Applying benefit cost analysis to the evaluation of mating strategies in beef production enterprises[1]

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Abstract

Livestock improvement programs increasingly incorporate economic criteria in their decision making process, and in particular, in the selection objectives. Frequently a simplified criteria for selecting strategies is applied which doesn't effectively incorporate all the information described. Genetic improvement is a major criteria for the evaluation of most livestock improvement programs, however, increasingly aspects such as the level of inbreeding are mediating factors and are leading to a reevaluation of selection schemes and reconsideration of the impact of selection based on Best Linear Unbiased Predictions (BLUP). This study analyses the results from a simulation using mate selection approaches to look at the joint regulation of inbreeding and genetic improvement. Seven schemes were compared in the simulation (including selection by BLUP estimates and Mass selection). The results from these schemes were assessed using a benefit cost analysis. A simplified model of the system is described, this allowing the time series data for general benefits and associated costs to be detailed and analysed. The analyses shows movement in the relative value of the normally applied strategy as the inclusion and impact of the inbreeding criteria is raised. This method provides an easily applied approach to the evaluation of such parallel time series data, common in the area of animal breeding.

1 Introduction

Benefit Cost Analysis (BCA) is a procedure for comparing alternative courses of action by reference to the net social benefits that they produce (Department of Finance, 1991). While its use originated in the evaluation of individual projects, directed particularly to the provision of such public infrastructure as dams (providing the capacity to assess both financial and welfare considerations) current applications cover a much broader range. A less formal definition of BCA, that it is a method for organising information to aid the decisions about the allocation of resources (Department of Finance, 1991) reflects this broader usage.

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This paper reports on the application of benefit cost analysis to the evaluation and ranking of selection and mating strategies - considered in the context of a beef production enterprise. Genetic selection schemes provide a mechanism through which targeted traits, such a growth rate, can be systematically improved. The objective of selection often cannot directly be targeted, thus selection is directed at measurable traits which are correlated with the targeted objective. An underlying objective of most selection programs is an improvement in the economic returns from an enterprise - reflected through increased production, fertility or product quality.

Increasingly, the relationship between selection strategies and the associated levels of inbreeding is being recognised (Quinton, Smith and Goddard, 1992, Wray and Thompson 1990), the increased inbreeding being associated with the co-selection of relatives that occurs. High levels of inbreeding have the potential to reduce the returns to producers from their current and future stock through loss in fertility, depressed production, reduction in genetic variance and genetic response (see, for example, Morley 1954, Quinton, *et al* 1992). Hill (1994) noted that fitness problems in one form or another are an inevitable consequence of long term selection. Therefore, an important aspect of any selection strategy will be its capacity to address aspects such as the genetic progress derived from the program as well as the rate of inbreeding associated with this progress

Current work in this area suggests that genetic gain and inbreeding can be effectively combined through selection strategies to provide better long term outcomes, with Meuwissen and Woolliams (1994) concluding that while specific studies vary, the general results are almost invariably the same; large reductions in risk are possible without decreasing genetic gain significantly. Such risk can refer to aspects such as the accuracy of estimated breeding values (e.g. Klieve, Kinghorn and Barwick, 1993), the level of inbreeding associated with a breeding strategy or the variation in returns. In a study considering the joint regulation of genetic gain and inbreeding (Klieve, Kinghorn and Barwick, 1994), stochastic simulations of a range of mating and selection strategies were undertaken. These strategies varied both in the selection criteria used (whether selection was based on the observed level, the phenotype, of the trait or on the estimated breeding value, the *ebv*) and on whether the steps of selection and mating were carried out sequentially (selection followed by random mating) or simultaneously (referred to as mate selection, where the optimal combination of mates defines the selected mating stock) The defined mate selection strategies were differentiated by an acceptable maximum level of decrease in the expected response with the selection objective directed to minimise inbreeding subject to the achievement of this minimum level of response.

