The Geneticization of Farm Management Advice: Add Farm Economics

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1. Introduction

'Geneticization refers to the increasing tendency to define differences between individuals as largely or entirely due to genetics'

Writing in 1981 about the bad old days of animal stud breeding, the pre-empirical days before performance recording of animals got underway in the 1970s and started providing accurate evidence about the potential performance of animals, Jack Makeham wrote that 'Probably no sector of agriculture has been more prone to the wiles of rapscallions than has the breeding game' (p.222)', as he set out to 'sort out the scientifically devised facts from the myths and mysticism hawked by those who stand to gain from the gullibility of some stock buyers' (p.222)'.

In recent decades, the science of quantitative genetics and biotechnology to identify animals with superior genetic potential has advanced apace. The modern science of identifying animal genetic potential in terms of a wide array of important traits is a wonder to behold, probably with much to offer productivity gains on animal farms. (As an aside, note that the heretic Beilhartz (1998), Beilharz and Nitter (1998), proposed an alternative paradigm, questioning the base assumptions of quantitative genetics, saying natural selection forces are assumed to not be at work and that the role of environmental constraints and the imperative to lift these constraints in order to achieve the potential of better genetics is under-rated in quantitative genetics).

Regardless, progress in genetic identification not been matched by progress in providing sound farm management economic information to farmers about investing in the animals with superior genetic potential. Indeed, it is almost a universal truth that geneticized advice about improving and fulfilling the genetic potential of livestock in animal farm systems is not grounded in the discipline and principles of farm management economics.

Advice from the quantitative genetics and genetics industries focussed on the gene instead of the organism, or on the individual animal instead of the animal farm system, along with insidious but spurious claims that the animal breed $Indices of amalgamated estimates of economic values of the Estimated Breeding Values of individual traits equate to additional profit from the animal containing that bundle of traits is not the useful nor valid information needed by managers of always unique animal farm businesses to make well-informed and sound farm management decisions.

The argument put in this paper is that:

(i) each animal farm business and the make-up of their herd/flock is unique; the economic value of a genetic trait is unique to the farm system and the environment in which the farm system operates

(ii) the economic value of a trait in an animal farm business from the viewpoint of an individual farmer depends on:

- The current distribution of animals with different genetic capability in the herd/flock
- The dynamics of the way the added genetic traits are disseminated through the herd/flock through subsequent generations
- the price of the output
- the cost of the input
- the existing level of the trait in the system
- the existing level of other traits in the system

Points (i) and (ii) mean:

(iii) there can be no general 'economic value' of additional units of genetic traits in animal farm systems or industries

The final parts of the argument are:

(iv) the performance of animal farm businesses is the result of the combination of all things (the mix of inputs in variable proportions) and a focus on one set of inputs to farm systems cannot lead to the best performance of such farm systems. Improving the genetic make-up of animals in the farm system is one among many ways to invest to improve farm profit.

(v) The worth of improved genetic potential of animals to an individual farm business is not the same as the value to 'an industry' or to the economy at large. This is because quantity and quality effects of genetic improvement of animals has aggregate supply, demand and price effects. Both producers and consumers benefit from improvements in efficiency of animal production.

In modern-times when 'pseudo-science' and 'fake news' abound, the flawed 'folk economics' that purports to be advice about the economics of animal farm genetic management, or indeed over-stated claims made about the (still significant) actual or potential economic benefits of genetic gain at a 'whole of industry level' (when this is not even estimated correctly at 'whole of farm level'), is constraining the potential of the technical information about animal genetic potential coming out of the modern animal genetic science.

As a dairy farmer once said, 'Trying to lift the performance of my business by focussing mainly on only a part of the whole system, such as animal genetics, is like trying to lift a bucket of milk while you are standing in it'. And, to continue the metaphor, by not getting the farm economics right, modern animal genetic science is akin to 'the dairy cow that gives a bucket-full of milk and then kicks it over'. More positively, marrying modern animal genetic science with established farm management economics theory shows the way forward, enabling soundly-informed management decisions about lifting productivity, improving whole farm profit and return on capital, and furthering the achievement of farmer goals.

In this paper, first in Section 2, the main principles of farm management economics are introduced briefly. In Section 3, genetic traits as an input to the whole farm production function is set out; cumulative dollar breeding indices are discussed; and animals as capital inputs depreciating assets are explained. Some concluding observations are in Section 4.

2. Principles of Farm Economics

The key principles of farm economics (Malcolm *et al* 2005) relevant to analysing decisions about introducing animals with improved genetic merit into animal farm systems and managing them to fulfil this potential are (see Figure 1):

- *The whole farm approach*: outcomes are the result of the combination of all things. The whole farm approach holds that solutions to problems of parts of the farm system are not solutions to problems of the whole. All inputs come into consideration when thinking about changes to the farm system. The whole farm approach rules out having a narrow focus on one dimension of the system at the expense of equally important other parts. The whole farm approach involves doing some analysis to see if a change to a farm system is beneficial, considering the farmer's goals such as building wealth through extra profit, extra cash flow, and with acceptable implications for risk, while helping to meet other important goals to the farm family. Changes in farm profit, cash and wealth that could result from changes to farm systems can only be assessed using whole farm economic analysis, including considering risk, dynamics and time.

Farm management economic analysis can only give correct advice if the analysis is built on a sound technical foundation. In the context of animal genetic improvement, the dynamics of the herd/flock is critical. The starting point of the distribution – not the average -of genetic make-up of the animals in the herd/flock is very significant. So too is the way the distribution of the genetic capacity of the animals change through the subsequent generations (see Shephard). The reason the average genetic quality of a herd/flock is not a valid unit of measurement in analyses of genetic improvement is that the response to added genetic merit of an animal depends on the existing level of genetic merit, and this varies considerably in most cases from animal to animal within the herd/flock. To correctly evaluate the worth of added genetic potential into a farm system the whole farm approach is needed; but to do whole farm analysis of the economic value of genetic gain, whole animal, not whole herd analysis is needed. Once the herd/flock dynamics are accounted for, all the complementary inputs required for the changed whole farm system need to be counted. The performance of a farm system is the result of the combination of all parts of the system.

