DEVELOPMENT OF ECONOMIC METHODOLOGY TO INCORPORATE ROBUSTNESS IN PIG BREEDING PROGRAMS

Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

By

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* AGBU is a joint venture between NSW Department of Primary Industries and University of New England

February 2013

An Australian Government Initiative

Established and supported under the Australian Government's Cooperative Research Centres Program

Executive Summary

Improving robustness is based on improving health and survival of pigs as well as reducing environmental sensitivity and variability in performance. Selection for improved robustness requires economic values for survival of pigs from birth to slaughter, sow longevity and for maternal genetic effects affecting growth of progeny. Further, new methodology is required to quantify economic importance of environmental sensitivity and variability in performance of pigs within batches in selection strategies.

The breeding objective defines the selection emphasis placed on individual traits based on the economic importance of each trait. Economic values for some performance traits had been derived for Australian conditions earlier. However, economic values for traits describing aspects of robustness were not available. Further, breeders required greater flexibility in the setup of company-specific breeding objectives.

The aims of this Project were to develop a user-friendly tool to derive economic values for a wider range of traits and to present concepts and methodology to quantify economic importance of environmental sensitivity and batch variability.

Development of methodology to consider environmental sensitivity and batch variability in pig breeding objectives.

Environmental sensitivity. Pig genotypes may vary in their response to variation in environments leading to genotype by environment interactions (GxE). Genetic analyses of GxE may be based on random regression models that provide reaction norms which quantify the phenotypic response of a genotype to variation in environments. The concept to include reaction norms in breeding objectives was evaluated for multiple scenarios with different assumptions. The economic importance of environmental sensitivity depends on the position of the selection environment relative to the environment of commercial pigs. Less environmental sensitivity is economically advantageous if selection is in a superior environment. In contrast, more environmental sensitivity is economically beneficial when selection occurs in an inferior environment. An implication of this is that environmental sensitivity is likely to be a very different trait (i.e. controlled by quite different genes) depending on whether selection is in a favourable, or an unfavourable environment.

<u>Industry relevance – environmental sensitivity</u>. The magnitude of economic values will depend on the difference between selection versus commercial environments as well as non-linearity of profit along the environmental trajectory. Further industry data are required to quantify the economic importance of environmental sensitivity for specific scenarios. Alternative concepts to derive economic values for measures of environmental sensitivity have been provided in this Project.

Batch variability. It was shown how batch variability can affect the profitability of a pig finishing system. The key assumptions and parameters required to quantify the cost of an increase in batch variability by a one-kg increase in the standard deviation of performance of a group of pigs reared together in a commercial finishing facility were outlined. The primary determinant of the economic impact of batch variability was the opportunity cost of delaying termination date of a batch of pigs in order to minimise the number of underweight pigs at termination. The nature of the price penalties applied for underweight carcases was also found to be important, although not as influential as might have been expected.

Industry relevance – batch variability. Batch variability in itself is not heritable and therefore not a breeding objective trait. Rather the costs of increased batch variability are economic value components for other genetic traits that directly lead to batch variability.

Development of PigEV

Model deployment. A spreadsheet, called PigEV, has been developed to compute economic values for individual traits. The spreadsheet has a number of worksheets, which capture the assumptions and calculations required to define the breeding objective. The spreadsheet generates a summary table of economic values as well as formatted tables of intermediate calculations and assumptions. These can be readily pasted from the spreadsheet into reports and other documents as required. Inputs are divided into those that are required to customise the breeding objective to a particular situation or operation, versus those that either have minimal impact, or alternatively, act as biological constants which are not expected to change over time, or across farms. Simple and transparent equations are used where possible.

Breeding objective traits of the sow. The sow component of the breeding objectives model uses equations to define the economic values of number of piglets born alive, piglet survival, age at puberty, sow mature weight and number of parities as a measure of sow longevity. Further, the genes of the sow affect growth of the progeny and an economic value has been derived for maternal genetic effects of growth rate. The economic value for litter size can be derived for a fixed number of sows relevant for a smaller operation versus a fixed piglet output relevant for a larger operation. Survival of pigs was separated into survival at birth, survival prior to weaning and survival post-weaning. The economic value for sow mature weight arises from higher gilt rearing costs, greater salvage value of culled sows as well as extra housing and maintenance feed requirements for larger sows.