From the time series information available from the simulation modelling on the levels of expected genetic gain and inbreeding it was demonstrated that for a small compromise in the expected level of genetic gain, considerable benefits through reduced levels of inbreeding were possible. However, this study did not provide a quantitative evaluation of the merit or utility of such strategies. While the question of whether a degree of joint regulation can be achieved between genetic gain and inbreeding was satisfied, the further issue of which strategy was preferred was not definitively addressed. A similar concern was addressed by Quinton and Smith (1994) who, in considering a range of genetic evaluation-selection systems, looked to ascertain if there was a generally optimal system. Their approach used graphical methods to compare the cumulative genetic response and inbreeding for varying numbers of sires.

Thus, while the assessment and comparison of schemes addressing a single objective is relatively straightfoward, such comparisons are more involved where competing objectives (such as genetic progress and rate of inbreeding) are measured over the period of selection. The different sources of information available (including the the costs and returns of implementing selection strategies) must be integrated to allow the complete picture to be considered. The information available on these strategies can usually be summarised either as benefits (for example, through increases in the expected level of response) or risks, or costs (the potential reduction in that response through, for example, inbreeding depression and reduced genetic variation).

By addressing this problem of the benefits and costs of mating strategies as a problem of assessing alternative mechanisms for resource allocation, the available information can be used, through a benefit cost analysis, to quantitatively assess possible investment strategies (specifically, mating strategies) This perspective, of viewing animals as investment options, and breeding and selection as a resource allocation issue, is becomming increasingly common in animal breeding research with techniques such as Linear Programming (for example Jansen and Wilton, 1985, Kinghorn 1987, Toro and Silio, 1992) and Portfolio Analysis (for example Schneeberger, Freeman and Boehlje, 1982, Klieve *et al*, 1994), being applied from this perspective The application of benefit cost approaches is a useful extension to the application of economic evaluation approaches in this area, providing an effective mechanism for such approaches.

2 Method

The genetic simulation model used by to evaluate strategies for the joint regulation of genetic gain and inbreeding (Klieve *et al*, 1994), is detailed below, along with the selection strategies defined. The results from this model (true breeding value and inbreeding level) are summarised in Figures 1 and 2, followed by a discussion of the Benefit Cost model used to evaluate and rank the strategies.

The Genetic Simulation Model

A stochastic simulation was used to model a breeding population over a 20 year period. A base population of 3 males and 15 females, with each male mating with 5 females, was generated as follows, for animal i:

breeding value:

