 be the initial net benefit before the trait is changed. This may be annual profit if the analysis is at the farm level. At the national level for the farming system it will be benefit less cost using some appropriate numeraire.

$$\pi_0^* = f(D_0^*, A, T) \quad (1)$$

where: D_0^* is a vector of optimal decision variables before improvement. A is a vector of parameters including prices, input-output coefficients, and technical constraints which are held constant. T is a vector of trait variables set at existing levels. π_0^* is optimal profit resulting from applying the vector of optimal decisions.

For the i^{th} trait the t-value in vector T is increased by a small amount Δt_i. A new vector of optimal decisions D_i^* is found which results in the maximum net benefit π_i^*. The economic value for the i^{th} trait, v_i is

$$v_i = (\pi_i^* - \pi_0^*)/\Delta t_i \quad (2)$$

These v - values can be expressed per animal by dividing through by the number of animals or be simply expressed as relative economic values.

Any one of a number of optimising methods could be used to find the best set of decision variables ranging from simple partial budgeting, through differential calculus and mathematical programming to simulation. Differential calculus is used in the application to follow and then

$$v_i = \partial\pi^*/\partial t_i \quad (3)$$

ECONOMIC VALUE FOR MILKFAT

An intensively farmed New Zealand dairy farm with a single decision variable (the number of cows per 100 ha) provides an instructive example of the application of equation 3. In this case the selection objective is to raise milkfat per cow. Following Wright and Pringle (1983), production per cow is a declining linear function of x; the number of cows per 100 ha. Because the number of cows is an input variable, production function terminology will be used. Average production per cow in kilos is the same as Average Product.

$$AP = a + bx \quad (4)$$

where a is positive and b is negative $|b|$ is the amount by which production per cow declines through the addition of another cow on the 100ha farm. Selection for production per cow is assumed to shift a but leave b unchanged so that a kilo increase in production per cow will result in an Average Product of $(a+1)+ bx$.

To find the economic value of milkfat, the change in optimal profit at the optimal stocking rate needs to be determined. This will be done firstly when there is no constraint on output of milkfat from the farm, and secondly where output is constrained by a quota.

Total Product is a function of x, the number of cows.

$$TP = ax + bx^2 \quad (5)$$

and Total Revenue where p is the price of milkfat per kilo is

$$TR = p(ax + bx^2) \tag{6}$$

Net Revenue π is the TR less costs which are the product of the number of cows and a constant cost per cow of c. c is really the price of the input.

$$\pi = (pa - c)x + pbx^2 \tag{7}$$

Value of the Marginal Product is the first derivative of Total Revenue with respect to the number of cows.

$$VMP = pa + 2pbx \tag{8}$$

Setting VMP equal to the price of the input (c in this case) and solving for x gives the optimal value for the decision variable x^* which is the only element in D_0^* of equation 1.

$$x^* = (c - pa)/2pb \tag{9}$$

If the farm runs the optimal number of cows, optimat profit π^* will be

$$\pi^* = (pa - c)x^* + pbx^{*2} \tag{10}$$

The economic value for milkfat is the first derivative of optimal profit with respect to a. Substituting equation 9 into 10 and simplifying results in

$$\pi^* = ac/2b - pa^2/4b - c^2/4pb \tag{11}$$

Economic Value v as in equation 3 is

$$v = d\pi^*/da = (c - pa)/2b \tag{12}$$

This change in net profit for a unit change in milkfat includes the adjustment in cow numbers to the optimal level for the genetically improved animals. It is a function of the output price p and the input price c as well as the technical parameters a and b. The marginal revenue could be used instead of the output price where appropriate.

Next, change in optimal profit will be found when Total Product is constrained to a quota of Q which becomes the LHS of equation 5. Profit will be maximised by producing at the quota level. The number of cows needed to produce the quota Q is x'

$$x' = (-a + (a^2 + 4bQ)^{1/2})/2b \tag{13}$$

If production per cow rises there will have to be a reduction in the number of cows to remain within the quota Q. This is dx'/da which will be negative

$$dx'/da = (a(a^2 + 4bQ)^{-1/2} - 1)/2b \tag{14}$$

This downward adjustment in cows will result in a saving of c for each cow not carried. Hence the constrained change in profit for a unit improvement in milkfat per cow, $d\pi'/da$, is

$$d\pi'/da = -c\ dx'/da = (c - ac(a^2 + 4bQ)^{-1/2})/2b \quad (15)$$

A comparison of this equation for constrained economic value under a quota with an unconstrained economic value from equation 12 shows that constrained economic value in equation 15 is a function of input price c and technical parameters a and b but does not include output price p.