Breeding objective traits of the growing pig. The finishing model estimates economic values for average daily gain, feed conversion ratio (or daily feed intake if preferred) and carcase fat depth at P2. The economic value for growth rate is higher when feed intake is part of the breeding objective instead of feed conversion ratio as it includes savings in feed costs due to higher growth. This difference in the economic value for growth rate has been incorporated into the model and users are able to choose between both approaches. The calculations also can take account of less than perfect relationships between feed conversion ratio or feed intake during a test period and these same traits when considered over the whole life of the pig.

Terminal and Maternal Index development. The models above are combined to construct a terminal line index and a maternal line index. While the terminal line index uses only traits relevant for the growing pig, the maternal line index accounts for the fact that sows contribute to profitability through expression of their own maternal traits and their direct genetic effects on growing pigs as they also contribute one half of the genes to the growing pigs.

Industry relevance – PigEV**.** The tool PigEV allows users to define breeding objectives in pigs using their own input parameters in regard to cost structures, performance and marketing information. Further this tool can be used to evaluate the economic consequences of alternative management practices. Therefore, it may be used by producers to evaluate the economic feasibility of introducing a new technology.

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1. Introduction

The breeding objective determines the direction of a breeding program, and ideally, should include all traits that affect profitability of pork production. The economic value for a trait included in the breeding objective quantifies the change in profitability resulting from improving this trait by one unit. Bio-economic models are a common tool to derive economic values. However, often a large amount of time is invested in detailed definition of biological interactions and their associations with input and output prices, which may have a minimal influence on the final breeding objective (Amer, 2006). Therefore, separate models for individual trait groups are advocated (sow model, growing pig model), that describe the main biological interactions and their economic implications, which can then be modified if further refinements seem warranted. The aspect of allowing for potential further modifications also implies that a software tool is being used that can easily be extended and adapted by researchers. This will be of particular interest to breeders who wish to include specific aspects of robustness in breeding decisions, which are described via traits quantifying survival of pigs, lifetime reproductive performance of sows including rebreeding success and the effects of the genes of sows on growth of their progeny.

Examples of bio-economic models used in pig breeding are available from de Vries (1989), Stewart et al. (1990) and Quinton et al. (2006). None of these models have considered genotype by environment interactions and consistency of performance across environments. Only Knap (2005) outlined conceptually how environmental sensitivity of sires, as estimated by random regression (reaction norm) models (Strandberg, 2006), may be incorporated in breeding objectives. Differences in environmental sensitivity between genotypes contribute to batch variability. No study was found that considered implications of batch variability for definition of breeding objectives in pigs.

2. Research outputs

A. Breeding for robustness in pigs – considerations for breeding objectives

In the context of pig breeding, robustness has been defined as a pig's ability to 'combine high production potential with resilience to external stressors, allowing for unproblematic expression of high production potential in a wide variety of environmental conditions' (Knap, 2005). Genetic improvement of robustness implies that the breeding objective includes aspects of robustness, which may be achieved by selection for traits describing survival, health and welfare of pigs as well as selection for reduced environmental sensitivity of pigs. Knap (2005) provided first examples to incorporate aspects of robustness in pig breeding objectives. Some of these examples were only relevant for specific situations and it was the aim of this document to extend the definition of pig breeding objectives further by discussing a wider range of scenarios and assumptions relevant for genetic improvement of more robust pig production.

Selection for reduced environmental sensitivity

Reaction norms describe the response of genotypes to varying environmental conditions. Thus, reaction norms reflect genotype by environment interactions and as such represent a new trait for pig breeding that can be used to select sires whose progeny perform more consistently across a range of environments. Knap (2005) derived the economic value for days to reach market assuming that pigs were selected in the superior environment of the nucleus (EP) leading to superior performance (PP) while production was at an inferior environment (EC) representing the average customer farm with lower performance (PC) (Figure A1).