$$u_i = X_{1i}\sigma_a \qquad 1$$

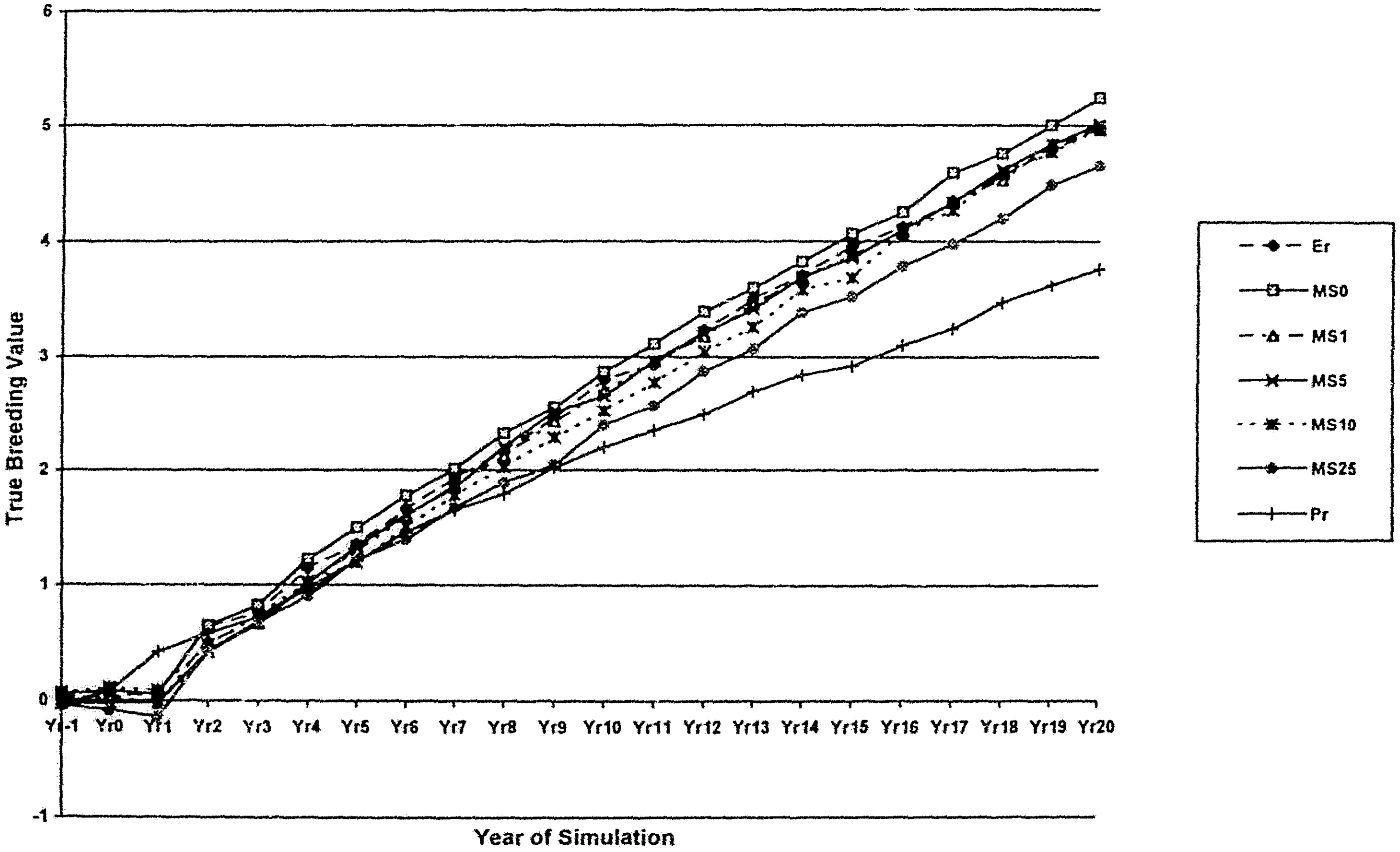

Figure 1 Simulated change in mean true breeding value for different selection strategies

