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"One size fits all"? – The relationship between the value of genetic traits and the farm system

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"One size fits all"? – The relationship between the value of genetic traits and the farm system

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ABSTRACT

The wide use of artificial insemination by dairy farmers has facilitated the development of a multi-billion dollar international market in animal genetics. In the major western dairy producing nations, each country has developed a single index to rank bulls, based on the value of traits they are expected to pass on to their offspring. One of the assumptions behind these indexes is that there is a positive linear relationship between profit (and welfare) with increases in a particular trait, regardless of the farm system. In this paper, it is shown, with examples, that the assumption of linearity is false. More importantly, it is shown that for a combination of reasons, including risk aversion, constraints and other issues, the optimal direction of genetic improvement for New Zealand dairy farmers on an individual and industry level could be quite different. Alternatives to the "one size fits all" index are described.

Abbreviations:

SI, Selection Index; **BW**, Breeding Worth (New Zealand); **EBI**, Economic Breeding Index (Ireland); **EV**, Economic Value; **LIC**, Livestock Improvement Corporation; **EFS**, Economic Farm Surplus; **TMR**, Total Mixed Ration; **OAD**, Once-a-day milking; **ROA**, Return on Assets:

1. INTRODUCTION

Genetic merit and changes in genetic merit

The productivity of a dairy cow is determined both by its management through feeding, health, and milking, as well as its inherent capabilities including genetic merit (Holmes et al, 2001). Management can influence the genetic merit of future generations of cows through breeding decisions, such as which semen to use for creating the next generation of cattle, which of the current cattle should be used as parents for the next generation and which cattle should be culled.

Most countries with a significant dairy industry have established organisations that provide assistance to dairy farmers in their decisions regarding genetic improvement. In New Zealand, this organisation is called the Livestock Improvement Corporation (LIC), and the comparable organisation in Australia is the Australian Dairy Herd

Improvement Scheme (ADHIS)[1]. A major role of these organisations is to collate the data from farmers on animal production and genetic histories in order to evaluate the genetic traits that will be passed to offspring by the cows and bull. This information is linearly combined with economic values into an index, called Breeding Worth (BW), which is then recommended as the primary tool for selection of genetic information.

The next section of this paper begins by describing genetic progress and the determination of linear selection indices which are in popular use around the world. A variety of non-linear relationships that could impact the effectiveness and accuracy of these indices are then described with examples. Following this some alternatives are proposed that may reduce the bias from simply using the linear selection tool that assumes "one size fits all".

2. GENETIC EVALUATION

Purpose of genetic evaluation

The purpose of genetic evaluation is to assist dairy farmers in their management decisions about how to improve the genetics of the herd. Genetic improvement requires breeding new animals which have superior merit to the animals they replace. However, raising a new individual is costly. Hence, there is a trade-off between increasing the rate of genetic improvement and reducing the cost of breeding and raising replacements. Holmes et al. (2001) implied that a 20 to 25% replacement rate is most profitable under New Zealand conditions.

As an example, consider a typical seasonally calving dairy herd in New Zealand, calving in late winter. The farmer may aim to replace 20% of the herd. 10% of the herd may be due to involuntary culling because of failure to conceive, or health problems such as mastitis, with the remainder culled to be replaced on the basis that they will contribute less to future profit than other members of the herd. This means that replacements equivalent to 20% of the herd are required to maintain the size of the herd, or 23.5% replacements are required if the herd grows at the average growth rate of 3.5% for all New Zealand farms at present (LIC, 2003). The actual percentage of the current herd selected to be inseminated primarily to provide future

[1] LIC is also a major producer and seller of dairy semen, whereas ADHIS is not.

replacements is around 60%. This takes into account that half of the newborn calves will be male, the cows that fail to conceive are unidentifiable at insemination, and it is two years between the birth of replacements and when they join the milking herd[2]. It may be higher if no calves from the heifers are intended to be kept[3]. Overall this implies that the decisions to be made which determine genetic improvement on farm are:

1) Identifying 60% of the herd as potential dams of replacements;
2) Which sire's semen to use for these replacements; and
3) Which members of the herd should be voluntarily replaced.

These issues can be currently managed with reference to the use of selection indices.

3. THEORY OF SELECTION INDICES

Selection Index

A selection index is commonly used to allow a valid comparison between potential sires and dams. The index reflects the linear aggregation of available information on the expressed genetic traits (breeding values) and the economic values of those traits:

$$SI = \sum_{i=N} BV_i . EV_i \qquad \text{(Equation 1)}$$

Where SI is the selection index, BV_i is the breeding value for trait *i*, and EVi is the economic value of a one unit change in the *i*th BV.

Estimating breeding values

An animal's genotype is defined by its genes, which are supplied by its parents. Breeding values represent the phenotype of the animal. The phenotype is the value of characteristics that are seen and measured, and these are determined by the genotype and by non-genetic (environmental) factors.

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[2] For the seasonal herd planning to calve annually, an attempt is made to get all cows pregnant in order to restart the lactation cycle.

[3] Heifer calves may not be kept if they a) calved to a low genetic merit bull run with heifers for the reduced cost or ease of management compared to artificial insemination, or b) a bull of undesired breed for dairy production was run with heifers to promote ease of calving or access alternative beef markets.

The genetic characteristics of a cow that can be measured and quantified are called traits. The main traits of dairy cows of interest to the dairy farmer include the production of milk and milk components, and non-production traits such as fertility, survival and liveweight. This is because they influence profitability. The breeding values represent the quantification of the genetic traits, and are estimated relative to a base animal using statistical techniques. In the New Zealand dairy industry, the base animal is the average cow born in 1985. The statistical technique primarily used is the Best Linear Unbiased Predictor (BLUP) (Holmes et al., 2001). This simultaneously estimates the genetic characteristics of animals (reflected in animal records) and the fixed effects that influence their performance, such as age and month of calving. Accurate trait estimation requires that the information is routinely and accurately measured, but this is not the case for all traits that relate to the profitability of animals. For example, milk production traits are regularly and quantitatively recorded, but feed intake is not recorded, due to the lack of a practical, cost-effective method for doing so.

Properties of breeding values

The estimated breeding value of an animal would be calculated as the average breeding value of its parents. For example, a bull with a breeding value of +20 units, mated to a cow of breeding value of +8 units, would produce offspring with a mean breeding value of +14 units. Offspring may vary from the average of their parents due to the chance sampling of genes at meiosis[4], and it is also possible for an offspring to exceed the highest breeding value of its parents.

[4] Meiosis is the process of cell division where the resulting cells, such as eggs and sperm, have only half the original number of chromosomes.

Generation of economic values

The value of a change in traits is primarily determined by using one, or a combination of, the following methods:

1. Derivatives of a profit function
2. Bio-economic model

The first approach consists of developing a profit function, and finding the economic weights as partial derivatives of that function, with respect to each trait, holding other variables and traits constant. This approach assumes small changes in traits where re-optimising all variables after the change in traits would make no material difference to the results (Goddard, 1983). Amer and Fox (1992) make the point that the management variables in the profit function should be continuously optimised, or some bias may appear in the economic weights and hence the selection index, particularly for large changes and over time. Goddard (1998) describes how the profit function has in various studies been defined as profit per unit of output, per animal, per unit of input and per farm. Amer and Fox (1992) show that under certain conditions, they provide equivalent results. However, those conditions include that decreasing returns to scale is explicitly modelled, which implies a finite optimal farm size. Decreasing returns to scale is routinely dismissed in the estimation of economic values, in favour of the more simply modelled constant returns to scale. Goddard (1998) also assumes that the range of farm sizes commonly seen imply constant returns to scale, but this ignores the likely explanation that a range of management abilities explains the range of optimal farm sizes. Goddard (1998) further concludes that "it remains to be shown that the difficulties in modelling optimum farm scale would be justified by significantly better weights."