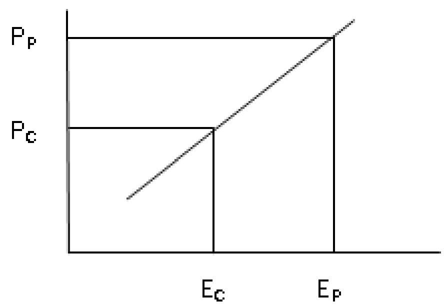


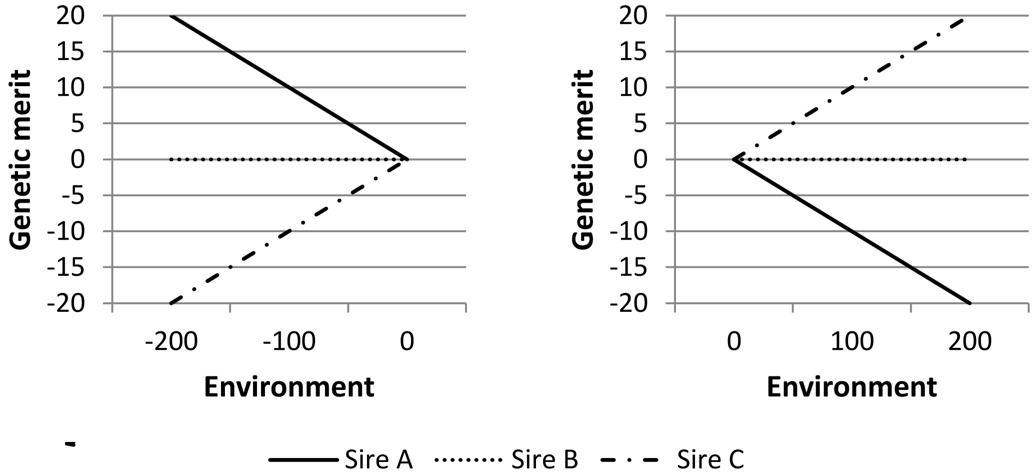
Figure A1. Aspects of environmental sensitivity relevant for the definition of breeding objectives where PP is the level of performance in the nucleus environment (EP) and PC is the level of performance of the average customer farm with the environment EC (Knap, 2005).

This approach is based on the specific assumption that pigs are selected in a superior environment. The concept is extended to include alternative scenarios and the implications of various assumptions for the definition of breeding objectives in pigs are discussed. Growth rate will be used as an example. Reaction norms for growth rate were found by Li and Hermesch (2012, Pork CRC Final Report 2B-101).

Selection in superior or inferior environment

Pigs are often selected in a superior nucleus environment and progeny of sires are expected to perform in a range of inferior environments prevalent on customer farms (Figure A2a). This situation was used by Knap (2005) to derive economic values for reaction norms of number of days to reach market weight. International breeding companies, however, have nucleus herds in multiple countries with varying climatic and husbandry conditions. It is therefore feasible, that sires may be selected in an inferior environment and progeny of sires are raised in superior environments (Figure A2b).

Economic benefits of reduced environmental sensitivity of genotypes differ between these scenarios. For growth rate, low environmental sensitivity of genotypes is desirable when sires are selected in the superior environment leading to superior performance of progeny in the inferior environments. In contrast, high environmental sensitivity of genotypes is economically beneficial when sires are selected in an inferior environment because progeny will exhibit superior performance in superior environments. Pig breeding programs need to consider these differences in the economic importance of environmental sensitivity resulting from the position of the selection environment on the environmental trajectory relative to the commercial environment. The vast majority of pig breeding programs currently focus much of their selection on performance in a favourable environment for a number of reasons, including the need for bio-security because of outward animal and germplasm transfer, and an expectation that selection criteria will be more heritable and therefore more accurately evaluated in selection candidates in a favourable environment.



a) Selection in superior environment b) Selection in inferior environment

Figure A2. Genetic merit in average daily gain of three sires with the same intercept in the superior (a) or inferior (b) environment and with reaction norms of -0.1 (Sire A), 0 (Sire B) or 0.1 (Sire C) g/day per one g/day in the environmental variable for growth assuming selection in a) a superior environment and b) inferior environment.

Knap (2005) defined the economic value for environmental sensitivity in growth as the economic value for growth (intercept) times the difference in the average performance of a group of pigs raised in the commercial environment versus the average performance of a group of pigs in a superior nucleus environment. The assumed difference in performance used by Knap (2005) was based on results from Schinckel et al. (1999) and no generic definition of the economic value for reaction norms for growth was provided. A more general definition of the economic value for reaction norms requires a more general definition for the variation in the environmental variable. This generic definition of the economic value for reaction norms quantifies the change in profit per trait unit per environmental unit. Often, the environmental unit is defined as the average performance of a group of pigs based on the same trait. Therefore, the economic value for growth rate may be defined as the change in profit per one-gram change in growth rate per one-gram change in the mean growth rate of the contemporary group. However, no genotype by environment interaction exists for this trait definition of environmental sensitivity as the variation in the environmental variable is too small to detect any genotype by environment interaction. It follows that the economic value for reaction norms should be based on a range of the environmental variable that allows detection of genotype by environment interactions. An obvious choice is the standard deviation in the environmental