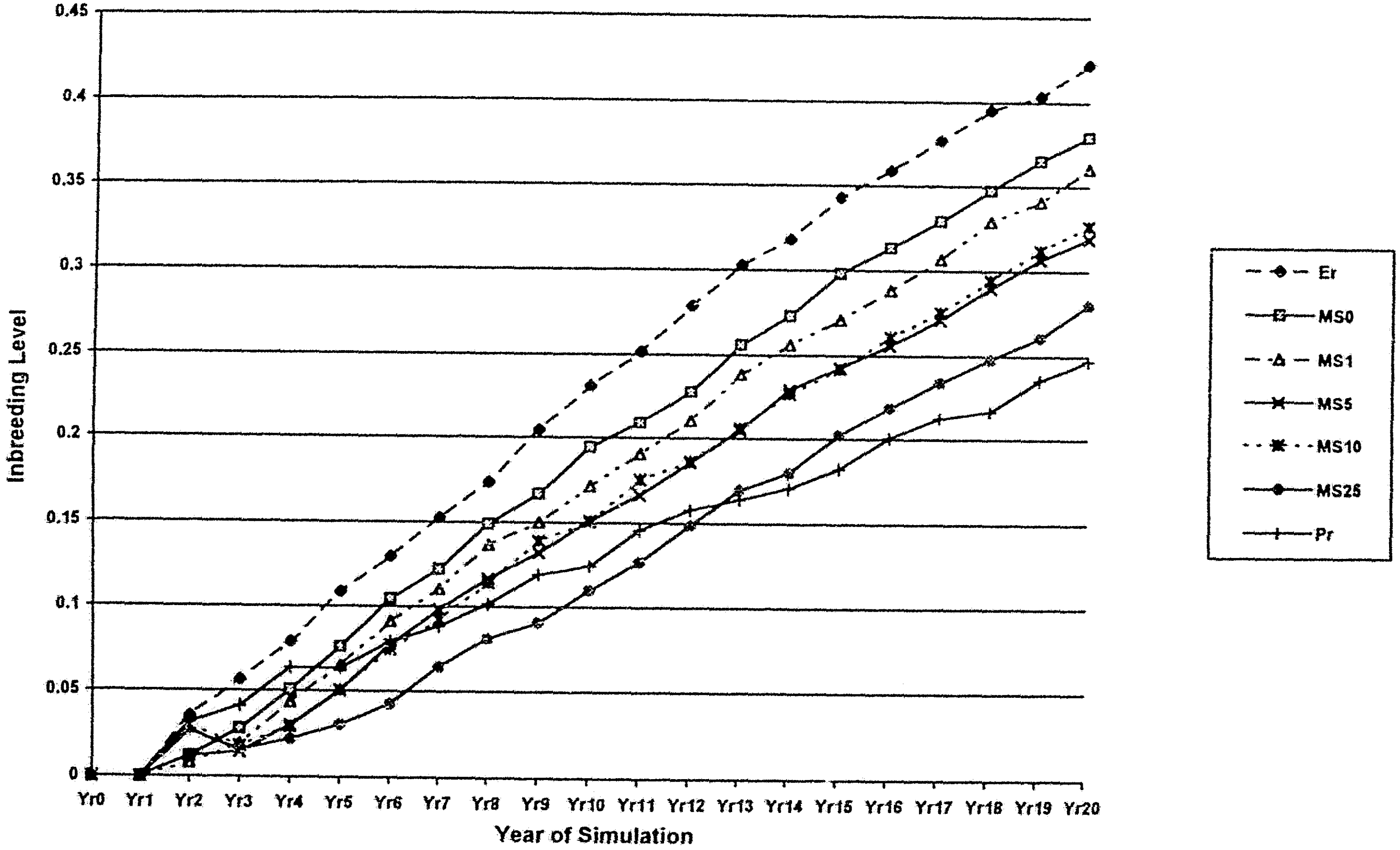

Figure 2 Simulated change in mean inbreeding level for different seection strategies.

phenotype:

$$y = a_i + X_{2i}\sigma_e \qquad 2$$

where X_1 , X_2 are independently sampled from N(0,1), and

$^2_a = 1$, $\sigma_e^2 = 4.0$ ($h^2 = 0.2$).

where h^2 is the heritability, σ_a^2 is the genetic variance and σ_e^2 is the environmental variance.

Animals were initially considered for inclusion in the breeding population at age 2, with the time animals remained in the breeding structure dependent upon their continued definition as mates - inferior animals being culled after each mating period.

After the initial generation, breeding values were generated using the following relationship:

$$a_i = 0.5(a_s + a_d) + X_{1i} * \sigma_a * 0.5 * \sqrt{(2 - F_s - F_d \;\;)} \qquad 3$$

where a_s and a_d (F_s and F_d) are the breeding values (inbreeding coefficients) of the sire and dam of animal i.

From Equation 3 it can be seen that the impact of reduced genetic variance from increased levels of inbreeding is included in the model, but effects of inbreeding depression on performance are not.

The phenotype of animals was then defined as

$$y_i = a_i + e_i \qquad 4$$

where $e \sim N(0, \sigma_e^2)$ BLUP estimates of the foundation population breeding values were then derived for use in the selection process.

The model united selection of breeding stock and the definition of mating pairs into a single step - thus mate selection. The female breeding population size was kept constant at *15* females, with maximum females per male set at *5* (*3* males used equally in each year). Mature animals not selected were culled, and each breeding female produced one offspring per mating.

Treatments were chosen to demonstrate the impact of the method and included 'controls' in the form of selection on BLUP *ebv's* (E_r) and on phenotypes (P_r), under random mating. A linear programming mate selection model which maximised the sum of the *ebvs* of offspring from selected parents was first run subject only to a defined breeding structure.

Treatments were defined by:

- the allowed reduction in the predicted attainable genetic response (defined from the difference between the best achievable average *ebv* of selected parents and the average *ebv* of all parents before selection);
- random mating or mate selection; and
- criteria addressed by selection (BLUP estimate or phenotype).