The bio-economic model approach sometimes uses linear programming, where the dual values represent the economic weights, with a similar interpretation to the profit function approach. Other bio-economic models used may be simulation models, where a partial budgeting approach is used to estimate the effect of trait changes on profit. The simulation approach does not have the theoretical appeal of ensuring that profit is optimised for the current level of genetic traits before the economic weights are determined.

Profit function

The genetics of a dairy herd is a characteristic that influences the profit of a dairy farm. The profit (y) of a dairy farm can be expressed as:

$$y = z.p_z + x.p_x \qquad \text{(Equation 2)}$$

where x is a vector of inputs, p_x is the price of inputs, z is a vector of outputs and p_z is a vector for the price of outputs.

Management controlled inputs include the number of cows, land, fertiliser, labour, fixed capital, plant and machinery,. The relationship between these inputs and outputs may be difficult to determine and/or model. Neal (2004) demonstrated the difficulties in empirically estimating a production function for a dairy farm that realistically reflects input-output relationships. The next sub-section shows the relative ease with which marginal revenue can be calculated for changes in production traits, and is followed by the development of the production worth and breeding worth indices that are used in New Zealand.

Revenue function

In a dairy enterprise, the major outputs are milk fat, milk protein, litres of milk, cull cattle and calves surplus to those required as replacements for cull cattle. Milk and its components are the focus of a dairy operation, accounting for approximately 90% of revenue. The milk revenue from a dairy enterprise is calculated as:

$$\text{Revenue} = a * \text{milk fat (kg)} + b * \text{milk protein (kg)} - c * \text{milk volume (litres)} \qquad \text{(Equation 3)}$$

For New Zealand, the unit value of milk fat (a) is around \$3 per kg, and the unit value of milk protein (b) is around \$6 per kg. These components are what farmers are paid on, and because about 87% of milk is water, a freight cost (c) of approximately \$0.01 per litre applies to the transport of milk. As an example, a marginal litre of milk (4% fat and 3% protein would yield revenue of:

Revenue = \$3* 0.04 + \$6 * 0.03 – \$0.01 * 1

= \$0.29

Hence, the marginal revenue from a change in production traits can be found reliably without much room for argument.

Production traits

Early selection indices (eg Australian Selection Index) were calculated using the breeding values for production traits multiplied by economic weights. The economic weights took into account the marginal revenue of milk components, and the marginal costs of feed, as estimated in a simple model. The weights were determined as profit per cow or profit per unit of feed, and may have taken into account the energy/feed cost of increasing the animal's liveweight.

Breeding worth

The Breeding Worth (BW) selection index was introduced to take into account other factors that significantly influenced profit – namely fertility and longevity. Because the seasonal system is generally most profitable, higher fertility reduces the need to cull for poor fertility those cows that do not conceive in a timely manner. It became important as breeding for higher production inadvertently led to the selection of less fertile cows. Higher longevity is more profitable as the cost of raising replacements can be reduced. The Breeding Worth selection index, as implemented for 2002 can be summarised as (Montgomerie, 2002):

$$BW = \$1.226 * BV_{milkfat} + \$5.968 * BV_{protein} - \$0.074 * BV_{milk} - \$0.923 * BV_{liveweight} + \$1.505 * BV_{fertility} + \$0.032\ BV_{longevity} \quad \text{(Equation 4)}$$

The assumed linearity in BV's and EV's also implies linearity in the selection index such that the expected BW of offspring is the average of the parents.

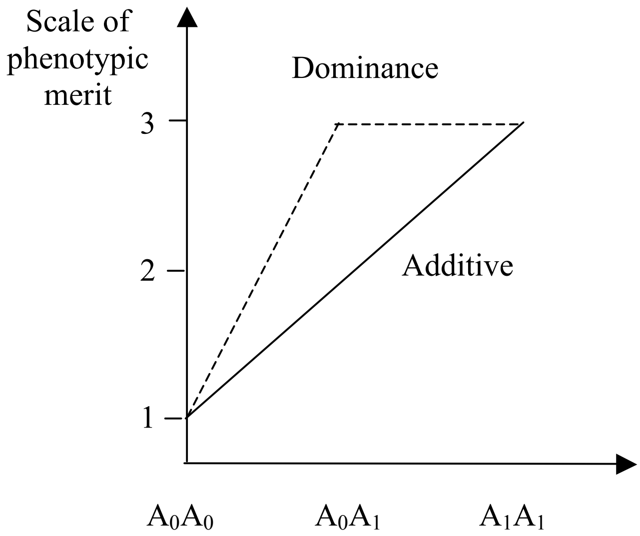
4. NON-LINEAR RELATIONSHIPS, CONSTRAINTS AND OTHER ISSUES IMPACTING THE EFFECTIVENESS OF A LINEAR SELECTION INDEX

I. Non-linearity in breeding values due to parental factors

The predicted improvement from a selection index is based on the assumption that predicted breeding value of the offspring is the average of the parents' breeding values. However, there are genetic reasons why the breeding value for an individual can predictably be different from the average of its parents. One reason why the offspring would be expected to have a higher breeding value than the average of its parents is through the effect of heterosis, also known as hybrid vigour. One reason for the offspring to have a lower than expected breeding value than the average of its parents is through the effect inbreeding depression. These effects will be discussed in turn.

When animals with widely different genotypes (eg different breeds) are crossed, the resulting offspring generally has a higher expected performance relative to the average of the parents' performance (Holmes et al., 2001). This effect is called heterosis, and results from the interaction of genes in a dominant manner. As an example, consider a gene positioned at a particular point on a specific chromosome. The gene can be expressed as A_0A_0, A_1A_0 (or the equivalent A_0A_1), and A_1A_1. Assuming A_0A_0 delivers 1 unit of performance on the phenotypic scale of merit and A_1A_1 delivers 3 units, if the effect of the genes was additive, A_0A_1 would deliver 2 units of performance (figure 1). If the effect of the genes is fully dominant, A_0A_1 would deliver the same performance as A_1A_1 (figure 1).

Figure 1: Additive and dominance relationships for a gene



Adapted from Holmes et al. (2001)

New dominance relationships are more likely to occur between two disparate breeds, and the effect is largest for the first cross. Estimates of heterosis for the first cross between the two most popular breeds, Holstein and Jersey, are presented in table 1 (Holmes et al., 2001). Without considering the heterosis effect on increasing fertility (estimated at 10% by Hansen et al, 2005), the estimated breeding worth added by heterosis would be $39 per unit of feed. This is large, relative to the average increase in BW per farm of just $5 BW per year. Thus, if the beneficial effect of heterosis can be maintained and managed as part of a dairy farm's reproductive plan, it can add significantly to the profit obtained through genetics.

Table 1: Heterosis effects of crossing Jersey and Friesian

	Heterosis gain (first cross)
Milk protein (kg)	5.2
Milk fat (kg)	7.1
Milk (litres)	137
Liveweight (kg)	7.7
Longevity (days)	222

Source: Holmes et al. (2001)

Inbreeding occurs when close relatives are mated together. Inbreeding increases the possibility that undesirable recessive genes may be passed on to offspring from both parents, leading to potential diseases or defects, such as complex vertebral malformation, as well as reduced fertility and lifespan. With the advent of artificial insemination and the international marketing of genetics, the selection pressure has increased and the genetics from superior bulls have been widely used. This has resulted in significant inbreeding in cattle populations. For example, two bulls, Elevation and Chief, make up 30% of the current Holstein herd in the US (Hansen et al., 2005). The inbreeding percentage is the percentage of all genes across a population that are identical because they trace to the same ancestor. The documented inbreeding percentage in the US is 5%, although because of limited data on pedigrees, it has been estimated to be as high as 7% (Hansen et al., 2005). This is higher than the recommended limit of 6.25% for commercial milk production. Most farmers are unaware of the financial trade-off between using the highest ranked sires from the selection index, and selecting sires that are not related to the cow being inseminated.