variable which is often used to describe variation in environments (Kolmodin and Bijma, 2004; Su et al., 2006). Li and Hermesch (2012) found multiple significant reaction norms for growth using average growth rate and average backfat of contemporary groups as the environmental variable. The standard deviations of these 2 environmental variables were 32 g/ day and 0.9 mm for least square means of contemporary groups for growth rate and backfat, respectively.
However, applying appropriate economic values for reaction norms may not be the best approach for these scenarios because in this method the intercept was defined for the selection environment of the nucleus which is assumed to be above (or below) the average environment of the full environmental trajectory defined by the differences between the nucleus and commercial environments. Van Tienderen and Koelewijn (1994) outlined the dependency of (co)variances of intercepts and slopes on the position of the intercept on the environmental scale and suggested to define the intercept for the average environment of the whole environmental trajectory. This recommendation has generally been adopted in animal breeding applications (e.g. Calus and Veerkamp, 2003; Kolmodin and Bijrma, 2004; Windig et al. 2011).

Selection in an average environment

When selection occurs in the average environment, reaction norms may be employed to quantify genotype by environment interactions. Genetic analyses using reaction norm models provide estimates of the intercept and slope also called reaction norms for each genotype. A genotype may be a sire with progeny recorded in multiple environments ideally covering a wide range of the environmental trajectory. Centering environments at the mean environment in these genetic analyses (van Tienderen and Koelewijn, 1994) implies that the intercept corresponds to the estimated breeding value of the trait in the average (zero) environment. For illustration, three sires are assumed that have the same intercept of zero but different reaction norms of -0.1, 0 and 0.1 g/day per one g/day change in the environment defined according to mean performance of contemporary groups based on results from Li and Hermesch (2012, Pork CRC Final Report 2B-101) (Figure A3). The study by Li and Hermesch (2012) used data from nine herds with similar health status and management practices. For lifetime growth rate an environmental spread of about 150 g/day per day was observed across contemporary groups from the different herds. A similar environmental range was also apparent among cohort groups within individual herds. In comparison, the four distinct health environments used by Schinckel et al. (1999) to evaluate line by environment interactions differed by less than 80 g/day. The spread of environments and potentially the magnitude of reaction norms could potentially be higher across more diverse herds.

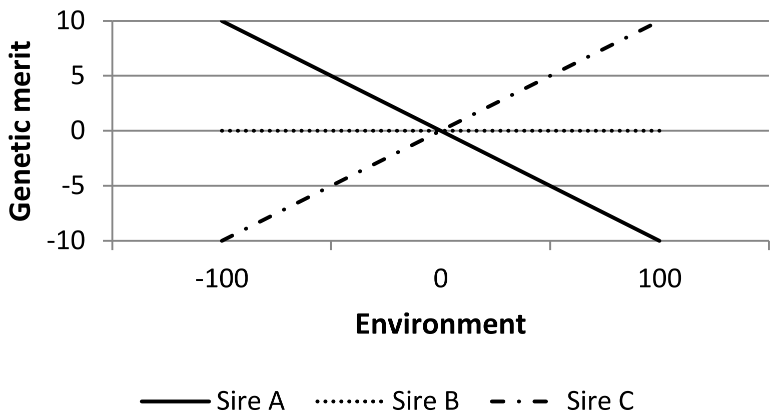
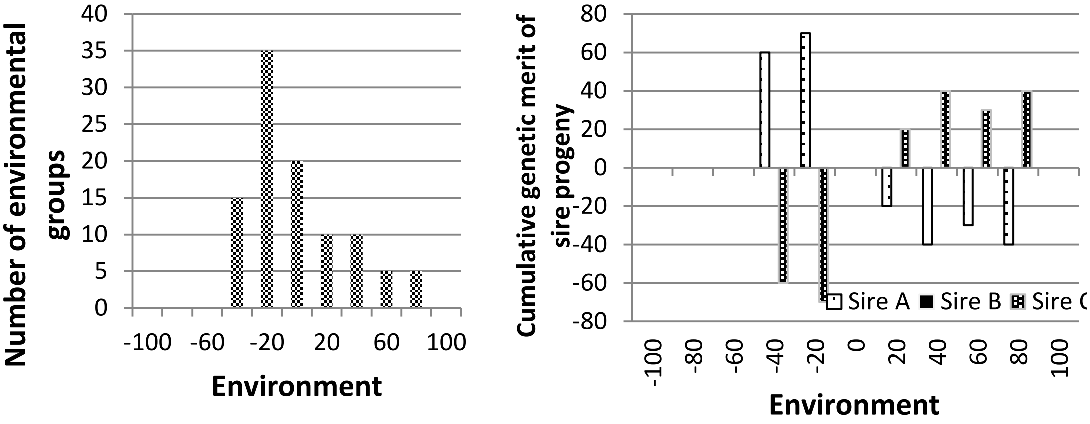


Figure A3. Genetic merit in average daily gain (g/day) of three sires with a zero intercept and reaction norms of -0.1 (Sire A), 0 (Sire B) or 0.1 (Sire C) g/day per one g/day in the environmental variable for growth.