With the exception of E_r and P_r, all treatments used mate selection (*MS*) and aimed to minimise inbreeding, subject to an allowed reduction in the attainable genetic response.

Treatments were:

MS_0 selection on BLUP *ebvs* - no decrease allowed in genetic response
MS_1 selection on BLUP *ebvs* - 1% decrease allowed in genetic response
MS_5 selection on BLUP *ebvs* - 5% decrease allowed in genetic response
MS_{10} selection on BLUP *ebvs* - 10% decrease allowed in genetic response
MS_{25} selection on BLUP *ebvs* - 25% decrease allowed in genetic response
E_r selection on BLUP *ebvs* - random mating
P_r selection on phenotype - random mating

The Benefit Cost Model

The aim of this model is to provide a mechanism through which the relative ranking of selection strategies, based on the output data from a simulation modelling study, can be achieved. Real estimates of either the total benefits or costs of such strategies was not an objective of the BCA - thus, a quantitative analysis is described, based on the variable costs and benefits of the enterprise, with common elements excluded.

The decision to apply the Net Present Value decision rule in this analysis was based on a range of factors, in particular the form of the information used. The use of the Benefit Cost Ratio (B/C) and the Internal Rate of Return (IRR) are commonly applied decision rules, however, some caution should be taken in their application, this concern being particularly applicable in the definition of benefits and costs applied in this analysis.

The Handbook of Cost-Benefit Analysis (Department of Finance, 1991) cautions that *the benefit cost ratio is only as reliable as the net present value rule when ... project alternatives are not mutually exclusive*. The alternatives used in this analysis are mutually exclusive. Further, Gittinger (1984), for example, in looking at the impact on the ratio of different netting out conventions, noted that different conventions would change the results from the results. A similar problem will occur here with a application of the B/C ratio. Costs and benefits common to all selection strategies are not assessed and the inclusion of such information would reduce the accuracy of the analysis by introducing information of variable reliability which is not required for the achievment of the objective of the analysis - the ranking selection schemes.

The model used for these evaluations arises from the basic genetic model, that phonotype is a combination of genetic and environmental contributions (see equation 4), where the impact of inbreeding depression is to reduce the expression of of the expected performance:

$$NPV_{b,S,r} = \sum_{t=1}^{20} \frac{(E_{t,b,S,r} + G_{t,b,S,r}) * (1-b) * F^{*}_{t,b,S,r}}{(1+r)^{t}} \qquad 4$$

where:

S is the mating strategy under assessment (E_r , P_r , MS_0 to MS_{25})

E_t representing the environmental impact, is selected from a N(0,4) distribution

G_t the genetic contribution, is selected from a N($\ddot{g}_{t-1}, \sigma^2_{g_{t-1}}$) distribution, where $\overline{g}_{n-1}$ is the mean geneti contribution in year i and $\sigma^2_{g_{t-1}}$ is the variance of this contribution

b is the weighting placed on the impact of inbreeding

F^*_t the associated inbreeding impact, selected from an $N(\overline{F}_{t-1} * W, \sigma^2_{f_{n-1}} * W)$ distribution, where $\overline{F}_{t-1}$ is the mean inbreeding level and $\sigma^2_{f_{n-1}}$ the variance of this level. Both parameters are multiplied by weighting factor, W, correlating higher merit with higher levels of inbreeding

r the interest rate used (6% or 10%)

Six levels of b, the weighting on inbreeding depression, were used, varying between 0 and 5 - this is comparable to suggested levels of inbreeding depression of the order of 5% reduction in production for a 10% increase in the level of inbreeding (Falconer, 1981).

The @ RISK for Excel spreadsheet was used to select values for the stochastic elements used in the spreadsheet, with a distribution for the NPV being produced from the simulation (250 replications of each variation of the model).

3 Results and Discussion

The results from the simulations are presented in Tables 1 and 2. Figures 3 and 4 provide a comparison of the relative rankings of the strategies under variation in interest rate and weighting on inbreeding.