A whole farm production function can be thought of as:
Output=function of (all fixed Inputs, all variable inputs, time)

The whole dairy farm production function is:
Annual outputs of milk and livestock = f(land, cattle, plant, labour, management, administrative, feed, herd, shed, soil moisture, temperatures, time)

- The *with:without* comparison: Farm economic analysis is farm benefit cost analysis. This involves comparing the likely future farm situation without a change and the likely future situation with a change. Alternative futures are compared. The dynamics of getting from 'now' to 'then' are accounted for, as too are the effects of time on the value of costs and benefits in the future, considering risk.

- *The marginal principle*: Diminishing marginal returns to an extra input with other inputs held constant (also known as the Law of Variable Proportions). The marginal principle is: 'a bit more of this, a bit less of that, am I better off?' This is the principle that requires farm analysts to think 'at the margin', knowing the principle of diminishing marginal returns to more inputs is at work and applies to all the inputs used in the farm system. The interest for the farm decision maker is the extra cost of an extra unit of input and the extra benefit that is created. If the extra benefit exceeds the extra cost, then extra profit is created, along with extra risk. This thinking is used, keeping in mind that an extra unit of a different input could create an even greater extra benefit.
- *Equi-marginal returns to all inputs maximizes profit*: The principle of equi-marginal returns tells that the input that adds the most extra benefit minus extra cost with acceptable risk should be used. The principle of equi-marginal returns tells that a farm is operating at its best when another input to reduce a constraint to output and profit cannot add more to output or profit than some other unit of any other input.
- *Opportunity cost:* All costs are opportunity costs. The concept of opportunity cost is a corollary of the principle of equi-marginal returns. Opportunity cost is the net benefit that is given up by doing one thing – using one input to production – instead of doing some other thing – using some other input to production. The concept of substitution comes in here. There are substitutes for inputs to milk production. For example, grain can substitute for pasture, purchased water for purchased fodder or grain. Capital can substitute for labour, such as automatic cup removers versus extra labour. Hectares with low pasture production per hectare can substitute for hectares with high pasture production. More smaller cows with lower production per head can substitute for fewer larger cows with higher production per head. Capital investment in more fertilizer, chemicals, cows, labour, capital equipment, land, water, purchased

grain and fodder are all potential substitutes for capital investment in improved genes.

- *The law of the minimum*: When a change is made to a farm system, each limiting constraint to extra production that are set by the existing fixed and variable resources of land, labour and capital of the farm system/business has to be lifted to enable expression of introduced enhanced genetic potential.
- *The principle of increasing financial risk*. The state of the balance sheet, the debt to equity, is relevant to all major farm decisions.
- *Risk creates return*: intensification increases average returns and the variability of returns above and below the average.
- *The effects of time on the value of benefits and costs*: All future benefits and costs must be discounted to their present value. The value of benefits and costs are affected by the time they are received or incurred. Benefits and costs occurring in the future have to be discounted to their equivalent present value before it is possible to assess their merit. Relatedly, the value of an asset is the discounted value of future net earnings. The benefits and worth of superior genetic traits in a dairy herd depend critically on the breadth and speed of dissemination of superior genetic traits through a herd. To understand and analyse this question the flow of genes through the herd and through time need mapping. The net benefits of these genes disseminated through the herd over time have to be discounted to their equivalent present value so the benefits can be added and the cumulative or lifetime net benefits assessed.
- *Asset valuation and depreciation*: the value of a depreciable asset is the capitalized value of the future net earnings of the asset after adjusting for the salvage value of the asset.
- *Beyond the farm gate*: the laws of supply and demand in the wider economy. Increases in supply relative to demand in an industry reduce prices received, increases in demand relative to supply increase prices received.

In the context of dairy farming further concepts are important:

- *Genetic traits as inputs to the production system* (in Section 3 below)
- *Animals as both capital inputs and outputs* (in Section 4 below)

3. Economics and Genetics

3.1 Genetic Input Production Functions in the Whole Farm Production Function

Applying agricultural production economics ways of thinking to questions about introducing improved animal genetic material into animal farm systems means treating genetic traits as one set of inputs among many inputs to a whole farm production function, seeing the animal production system as part of a whole farm production function made up of myriad of 'micro' farm response functions. (see summary box 1 below).

With the dynamics of animal production process represented a whole farm production function, output includes the multiple products or outputs that result from multiple inputs, for a given technology. Genetic material is brought into whole farm production function by re-writing it on first an animal, then a herd basis. The whole farm production function becomes:

Outputs 1,2 =function of Inputs (feed, water, labour, management, shed costs, breeding costs, …., Cows (genetic trait 1, genetic trait 2,….)

There are two main ways of estimating economic values of traits. One way is to estimate a whole farm production function of an optimized farm system with the existing distribution of the mix of genetic potential represented by the animals that make up the current herd/flock, then introduce an extra unit of a genetic trait counting the extra costs and extra benefits of doing so. The partial derivatives of the profit function indicate the marginal addition to whole farm profit. The other method is to use bio-economic models of optimized farm systems with and without the additional genetic traits, allowing for stochasticity, the dynamics of animal generations and time.

Genetic characteristics of animals are genetic inputs of a medium to long term and fixed nature, producing annual outputs and reproducing over time. The marginal benefits of superior genetic material vary according to the starting point, i.e. the genetic merit of the animal being used to breed animals of higher genetic merit. There is a distribution of animals with different genetic merit within a herd. Further, the relevant benefits occur over many years, and the relevant costs are both the fixed and variable costs of the farm system as it changes over time. Indeed, fixed capital investments are necessary costs at times to enable the expression of the improved genetic potential of the superior animals. The confounding characteristic of animal genetic inputs to farm systems is that they do not come as separate inputs; they come in 'bundles' of characteristics.