For this scenario, the economic value for the reaction nom of a trait is zero as the average genetic merit and profit of progeny from these three sires is the same across the environmental trajectory. This conclusion ignores the benefits of more consistent genetic merit resulting in more consistent performance of progeny from sire B across environments and is further based on the assumptions that a) environments are normally distributed, b) progeny of sires are normally distributed around the average environment, c) the economic value for a trait is constant across all environments and d) reaction norms are linear. These assumptions may not always be valid as discussed below.

Assumption: environments are normally distributed

The environmental trajectory is based on a specific environmental variable such as the adjusted mean performance of contemporary groups. The environmental variable is defined for each contemporary group and is expected to be normally distributed for most situations as was found by Li and Hermesch (2012). A distinct environmental factor such as herd may, however, lead to skewness in the environmental variable as some values of the environmental variable may be more represented than others by individual contemporary groups (Figure A4). It is assumed that sires are equally represented across individual contemporary groups, which results in skewed representation of sires across the environmental trajectory corresponding to the skewness of contemporary groups. The cumulative genetic merit of sire progeny is zero across the environmental trajectory for three sires with different environmental sensitivity (Figure 5). Sire B is not sensitive to environmental changes and has a zero genetic merit across the environmental trajectory. The superior (inferior) genetic merit of sire A (sire B) for the inferior environmental variables below the average environment is matched by the inferior (superior) genetic merit of sire A (sire B) for the superior environmental variable above the average environment. Therefore, a skewed distribution of the environment per se does not lead to an economic advantage for less environmentally sensitive genotypes. Again, the economic benefits of more consistent genetic merit and therefore performance of progeny groups of sire B across the environmental trajectory are ignored.



a) Distribution of environment b) Genetic merit of sire progeny

Figure A4. Example of a) skewed distribution of environmental variable for growth and b) cumulative genetic merit for each environmental variable of three sires with a zero intercept and reaction norms of -0.1 (Sire A), 0 (Sire B) or 0.1 (Sire C) g/day per one g/day in the environmental variable for growth.

Assumption: Progeny of sires are normally distributed around average environment

It is plausible that progeny of sires are not equally represented across contemporary groups and the environmental variable. This leads to skewness of sire representation across the environmental trajectory. Some sires may have more progeny in the superior environments above the mean environment, while other sires may have most progeny performing in inferior environments below the average environment. Examples include the selection of sires whose progeny are expected to be raised in herds with inferior or superior husbandry and health status or selection of sires whose progeny will be grown in hot climates during summer which leads to inferior performance. For these situations, the economic implications of selection in a superior or inferior environment relative to the commercial environment outlined above apply. The genetic merit for the intercept is defined for the average environment and less (more) environmental sensitivity is preferred when progeny are predominantly raised in superior (inferior) environments.

Assumption: The economic value of a trait is constant across the environmental trajectory

The approach by Knap (2005) to define economic values for reaction norms included the economic value for the intercept of the trait. It was assumed that the economic value for days to reach market weight was the same across the environmental trajectory and independent of the actual level of performance in growth. For lifetime average daily gain together with feed conversion ratio in the breeding objective, the economic value was defined as:

$$ADG_{FCR}\_EV = \left(\frac{Age_P}{GrP}\right) \times C_{NF}$$

AgeP where is the age of a finished pig (130 days); GrP is the growth rate of a finished pig just prior to slaughter (900 g/day) and CFN is the daily non-feed costs per pig from weaning to slaughter ($ 0.8 per day). The economic value for growth is $ 0.11 per gram/day for this level of performance. It was assumed that pigs are slaughtered at 90 kg body weight leading to a lifetime growth rate of 692 g/day. Variation in lifetime growth rate affects the economic value for growth leading to higher economic values for low-growth environments (Figure A5).