Only two levels of interest rate were considered in this analysis, and while there is a significant difference between the absolute value of strategies (the NPV) under the different levels of *r*, its impact on the rankings of the strategies is not - these maintaining a similar pattern for both levels

Of greater interest is the impact of the weighting, *b*, on inbreeding. In both Figure 3 and 4 there is a marked change from b= 0 to 5. As expected, E_r is the preferred strategy where inbreeding depression has a zero weighting, however, this position is only maintained for the smallest weight on *b*, with E_r rapidly dropping to least preferred strategy from $b=2$. This move is mirrored by the change in P_r, this moving from least to most preferred, although not quite as rapidly as E_r. (occuring at $b=3$ and *4* for *r* levels of .06 and .10).

The mate selection strategies offer some compromise in this area, with MS_5, , for example, offering a consistently attractive option under all levels of *b* and the highest consistently positive return for r= 06.

From both Figures 3 and 4 the same initial and final ranking are apparent. Initially, E_r and MS_0 are (almost) equally first, the second group includes the three central mate selection strategies, MS_1, MS_5 and MS_{10}, while MS_{25} and P_r share the lowest position. However, with increasing weight on inbreeding, the greatest impact occure to the non-mate selection strategies, with MS_0 showing considerable superiority over E_r - particularly compared to their initial relative position.

While obviously the preferred strategy must be related to the level of inbreeding depression (a factor of the type of trait under consideration, whether production or fertility, for example) the mate selection strategies do appear to confer considerable benefit in mediating the impact of inbreeding depression.

In addition to the specific results from this analysis, it is apparent that this approach has providing one means of jointly considering the available information of such selection schemes. The provides a capacity to consider such resource allocation options from an objective perspective addressing both the costs and returns associated with the adoption of such a strategy.

Table 1 The NPV (standard error) of selection strategies for varying weights on inbreeding for an interest rate, r of .06. As the analysis used only the variable costs and benefits, the numbers indicate the relative returns associated with each selection option.

	Weighting on Inbreeding % decrease in production per 10 % increase in F					
Selection Strategy	**0**	**1**	**2**	**3**	**4**	**5**
E_r	24.64 (0.73)	17.98 (0.56)	11.39 (0.51)	4.72 (0.46)	-1.94 (0.48)	-8.54 (0.42)
MS_0	24.50 (0.69)	18.93 (0.52)	13.33 (0.53)	7.72 (0.48)	2.07 (0.45)	-3.49 (0.45)
MS_1	22.80 (0.67)	17.89 (0.61)	12.96 (0.56)	8.06 (0.48)	3.18 (0.50)	-1.79 (0.49)
MS_5	22.76 (0.67)	18.56 (0.62)	14.36 (0.54)	10.20 (0.56)	6.01 (0.46)	1.08 (0.51)
MS_{10}	22.19 (0.66)	17.94 (0.61)	13.71 (0.55)	9.45 (0.52)	5.15 (0.46)	0.91 (0.46)
MS_{25}	20.38 (0.61)	17.20 (0.61)	14.03 (0.56)	10.83 (0.55)	7.63 (0.55)	4.44 (0.50)
P_r	19.65 (0.67)	16.72 (0.65)	13.77 (0.60)	10.85 (0.58)	7.95 (0.50)	5.05 (0.55)

Table 2 The NPV (standard error) of selection strategies for varying weights on inbreeding for an interest rate, r of 10. As the analysis used only the variable costs and benefits, the numbers indicate the relative returns associated with each selection option. NPV (standard errors) r= 10