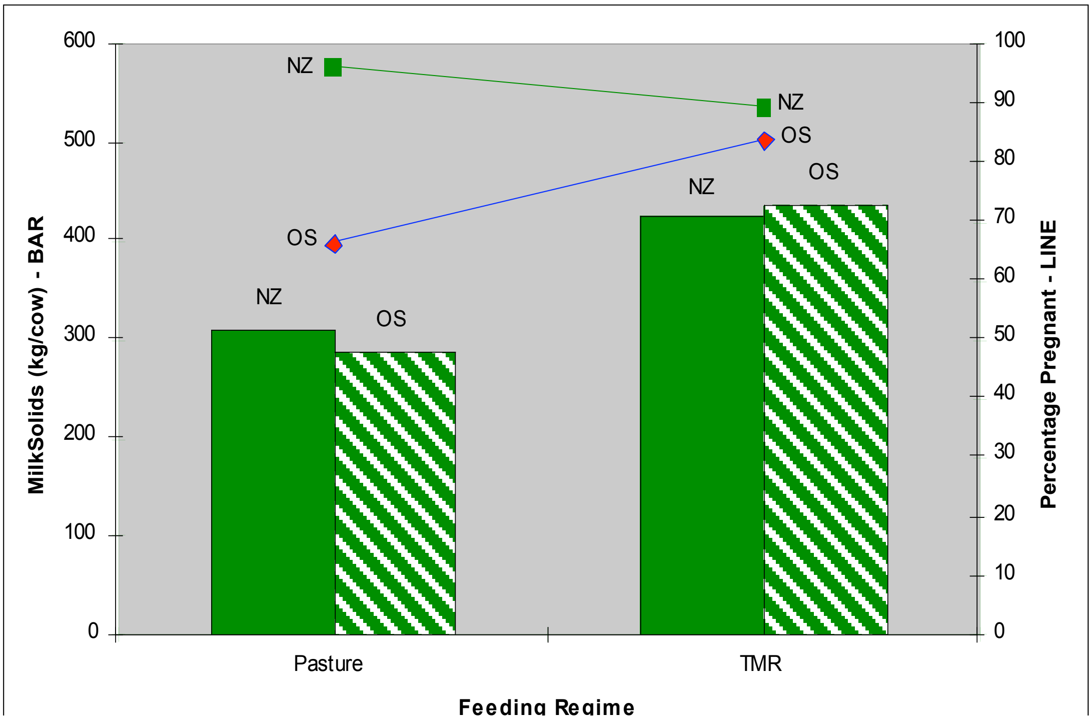
In summary, breeding decisions that involve disparate breeds could provide higher returns to genetic change than estimated by the linear selection index. Conversely, breeding decisions involving populations that are highly inbred with closely related sires can lead to returns from genetic change that are less than those predicted by the linear model.

II. Breeding values non-linearly related amongst different environments

A genotype-environment interaction occurs when the genotypes that perform best in some scenarios do not perform the best in other scenarios (Holmes et al., 2001). Early work by Syrstad (1976) implied that the different response of bulls used in different feeding regimes resulted in few consequences for breeding decisions. The Strain Comparison in New Zealand (Penno and Kolver, 2000) aimed to examine the effect of New Zealand (NZ) or Overseas high production (OS) genetics under pasture or Total Mixed Ration (TMR) feeding regimes. Under the pasture regime for which they were bred, the NZ genotype marginally outperformed OS in terms of milk production, and significantly outperformed them in terms of pregnancy rate (figure 2). Under the TMR regime, OS outperformed the NZ genotype in terms of production, and there was no statistical difference in the pregnancy percentage. Desktop modelling by Speight and

Hedley (2003) showed that for certain conditions, systems that used TMR for more than half the animal's diet could be as profitable as a more traditional pasture diet. In this case it is reasonable to suggest that the breeding objectives for the industry as a whole may not cater best for those systems at the extremes.

Figure 2: Genotype-environment interaction for Milksolids production and pregnancy rate



Data from Penno and Kolver, (2000)

Fulkerson (2000) performed a study of a high production genotype and a low production genotype under the three feeding regimes of low, medium and high concentrates per cow. Table 2 presents the difference in production predicted by breeding values and the actual differences found in the study. The results show that for a low feeding regime, the difference in production is significantly overstated. This result is called a scaling effect, where herds with larger average production per cow have a larger difference in production between high and low genetic merit animals. It is also a type of genotype-environment interaction where the change in environment is not as severe as for the Strain Comparison, although it may still affect the widespread applicability of a single selection index.

Table 2: Predicted and actual differences in production

	Predicted difference in production	Actual difference in production		
		Feeding Regime		
		Low	Medium	High
Concentrates per cow (t)	-	0.34	0.84	1.71
Fat+Protein (kg)	46.8	27	48	51

Source: Fulkerson (2000)

The results of Fulkerson (2000) also show that there was a significant difference in pregnancy rates between genotypes on the low and medium feeding regime, but that the difference was smaller at the highest feeding regime (table 3). This result was similar to the results from the Strain Comparison and reiterates the effect of improved nutrition on improved fertility for high production genotypes. Hence, if a farm has a significantly higher or lower plane of nutrition than most farms, actual fertility may be poorly estimated by breeding values.

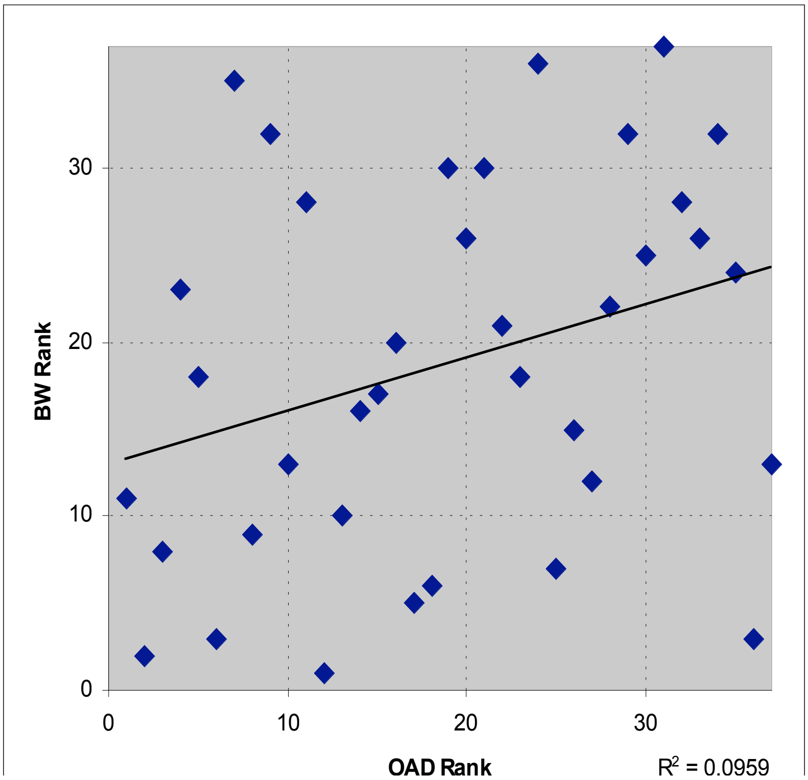
Table 3: Pregnancy rates

	Pregnancy rates (%)		
	Feeding Regime		
	Low	Medium	High
High production genotype	70	79	81
Low production genotype	83	90	84

Source: Fulkerson (2000)

The source of the genotype-environment interaction above was the feeding regime. Another factor that could result in a genotype-environment interaction is switching from twice to once-a-day (OAD) milking of cows. In New Zealand, there are a significant number of farms switching from the traditional twice daily milking of cows to OAD milking. In response to farmer demand, and taking into account the trial work that found a critical success factor is having the correct cows for the relevant system (Dexcel, 2004), LIC created a OAD index that can be used to select cows suitable for these farmers. Figure 3 shows that there is a correlation between the rankings from LIC’s sires ranked for Breeding Worth versus the OAD index. For example, only two sires are in the five highest ranked sires for both indices.