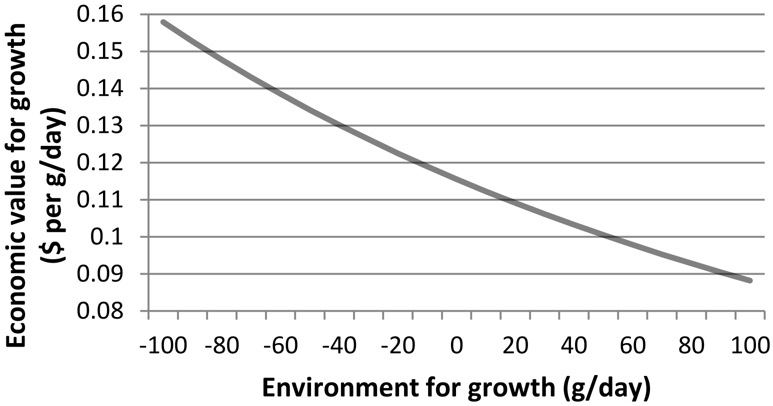


Figure A5. Changes in the economic value for growth ($ per g/day; per growing pig) resulting from different performance levels in growth. The mean environment was defined as 692 g/day lifetime average daily gain (ADG) and growth prior to slaughter was 1.3*ADG.

When selection occurs in the average environment (illustrated in Figure A3), a less environmentally sensitive genotype is economically advantageous as the economic losses of a reduced growth rate in high environments are lower than the economic benefits resulting from a higher growth rate in the low environments due to the non-linear relationship between growth rate and farm profit. However, the economic benefits of less environmentally sensitive genotypes may be small in this context when the economic value for growth is not sufficiently non-linear across a practical environmental trajectory where only a small proportion of progeny would be grown in the most extreme environments.

Differences in environmental sensitivity of sires contribute to variability in performance of pigs within a batch. This variability within a batch may lead to non-linearity in profitability, resulting from lost revenues of light weight pigs that do not reach target market weight. These under-weight pigs are sent to market in order to vacate housing facilities for the next batch. The economic value for growth rate does not capture this loss in revenue as it assumes that all pigs reach target weight. The economic implications of batch variability are discussed in the next section of this report.

<u>Assumption: Linear reaction norms</u>

Non-linear reaction norms imply non-linear profitability across the environmental trajectory, which results in an economic value for environmental sensitivity when selection is in the average environment. Higher order polynomials have been found in reaction norm analyses that quantified genetic differences between sows in feed intake to variation in temperature (i.e. Bergsma and Hermesch, 2012). Deriving economic values for multiple, higher order reaction norm parameters would be challenging with a higher order polynomial parameterisation because of multi co-linearity with the other reaction norm traits including the slope and the intercept in the breeding objective. However, it is conceivable that a strong economic rationale could be established to penalise genotypes that were predicted as being likely to deteriorate rapidly at an extreme end of the environmental continuum. An empirical approach would be required to integrate the economic rationale with the polynomial coefficients.

Selection strategies for genotype by environment interactions

Environmental sensitivity is of economic importance when selection is in a superior (or inferior) environment relative to the commercial environment of slaughter pigs. Differences in environmental conditions are likely to be distinct rather than continuous resulting from the differences in husbandry practices and health status of the nucleus versus the commercial herds. The use of multi-trait models may be more appropriate than reaction norm models for these situations with distinctly defined environments. If reaction norm models are used, then the intercept should be defined for the average environment which is likely to represent an intermediate environment between nucleus versus commercial environments. However, the position of the intercept affects the economic value of the slope. Economic values for reaction norms are lower when the intercept is defined in the average rather than the superior (or inferior) environment as the difference between environments is lower and the intercept of the average environment partially accounts for differences in environmental sensitivity of two genotypes with equal genetic merit (intercept) in the superior (or inferior) environment.

However, data are not always available from the commercial environments and reaction norms may be used to extrapolate environmental sensitivity of genotypes estimated from the within-herd variation in environments. Li and Hermesch (2012) found similar environmental variation within herds versus across herds and reaction norms could be estimated within herds provided that sufficient numbers of records are available within herds

Environmental sensitivity is of low economic importance if selection is in the average environment. The economic consequences of differences in environmental sensitivity depend on the extent of non-linearity in profit across the environmental trajectory. For growth rate, the extent of non-linearity in profit is predominantly due to variability in performance of pigs within a batch resulting in lost revenue due to selling pigs below target market weight. Further, more stringent price penalties may apply for pigs that do not reach a minimum market weight. Other traits like backfat have been shown to exhibit considerable non-linearity in profit for different levels of performance (Hermesch, 2005). However, genotype by environment interaction has not been found for backfat and reaction norms for backfat cannot be included in breeding objectives for pig breeding as they are not heritable.

In conclusion, the magnitude of economic values will depend on the difference between selection versus commercial environments as well as non-linearity of profit along the environmental trajectory. Further industry data are required to quantify the economic importance of environmental sensitivity for specific scenarios. Alternative concepts to derive economic values for measures of environmental sensitivity have been provided in this Project.

