Returns from genetic improvement on indices that include production, longevity, mastitis and fertility in UK circumstances

Jennie Pryce[1], Geoff Simm[1], Peter Amer[2], Mike Coffey[1] and Alistair Stott[3]

[1]*Animal Biology Division, SAC, West Mains Road, Edinburgh, EH9 3JG UK*
[2]*AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel, New Zealand*
[3]*SAC Aberdeen, Craibstone Estate, Bucksburn, Aberdeen AB21 9YA UK*

Abstract

In the UK, two selection indexes are in use by the dairy industry, they are PIN (Profit Index; production only) and £PLI (Profitable Lifetime Index; production plus lifespan). Expected economic returns over a twenty year period were calculated for PIN and £PLI in addition to returns when selection is on a hypothetical index based on £PLI and assuming that PTAs (predicted transmitting abilities) for mastitis and calving interval were available (£PLI+M+C). Selection responses for a single round of selection were calculated using selection index methodology. Genetic covariance matrices were constructed using published genetic and phenotypic parameter estimates assuming that sire PTAs based on progeny groups of 75 daughters were available. Economic values per genetic standard deviation were: £-12, £7, £49, £29, £28 and £7 for milk, fat, protein, lifespan, calving interval and mastitis, respectively. Annual economic responses were calculated as 0.22 standard deviation change of the indexes and were £5.41, £7.66 and £9.63 for PIN, £PLI and £PLI+M+C. Responses in £PLI+M+C were sensitive to the heritability assumed for calving interval (between 0.02 and 0.05). Discounted returns over a twenty year period were calculated assuming that genetic progress will continue at around 1.6% per year. The accumulated discounted returns from selection alone for the UK dairy industry in twenty years time are estimated to be £457m, £653m and £813m (2 million dairy cows) when selection is on PIN, £PLI and £PLI+M+C respectively. Comparisons between the results of selection on differing indexes are complicated by the fact that there have been several generations of selection on PIN, or criteria close to it, whereas £PLI has only become available recently and PTAs for calving interval and mastitis are not yet available. Also, in practice, selection in different pathways may not give equal emphasis to these indexes, especially as the UK relies on 80% imported semen. Thus breeding programmes in other countries will be influential. However, it is clear that (i) selection on criteria available in the last decade (e.g. PIN) has led to major economic benefits for the UK dairy industry; (ii) there will be substantial economic cost to continuing selection on production criteria alone in terms of an increased susceptibility to mastitis and decline in fertility; and (iii) these negative consequences of selection can be very effectively mitigated by broadening of selection criteria with substantial expected animal welfare and economic benefits.

1. Introduction

Genetic improvement is permanent, cumulative and highly cost-effective (Simm, 1998). Improvements made in one generation are passed on to the next. So when selection is continuous, the benefits are accumulated across generations. For the potential benefits to be realised, selection must be for an appropriate breeding goal. In the past most breeding programmes have centred on production. However, optimum genetic improvement can be achieved by assigning correct economic values and by expanding the breeding goal to include other ‘functional traits’ that impact on farmer profitability and animal welfare (thus public perception of the final product); examples include feed costs, health, fertility, calving ease and milkability (Groen *et al*., 1997).

In the UK, two indexes are currently available for dairy farmers and breeding organisations to use. These are PIN (Profit Index) and £PLI (Profitable Lifetime Index). PIN is based on PTAs for milk, fat and protein weighted by their assumed future economic values. £PLI is a descendant of PIN and thus includes PTAs for milk, fat and protein, weighted by the same economic values as PIN, but also includes a PTA for lifespan. Lifespan PTAs are predicted using a bivariate analysis of lifespan (measured in lactations) and four linear type traits (Brotherstone *et al*., 1998). Although lifespan is correlated to some health and fertility traits (Pryce and Brotherstone, 1999), there is extra economic benefit in including some health and fertility measures directly in the breeding goal (e.g. Philipsson *et al*., 1994; Lindhe and Philipsson, 1999). At present PTAs for SCC are available in the UK, but PTAs for direct clinical measurements of mastitis or fertility traits are not yet available. However, research is in progress in the UK on the genetics of health and fertility traits.