The value of extra profit that results from an additional input of a unit of a genetic trait depends on the price of the extra product produced or of inputs saved at the same level of output, the cost of the extra genetic traits and, importantly, the levels of the introduced traits and other traits that already exist in the farm system. As genetic change occurs over time in the mean of the characteristics, or other characteristics in the herd, the economic value of the added genetic trait will change. Inter-relationships between the values of characteristics as their mean values change over time need to be accounted for. If the farm system is operating efficiently, where within the limits of the environmental constraints all inputs are being used up to the point of equi-marginal returns between inputs, then an addition to profit from an extra unit of a single input cannot occur without substitution of more of the new input for less of other inputs, thereby creating new profit maximizing combinations of all inputs. Or, additional investment to the level of raise limiting factors.

The principle of equi-marginal returns dictates that the next investment to increase farm profit should be the investment with the highest expected return on the extra capital invested. Profit maximizing conditions are met when, if capital was not limiting, the marginal return (MR) from an additional unit of an input equals its marginal cost (MC). More realistically, with capital limiting, the ratio of MR:MC for each additional unit of each input are equal (Principle of Equi-marginal Returns). The profit maximizing levels of each input depends on output prices, input prices, the levels of all traits and the technology of production. The actual prices received for outputs and costs of inputs for each farm system are critical determinants of the economic value of extra genetic traits in farm systems. These costs and prices are unique to each farm system.

Table 1 Economic Value of Genetic Gain

Farm	**Added Input**
- whole farm production function - all inputs and outputs, including genetic traits as inputs - numerous micro-response functions - a current distribution genetic capability of animals in the herd/flock - generating over a run of years a distribution of annual returns to capital and net cash flows and additions to wealth	e.g. extra animal genetic trait (comes in a bundle of animal genetic traits)

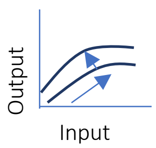
Economic Value of extra animal genetic traits introduced into a herd/flock are determined by the whole farm system:

- The starting point, i.e. the current distribution of genetic potentials of the animals in the herd/flock
- Where the herd/flock genetic potential gets to, i.e. the dynamics of the dissemination of extra genetic potential through the herd over the ensuing generations
- The extra quantity and quality of output that results
- The price of extra quantity and quality of output (individual vs economy-wide effects)
- The extra cost of the extra genetic trait
- The other farm input costs saved and incurred (e.g. intensification increases mean profit and volatility of annual profit)

The **Economic Value** of the extra genetic trait input depends on:

- Pre-existing level and distribution within the herd/flock of this animal genetic trait
- Pre-existing level, and distribution within the herd/flock of all other animal genetic traits
- The dynamics of the dissemination of the added genetic traits through herd/flock through time
- Extent of expression of genetic potential of the added genetic trait, which depends on constraints on other inputs and on the added genetic trait input to the farm system.
- Diminishing marginal returns to the added genetic input applies, whether the extra input of a genetic trait is added to the existing whole farm production function (i.e. meaning other genetic and non-genetic inputs are unchanged) or extra other farm inputs added to establish a new whole farm production function.
- Higher depreciation cost of higher capital value animals
- Net benefits of extra genetic trait depend on time (life in herd/flock) so discounted future net benefits need to be included
- Risks associated with the pre-existing and changed whole farm system Each of these effects must be reflected in a bioeconomic model if we are to correctly estimate the economic values of genetically influenced trait

Economic criterion is farm business return on capital with and without the changed genetic mix
Economic Value of extra genetic trait depends on the extra output (quantity and quality) or costs saved, which depends on the marginal responses attributable to introduction of the extra input of the genetic trait to a farm business that is already optimized. Marginal responses not linear.
Whether pre-existing or new farm production function – environmental constraints must be lifted to enable expression of genetic potential.



Moving onto new production functions and along production functions –happening at same times and various times

The economic value of a trait may thus changes for changes in the level of a trait; input or output price changes; or changes in the levels of other traits. Each of these effects must be reflected in a bioeconomic model if we are to correctly estimate the economic values of genetically influenced traits.

Theoretically a breeder wishing to maximize profit would use an animal genetic trait up to the level where the marginal value product of further increase in genetic potential equals the market cost of the additional unit of genetic merit. This would only be possible if it was possible to obtain the traits in individual quantities, independently. But, genetic inputs come in animals made up of many combined traits. Diminishing marginal returns occurs because of other resource limits and because of input substitution. More of an input used and diminishing extra output causes the cost of extra output to increase at an increasing, not linear rate. Rising marginal cost changes the Marginal Revenue=Marginal Cost optimum level of input use. The economic value of a trait changes as the prices and costs change. For example, the value of a genetic trait for increased feed use efficiency varies with the market price of the feed, and thus the value to the farm business of the feed saved.

The market value of one trait is confounded by being mixed up with the market value of all the other characteristics of the animal. As well, while farmers may be buying some breeding stock, often they are not buying traits in markets but are selecting from the existing herd. This has implications for the size and dissemination of genetic improvements through a herd or flock.

An angle often ignored is the potential market price effects that can occur at an industry-wide level if aggregate supply of output is affected. This can affect the market price, which in turn affects the optimal level of a genetic trait, according to the rule, the Marginal Value Product of Input=Cost of Input.

3.2 Economic value of a genetic trait changes with (i) the levels in the herd of the trait which is being increased and (ii) the levels of other traits in the animals being used to breed improved offspring.

