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Are economic selection indices always superior to a desired gains index?

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Introduction

Gibson and Kennedy (1990) discussed the use of desired gains selection indices in applied breeding and concluded that any restricted selection index should be avoided for economic selection because of its inefficiency. They also stated that the aim of their study was not to question the various methods proposed for deriving restricted selection indices but rather to question whether, except in the case of experimental laboratory animal breeding, constrained indices should have a role in applied breeding. However, several points need to be discussed before their conclusion can be accepted. The objectives of the present note are (1) to compare the efficiencies of economic and desired selection indices under various economic conditions, and (2) to examine economic returns by two alternative indices when a profit equation is non-linear with an intermediate optimum.

Source of data and methodology

As Gibson and Kennedy (1990) presented their argument based on the numerical example given by Yamada et al. (1975) the same data are also used in this paper. Table 1 gives phenotypic (**P**) and genetic (**G**) variance-covariance matrices taken from Yamada et al. (1975) after correcting for the genetic relationship of full sibs ($r_G = 0.5625$ instead of 0.50 in the original paper) and for typographical errors in Gibson and Kennedy (1990).

The methodology pertaining to the derivation of the selection indices for a desired gains index was presented by Yamada et al. (1975) and is given in more detail by Itoh and Yamada (1988a).

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Computation and results

First I would like to discuss briefly the derivation of economic weights (**v**) and index weight (**b**) by Gibson and Kennedy (1990) in ordery to elucidate the issue more clearly. In the numerical example, the derived index is composed of EW (egg weight, g), EP (part record of egg-production rate, %) and BW (body weight, 10 g) to improve EF (full year record of egg-production rate, %), FC (feed requirement, x10) and EW. The order of the elements in the vector **v** is EF, FC and EW, while those in **b** are EW, EP and BW, respectively.

The economic wieghts for EF, FC and EW in the economic index given by Gibson and Kennedy (1990), under Canadian market conditions for feed and eggs, are:

$$\mathbf{v}'_{GK} = (0.6029), -1.6733, -0.8111) \quad (1)$$

and the derived economic index is:

$$\mathbf{b}'_{GK} = (-0.0633, 0.3211, 0.0094). \quad (2)$$

On the other hand, Yamada et al. (1975) derived their desired gains index to attain the breeding goal $\mathbf{k}' = (8, -3, 0)$ for EF, FC and BW in a population in which population averages of these traits were EF = 65%, FC = 28, EW = 58.0 g, and obtained the following index:

$$\mathbf{b}'_{Y} = (0.3890, 0.9352, -0.4314) \quad \text{with} \quad \sigma = 8.8489 \quad (3)$$

either from $\mathbf{b} = (\mathbf{G}')^{-1}\,\mathbf{k}$ or $\mathbf{b} = \mathbf{P}^{-1}\,\mathbf{G}(\mathbf{G}'\mathbf{P}^{-1}\mathbf{G})^{-1}\mathbf{k}$.

To compare the efficiencies of these two indices, equations (2) and (3), Gibson and Kennedy (1990) derived economic weights in retrospect for the numerical example of Yamada et al. (1975) as:

$$\mathbf{v}'_{Y(GK)} = (0.0025, -1.6733, -0.2525) \quad (4)$$

$$\mathbf{b}'_{Y(GK)} = (0.0251, 0.0603, -0.0278) \text{ with } \sigma = 0.5680 \quad (5)$$

Table 1 Variance-covariance matrices for illustration. The abbreviated symbols of the trait are: EF = full-year egg production rate, FC = feed requirement, EW = average egg weight, and BW = body weight

$$\mathbf{P} = \begin{array}{c} \\ EW \\ EP \\ BW \end{array} \begin{array}{ccc} EW & EP & BW \\ \end{array} \begin{bmatrix} 16.000 & 1.533 & 28.800 \\ 1.533 & 25.625 & -1.125 \\ 28.800 & -1.125 & 324.000 \end{bmatrix}$$

with rows and columns EW, EP, BW;

$$\mathbf{G} = \begin{bmatrix} -7.5895 & -1.0199 & 8.0000 \\ 11.7116 & -1.3778 & 2.6143 \\ 0 & 3.0547 & 12.8798 \end{bmatrix}$$

with rows EW, EP, BW and columns EF, FC, EW.