Figure 3: LIC sires ranked by Breeding Worth and Once-a-day index.



Source for data: LIC (2006)

Other sources of potential genetic-environment interactions include the potential for extended lactation systems (eg Borman et al., 2004) and voluntary (robotic) milking (Woolford, 2004)[5]. Extended lactation systems aim to calve cows every 18 to 24 months, as opposed to the traditional 12 monthly period for seasonal herds. This is driven partly by premiums for milk delivered in non-peak times, partly due to the high costs of inseminating and calving cows, and partly due to the inability to get cows back into calf. This reduces the value of fertility within a short fixed period, and increases the value of persistency of production. Voluntary milking systems aim to substitute capital for labour on the expectation of technology prices falling and labour costs continuing to rise. The preferred features for a cow that is voluntarily milked are yet to be detailed, although Mulder et al. (2004) found only a small genetic-environment interaction between the milk yields and somatic cells (a quality issue) comparing conventional and voluntary systems.

[5] Konig et al. (2005) found that geographic regions (East vs West Germany) were a source of small genotype-environment interactions, but a larger effect was found due to herd size.

In summary, genotype-environment interactions are a reason why a single selection index may not be appropriate for all farmers. Changing to a different system now, or expecting to change in the future, are potential reasons for using a selection tool that is different to the industry selection index.

III. Non-linearity of economic values across herds and between individual animals

A significant problem with the marginal values of genetic traits is the fact that an average (modelled) farm is used for the calculation of the marginal values. To take an extreme case, a seasonal farmer who has no problem getting cows in calf, due to the high fertility of the current herd, may have a zero value for a reduction in calving interval. In contrast, a seasonal farmer whose current herd is very poor in reproduction may highly value a reduction in calving interval. The industry selection index uses a single value in between these two extremes, and using different values would rank sires differently.

Many farmers make breeding decisions for individual animals using a philosophy of corrective mating. Corrective mating is when a sire is chosen with the intention of reducing the extent of the dam’s deficiencies being expressed in the offspring. For example, if a cow has high milk production, but poor reproduction, it makes sense to breed the cow with a sire that has good reproduction (displayed in his daughters). The bull ranked highest in the selection index may have excellent production that is slightly penalised by poor reproduction, but mating it to a cow with already poor reproduction increases the likelihood that the offspring will be culled for poor reproduction before the excellent production can be fully exploited. In other words, corrective mating is the recognition that for individual animals, breeding values cannot be substituted by simply using the linear economic weights of the selection index.

IV. Non-linearity in progress because of failure to include important traits

The Breeding Worth selection index used prior to 2002 in the New Zealand industry included 5 traits, milk, milk fat, milk protein, liveweight and longevity. Subsequently, when the importance of fertility was recognised, fertility was added to the index (Montgomerie, 2002). More recently, the somatic cell trait has been added to the index (LIC, 2006). In the Australian dairy industry a similar pattern of adding traits, including fertility, occurred over time. Fertility became more important because there is an antagonistic relationship between production traits and reproduction traits, and so breeding for production increased the level of infertility. It is also likely that at some point in the future, another trait of importance will become apparent and need to be added to the selection index. Hence, as a trait is added to the index, it shows that the linear gains in past breeding were overstated. The discovery of new traits of importance over time leads to a non-linear progress in genetics. Future traits of importance could include grazing ability, walking ability or persistency. In summary, there may be a non-linear relationship between profit and breeding worth, over time, because all relevant traits are not currently included.

V. Linearity in the average return need not be linearity in farmer's welfare

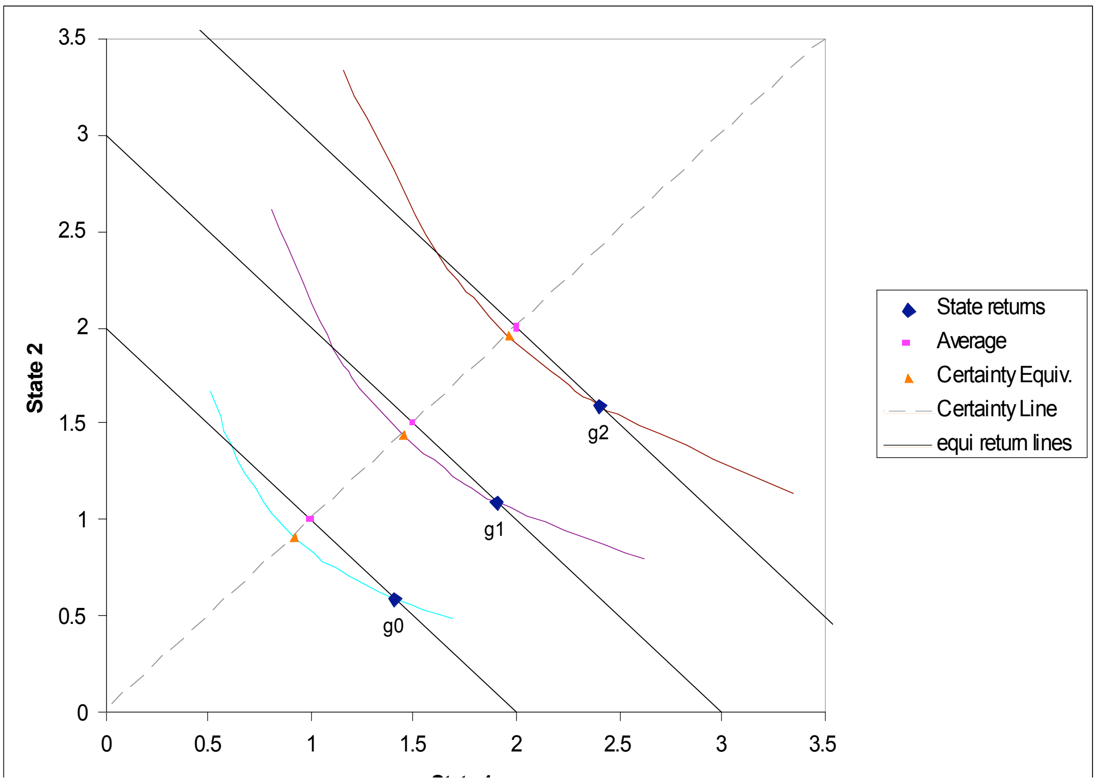
The profit functions or models generally, and perhaps exclusively, focus on one average or likely scenario to determine economic weights. However, uncertainty in prices and production is a common feature of many agricultural situations, and dairy farming is no exception. Representing uncertainty as a series of states of nature has gained new interest due to the work of Hirschleifer and Riley (1995) and Chambers and Quiggin (2000), among others. When uncertainty is taken into account, it is not necessarily the case that the average return from multiple states is the same as the return in the "average" state[6]. Ignoring this potential bias, the farmers' measure of welfare under uncertainty should not be considered simply profit or average profit, but the more general concept of certainty equivalent to take into account the likely risk

[6] Consider uncertainty is represented by two possible seasons occurring: A poor season (low pasture production), and a good season with higher than average pasture production. The impact of a poor season would be lower production and potential reproductive problems. This impact could not be balanced by the improved reproduction in a good state due to concave non-linearity in reproductive performance. Thus an average-based model overestimates the expected benefit of an increase in the trait.

aversion that exists[7]. This section shows through the use of a theoretical example that even if changes in an input (eg genetic merit) lead to linear changes in the average return, this may not lead to linear changes in farmer welfare, assuming risk aversion.

Consider uncertainty is represented by two possible (and equally probable) seasons occurring: A poor season (low pasture production), and a good season with higher than average pasture production. The current level of genetics leads to an optimal set of returns for the two states shown by the point g0 in figure 4, assuming constant relative risk aversion. Increases in genetics to points g1 and g2 occur as an equal amount of profit is added to the returns in each state. In this case there are linear increases in average returns. The increases in certainty equivalent are, in this case, slightly higher than the increases in average returns because the relative disparity between state returns is reduced.