The economic value of an additional amount of a genetic trait as an input to a herd/flock in a whole farm system is determined by the amount by which the profit of the whole system increases with an additional unit improvement in the trait in the animals making up the herd/flock. Paraphrasing Melton (1978), the important question is ‘how much will an additional unit of a genetic trait in an animal system contribute to whole farm profit, remembering that adding units of the genetic trait to all other inputs to the production system will, like the other inputs, be subject to diminishing marginal returns as more of the genetic trait is added into the system’.

The marginal response of an extra unit of a genetic trait depends on whether additional costs are incurred beyond the cost of the trait to lift environmental constraints; or whether the marginal benefit of the additional unit of the genetic trait comes from substituting for other inputs and maintaining output at pre-existing levels. In practice both effects are at work.

Also relevant to marginal response is the existing level of all genetic traits in the farm system. The higher the level of genetic traits, the less will be the marginal response. And, as the proportions of inputs in the input mix, relative to each other, changes, so too does the marginal contribution of an additional unit of an input (Law of Variable Proportions or Law of Diminishing Marginal Returns). The Economic Value of a trait changes as the mean level of genetic potential of that trait and other traits changes. This means economic values need re-calculating as herd genetic mean changes.

The diagram of a genetic trait response function in Figure 1 (from Melton 1978) shows the effects on profit of changes in the levels of a genetic trait in any one time. The third dimension, time itself, is not represented, but it matters. The diagram reflects the phenomena that (i) the value of a change in a unit of a genetic trait is affected by the levels of other traits and (ii) as the level of a genetic trait increases in the bundle of traits in an animal, the contribution to profit of extra units of that trait diminishes. That is, the relative proportions of the total mix of traits in the animal and of inputs used in the system changes.

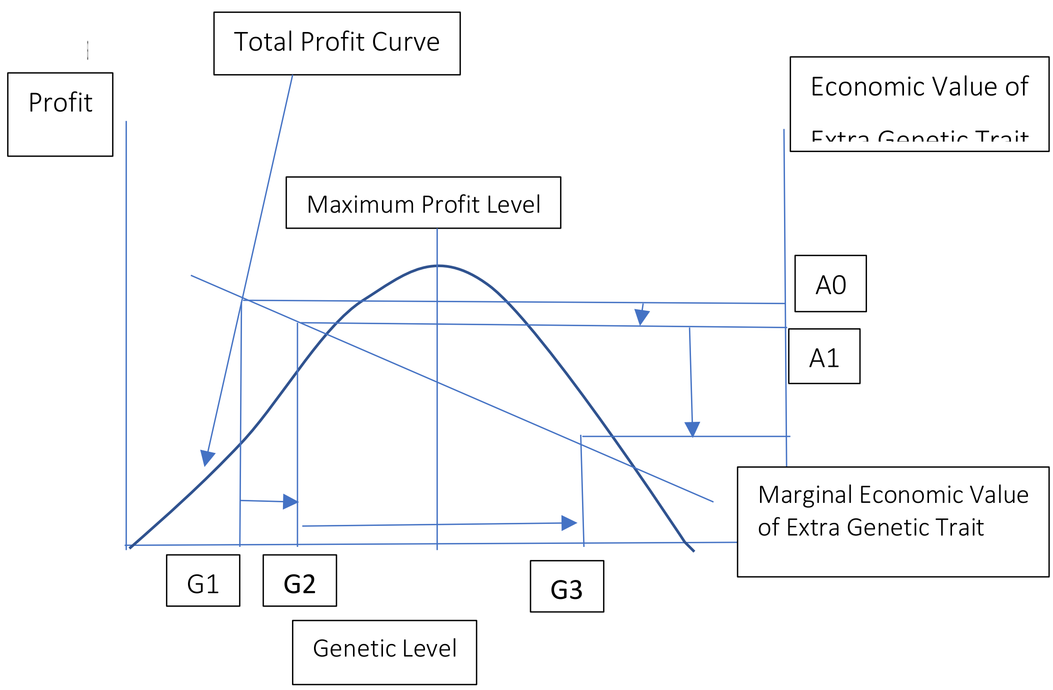


Figure 1 Diminishing genetic trait response function, other inputs held constant (following Melton1995), i.e. if other constraints such as environment, other genetic traits potential, are not lifted when additional quantities of a genetic trait is added

In Figure 1, the increase in a genetic trait from G1 to G2 changes the relative proportions of traits in the animal and in the mix of total inputs in the whole system. This adds to whole farm profit. At a different mix of traits and total inputs, the rate of addition to farm profit declines and with the change from G2 to G3, farm profit declines.

When all the other variables in the profit function are held constant, the profit effect of a genetic trait can be expressed as a function of the level of the traits. The economic value of the trait is a function of the level of the trait and the economic value of the more of the trait declines at every increased level of the trait. In Figure 1, as the level of trait input to a production system changes from G0 to G1, the economic value of the trait declines from A0 to A1. The response is not linear[1]: if it was then there would be no maximum amount of the genetic input and no maximum profit. There would be no limit to the use of more of the trait as more of the trait would mean more profit, *ad infinitum*. Regarding non-linear responses, Amer and Fox (1993) explain, citing Goddard (1983):

> When (the profit function) is non-linear, partial derivatives are normally calculated at .. the level of the population mean for (the) trait … This is because rates of genetic change in livestock are low (Goddard, 1983; Smith, 1984; Brascamp *et al.,*1985).

Further, for many traits, 'marginal products' of more units depend on the prevailing levels of other traits. An added complication is that with animals, individual traits come in bundles comprising the animal.

3.3 Profit indices

Profit indices do not tell how much whole farm profit will change if the bundle of genetics represented in the index is introduced into a farm system.