by solving $\mathbf{b}=\phi\mathbf{P}^{-1}\mathbf{G}(\mathbf{G}'\mathbf{P}^{-1}\mathbf{G})^{-1}\mathbf{k}$ and $\mathbf{v}=\phi(\mathbf{G}'\mathbf{P}^{-1}\mathbf{G})^{-1}\mathbf{k}$, where ϕ is a constant (see Itoh and Yamada 1988a). Equation (3) and (5) did not appear in Gibson and Kennedy (1990).

Because the number of traits in the breeding goal and that in the selection index are the same, we can derive economic weights in retrospect directly from $\mathbf{v}=(\mathbf{G}'\mathbf{G})^{-1}\,\mathbf{G}'\mathbf{P}\mathbf{b}$ as:

$$\mathbf{v}'_{GK(Y)}=(-0.0391,\ -25.3960,\ -3.9136). \qquad (6)$$

Equations (4) and (5) given by Gibson and Kennedy (1990) are proportionally equal to equations (6) and (3), respectively, in this study, because in Gibson and Kennedy (1990) $\phi=0.0645$ was used whereas $\phi=1$ is employed in this paper for deriving (6).

The efficiencies of the two indices, (2) and (3), were compared by Gibson and Kennedy (1990) in terms of aggregate economic return ($\Delta\mathbf{H}$) per generation, applying a selection intensity of one standard deviation. The expected selection gains in EF, FC and EW by the two indices were obtained by

$$\Delta\mathbf{G}=(i/\sigma)\mathbf{G}'\mathbf{b} \qquad (7)$$

in which i, the selection intensity factor is equal to unity. Thus we obtain:

$$\Delta\mathbf{G}'_{GK}=(3.007,\ 0.080,\ -1.441) \qquad (8)$$

$$\Delta\mathbf{G}'_{Y}=(0.909,\ -0.341,\ 0), \qquad (9)$$

which are identical to the values presented in Table 1 of Gibson and Kennedy (1990). Expected economic genetic gains were calculated from $\Delta\mathbf{H}=\mathbf{v}'_{GK}\,\Delta\mathbf{G}$.

Gibson and Kenndey (1990) stated that the desired gains index gave only 39% of the economic genetic gain achievable by the economic index in terms of equation (1). However, the logical problem is that of comparing $\mathbf{b}_E$ and $\mathbf{b}_D$, derived from $\mathbf{b}_E=\mathbf{P}^{-1}\ \mathbf{G}\mathbf{v}$ and $\mathbf{b}_D=\mathbf{P}^{-1}\,\mathbf{G}(\mathbf{G}'\mathbf{P}^{-1}\mathbf{G})^{-1}\,\mathbf{k}$, in terms of $\Delta\mathbf{H}$, to get $\mathbf{v}_{Y(GK)}=(\mathbf{G}'\mathbf{P}^{-1}\mathbf{G})^{-1}\,\mathbf{k}$ (equation 6). If the breeding goal is defined as a linear function, $\mathbf{b}_E$ should be the most efficeint one, because the index was derived to optimize the correlation between H and i. But, if the profit function is non-linear, the situation is different. It is not easy to evaluate the efficiency of the selection index unless we do iterative evaluation. This problem has been discussed by Itoh and Yamada (1988b). The two indices in question were constructed to achieve entirely different objectives, one to maximize $\Delta\mathbf{H}$ and the other to attain $\mathbf{k}$ in the shortest possible time for the three traits. If the comparison between these two indices were feasible, an alternative comparison between the two indices in terms of desired gains in retrospect would also be acceptable, which results in $\mathbf{k}''_E=(8.50,\ 0.23,\ -4.08)$, in contrast to $\mathbf{k}'_D=(8,\ -3,\ 0)$. This implies that the breeder wants improvement by changing egg-production rate, at the expense of egg weight, with a slight increase in feed requirement, which would not be accepted by most breeders. This comparison would not be justified unless a common definition of aggregate economic gains is used.