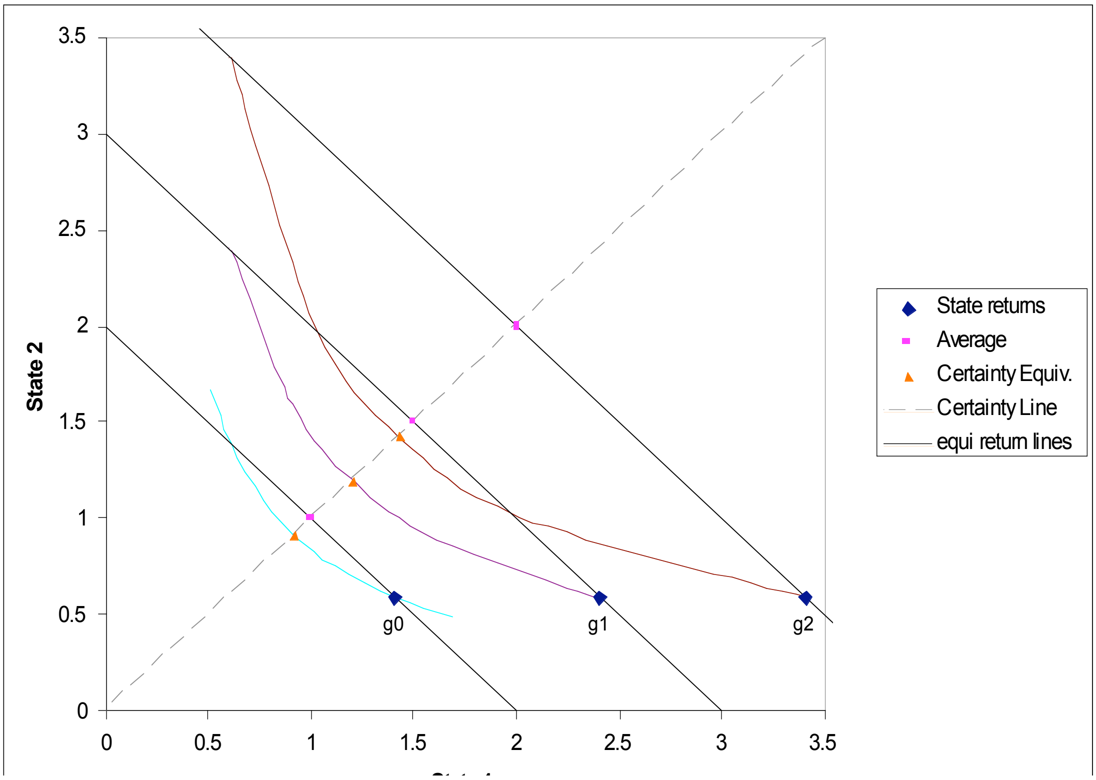
Figure 4: Changes in genetics affect returns in both states



[7] The measurement of welfare by certainty equivalent depends, in the example here, upon the assumption that the von-Neumann Morgenstern axioms of choice are considered reasonable and that return is the only argument of the utility function.

In figure 5, the increases in genetic merit are assumed to only increase the returns in state 1, the state that originally has the highest net return. Although there are still linear increases in the average return, this scenario results in an increasing disparity in net returns between the two states that causes the increases in certainty equivalent to diminish with respect to increases in genetic merit. In reality, it is likely that increasing genetic merit would increase returns in most, but not all, possible states of nature. It is also likely that the current high-return states occur because of favourable conditions such as high pasture production, low purchased feed costs and a high milk price, and so an increase in genetic merit would result in the profits increasing in the high return states more than less favourable states. Therefore, the second scenario is more likely to occur, meaning that increases in the average return will overestimate increases in the farmer's welfare, as measured by certainty equivalent.

Figure 5: Changes in genetics affect returns in state with high returns



In summary, when traits add returns mainly to high return states (eg production), the increase in average return overestimates the increase in welfare (as measured by certainty equivalent). Furthermore, some traits that improve returns in high-return states (eg production) may be overvalued relative to traits that improve returns in all states (eg fertility).

VI. Linearity in returns may ignore lumpiness of inputs

The profit function may imply that there is a linear increase in profit from increases in valuable genetic traits. Over time, for this linearity to hold, other inputs may need to be flexible and increase as required. However, many inputs are "lumpy" and are difficult to increase as required with small increases in genetics. As an example, feed-related capital is difficult to increase in small proportions. Speight and Hedley (2003) outline several farm systems that differ in their levels of feed-related capital, or more specifically, the type of feed-pad and equipment used to deliver supplementary feed. Three systems outlined in Neal (2005) are presented in table 4, showing the large steps in capital expenditure and feeds used as the level of feed-related capital changes (given a standard sized farm of 80 Ha).

Table 4: Key distinctions between capital intensity levels

	Low feed-related capital	Med. Feed-related capital	High feed-related capital
Main supplementary feed	Grass silage	Maize silage	Total mixed ration
Cost of machinery	$87,000	$151,000	$241,000
Costs of dairy and feedpad	$300,000	$440,000	$615,000
Losses when feeding out	30%	18%	8%
Repair and maint. cost per ha	$135	$150	$195

Neal (2005) found the stocking rate and genetic level of peak daily milk yield that maximised excess return per unit of risk for the three systems described in table 4, using the Dexcel Whole-farm Model (Wastney et al., 2002). The optimal values for those inputs are shown in table 5, together with the average return on assets. It was found that as the farmer increased milk production genetics, profit could be increased by adding feed-related capital. However, given that improvements in genetics generally occur slowly, and feed-related capital is a lumpy input, a farmer's profitability may fall relative to that predicted by Breeding Worth. This is because they have genetics beyond the optimal level for one system, but below the optimum for the next level of capital. This leads to a non-linearity between increases in genetic merit and profit.

Table 5: Feed-related capital; optimal stocking rate and genetics

	Low feed-related capital	Med. Feed-related capital	High feed-related capital
Results			
Average ROA	12.1%	12.7%	14.1%
Risk/Variability (Std. dev. of ROA)	5.8%	6.2%	6.4%
Choice variables			
Stocking rate (cows per ha)	2.25	3.6	3.47
Milk production genetics (Peak daily litres)	32.7	35.1	39.6

In summary, relative to genetic improvement, the "lumpy" nature and different time frames and over which inputs such as feed-related capital change, can cause Breeding Worth to overestimate gains from changes in traits in the short term.

VII. Constraints to the system that alter the economic values

It has been well recognised for several decades that if there are constraints to the system that the economic values for the index will be different relative to the unconstrained case (eg Groen, 1989). The main constraint considered in previous literature is the example of a quota. For example, economic weights were calculated for the case of an Irish farm with fixed cattle numbers under two scenarios (Table 6). The first scenario assumed a quota system where quota purchase was possible, and the second scenario assumed that no quota existed.

