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# The Geneticisation of Farm Management Advice: Add Farm Economics

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## Abstract

The discipline of farm economics is central to sound advice about farm management decisions, including decisions about investing in animals with superior genetic make-up. The economic value of a genetic trait in an animal farm system depends on the sum of its capacity to create more income from sale of product at the same level of input use, or capacity of the superior animal to use less input and produce the same income, and the capacity to contribute extra profit in a changed farm system in which environmental and genetic constraints are lifted. Understanding and applying principles of production economics, including diminishing marginal returns to added inputs of superior genetic merit and equi-marginal returns to all inputs to farm systems, leads to realistic assessments of the potential contribution added gene inputs can make to farm profit. The key is recognizing that the contribution of additional improved inputs of a genetic trait varies depending on the existing state of genetic potential of animals in the system and assists the interpretation of the output from genetic traits indices and the associated combined dollar indices.


***Keywords:*** Farm economics, animal genetic improvement, genetic traits, breed indices.

## 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 (Makeham and Malcolm, 1981) 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[1].

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. There were also insidious but spurious claims that the animal breed profit indices of amalgamated estimates of economic values of the Estimated Breeding Values of individual traits equate to additional profit to the farm business from the animal containing that bundle of traits. This is not the useful nor valid information that managers of always unique animal farm businesses require 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; and
(ii) the economic value of a trait in an animal farm business from the viewpoint of an individual farm and 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 values' of additional units of genetic traits in animal farm systems, let alone industries.

The final parts of the argument are:
(iv) the performance of animal farm businesses in meeting farmer goals is the result of the combination of all things (the mix of inputs in variable proportions) and a focus on one input or 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 performance; and
(v) The worth of improved genetic potential of animals to an individual farm business and farmer cannot be the same as the value to 'an industry' or to the economy at large because quantity and quality effects of genetic improvement of animals has effect on industry supply, demand and price. Producers and consumers benefit from improvements in efficiency of animal production.

[1] As an aside, note that the heretic Beilhartz (1998) and 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.

In modern-times when 'pseudo-science' and 'fake news' abound, the flawed 'folk economics' that purports to be advice about the economics of animal genetic improvement in animal farm systems, or the indeed over-stated claims about the 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 valid and useful technical information about animal genetic potential that is coming out of modern animal genetic science and technology. Analysed correctly in a whole farm context, animal genetic improvement in farm systems, though small and slow, is well worthwhile, provided the constraints to expression of superior genetic potential are lifted and all the other, larger and quicker, investment opportunities in animal farm systems are exploited fully.

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, 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 are set out; and cumulative dollar breeding indices are discussed. Some concluding observations are in Section 4.

## 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 as follows (see also 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 and their marginal contributions to output come into consideration when thinking about changes to farm systems. The whole farm approach rules out having a narrow focus on one dimension of the system or one perspective on time, at the expense of equally important other parts and time dimensions. The whole farm approach involves doing some analysis to see if a change to a farm system is beneficial, according to 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 properly using whole farm economic analysis, and 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 distribution – not the average - of genetic make-up of the animals in the herd/flock is key. So too is the way the distribution of the genetic capacity of the herd or flock of animals changes with subsequent generations (see Shephard and Malcom, 2019). 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 added response to added genetic merit of an animal depends on the existing level of genetic merit, and this added response varies considerably from animal to animal depending on the genetic merit of the animal.

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

For example, 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 is 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 as the relative proportions of inputs in the mix changes, 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 indicates that the input that adds the most extra benefit minus extra cost with acceptable risk should be used. The principle of equi-marginal returns indicates 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 of land 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 set by the existing fixed and variable resources of land, labour and capital of the farm system/business must be lifted to enable expression of introduced extra inputs, such as enhanced genetic potential.

*The principle of increasing financial risk:* the state of the balance sheet, the debt to equity ratio and annual net cash flow available for servicing debt, before and after an investment, is relevant to all major farm decisions.

*Risk creates return*: intensification increases average returns and the variability of those 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 to correctly include the effects of time on benefits and costs in an analysis. The value of benefits and costs to an investor are affected by the time they are received or incurred. Thus benefits and costs occurring in the future must 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 herd depend critically on the breadth and speed of dissemination of superior genetic traits through the 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 must 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 are always in play. 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, two further concepts are important:
- *Genetic traits as inputs to the production system*,
- *Animals as both capital inputs and outputs*.