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[1] Goddard (1983) investigated the implications of non-linear farm profit functions. Regarding this, Goddard concluded that the diminishing marginal returns to additional traits did not matter much because the marginal changes are so small anyway. However, in an interesting follow-up, Melton *et al* 1993 wrote a journal Note responding to Goddard (1983) on the grounds that in their view, 'certain aspects of…Goddard's (1983) comments suggest fundamental misinterpretations regarding both the method and results presented in the initial article (of Melton et al 1979).

An animal with a profit index of $300 does not contribute $300 to farm profit. An animal with a profit index of $300 does not contribute $200 more to farm profit than a cow with a profit index of $100. This question about contribution of an animal to whole farm profit can only be answered by detailed whole of herd and farm analysis incorporating *inter alia* detail about marginal feed conversion efficiencies.

To be useful to breeders the methods used to estimate the economic value of genetic traits should be rigorously consistent with the established relevant disciplinary theory (Melton *et al* 1995); in this case, the discipline of farm management economics. Nowadays, combining the estimated breeding values of individual traits into a composite 'Profit Index' is standard practice in all animal industries. The question that breeding profit indices try to help answer is: what is it worth, in terms of added profits, to achieve marginal changes in the mean level of a range of animal genetic traits through genetic selection? The starting distribution of genetic potential of animals comprising the herd/flock is important, as does the rate and spread of changed genetic potential through the herd/flock over time (Shephard). The approach to estimating breeding profit indices is: (also see Figure 2)

- Establish a bio-economic model of a farm operating in some 'typical' annual manner. Estimate annual operating profit under defined technical, climatic and market conditions before the new levels of a collection of genetic traits are introduced. This should be an economically optimized system before the additional bundle of superior genetic traits is introduced to the farm system. That is, obeying the principle of equi-marginal returns to optimize profit, the returns to new investment in each means of increasing profit will be equalized.
- Estimate the higher production in the model of the farm system resulting from a small change in one of the genetically influenced traits in the bundle of traits in the animal, holding the level of other genetic traits constant, subject to the rules of breeding – antagonisms, complementarities etc – assuming linear responses to the additional inputs of traits, irrespective of pre-existing levels of the all genetic traits.
- Re-estimate annual farm operating profit of the now-changed farm system, counting all additional associated costs and returns.
- Interpret an increased operating profit of the changed system as the contribution of the characteristics of the changed input.
- Repeat the process for additional inputs of other relevant traits of an input that can be influenced by breeding.
- Weight the importance of the contributions to additional annual farm profit of various traits of the input in question, according to their contribution to additional annual farm profit and other wider criteria.
- Sum the dollar contributions to profit of each of various traits and call this a '$Index or total dollar or profit value' of the complete package of traits in the animal.

* Animals with the high breeding value traits and $Indices are then commonly promoted as having the potential to contribute more to farm profit than animals with less of these characteristics and lower $Indices. Going beyond this, breed societies and other breeding industry agencies commonly claim or imply the $Index figure is the contribution a bull or cow will make to farm profit. Or, the difference in $Indices between animals is the difference in contribution to farm profit that different animals will make. (Neither of these claims is correct because the $Index value is does not indicate the potential contribution to profit of a farm system).

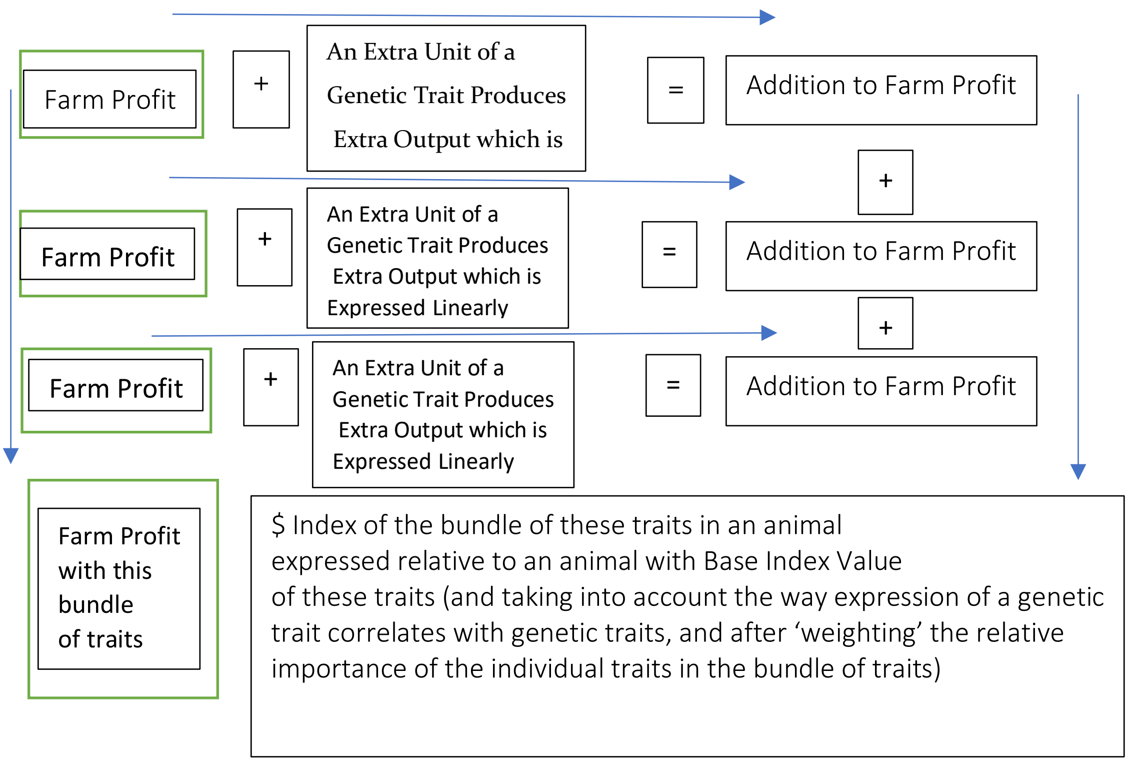

Figure 2 Estimating Breeding Values and Breed Profit Indices.