It is therefore instructive to compare the efficiencies of the two indices using some common objective. One such basis is 'income over feed cost' (IOFC), which has been in use as the official poultry random sample test worldwide.

Under market conditions in Japan, the current wholesale egg price is ¥216 per kg and feed cost is ¥40 per kg, which gives a profit equation of:

$$\mathbf{P}=216(365EF*EW)-40(365EF*EW*FC')$$

$$=365EM(216-40FC') \qquad (10)$$

where EM and FC′ are respectively, the average daily egg output (EM = EF*EW) in kg and feed conversion (FC′ = FC/10). Substituting the population averages of EF = 65%, FC′ = 2.8 and EW = 0.058 kg, taken from Yamada et al. (1975) at generation 0, we obtain $\mathbf{P}$ = ¥1,431. Next, substituting equation (8) and (9) into equation (10), the IOFC at generation 1 would be ¥1459 for the economic index selection and ¥1470 for the desired gains index selection, demonstrating that the desired gains index can produce greater profit (¥39) than the economic index (¥28). This situation reverses the conclusion of Gibson and Kennedy (1990). However, this does not mean that desired gains index is superior in general to the economic index, because neither index was optimized with respect to the profit equation (10).

In addition, equation (10) does not accurately reflect the effect of egg size. As Kempthorne and Nordskog (1959) described, egg weight in poultry has an optimum size, the optimum is 58–60 g in our market. Values above and below this range result in some reduction in price per kg. The profit equation can, therefore, be modified to be:

$$\mathbf{P}=365EM\{216[1-(EW-60)^2/1000]-40FC'\} \qquad (11)$$

In this example the optimum egg weight is taken as 60 g rather than the range of 58–60 g. Now assume derivations from 60 g are penalized by the square of the difference. This squared diviation is divided by 1000 to adjust the degradation rate of the price. This makes the price of 55-g eggs to be ¥ 5.4 less per kg than that of 60-g eggs.

Under this condition, the aggregate economic breeding value for an economic selection index may be expressed in a linear form as:

$$\mathbf{H} = v_{ECGEF} + v_{FC}G_{FC} + v_{EW}G_{EW} \quad (12)$$

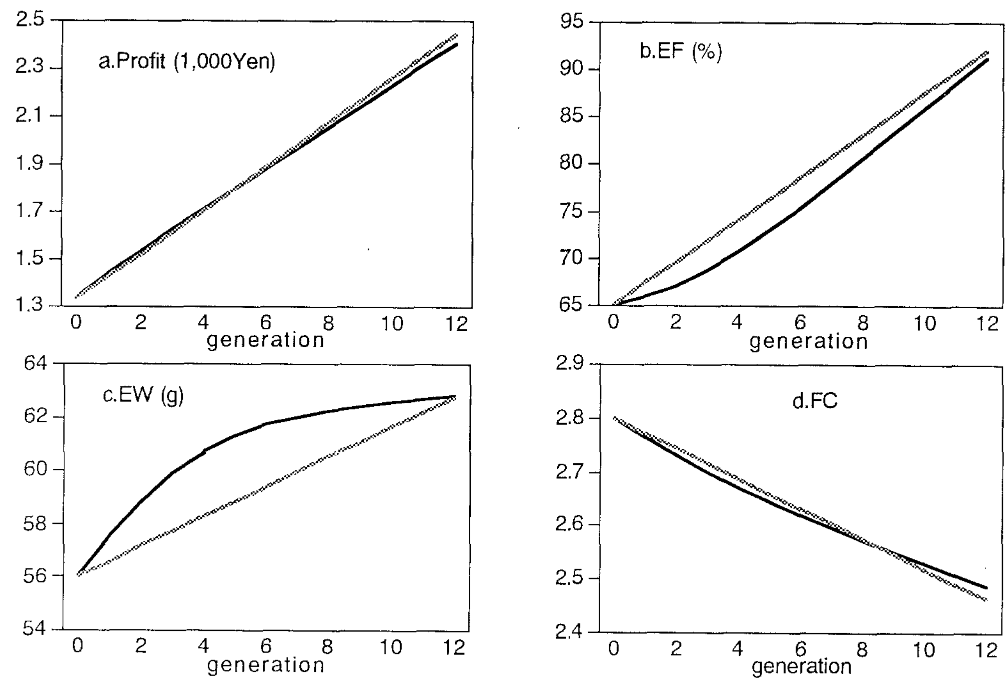
where G stands for the genotype of the component trait. These economic weights can be determined according to the method suggested by Hazel (1943), which are equivalent to partial derivatives of **H** with respect to v_{EF}, v_{FC} and v_{EW}, evaluated at the mean of each component trait obtained every generation by equation (7). Thus, the economic weights of these component traits change according to the level of performance every generation. The profit from the economic selection index was calculated from equation (11) after substituting appropriate correlated gains estimated from equation (7). On the other hand, the breeding objective of a desired gains index is to improve the profit for the function described in equation (11) by assigning a proper, but fixed, balance to the component traits to obtain the highest return.