## Economics and Genetics

### Genetic input production functions in the whole farm production function

Applying the agricultural production economics way 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. Thus the animal production system is 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 the animal production process represented as 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 the whole farm production function by including it first on an animal basis, then on 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 and addition to profit of doing so. The partial derivatives of the profit function indicate the marginal addition to whole farm profit. The other method to estimate the economic value of an additional unit of a genetic trait is to use bio-economic models of optimized farm systems with and without the additional genetic traits, allowing for stochasticity, dynamics of animal generations, and time.

**Box 1. Economic Value of Genetic Gain**

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

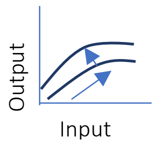
the extra input of a genetic trait is added to the existing whole farm production function (i.e. meaning other genetic and non-genetic inputs are unchanged) or extra other farm inputs added to establish a new whole farm production function

- 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 change 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

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 quality 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. A 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 the value of inputs saved at the same level of output, the cost of the extra genetic traits and, most important, the levels of the introduced traits and other traits that already exist in the individual animals in the farm system. As genetic change occurs over time in the mean of the characteristics, or other characteristics in the animal and in the mean of the herd, the economic value of the added genetic trait will change per animal and per herd. Inter-relationships between the values of characteristics in animals and herds as their values change over time need to be taken into account. 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, without additional investment to the raise the level of the most 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 (this is the 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.

Theoretically a breeder wishing to maximize profit would use more of an animal genetic trait up to the level where the marginal value product (extra revenue) of a further increase in genetic potential equals the market cost of the additional unit of genetic merit. This would only be possible if the traits could be obtained in individual, independent amounts. But, genetic inputs come in animals made up of many combined traits, i.e. in a bundle of traits. Diminishing marginal returns to additional inputs, with other inputs held constant, occurs because of other resource limits and because of input substitution. More of an input used and with diminishing extra output causes the cost of extra output to increase at an increasing, not linear rate. Rising marginal cost changes the MR=MC optimum level of input to 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 economic value of one trait is further 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 them from supply in the existing herd. This has implications for the size and extent of dissemination and rate of genetic improvements through a herd or flock.

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

**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**

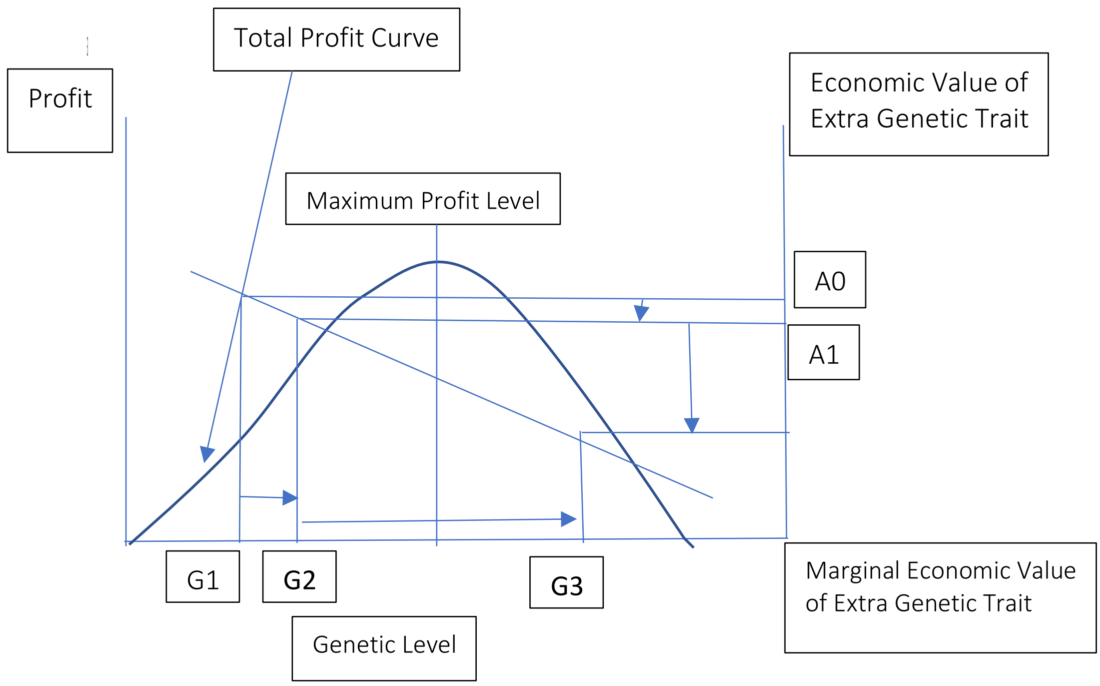
The economic value of an additional amount of a genetic trait as an input to a herd/flock in a whole farm system is determined by the amount the profit of the whole system increases with an additional unit of a trait in the animals making up the herd/flock. Paraphrasing Melton (1978), the important question 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 and with other inputs unchanged? This will also depend on the starting points of potential of the animals in the herd to which the extra trait is being added'.