Estimates of economic value of an additional unit of a trait have to be made for farm systems that are economically optimized (Solkner *et al* 2007). The reason the calculations of the value of additional genetic merit into an animal farm system is done for a system that is already optimized is that other sources of non-genetic productivity and profit gains are achieved more quickly than by animal breeding (Amer and Fox 1992) and estimating the economic value of additional genetic resources in a sub-optimal system introduces bias (Dekkers 1991).

A key assumption underlying the calculation of a Breed Profit Index is that adding more of one trait of genetic potential to the total bundle of all other traits of genetic potential in the animal, and in the farm system, has a linear response. The extra output from fulfilling the extra genetic potential of this trait is not subject to the Law of Variable Proportions/Law of Diminishing Marginal Returns, the biological rules about different effects on output from an extra unit of an input added to a farm production system when other farm fixed and variable inputs, including genetic traits, are held constant. Adding more of one input, even a single genetic trait, to a farm system including existing bundles of inputs including genetic traits, changes the proportions of the total mix of inputs in the farm system. Even with environmental constraints lifted, changing the proportions of the mix of genetic traits unavoidably raises the likelihood of diminishing marginal returns, not linear marginal returns as is assumed in calculating profit indices (Melton *et al* 1995, Melton *et al* 1979, Melton *et al* 1993). The value of more of one trait will eventually decline with increases in another trait. For example, in dairying, the value of more of a fat or protein trait in an animal would be less in an animal in which the trait for survival in herd (lifetime earnings) or fertility (probability of trait being disseminated through the herd) was reduced.

The genetic traits in a breeding profit index are not individually, directly valued by the buyer of the farm product: they come as a 'bundle' in the form of an animal. The market value of one trait is confounded by being mixed up with the market value of all the other characteristics of the animal. As well, while farmers may be buying some breeding stock, often they are not buying traits in markets but are selecting from the existing herd. This has implications for the size and dissemination of genetic improvements through a herd or flock.

Genetic superiority is expressed over the life of the animal, and at declining rates by offspring of the animal. This introduces the effects of time on future gains from investment in animals of superior genetic merit. These benefits and costs in the future need to be discounted to their present values using discounted cash flow budgeting methods.

Knowing that a breeding $Index cannot indicate the addition to profit of introducing this mix of genetic traits into any particular farm system, how then to use the information contained in the $Index? Given the limitations, it is most usefully seen as a cumulative sign-post, a selection index, indicating overall direction and rate of change in the mean herd genetic potential for the bundle or mix of genetic traits the index represents. The Estimated Breeding Value information about individual traits that make up a breeding $index remain equally, or more important, information to investors in improved animal genetics.

3.4 Animals as Capital Inputs and Depreciating Assets

Animals are 'lumps' of capital. The capital value of animals with different potential to contribute extra profit, and thus different annual depreciation costs, has to be accounted for when estimating the economic value of genetic traits.

Capital of long-lived livestock is *both* a farm input that supplies services to the farm system and an output of the farm system. The animal is also a bundle of genetic traits. In dairy farming cows the fixed capital that is dairy cows supply several streams of inputs to the farm system: (i) an input to milk solid production, (ii) an input to genetic material of offspring and (iii) an input to replacement of fixed capital and (iv) an input to meat production.

3.4.1 Value of an animal asset

The value of an asset is the capitalized value of the net earnings over its lifetime. Real risk-free returns to capital in the economy have ranged from 2% to 6% over the past half century. If 5% p.a. is the relevant annual discount rate, an animal that produces a net return of $95/year for 5 years and has an end-of -life value (called salvage value) of 50% of purchase price, has a starting capital value on day one of year one of $734. Lifetime depreciation is $367 or an average depreciation of $367/5=$73.40.

If superior genetic merit of animals relates to production including subsequent generations, over the animals replaced, and does not affect the length of life in the herd, and the superior animals have the same salvage value as the animals they replace, then the superior animals have a higher capital value and a higher annual depreciation. The annual net return from the superior animals needs to cover a higher annual depreciation.

The three critical numbers in determining the value of a cow of each age group in a herd, (as well as the annual depreciation of the capital of a dairy cow), are (i) the expected stream of annual future net benefits, (ii) the expected life and (iii) the expected salvage value of the cow.

The value of a bundle of superior genetic traits can only be valued in the context of the combined effects of the expression of these traits in the context of a whole farm system. Suppose the contribution to whole farm profit attributable to changes that stem directly from introducing a straw of semen containing a bundle of superior genetic traits is equivalent to $50 more per year extra farm profit more than using a straw of average quality bull semen, after all system change costs are counted over say a 10 year life of the superior genetics in the system, and after discounting the values of future benefits and costs.

If the straw of semen comprising a bundle of superior genetics was expected to contribute the equivalent of $50 extra profit to the farm system each year for 10 years, and if the investor had an opportunity cost of 10% real return on capital (i.e. could invest elsewhere in the farm or the economy in a similarly risky way and earn 10% real return), then the bundle of superior genetic traits would have a lifetime discounted present value of $307 more than an alternative bundle of average or base index value genetic traits.

Turning this logic around, if someone paid around $300 more for one sire over another sire, both of whose offspring would contribute for several generations over 10 years, and the required rate of return on investment was 10%, then they are anticipating the superior sire will add $50 more per year to farm profit over its lifetime than the alternative average quality sire.

Once capital aspects of a dairy herd are considered, and the fungible nature of capital is considered, it becomes clear that many different combinations of forms of capital inputs can earn competitive market rates of return to capital. For example, more capital invested in land and equipment and less in herd quality, or more capital invested in herd quality and less in land and equipment can be equally profitable, i.e. earn the same return to capital.