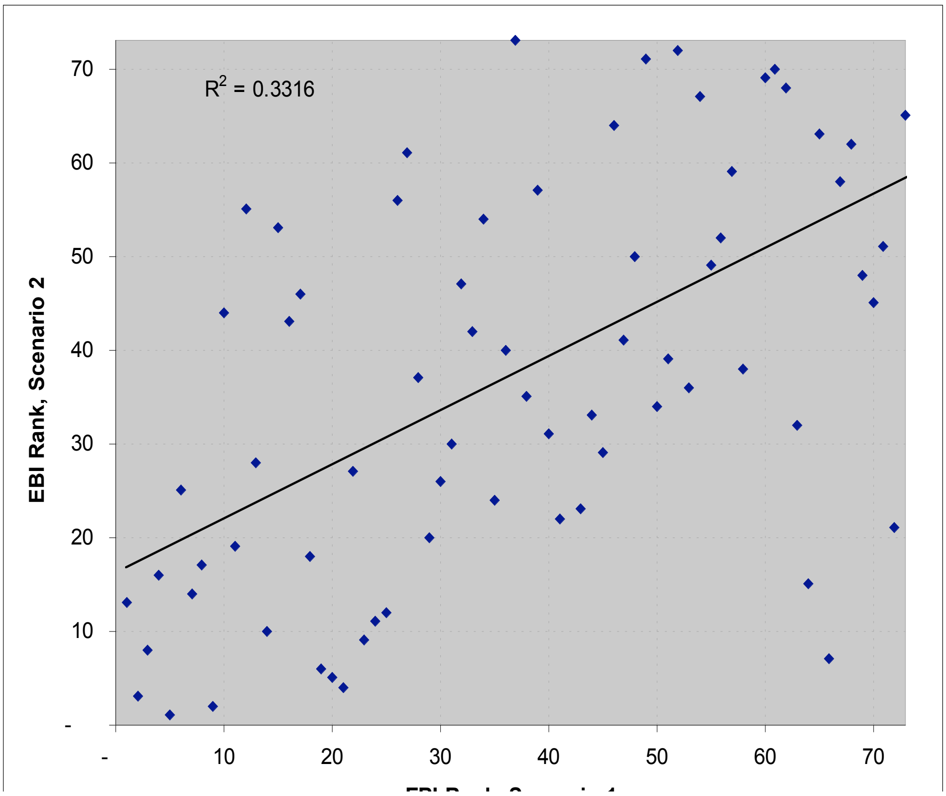
Table 6: Different economic weights for different scenarios (€ per cow)

	EBI Scenario 1	EBI Scenario 2
	Quota purchase	No quota
Milk	-0.08	-0.06
Fat	1.50	2.35
Protein	5.22	5.22
Survival	10.77	11.74
Calving interval	-7.09	-7.24

Source: Shalloo et al. (2004)

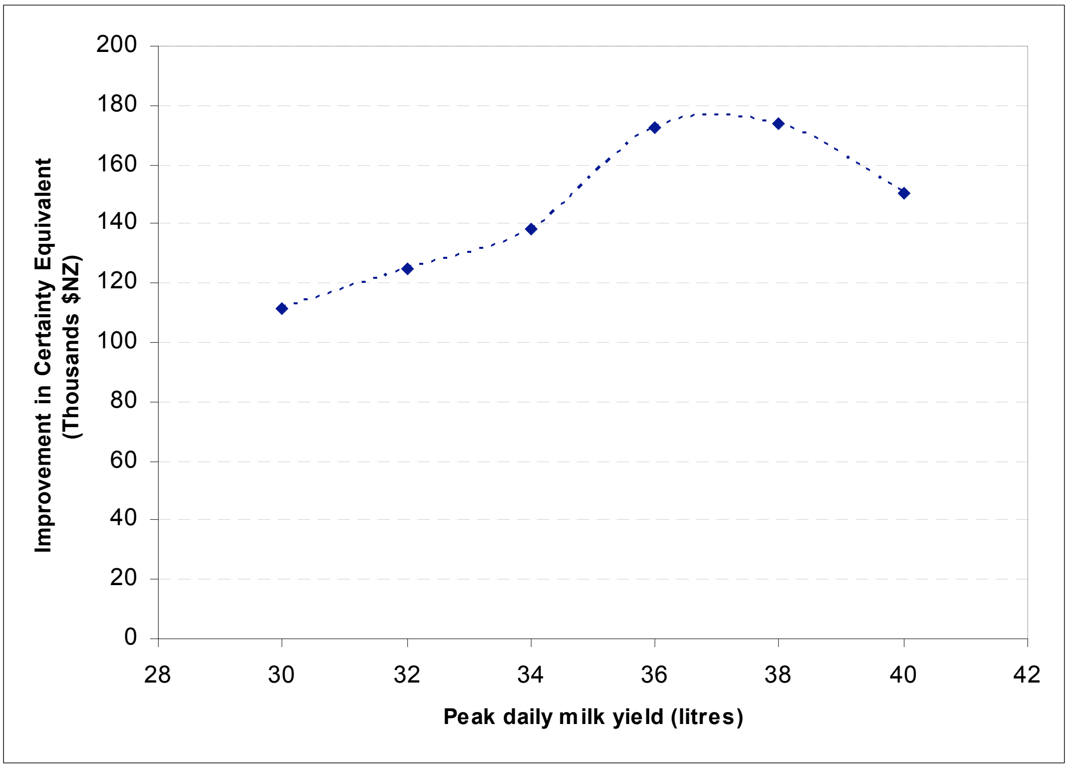
Figure 6 shows the correlation between sires ranked by EBI assuming scenario 1 and sires ranked under scenario 2. If a farmer picked the five best artificial insemination sires for their herd using the scenario 1 selection index, there would only be two bulls in common with the farmer who selected five bulls based on the scenario 2 selection index. The top five bulls ranked by the scenario 2 selection index average an EBI of 179. The top five bulls under scenario one would average an EBI under scenario 2 of 165. The difference of €14 implies that there would be a €7 difference in profit per daughter between the different selection indices assuming scenario 2 existed. This is small relative to the average net margin per cow of €463 (Fingleton, 2002). This small difference for one year as a result of applying economic weights from the wrong scenario could be exacerbated over time, although there is uncertainty with respect to if or when the quota constraint will be removed.

Figure 6: Bulls ranked by Economic Breeding Index (EBI) for two different scenarios



The model described in Neal (2005) was used to model the impact of changes in the genetic level of peak daily milk yield for a New Zealand dairy farmer who is limited to a low feed-related capital system. This constraint could potentially occur because of limited managerial ability or environmental regulations. The certainty equivalent was optimised for the farmer, assuming unitary constant relative risk aversion, at each level of genetics by changing the stocking rate and initial level of supplement. Figure 7 showing positive change in certainty equivalent with milk production genetics at low to moderate levels, but falling at high levels.

Figure 7: Change in certainty equivalent as genetic level of peak daily milk yield increases



The existence of constraints that may affect economic values in a relatively competitive market such as New Zealand has not been comprehensively examined, although Neal et al. (2006) considers the effect of potential environmental regulations. Limits to managerial ability are less likely, as managerial ability may grow with the manager's experience at a similar rate to genetic improvement.

VIII. Flat returns mean non-financial preferences can have a larger impact

Flat monetary (or certainty equivalent) returns for a wide range of management decisions are frequently found in agricultural problems (eg Pannell, 2002). If this is the case, the manager's preferences for non-monetary goals may be satisfied by a change in strategy that gives a small reduction in profit. For example, in the Republic of Ireland, Wallace and Moss (2002) undertook a study with recursive goal programming. The number of cows, operating capital and level of fixed capital were optimised over a seven year time period for farmers who had alternative rankings across five goals. The five goals related to the level of growth in net worth, fixed investment, farm profit, family consumption and short-run borrowing. Their conclusions were that through sacrificing a low level of profit (approximately 5%), a large degree of satisfaction could be gained in other important goals such as family consumption and the avoidance of borrowing.

In terms of New Zealand, farmers may switch to once-a-day milking systems if available labour can't be found, or if the manager does not wish to manage the available labour. This means that the farmer is not following the assumed route of profit maximisation, and as a result, the industry selection index may be inappropriate.

IX. Reduced genetic progress due to asymmetric information in cattle markets

If a perfect market for cattle existed, animals could be sold at a price that took into account the relative profitability of their genetics. In reality, the inability to identify the quality of animals, particularly "lemon" cows that are being sold with health, temperament or fertility problems, leads to a market where less high quality cows are sold[8] (Pindyck and Rubinfeld, 1994). Thus, for farmers that are expecting to change from one system to another, they could sell their current herd to buy new cows more suited to the new system. However, a farmer could reasonably expect that there would be a cost incurred through buying a certain percentage of lemons.