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.

Critically important to the marginal response achievable from adding more of one or several traits to a herd is the existing level of all the other genetic traits in the farm system. (The herd mean level of traits is the analytical measure usually). The higher the level of genetic traits, the less will be the marginal response to more of it. 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. This response will not be linear over a range of levels of additional input of the trait: the rate of gain will diminish. This means that the Economic Value of a trait changes as the level of genetic potential of that trait and other traits, in animals and the herd mean, also change. Economic values need re-calculating as animals and the 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, with added units of a trait and other inputs held constant. 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. This occurs because the relative proportions of the total mix of traits in the animal, and of inputs used in the system, changes. 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.

**Figure 1. Diminishing genetic trait response function, other inputs held constant**




*Source*: following Melton (1995)

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[2]: if it was then there would be no maximum amount of the genetic input to use, 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. The added complication is that with animals, individual traits come in bundles comprising the animal.

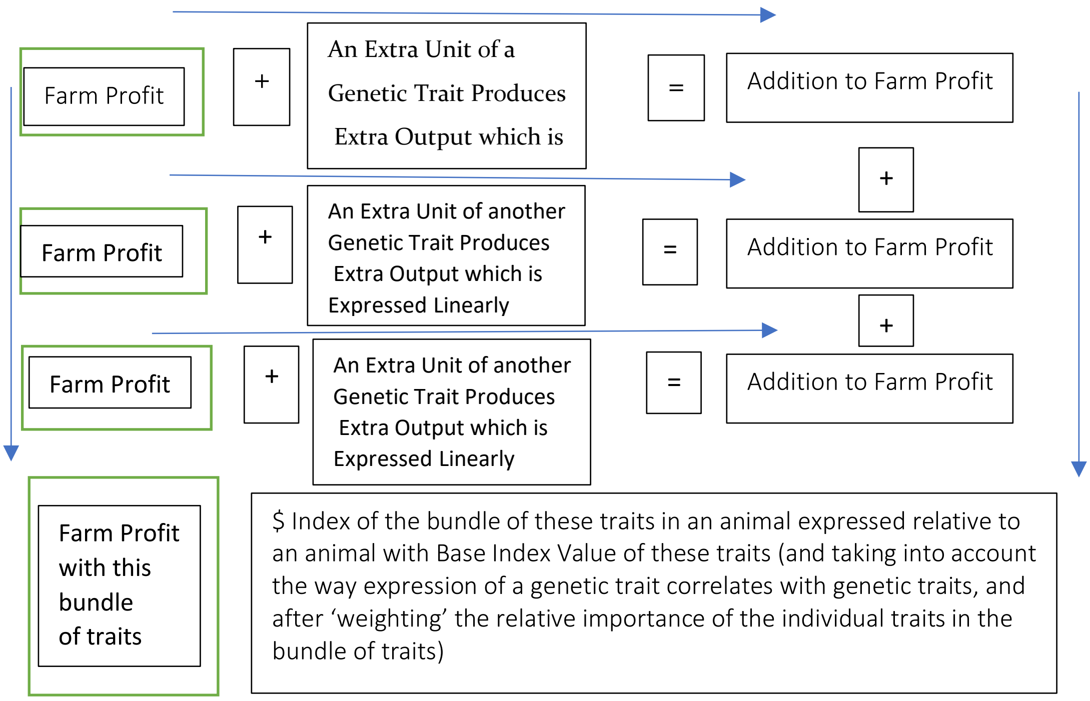
[2] Goddard (1983) investigated the implications of non-linear farm profit functions. Regarding this, Goddard concluded that the diminishing marginal returns to additional traits did not matter much because the marginal changes are so small anyway. However, in an interesting follow-up, Melton et al. (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).