3.4.2 Depreciation

As a fixed input to the system, the annual costs of owning — not running — a dairy cow is the same form as the annual cost of owning a tractor or other capital equipment. The ownership costs of fixed capital are:

(i) annual depreciation is a measure of the asset losing value because of obsolescence or wearing out. This is estimated as (Start of year value - expected salvage value in current dollars at end of life in the system)/(no. of years of expected life remaining in the system).
(ii) annual opportunity interest cost of the capital tied up in the machinery.
(iii) annual overhead costs such as registration, insurances or annual shedding costs

The relevant annual ownership cost of a dairy cow is the annual depreciation of the start of year capital value and lifetime depreciation as a result of wearing out or obsolescence. The annual depreciation cost of a dairy cow depends on the value at the start of the year minus the value at the end of the year. The value at the start of the year is determined by the expected profit from the cow over the rest of her life, thus expected milk production, milk prices and feed costs help determine cow value. The salvage value of a dairy cow is determined by the cow-beef price, which has been between $2-$3/kg cwt ($1-$2/lwt) over the past 20 years, with prices only being above this trend in the past couple of years. A 500kg lwt/275kg cwt cow at $2.75/kg cwt would sell for $750. A $1500 investment (a cow) with a life of 5 years and a salvage value of $750 has an annual average depreciation cost of ($1500–$750)/5=$150/cow/year. If the average time of a cow in the herd was 4 years, annual average depreciation cost per cow would be $187.50. If a cow lasted 3 years in the herd, average annual depreciation per cow would be $250. (See Table 1).

Total Lifetime Depreciation: $750

Years in Herd	Annual average depreciation
1	$750
2	$375
3	$250
4	$188
5	$150
6	$125
7	$107
8	$94
9	$83
10	$75

Another way to estimate annual herd depreciation cost is shown in the following example. Suppose we have a 500 cow herd, with 100 cows in each of the age groups 2, 3, 4, 5, 6 years old. Suppose the 2-year-old (YO) cows are each worth $1800/head, giving $180,000 capital as 2-year-old cows. Suppose there are no deaths and the 100 six-year-old cows are culled at the end of their 6th year, for $750 each, giving a total of $75,000. The annual herd depreciation is estimated as $180,000-$75,000=$105,000, or $210 per cow per year.

3.5 In sum

In sum, from the viewpoint of the farmer, the economic value of a genetic trait animal farm system depends on the sum of its capacity to create more product for sale at the same level of input use, capacity to use less input for the same production, and capacity to contribute extra profit in a changed farm system in which environmental and genetic constraints are lifted. These effects come from effects on product quality and prices received; ability to shift the production function and the costs and benefits of that shift;and the time over which the animal contributes to farm profit which has implications for annual depreciation and for discounted value of future net benefits. In summary, the marginal value of a marginal unit of a genetic trait introduced into a farm business is determined, for that individual farm business, by:

- The extent to which additional costs are incurred to lift environmental constraints
- The existing level of the introduced genetic trait and all other genetic traits in the system
- The price of the output from the extra units of the genetic trait
- The quantity of the extra output from the extra units of the genetic trait
- The quality of the output from the extra units of the genetic trait
- The cost of the extra units of the genetic trait
- The time involved: the life of the genetic trait in the farm system
- The effective dissemination of the trait through the animals in the system
- More profitable animals have a higher capital value than less productive animals
- Higher capital value animals can have higher annual depreciation than less productive animals, depending on (i) salvage value and (ii) life in herd
- Capital inputs can substitute, and many combinations of forms of capital to make up a farm system – of cows, land, equipment – can earn the same return to capital.

Changes in farm profit that could result from changes to farm systems is most accurately assessed using whole farm economic analysis that includes risk, dynamics and time, and by obeying fundamental physical and profit maximizing rules of the commercial operation of farm system.

4. Concluding comments about practical geneticization of farm advice

Focussing narrowly on the gene and not the organism, or on the organism and not the farm system and its environment in which the organism produces output and contributes to profit, is quite a few steps removed from the realities of the farm business and of farm management economic analysis. Solutions to isolated parts of systems are not solutions to problems of whole systems. A narrow perspective of animal genetic gain does not provide whole farm advice to animal farmers about introducing superior genetics into their farm businesses. The need is stronger now than ever for farm management economic analysis, comparing all the benefits, costs and risks of changes to a farm business at a time and over time to a range of inputs and input combinations, built on sound technical foundations and understandings, applying with rigour the long-established principles of farm economics.

Tight focus and strong emphasis on animal genetic material as an input to production systems has the implicit assumption that more of this input would add the more to whole farm profit than would more of some other input which is substitute input for genetics. This is an empirical question, not answered sensibly by assumption of 'belief' about where the biggest marginal returns will come from with additional investment in any farm business.

Simple answers to complex questions are wrong. Interpreting $Index values as being the amount an extra unit of a genetic trait added to a farm business will add to farm profit is not correct. The economic value of genetic traits, and extra profit from more of genetic traits in an animal farm system, is the result of a complicated set of dynamic relationships and interactions with all the other inputs in the whole farm system. These responses and associated values are unique to each farm system, and these change as the mean level of genetic merit of the herd changes. Economic values of genetic traits are not constant; they change as the genetic merit of a herd/flock changes. Unique too is the starting point distribution of genetic merit of a herd/flock; as too are the prices of the extra output, the costs of the extra inputs and opportunities for substitution of other inputs for genetic traits in farm systems. The goals and skills of the farmers running their businesses too are unique. The worth of a genetic trait is correctly estimated using case by case farm management analysis for herd/flocks with defined starting distributions of genetic merit, estimating herd/flock dynamics over time, and comparing alternative futures with and without the additional traits, encompassing farmer goals, dynamics, time, risk. That is, all the methods of traditional farm management economic analysis.