	Weighting on Inbreeding % decrease in production per 10 % increase in F					
Selection Strategy	0	1	2	3	4	5
E_r	15.45 (.55)	11.57 (0.53)	7.78 (0.45)	3.95 (0.42)	0.13 (0.43)	-3.69 (0.43)
MS_0	15.39 (0.47)	12.19 (0.46)	8.97 (0.47)	5.77 (0.42)	2.54 (0.40)	-0.67 (0.44)
MS_1	14.17 (0.54)	11.37 (0.47)	8.59 (0.46)	5.80 (0.41)	3.03 (0.42)	0.25 (0.41)
MS_5	14.17 (0.51)	11.77 (0.49)	9.39 (0.46)	6.99 (0.51)	4.69 ((0.43)	2.27 (0.41)
MS_{10}	13.85 (0.52)	11.45 (0.48)	9.03 (0.48)	6.63 (0.44)	4.19 (0.45)	1.78 (0.44)
MS_{25}	12.57 (0.50)	10.81 0.53)	9.02 (0.49)	7.24 (0.44)	5.48 (0.44)	3.69 (0.44)
P_r	12.41 (0.53)	10.75 (0.52)	8.18 (0.49)	7.16 (0.46)	7.33 (0.51)	3.92 (0.45)

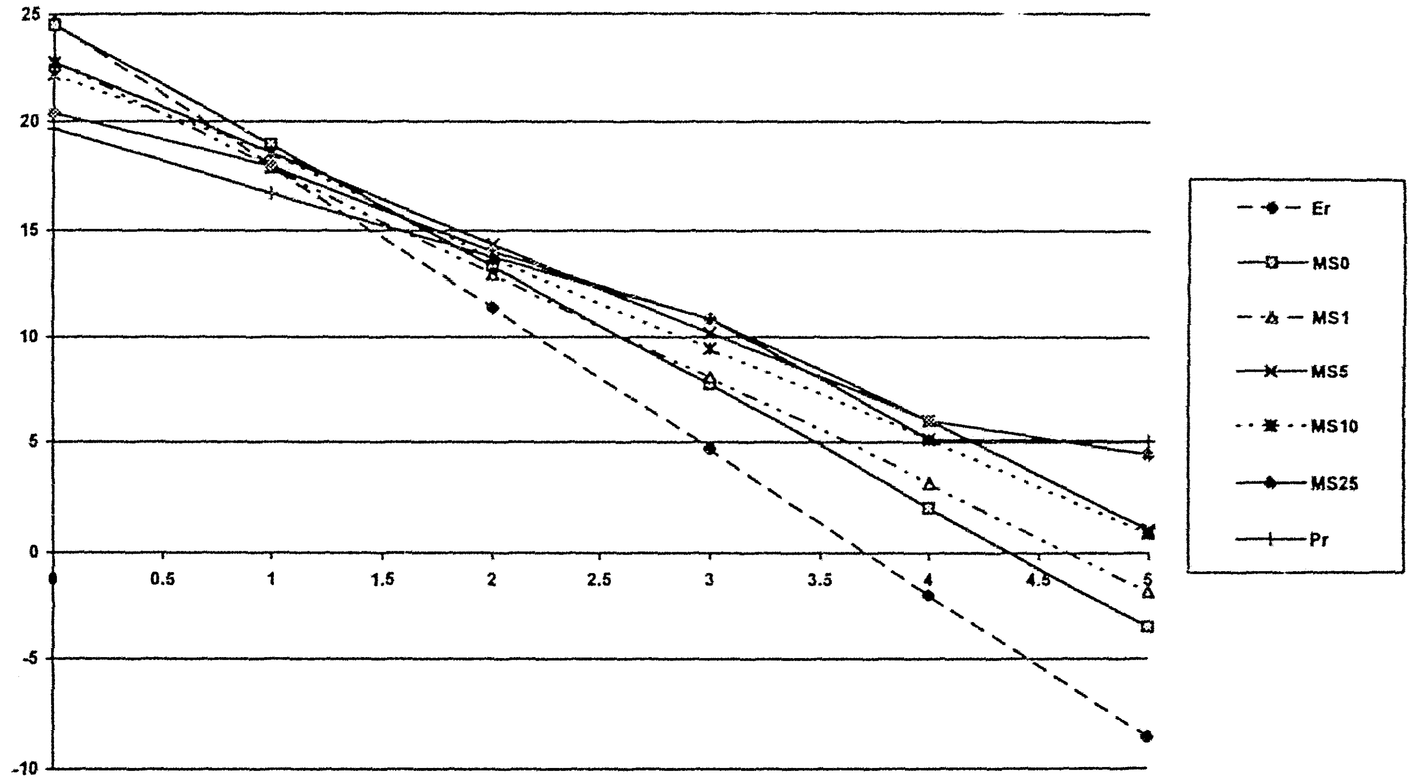

Figure 3 The change in value (ranking) of selection strategies for varying levels of *b*, the weight on inbreeding, where *r* =0 06.