The consequences of selection on various indexes are important from both a biological and economic perspective. Genetic correlation estimates between production, health and fertility are predominantly unfavourable. So at the biological level there are concerns regarding the implications of selection solely for production on animal health and welfare (e.g. Lawrence *et al*., 1999). Furthermore, it is helpful for economic consequences are useful as a means of convincing farmers and the founders of research to know the potential economic benefits of genetic improvement.

Calculating the economic consequences of selection is relatively simple, assuming that returns are linear and cumulative. The economic value of selection, is not solely a result of the present generation, but also a result of decisions made in previous years. When calculating economic benefits over a long time period it is simpler to assume consistent selection criteria.

The aim of this study was to calculate discounted returns for selection over a twenty years period when three different indexes are used.

2. Material and methods

Genetic and phenotypic variance-covariance matrices were constructed using parameter estimates from the UK Holstein population (Brotherstone *et al.*, 1997; Pryce *et al.*, 1998; Pryce and Brotherstone, 1999). It was assumed that each sire would have an average progeny group size of 75 daughters. The economic values assumed for goal traits are presented in Table 1. These differ from economic values used in the current versions on PIN and £PLI as they reflect the lower milk price received by farmers for sales. Implementation of these economic values is currently under consideration by the UK Animal Data Centre.

Using selection index methodology, the consequences of selection following a single round of selection were calculated for four different indexes:

Table 1 **Economic values and relative economic values per genetic standard deviation of goal traits**

Trait	Economic value (£)	Relative economic value/SD (£)
Milk (kg)	-0.02	-12
Fat (kg)	0.3	7
Prot (kg)	2.62	49
LS (lacts)	27.5	29
CI (d)	4	28
Mast (0/1)	100	7

1. production only (PIN): based on Milk, Fat and Protein PTAs
2. Production and lifespan (£PLI): Milk, Fat, Protein and Lifespan PTAs
3. £PLI+M: Milk, Fat, Protein, Lifespan PTAs and assumed future PTAs for Mastitis incidence.
4. £PLI+M+C: Milk, Fat, Protein, Lifespan PTAs and assumed future PTAs for Mastitis incidence and Calving Interval.

Annual returns were calculated as 0.22 standard deviations of the aggregate genotype. This value approximates selection response in 'typical' four-pathway dairy cattle breeding schemes (Robertson and Rendel, 1950). Over the past ten years an annual improvement of £6 PIN per year has been achieved in Holstein bulls. In the last five years this has increased to £10 PIN per year (Animal Data Centre, 1999; http://www.animaldata.co.uk) due to better selection decisions. A cautious approach to the future is to take the pessimistic view that the annual rate of genetic improvement in sires will continue to be £6 in PIN per year. The annual improvement of £6 is similar to the Robertson and Rendel (1950) expectation. It is difficult to predict future industry responses to selection, however it is anticipated that genetic progress will be maintained at least at 0.22 standard deviations per year.

Expected discounted returns were calculated assuming selection on the indexes described at current and assumed future rates of genetic improvement. The cumulative economic response to selection in four indexes was calculated using the formula by Smith (1978) adapted to include the effect of several years of selection (equation 1). It was assumed that returns would be recouped starting at year 8 (y) that is the age of proven bulls when their daughters start milking. The final year after selection was assumed to have started was 20 (n). An inflation free discount rate of 5% was also assumed (d). Annual returns (G) were calculated for each of the indexes in assuming a population of 2 million dairy cows.