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Appendix 1

Farm

- whole farm production function
- all inputs and outputs, including genetic traits as inputs
- numerous micro-response functions
- a current distribution genetic capability of animals in the herd/flock
- generating over a run of years a distribution of annual returns to capital and net cash flows and additions to wealth

Added Input

e.g. extra animal genetic trait (comes in a bundle of animal genetic traits)

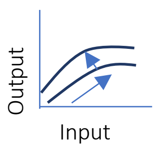
Economic Value of extra animal genetic traits introduced into a herd/flock are determined by the whole farm system:

- The starting point, i.e. the current distribution of genetic potentials of the animals in the herd/flock
- Where the herd/flock genetic potential gets to, i.e. the dynamics of the dissemination of extra genetic potential through the herd over the ensuing generations
- The extra quantity and quality of output that results
- The price of extra quantity and quality of output (individual vs economy-wide effects)
- The extra cost of the extra genetic trait
- The other farm input costs saved and incurred (e.g. intensification increases mean profit and volatility of annual profit)

The **Economic Value** of the extra genetic trait input depends on:

- Pre-existing level and distribution within the herd/flock of this animal genetic trait
- Pre-existing level, and distribution within the herd/flock of all other animal genetic traits
- The dynamics of the dissemination of the added genetic traits through herd/flock through time
- Extent of expression of genetic potential of the added genetic trait, which depends on constraints on other inputs and on the added genetic trait input to the farm system.
- Diminishing marginal returns to the added genetic input applies, whether the extra input of a genetic trait is added to the existing whole farm production function (i.e. meaning other genetic and non-genetic inputs are unchanged) or extra other farm inputs added to establish a new whole farm production function.
- Higher depreciation cost of higher capital value animals
- Net benefits of extra genetic trait depend on time (life in herd/flock) so discounted future net benefits need to be included
- Risks associated with the pre-existing and changed whole farm system Each of these effects must be reflected in a bioeconomic model if we are to correctly estimate the economic values of genetically influenced trait

Economic criterion is farm business return on capital with and without the changed genetic mix
Economic Value of extra genetic trait depends on the extra output (quantity and quality) or costs saved, which depends on the marginal responses attributable to introduction of the extra input of the genetic trait to a farm business that is already optimized. Marginal responses not linear.
Whether pre-existing or new farm production function – environmental constraints must be lifted to enable expression of genetic potential.



Moving onto new production functions and along production functions –happening at same times and various times

The economic value of a trait may thus changes for changes in the level of a trait; input or output price changes; or changes in the levels of other traits. Each of these effects must be reflected in a bioeconomic model if we are to correctly estimate the economic values of genetically influenced traits.

Appendix 2

Some practical historic context: From Ian Gibb (Dairy Consultant, mostly retired)

There is always something to be learned from history.

Back in the 1970's and 1980's the dairy industry was going through a phase of very rapid expansion both through individual farms increasing in size and conversions from grazing popping up. At that stage the Department of Agriculture had a team of enthusiastic extension officers scattered across the State, their main task being to encourage the exchange of ideas between dairy farmers. Most of the extension officers had at least a cursory understanding of basic economic principles. At the time, their job was made much easier by the fact that in most cases, the farms they dealt with had multiple opportunities to improve business performance. The difficult part of the job was often to help sort out the priorities. The 'opportunities' for improvement often included things as diverse as the block of land next door, a new tractor, pasture improvement, fertiliser (not always more), a new dairy and investment in genetics.

Observing how different farmers prioritised these opportunities was very instructive for us extension officers. With a basic understanding of economics, we had a reasonable grasp of marginal returns and opportunity costs and the need for a whole-of-system approach. I don't think we could have explained equi-marginal returns, but as Bill states in his paper, it was very clear that those farmers who focussed on a single aspect of their system rarely thrived, even when the case for single emphasis was very strong.

The difficult aspect of comparing 'opportunities' was always (and still is) evaluating projects with very different cost/benefit profiles in value, time and risk. Working out the immediate cost of a project was usually easy; valuing the benefits and costs, the time frame over which they would arrive, and the associated risks was much more difficult.

In the context of the foregoing paper, it is now clear to me that the highly successful farmers had some kind of intuitive understanding of equi-marginal returns. They usually had multiple projects going on at once and would sometimes take on what appeared to be huge risks to create future opportunities; for example, buying the block next door when the old dairy was already at its limit, or when they didn't have the replacements coming through to be able to increase herd size quickly. I now think these really smart farmers understood that marginal return projections for a single project were only relevant as part of their whole farming system and in fact, interdependent with marginal returns for other projects. In other words, in order to be able to improve the whole system in the long-term, you needed to have multiple parts of the system in the right state at the right time and sometimes that meant making investments that appeared risky or imprudent in the short-term.

The job of the extension officers in decision making was often to provide some rational basis for a decision that had already been made, more or less as a sounding board and a bit of reassurance.

Genetic improvement of dairy herds was a frequent discussion point. Farmers thought of dairy genetics as a bit like an education; you could go a long way without a good formal education as long as you had common sense, although most recognised that the path was easier and the ceiling potentially higher with a good education. Genetics was a bit the same; dairy businesses could prosper without a strong emphasis on genetic improvement, but at some point, it would be necessary to have that strong genetic background in the herd in order to be able to achieve the full benefit of other projects. The smart farmers gave their kids a good education, learned from other farmers and invested in genetic improvement even though they had other far more obvious high-return projects.

Even though we like to think that farming systems are much more sophisticated and fine-tuned than they were in the 1970's and 1980's, I'm sure that the same concepts of good farm business management still apply. Herd genetics as a project still needs to be viewed in a whole-of-farm context and against the unique characteristics of each individual farming system. The benefits of genetic improvement must also be viewed in the context of competing investment opportunities for that business.