**Profit indices**

Nowadays, combining the estimated breeding values of individual traits into a composite 'Profit Index' is standard practice in all animal industries.

The approach to estimating breeding profit indices is as follows (also see Figure 2):

**Figure 2. Estimating Breeding Values and Breed Profit Indices**.




- 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 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).

The application and critique of economic principles to genetic analysis set out above suggests the limitations of the usefulness of breed profit indexes to farmers making decisions about genetic selection. These limits are compounded by the arbitrary weighting of traits in the process of combining the estimated economic values of traits (with its attendant problems). If the weightings applied to different traits is not apt for a system and the goals of the operator, that combination of traits as represented by the 'profit index' cannot be apt for that system or operator.

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. The question that breeding profit indices try to help answer is: what is it worth, in terms of added annual and cumulative farm profit, to achieve marginal changes in the animals and in the herd mean levels of a range of animal genetic traits through genetic selection? The starting point when it comes to estimating the contribution a bundle of superior genetics can make to the profit of animal farms, the estimates of economic value of an additional unit of a trait, must be made for farm systems that are already economically optimized (Solkner et al., 2007). The reason the calculations of the value of introducing additional genetic merit into an animal farm system have to be done for a system that is already optimized is two-fold: (i) other sources of non-genetic productivity and profit gains are achieved more quickly than by animal breeding (Amer and Fox, 1992) and (ii) estimating the economic value of additional genetic resources in a sub-optimal system introduces bias (Dekkers, 1991).

Next, the starting distribution of genetic potential of animals comprising the herd/flock is important, as is the rate and spread of changed genetic potential through the herd/flock over time (Shephard and Malcolm, 2019). A key assumption underlying the calculation of a genetic 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, is that the extra output from fulfilling the extra genetic potential of this trait is not subject to the Law of Diminishing Marginal Returns. That is, 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.

Further, 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.

Despite being represented as doing so, partly for the reasons outlined above, and because of the way 'profit indices' are calculated, profit indices do not and cannot tell how much whole farm profit will change if the bundle of genetics represented in a genetic profit index is introduced into a farm system.

An animal with a profit index of $300 does not contribute $300 p.a. to farm profit. An animal with a profit index of $300 does not contribute $200 more to farm profit p.a. than a cow with a profit index of $100. This question about the animal in a herd contributing to whole farm profit can only be answered by detailed whole of herd and whole of farm analysis incorporating considerations not included in the calculations of the profit index, inter alia, detail about (i) marginal feed conversion efficiencies as the production of animals increase, and (ii) by accounting for animals of higher genetic merit and thus capital value, if they have the same life in herd as lower genetic merit and lower value animals, having the same salvage value and higher annual depreciation. The more valuable animals have higher annual depreciation cost to set against their higher production potential.

While a genetic Profit Index is 'summary information, handy for marketing messages for sellers of genetics', for a farmer knowing that a breed profit index cannot indicate the addition to profit of introducing this mix of genetic traits into any farm system, or a farmer with an emphasis in the balance of the traits in the bundle that is different from the weightings set by the developers of the index, how then to use the information contained in the profit index? Given the limitations, it is most usefully seen, if the weightings of traits accord with a farm system and farmer's objectives, as a cumulative sign-post to potential change, indicating an overall direction to go in – or not to go in. The Estimated Breeding Value information about the individual traits that make up a breed profit index remain valuable information for investors in improved animal genetics to weigh and balance to meet the particular strength and weakness of their whole system.

## In Sum

In sum, from the viewpoint of the farmer, the economic value of a genetic trait in an animal farm system depends on the sum of its capacity to create more income from sale of product at the same level of input use, or capacity to use less input for the same income, 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 animals in the herd and 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
- The extent animals with superior genetic potential have a higher capital value than lesser animals and their relative lives in the herd, thus annual depreciation cost
- Capital inputs can substitute, and many combinations of forms of capital – 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 the farm system.

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.

Simple answers to complex questions are wrong. Interpreting breed profit 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 simply not correct- indeed, cannot ever be 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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