Obviously the use of output constrained economic values will not reflect the willingness of the consumer to pay different prices for different products - lamb versus wool, milkfat versus solids-not-fat versus beef and so on. Constrained economic values should not be used in economies where the consumer is sovereign.

Table 1 compares economic values under quotas of 52 500 kg and 56 000 kg with an unconstrained economic value at the optimal number of cows.

TABLE 1 - ECONOMIC VALUES*

Constraint	No of Cows	Average Product	Econ Value	Econ Val/x
Q	x	Eq 4	$d\pi/da$	$1/x\ d\pi/da$
52 500	350(1)	150	$ 656(3)	$1.9
56 000	400(1)	140	$1000(3)	$2.9
none	456.25(2)	128.75	$1825(4)	$4.0

*Parameter Values a = 220, b = -0.2, c = $150, p = $4.

Notes: (1) = Eq 13, (2) = Eq 9, (3) = Eq 15, (4) = Eq 12.

Points to notice about Table 1 are:

1) Constrained economic values under quotas are lower than this unconstrained economic value measured at optimal cow numbers.

2) As the constraint is lightened so the constrained economic values rise.

COMPARISON WITH RESCALING

It is appropriate to compare the method of estimating economic values used here with the method suggested by Smith, James, and Brascamp (1986). In describing their method in which output was rescaled, they used a linear production function in that the number of animals could be increased without any falloff in output per animal. This is an unlikely scenario when other inputs are fixed. Average Product is

$$AP = a \qquad (16)$$

$$TP = ax \qquad (17)$$

$$\pi = (pa - c)\ x \qquad (18)$$

This net revenue function has no optimum. The unconstrained economic value at any level of x is

$$d\pi/da = px \qquad (19)$$

and the economic value per animal is p. In otherwords a unit change in output per animal is equal to its product price.

If Total Product is constrained by a quota of Q, the enterprise can only run Q/a animals and the maximum net revenue is

$$\pi^* = (pa - c)\ Q/a \qquad (20)$$

The constrained economic value for v is

$$d\pi^*/da = cQ/a^2 = cx/a \qquad (21)$$

which is c/a per animal. In other words the constrained economic value of a unit of extra production per animal is simply the cost per kilogram of Average Product.

Rescaling using Smith-James-Brascamp (S-J-B) economic values produces the same result. Net revenue in equation 18 if average product rises by 1 unit becomes

$$\pi_1 = (\ p(a+1) - c)\ x \qquad (22)$$

Total product will be equal to (a+1)x. This Total Product could alternatively have been produced with unimproved animals producing only a, if the enterprise was rescaled so that it ran (a+1)x/a animals. This rescaling is possible because AP is not affected by the number of animals. In other words returns are not diminishing.

Net Revenue from the rescaled enterprise is

$$\pi_2 = (pa - c\ )\ (a+1)x/a \qquad (23)$$

The authors argue that to measure the true effect of a unit change in a it is necessary to remove the effect of a change in output though why this should be is not explained. Removing the effect of the change in output results in a S-J-B economic value of

$$\pi_1 - \pi_2 = cx/a \qquad (24)$$

which again is c/a per animal.

With a linear production function, an S-J-B output rescaled economic value measures output constrained economic value as in equation 21. It ignores output prices and thus the consumer's willingness to pay and, because there is no optimum, any gains from decisions exploiting better animals are ignored.

The arguments in favour of using S-J-B economic values or output constrained economic values are not clear. However the effects of government intervention on agriculture may explain why some favour them.

In wealthy industrialised countries it is normal to support the welfare of rural people by raising the prices of agricultural products above their world market levels. The practice of imposing quotas on producers prevents the growth of surpluses which are otherwise dumped on world markets. Thus the use of S-J-B or output constrained economic values which are lower than unconstrained values (See Table 1) might seem at first sight to be appropriate for farms which are output constrained.

However farmers protected from the realities of the market may be wise to assume that the political power of the minority rural interest will wain in this era of food abundance and that, in the long run, countries will trade in agricultural products in the same way they trade in other goods and services. In designing selection indexes for improving stock for state aided farmers there is a case for the trait to determine economic value.

An application to a New Zealand dairy farm showing diminishing returns to cow numbers amplifies the above approach. Unconstrained economic values are a function of input and output prices together with technological parameters. When output is constrained by a quota, economic values do not reflect output prices.

For a linear production function an output rescaled economic value is the same as a quota constrained economic value. Even though a government may impose quotas on its producers, neither output constrained nor S-J-B economic values are recommended. In estimating unconstrained economic values it is better to use world or border prices which, in the long run, are more likely to reflect social costs and benefits.

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