Broadening the breeding goal

Taking an assumption that breeding intensely for a long time in a highly correlated environment for a narrow range of traits leads to pigs whose performance is more sensitive to environmental perturbations, the robustness of pigs is likely to be improved by broadening the focus of selection on to a wider range of traits. This is particular so if the new traits have direct links to the adaptability of the pig. Survival traits are a classic example. Having a broader focus will lead to less extreme genotypes for specific traits, and also draw selection effort away from traits that are thought to contribute to environmental sensitivity.

Implications for breeding for robustness: Broadening the breeding goal, and in particular adding female reproduction, survival and disease resistance traits should result in more robust animals that are still highly profitable. Models to derive economic values for a number of survival traits, sow longevity and the effects of the genes of the sow on growth of the progeny have been developed in this Project and are available to the Australian pig industry via the tool PigEV developed in this Project.

Disease traits

In some instances, it is possible to develop selection criteria for disease traits. We can classify these selection criteria into QTLs, or challenge based phenotypes. A simple method to derive the economic value for disease traits was developed for footrot in sheep by Byrne et al. (2010) who compared the profitability of two different flocks that differ in their levels of disease. This took account of differences in production performance, prevention measures, and treatment between the flocks. Then, it is necessary to make a call as to what difference in genetic merit for the disease trait selection criteria would be required to bring about the assumed level of difference between the flocks. The economic value expressed per unit of disease per animal was calculated as the per-animal difference between flocks in profitability, divided by the difference between flocks in average genetic merit for the selection criteria. However, generally the actual practical calculation of economic values for disease traits and/or QTLs known to affect disease is problematic for at least the following reasons:

a. Variable incidence - Because of the variable incidence of disease challenge, there is a requirement for standardisation of the amount of spread in estimated breeding values to an arbitrary intermediate value. This standardisation, plus the variability in incidence makes it hard to predict how a genetic change in the trait with somewhat arbitrary units will lead to a long term reduction in treatment costs and lost productivity associated with the disease.

b. Epidemiology - Genetic traits linked to disease often work by disrupting the spread of the disease from one animal to another. In this instance, reduction in infectivity of a relatively few but highly infectious individuals in a group can lead to much more widespread benefits across a large proportion of the herd, through lower overall levels of challenge. This makes it easy to under-estimate the true value of disease resistance traits, especially when conventional approaches are taken to estimating the economic value.

c. Double counting effects on non-disease traits - The disease infection often manifests itself as a reduction in productivity traits. Animals stop growing and reproducing when they are diseased. They can also die. Conventional genetic selection for the traits affected by the disease when selection candidates are subject to disease challenge can inherently select for disease resistance, or more likely disease tolerance. However, the intensity of selection against the disease in this way depends on the level of challenge at any specific time. This becomes problematic, because if disease infection is scored as a trait in its own right, there will be variable amounts of double counting. This is because the economic weighting applied to the disease trait is likely to take account of the expected effects of the disease on productivity traits. Allowing for this double counting when defining the breeding objective is difficult when the extent of double counting varies from year to year.

d. Subclinical effects - Under reporting of the disease, or uncertain extra effects due to subclinical effects of the disease can result in the total economic impact of disease incidence being under-estimated. This can result in too little emphasis being given to the disease trait.

e. Vaccination and treatment - If selection candidates are vaccinated, or animals are effectively treated so that the economic effects of the disease come at least partly as treatment and prevention costs, rather than just lost production and mortality, then economic benefits from genetic improvements in disease resistance only come if farmers are prepared to reduce expenditure on treatment and prevention. This effectively creates a highly nonlinear relationship between genetic level of disease resistance in the population and profit. Once a certain threshold level of genetic resistance is achieved, it is possible to make a step change reduction in disease treatment or prevention, resulting in significant reductions in costs. Either side of this threshold population level of resistance, the effects of further genetic changes in disease resistance will be modest.

f. Uncertain treatment efficacy - If there is a risk that current treatment and prevention options for a disease are unsustainable, the economic value needs to take account of the probability of loss of treatment or prevention alternatives. Consumer objections to antibiotics or other preventative measures, along with the potential for pathogens to evolve to become genetically resistant themselves to the treatment and prevention options are both examples of how treatment and prevention options can be lost. However, formalising this into an economic value calculation is extremely difficult because it is very difficult to quantify the risk using a formal methodology, and so accounting for this risk becomes highly subjective and therefore variable from person to person.