Assume an economic index which maximizes the correlation between the index and equation (12) and a desired gains index to attain the breeding goal of $\mathbf{k}' = (EF = 85\%\ \ FC' = 2.55\ \ EW = 61\ g)$, where the initial levels of performance in the base population are EF = 65%, FC′ = 2.8, and EW = 56 g. Assuming selection does not change genetic parameters, genetic trends for selection with the two indices can be calculated and are shown in Figs. 1 a–d.

Figure 1a shows the changes in profit for the two indices. Profit for the economic index exceeds that for the desired gains index until generation 5, after which profit by the desired gains index exceeds that for the economic index. Figure 1b shows the trends of genetic gain in EF, where the gain with the desired gains index is superior to that with the economic index. Figure 1c shows that the correlated gains in EW with the economic index is curvilinear. Changes observed in the first few generations are much higher than for the desired gains index, whereas they approach a plateau at approximately 63 g, in contrast to a striaght-line gain for the desired gains index. This means that for equation (11), EW is the more sensitive or influential trait in the beginning, but the restriction on EW becomes more influential in later generations. Lastly, Fig. 1d shows the genetic changes in FC, in which the decrement with the economic index is larger than that of the desired gains index until generation 8, whereas the reverse is true afterwards. It is interesting to note that the changes in EF, FC and EW are all linear with the desired gains index, while they are non-linear with the economic index, although its breeding goal is a linear function. This suggests that if the profit equation is non-linear, the rates of genetic change in component traits observed in early generations will not be an appropriate measure for predicting correlated changes in the traits involved.

It is also worth noting that restriction of egg size to the optimum of 60 g resulted in lower profit than setting EW = 61 g, which appears odd, but is due to the uniqueness of the profit equation (11).

Fig. 1 a–d **a** Expected genetic changes in profit for the linear economic index (–) and the desired gains index (—). **b** Expected genetic changes in EF for the linear economic index and the desired gains index. **c** Expected genetic changes in EW for the linear economic index and the desired gains index. **d** Expected genetic changes in FC for the linear economic index and the desired gains index



Conclusions

The comparison of different selection indices is justified only if the indices are constrated to achieve the same profit function, even when each index is not optimized with respect to that profit function.

When a profit function is known and is non-linear, the desired gains index may be more efficient than the economic index. The optimum desired gains index should be determined by iterative techniques over several generations to compare the genetic progress with the economic index, because gains by the economic index are not linear and the changes observed in the initial generations of selection are not the same rates in future generations, although those changes are linear in the case of the desired gains index.

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