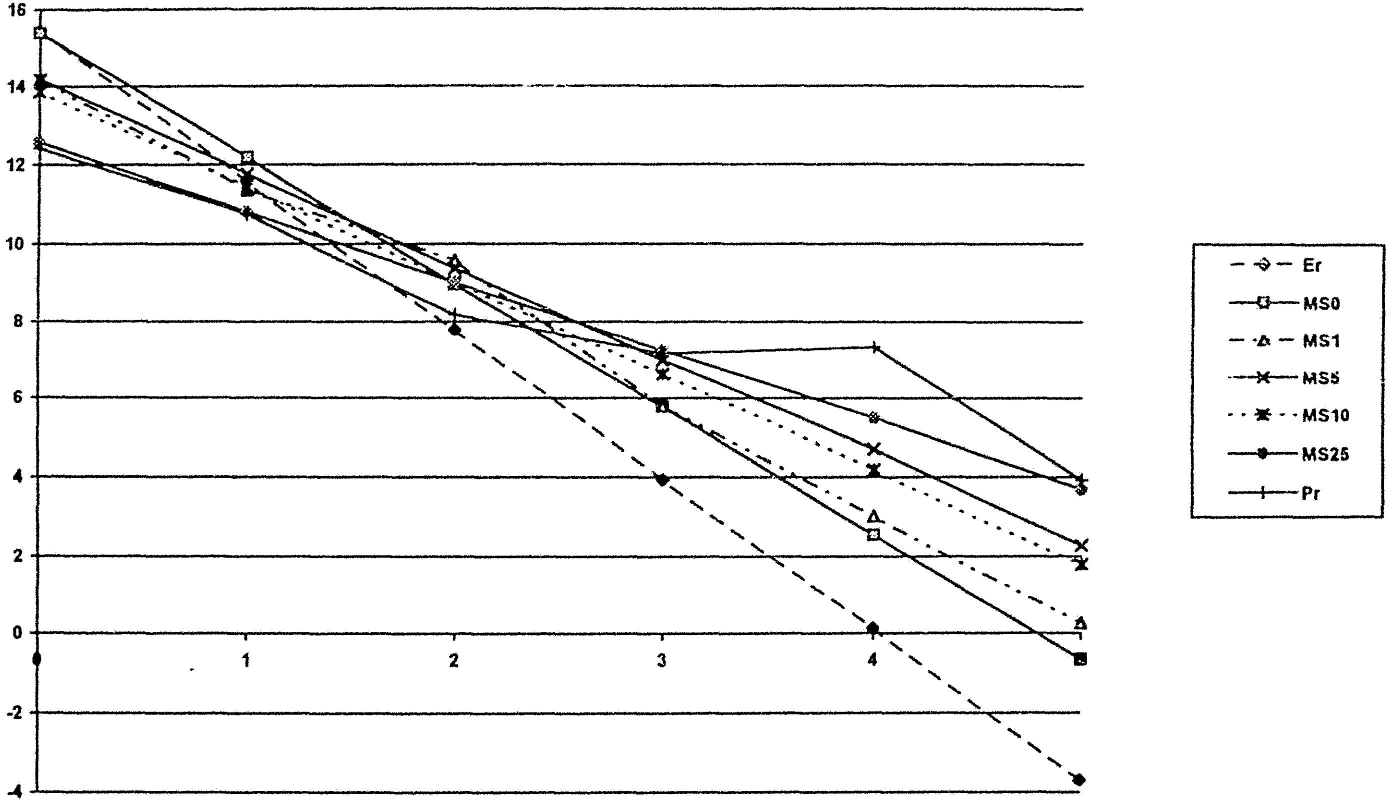

Figure 4 The change in value (ranking) of selection strategies for varying levels of *b*, the weight on inbreeding, where *r* =0.10

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