Discounted returns from selection were calculated using an extension of the formula presented by Smith (1978). Smith (1978) assumed that selection would only take place in the first year, but that benefits would accrue several years afterwards. The modified formula allows for continuous selection from year 1 up to a pre-defined end point (in this case 20 years). The modified EQN. (1):

$$\text{Returns}(n,t) = \sum_{m=1}^{n-y+1} \sum_{t=y+m-1}^{n} \left(\frac{1}{1+d}\right) \cdot G$$

3. Results

Expected annual responses to selection using the four indexes are presented in Table 2. The aggregate genotype or total economic response included responses in milk, fat, protein, mastitis, calving interval and lifespan for all indexes.

Calving intervals and mastitis continue to increase for all indexes except for PLI+M+C. Broadening breeding goals to include lifespan, mastitis and calving interval increases the total economic response, the greatest economic response is achieved when all traits are included in the goal (£9.63; £PLI+M+C).

Although responses to selection are robust to large changes in economic values (Veerkamp *et al.*, 1995), they are sensitive to the heritability assumed. In the review of Pryce (1997) heritability estimates for calving interval ranged between about 0.02 and 0.05. Assuming these heritabilities, the response in £PLI+M+C was £9.31 and £11.90 respectively.

Table 2. Expected annual responses to selection on PIN (1), £PLI (2) and £PLI+M (3) and PLI+M+C (4)

Index	1	2	3	4
Total response (£)[I]	5.41	7.66	7.74	9.63
Milk (kg)	103	93.5	90.7	53.2
Fat (kg)	4.56	4.12	4	1.88
Protein (kg)	3.36	3.05	2.96	1.94
Mastitis[ii]	0.3	0.2	0.09	-0.04
Calving interval (d)	0.6	0.28	0.24	-0.57
Lifespan (lactations)	0	0.059	0.06	0.099

[i]Economic response derived from all traits included in the £PLI+M+C index.
[ii]Cows with mastitis in a lactation x100

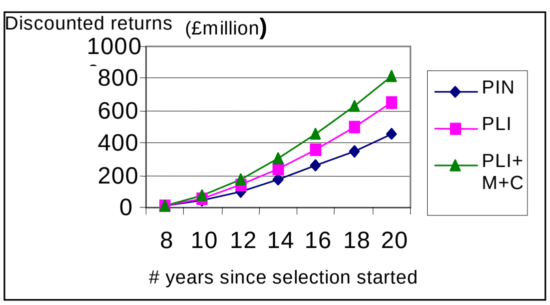

Figure 1. **Discounted returns accumulated following selection on PIN, £PLI, and £PLI+M+C over 20 years of selection**

Discounted returns accumulated over 20 years of selection are presented in Figure 1. The response after 20 years includes the cumulative effect of previous years of selection. After 20 years of selection, the total economic benefits are £457m, £647m, £653m and £813m. Put another way, the discounted returns for a 100 cow herd after 20 years of selection would be £23k, £32k, £33k and £41k from genetic improvement alone.

4. Discussion

Comparing the results of selecting on differing indexes is complicated by the fact that there have been several generations of selection on PIN, or criteria close to it, whereas £PLI has only become available recently and PTAs for calving interval and mastitis are not yet available in the UK. So £PLI+M and £PLI+M+C are still hypothetical indexes. Also, in practice, selection in different pathways may not give equal emphasis to these indexes. However, it is clear that

(i) selection on criteria available in the last decade (PIN) has led to major economic benefits for the UK dairy industry;

(ii) there will be substantial economic cost to continuing selection on production criteria alone in terms of a decline in mastitis resistance and infertility; and

(iii) these negative consequences of selection can be very effectively mitigated by broadening of selection criteria (£PLI, £PLI+M, £PLI+M+C) with substantial expected animal welfare and economic benefits.

The benefits of selection will only be accrued in full if the predicted production circumstances equal the actual production circumstances (Groen *et al.*, 1997). So, despite making pessimistic assumptions, the actual returns may differ from our predictions, even though selection indexes are robust to economic weights (Philipsson *et al.*, 1994).