If the farmer believes that breeding from their own herd before they switch systems would be more profitable that selling the herd and buying some percentage of lemons, the current selection index provides little advice on which sires to use. For example, should the farmer expecting to switch from twice-daily milking to OAD milking in 5 years time use solely sires ranked high under a OAD index, or some weighted average of sires ranked highly under OAD and TAD systems? In any case, the increase in profit from breeding cows for a OAD system from cows more suited to twice daily makings will be less than that potentially achieved by the sale of the current herd and purchase of more suitable cattle in a perfect market.

X. Responses in product markets to changes in genetics

The benefits of improvements in genetic are estimated as increases in profit by the selection index. Amer and Fox (1992) note that the effect of perfect competition at industry level will result in all the benefits accruing to consumers in the form of reduced prices[9]. Goddard (1998) argues that this does not bias the economic values so long as market signals are passed onto consumers. In practise, it may be possible that production traits may be more likely to reduce prices (through increases in supply) relative to non-production traits that increase profit while production is held constant (eg fertility). In this case, production traits may be overvalued relative to non-production traits in the selection index.

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[8] Clearing sales (where a farmer sells all their cows) are an exception to the general rule. Because all cows are being sold, the buyer can make reasonable expectations about the average quality of purchases.

[9] Benefits could be passed on to consumers, or be capitalised into the value of cows or land. The actual distribution of benefits is a question that bears further investigation.

5. EMPIRICAL DATA ON THE RELATIONSHIP BETWEEN PROFIT AND THE SELECTION INDEX

The hypothesis that an increase in the selection index leads to linear increases in profit has not been regularly tested against empirical data. However, many countries could easily collect sample data, if they do not already do so. Farm data was sourced from the Dexcel ProfitWatch database for 197 owner operators in New Zealand for the 2001-02 year. The data included the Economic Farm Surplus (EFS), which is a measure of farm operating profit, as well as herd and farm characteristics[10]. Linear and quadratic models were estimated for the relationship between EFS per cow and the herds Breeding Worth, followed by EFS per hectare and the herds Breeding Worth. The hypothesis that the coefficient of BW^2 was zero could not be rejected for either EFS per cow or EFS per hectare at the 5% level[11]. Equation 5 and Equation 6 represent the linear models.

$$\widehat{EFS/COW} = 553 + 1.79 * BW \qquad \text{(Equation 5)}$$

(8.89) (2.30) *t-statistics*

Adjusted R Square = 0.021

$$\widehat{EFS/HA} = 1060 + 10.2 * BW \qquad \text{(Equation 6)}$$

(5.50) (4.22) *t-statistics*

Adjusted R Square = 0.079

A cow with a positive BW generally consumes more than one unit of feed (as defined by the BW index), and the cow's consumption increases slowly with BW. Therefore the expected sign of the linear coefficient should be positive and slightly more than one, assuming that actual conditions meet those assumed by the index. The actual coefficient is 1.79. The larger than expected size of the coefficient is probably

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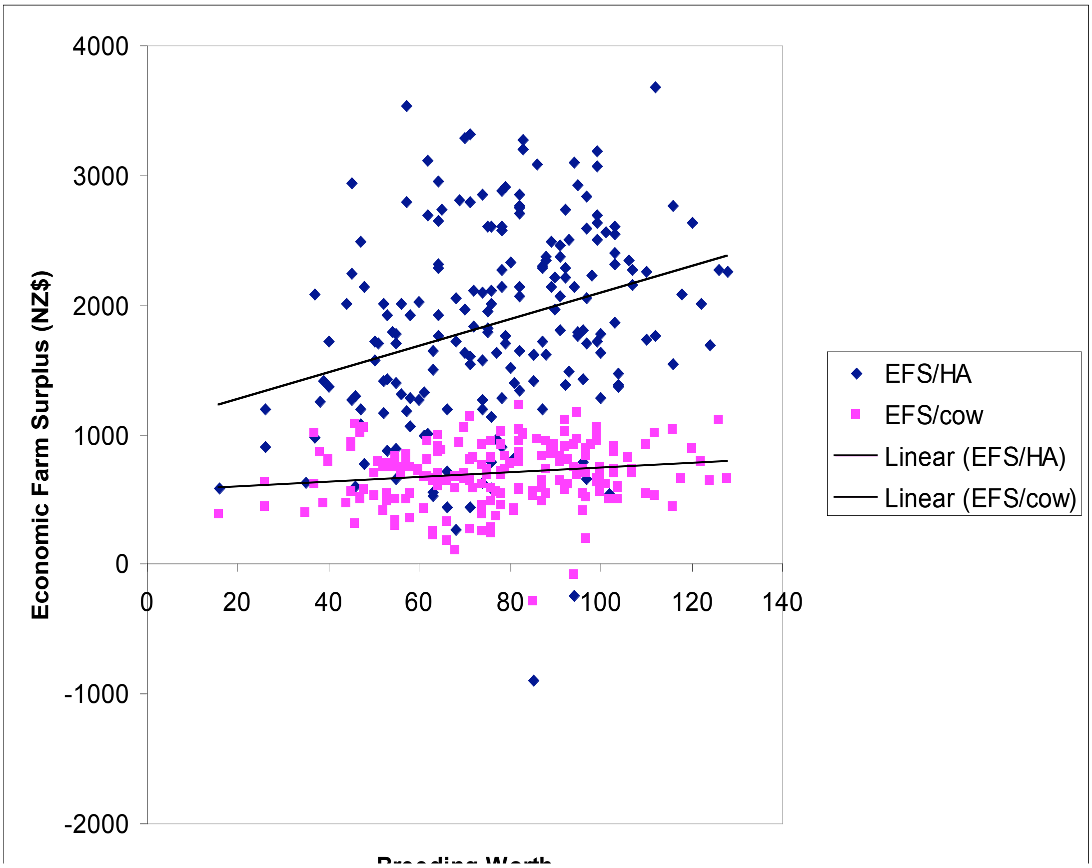
[10] All statistics were collected at the end of the financial year. Although the breeding worth should have been reported for the level at the start of the financial year, many farmers may have reported the level at the end of the financial year (Glassey, C., Pers.comm.). Assuming no relationship between reporting and Breeding Worth, the coefficients would not be significantly biased, although residual variance would be overstated.

[11] The hypothesis that the coefficient of BW^2 was zero could be rejected for EFS per hectare at the 10% level of significance.

explained, at least in part, by the significantly higher than average price for MilkSolids in 2001-02 ($5.26 compared to approx $4.00 per kg long term average). Assuming that each hectare produces the same amount of feed per hectare (approximately 12 tonnes per ha), the relationship between BW and EFS per hectare should also be linear. The hypothesised size of the coefficient should be equal to the average pasture production (12 t/ha), divided by the unit of feed over which BW is calculated (4.5t). This gives 2.67, which is also the average stocking rate from the data. However, taking into account the large milk price, the coefficient could be expected to be around 2.67 times the estimated coefficient on BW found for EFS/cow (1.79), which would be 4.78. The estimated coefficient in equation 6 is much higher at 10.2. The data and the lines of best fit are shown in figure 8[12].