In fact, as breeding goals are broadened further it seems likely that the economic response over a twenty year period would result from selection on several different indexes. For example, in the UK selection over the last 10 years has mainly been on PIN. In 1995 ITEM was launched. ITEM included production and longevity predicted by four type traits (Veerkamp *et al.,* 1995). ITEM has recently (February, 1999) been superseded by £PLI, which includes a more sophisticated prediction of survival (lifespan). So there is a gradual evolution of indexes which occurs as the definition of the overall breeding goal improves, by incorporating more traits that contribute to overall profitability. The reliability of prediction of genetic merit of individual traits (which contribute to the aggregate genotype) continues to improve through better use of data and improved methods of prediction.

Impact of imported semen

About 80% of the semen used in the UK at present is imported. Most of the genetic gain from dairy cattle breeding programmes comes from the selection of bulls to breed the next generation of AI bulls i.e. the selection that is done by breeding companies, rather than by commercial dairy farmers. Selection in breeding programmes in most exporting countries is primarily on production. Hence, it could be argued that all or most of the response expected from selection on PIN in the UK (Figure 1) could be achieved simply by importing all of the semen required, with no need for progeny testing, genetic evaluation or dairy cattle breeding research in the UK. (Indeed, the rate of genetic progress in UK cows mentioned earlier has been achieved primarily through imports of semen.) Banos and Smith (1991) demonstrated that for two countries with a difference of 0.5 standard deviations, the low mean country can improve quickly and approach the mean of the high country in 2-3 generations, assuming both countries have the same breeding goal. However, where breeding goals differ, the benefits of importing become less, thus there will be greater benefits from having successful breeding programmes within countries (or defined regions).

Research within countries produces indexes which are directly relevant to the production circumstances of that country, and which are more comprehensive, and likely to lead to more sustainable improvement, than those in use in exporting countries. Even the current modest use of semen from UK breeding programmes could produce benefits of over £813 million after 20 years of selection, if these programmes base selection on more comprehensive indexes such as £PLI+M+C rather than PIN. Obviously, even greater benefits can be achieved if the market share of semen from UK breeding programmes increases in future, and these programmes base selection on £PLI+M+C, or similar more comprehensive indexes. (The uppermost line in Figure 1 represents the gains that could be achieved if all selection in the UK, both in breeding programmes and in commercial herds, were based on £PLI+M+C.)

Comparison of benefits and costs

It is difficult to estimate the full net costs of operating progeny testing schemes and genetic evaluation services. Also, with the increasing globalisation of cattle breeding national demarcations have become less relevant. However, we estimate that in the UK the cost of progeny testing sires, dairy genetics research and operation of the Animal Data Centre together totals around £6 million. Adoption of £PLI+M+C will result in a benefit of £356m over selection on PIN over a 20 year period. The benefit to cost ratio of genetic improvement at current modest use of UK bred and tested bulls (20%) would be in the region of 3.8:1 to 6.8:1 (for PIN and PLI+M+C respectively) twenty years after selection started. This compares very favourably with returns on alternative investments of industry or public funds.

The benefit: cost can be improved further by:

a) Encouraging the wider use of high index sires especially those bred and tested in UK breeding programmes.

b) The development of even better selection tools. Two preliminary indexes (£PLI+M and £PLI+M+C) are described here and may need further refinement in the future, but the results clearly demonstrate the benefits of expanding breeding goals to include health and fertility traits.

Who Benefits?

Genetic improvement leads to increased product value, reduced costs of production, or both. Technical change within an industry means extra benefits to the innovators, although these are obtained at some risk, while those who do not adopt technology in the first place may lose out (Amer and Fox, 1992). As adoption becomes significant within an industry, then benefits can either accrue to producers, consumers or both.

For the dairy industry to reap the benefits of new indexes, breeding organisations operating progeny testing schemes would need to select on these indexes, as the most important route of creating genetic improvement is through selecting the parents of progeny test sires. In the case of future indexes, where there is more emphasis on non-production traits, larger groups of daughters than are currently used in progeny testing may be needed to achieve optimal responses from a breeding programme as a whole.