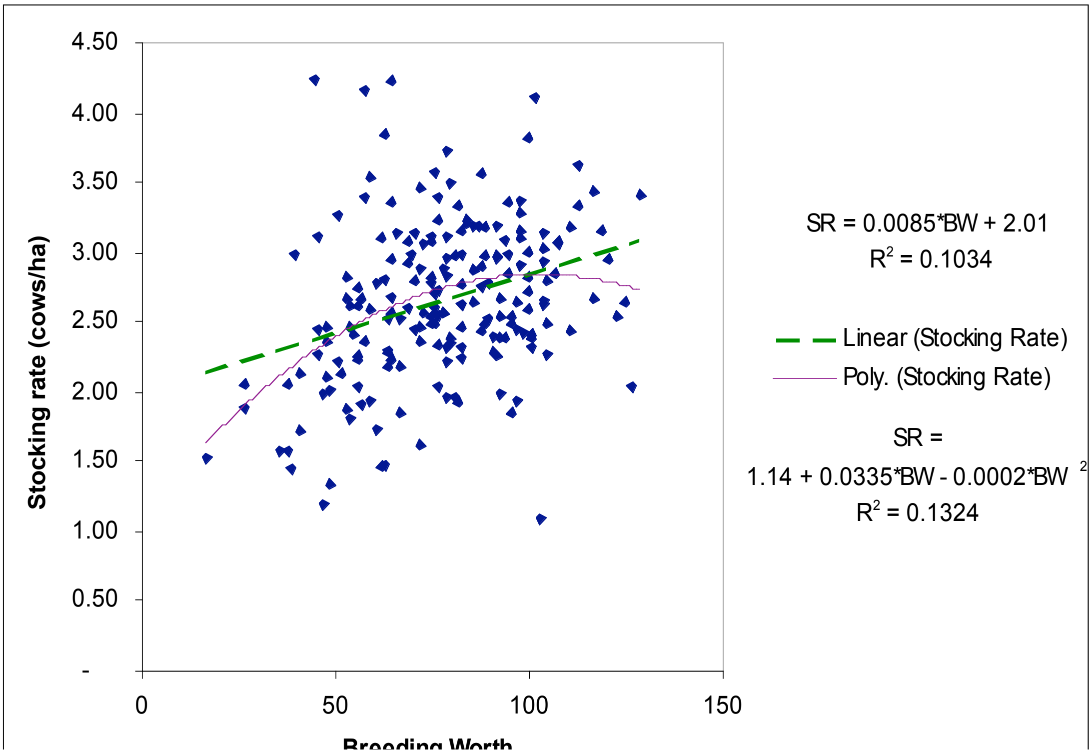
Figure 8: The relationship between Breeding Worth and Economic Farm Surplus per cow and per hectare.



[12] A further point is that there is a large amount of unexplained variation, and so the most profitable farmer with average genetics is far more profitable that the average farmer with top genetics.

A potential reason for the high coefficient of EFS per hectare could be that feed supply per hectare has increased with the increase in Breeding Worth. This is very likely to have occurred, as figure 9 show the relationship between stocking rate and BW[13]. Two factors may be at work to cause this relationship. Firstly, higher managerial ability could have led to higher BW through breeding, and the higher managerial ability was also responsible for increasing the pasture yield per hectare, with higher stocking rates to take advantage of the increase in feed supply. Secondly, higher BW cows make a higher level of purchased feed profitable, particularly under favourable states such as high milk prices.

Figure 9: Relationship between stocking rate and Breeding Worth



In summary, there is a linear relationship between profit and breeding worth for New Zealand Farm Data in the year 2001-02, although the coefficient is likely to be exaggerated by the higher than average milk price in that year. Accepting that it is possible that in the industry there is a linear relationship between profit and breeding worth, it does not necessarily follow that there is a linear relationship in profit for each farmer. This is because their individual circumstances may significantly affect

[13] All coefficients in the second order polynomial are significant at the 5% level of significance.

the contribution that increased breeding worth makes to profit. Furthermore, the increased stocking rate used to achieve the higher levels of profit create more exposure to seasons with poor pasture production and/or low milk prices, ensuring the increase in welfare is less than the increase in average profit, assuming risk aversion.

6. ALTERNATIVE SYSTEMS FOR GENETIC IMPROVEMENT DECISIONS

Customised economic values at the farm level

There have been various improvements in technology and computing that lead to possible solutions for the potential problems identified in the previous section. For example, it would be relatively simple to create a program (standalone pc- or web-based) that could recalculate the selection index or ranking of sires based on user defined economic values. This could reduce the problem identified for a farmer who had different economic values for traits than the industry index. The danger is that farmers using the system do not understand how to determine economic values and could easily generate sub-optimal decisions. A broader software model that accepted user-specific information such as constraints, and model genetic progress over a number of years while taking into account uncertainty and risk aversion, could potentially determine better economic values for the industry and individual farmers.

Farm-level effects on Breeding Values

The genotype-environment interaction could be taken into account if data was collected for broad groupings of farm systems to estimating breeding values dependent on environment. Then an individual farmer could estimate progress for their farm using the relevant breeding values, together with the relevant economic weights, using appropriate software. The farmer's current herd makeup would also be important information in estimating the benefits to genetic improvement. For example, a farmer with Friesian cattle, who considered there was no constraint to crossbreeding, could find an optimal plan for their herd for a certain time horizon, taking into account beneficial heterosis effects.

Customised animal level mating

Individual animal centred advice is a further step in using software to enhance genetic improvement. For example, New Zealand farmers can currently use a program called Cust-o-mate (LIC, 2006) that allows for corrective and selective mating to be carried out for individual animals. This allows farmer to select the “importance” of traits for themselves, and ensures that inbreeding and genetic diseases can be controlled. Future versions are expected to take heterosis into account. The benefits of this approach, and the potential problems, have not yet been fully explored in an economic study. However, it seems almost certain that modelling the benefits to changes in genetic traits at the animal level could improve the approach rather than simply using the transformations of the farmer’s “importance” ratings.

Trading specialised genetics

Using technology to improve markets, via reduced transactions costs, could improve farmer welfare by allowing trade of specialised genetics. For example, a farmer switching to OAD milking would probably breed from their current animals due to the large transactions costs involved in selling animals bred for twice-a-day milking to buy animals more suited to OAD milking. The commercial introduction of genetic testing (eg TruParent, LIC, 2006) could reduce the transactions costs of buying and selling livestock by ensuring that the animal’s estimated performance can be independently verified. Thus a farmer who expected to change to OAD milking in the future could potentially improve profit by continuing to breed the current herd for profit under a twice a day system, and then at the conversion point, sell twice a day animals to buy animals suitable for OAD milking. Other variations of the “specialisation” approach could include breeding the suitable proportion of the current herd with OAD sires, and leasing the OAD offspring to other OAD farms until the conversion point.

Sexed semen opportunities to reduce costs

Combinations of technologies could also lead to substantial improvement in welfare. For example, cost-effective sexed semen (where sperm carry only Y chromosomes, producing only female offspring) means that the same number of replacements can be generated by half the number of pregnancies. In a 24 month extended lactation system, sexed semen could allow the same rate of genetic progress while halving the cost of calving animals and reducing fertility problems could offset any loss in milk production and revenue. Alternatively, in a low labour system, beef bulls could naturally service the milking herd to produce offspring for sale on the beef market.

Replacement milking animals could come from a seasonal calving farm that uses sexed semen to breed twice as many replacements as required.

Modelling competition in the industry

The change in profit may be overstated by the selection index because competition in the industry results in benefits being passed on to consumers. However, if there are reasons why changes in some traits would result in a higher proportion of benefits being captured by dairy farmers, it may be appropriate to adjust the economic weights. A model of competition in the dairy industry could potentially be used this way.

7. CONCLUSIONS

A range of reasons were outlined in section 4 as to why the linearly aggregated industry-wide selection index may not provide the appropriate tool for breeding decisions for all farmers. In particular, the effects of constraints and uncertainty lead increases in welfare to be overstated by the selection index. The ability for users to define economic values for their farm system could be delivered via the web to immediately rank bulls appropriately for their conditions. The ability to tailor breeding advice for the individual animal, taking into account genetic factors such as heterosis and inbreeding already exists. It seems only minor improvements would be required to allow the economic values to be adjusted, taking into account the farmer's economic conditions.

Advances in technology and breeding, together with changes in input availability and prices, may lead to future farm systems that are radically different to today's predominant system, the twice daily milking, seasonal calving farm. The ability to identify the genetics of an individual animal at low cost could facilitate better markets for buying and selling cattle where superior genetics captures a premium. The reduced transactions costs in this market may allow dairy farmers to cost effectively outsource the replacement raising activity, or at least focus on breeding a cow appropriate to one system, even if they later expect to switch to an alternative system.

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