Expanding selection indexes to include longevity, health and fertility traits is not only of benefit to producers, as using £PLI and £PLI+M and £PLI+M+C will result in more profit, but there are also welfare benefits for dairy cows themselves. £PLI will result in cows that, on average, live longer and have a slower increase in calving interval and incidence of mastitis than expected from selection on production alone. While using £PLI+M+C will improve (shorten) calving intervals, the incidence of mastitis will continue to increase, but at a much slower rate than with selection on PIN or £PLI. The welfare benefits of improving fertility and longevity arise from more choice of candidates for culling, as cows would live longer and fewer would need to be culled for reproductive failure, giving more opportunity to cull for low yield and other reasons which might compromise welfare. These health and welfare benefits should, in turn, help to create an improved image and competitive advantage for the dairy industry.

Acknowledgements

We are grateful to the Animal Data Centre for supplying information and to the Edinburgh Consortium for useful comments.

References

Amer, P.R. and Fox, G.C. 1992. Estimation of economic weights in genetic improvement using neoclassical production theory: an alternative to rescaling. *Animal Production* 54: 341-350.

Banos, G. and Smith C. (1991) Selecting bulls across countries to maximize genetic improvement in dairy cattle. J. Anim. Breed. Genet. 108: 174-181.

Brotherstone, S; Veerkamp, R F; Hill, W G 1997. Genetic parameters for a simple predictor of the lifespan of Holstein-Friesian dairy cattle and its relationship to production. Animal Science 65: 31-37.

Brotherstone, S, Veerkamp, R.F. and Hill, W.G. 1998. Predicting breeding values for herd life of Holstein Friesian dairy cattle from lifespan and type. Animal Science 67: 405-411.

Groen, A.F., Steine, T., Colleau, J.J., Pedersen, J., Pribyl, J. and Reinsch, N. 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livestock Production Science 49: 1-21.

Lawrence, A.B., Pryce, J.E. and Stott, A.W. 1999. Animal Welfare and public perceptions as potential constraints to genetic change in animal production. British Society of Animal Science Occasional Meeting, 'The challenge of genetic change in animal production'. Edinburgh, UK.

Lindhe, B. and Philipsson, J. 1999. The Scandinavian experience of including reproductive traits in breeding programmes. British Society of Animal Science Occasional meeting, Galway, Ireland.

Philipsson, J. Banos, G. and Arnason, T. 1994. Present and future uses of selection index methodology in dairy cattle. J. Dairy Sci. 77: 3252-3261.

Pryce, J.E. 1997. Genetics of Health and Fertility in dairy cattle. PhD thesis University of Edinburgh, Edinburgh.

Pryce, J.E. and Brotherstone, S. 1999. Estimation of lifespan breeding values in the UK and their relationship with health and fertility traits. Proceedings of International Workshop on Genetic Improvement of Functional Traits in cattle (GIFT) - Longevity. INTERBULL bulletin no. 21: 166-169.

Pryce, J.E., Veerkamp, R.F., Simm, G. 1998. Expected correlated responses in health and fertility traits to selection on production in dairy cattle. Proceedings of the 6th World Congress on Genetics Applied to Livestock Production, Armidale, Australia, January 1998. Volume 23: 383-386.

Robertson, A. and Rendel, J.M. 1950. The use of progeny testing with artificial insemination in dairy cattle. Journal of Genetics 50: 21-31.

Simm G. 1998. Genetic improvement of cattle and sheep. Farming Press, Ipswich, UK.

Smith, C. 1978. The effect of inflation and form of investment on the estimated value of genetic improvement in farm livestock. Animal Production 26: 101-110.

Veerkamp, R.F. Hill, W.G., Stott, A.W., Brotherstone, S. and Simm, G. 1995. Selection for longevity and yield in dairy cows using transmitting abilities for type and yield. Animal Science 61: 189-198