Implications for breeding for robustness. It is extremely difficult to estimate economic values for disease traits. Therefore, it is sensible to use a simple method to derive the economic values, and then using desired gains principles, manipulate the economic values within an acceptable range of the estimated values (e.g. +/- 100%), and check the expected magnitude and direction of genetic change in the disease trait and subjectively compare this against the value of response to selection in all of the other traits. This will show the trade-off between genetic progress in the disease traits versus the value of genetic progress in the other traits. It should then be possible to make an informed judgment about what final weighting to use for the disease trait.

Use of commercial data to support nucleus selection

There are a number of factors that make it theoretically attractive to record phenotypes in commercial pig populations, and use these additional data in the genetic evaluation of nucleus stocks. For example, using commercial data provides opportunities to obtain more data, which benefits lowly heritable traits such as survival traits. Further opportunities exist to record disease incidence and genotype by environment interactions in a wider range of environments.

The main disadvantages centre around the costs of recording the extra data, and the fact that there is limited scope to use the animals tested in the commercial environment as nucleus parents, rather they just contribute information as relatives of selection candidates. This can result either in longer generation intervals (because you have to wait for male selection candidates to have progeny in commercial farms before they can be used as nucleus sires), or relationships between nucleus candidates and their commercially recorded relatives becoming quite distant. Thus, the extra information generated needs to be very valuable to justify the cost and expense.

Use of genomic selection may provide an opportunity to link phenotypes from crossbred relatives back to purebred selection candidates in a breeding nucleus. This option will increase the contribution of information from moderately distant relatives in the commercial sector. However, phenotyping costs will still be high, and the cost of high density SNP marker information is likely to exceed the cost of recording parentage in the commercial herd. Selection candidates would also need to be tested for SNP markers.

In principle, recording and genetic evaluation of information from commercial herds has limited impact on definition of breeding objectives. However, when breeding values with similar trait names and definitions are calculated for both, commercial and nucleus environments, then the breeding values corresponding to the commercial environment should be used in the selection index calculations.

Genotype by environment interactions between commercial and nucleus herds

Same heritability and genetic correlation of one for survival in commercial and nucleus herd

Because of the directional flow of breeding boars, semen, embryos and sometimes sows from breeding programs to commercial multiplier and farm units, it is typical for the breeding nucleus management environment to be as free as possible from any sort of disease challenge that could potentially be transferred to large numbers of commercial farms. Having a highly controlled environment also allows the genetic potential of selection candidates to be observed without the clouding impact of random environmental variation. However, it is commonly not cost effective to manage commercial farms with the same stringent levels of management, disease control and high performance as in a breeding nucleus. Thus, there is a potential for genotype by environment interaction, in that genotypes that perform very well in the controlled breeding nucleus environment struggle to perform under environments more typical to commercial farms.

Genotype by environment interactions at trait level are in theory a problem for the genetic evaluation systems, and also have major implications as to what traits should be recorded and in which environments. Options include splitting what was previously a single trait into two separate genetic traits for genetic evaluation corresponding to two different environments, and where the genetic correlation between the two traits is meaningfully different from one, and or the genetic variance in the traits differs significantly. This adds complexity to genetic evaluation systems, particular when large numbers of traits are being evaluated. There is also the problem of correctly assigning similar phenotypic trait records to their appropriate environment.

For the reasons outlined above, there is a tendency for genotype by environment interactions to be ignored at the level of genetic evaluation systems. In this instance, there are two modifications that can potentially be made to breeding objectives in an attempt to address them without disrupting the genetic evaluation process. Both modifications effectively influence the relative importance of traits when ranking selection candidates, although they do use different assumptions and rationales.

The first modification involves accounting for the magnitude of genetic differences in the commercial-farm environment which may be greater or less than those in the breeding program. In theory, it is the spread of estimated breeding values that should be manipulated, but it can often be more practical to modify the economic values so that the same effect is achieved. We take a binomial trait such as survival as an example assuming that the genetic correlation between survival in the commercial and nucleus environment is one and the heritability is the same for each environment. For this scenario, the only remaining factor affecting variance of estimated breeding values is the difference in phenotypic variance between the environments leading to differences in additive genetic variances between both environments. If the average rate of survival is 98% (p of 0.98) in the breeding herd, then the phenotypic variance of survival is p times 1-p (0.98 x .02 = .0196). Assuming a heritability of 0.03 for survival, the genetic standard deviation would be 0.24 or 2.4% (square root of (0.03 x 0.0196). In comparison, the genetic standard deviation would be 4.1% if the average rate of survival in a commercial herd was only 94% then using the same calculation. With equal heritabilities and a genetic correlation of one, the estimated breeding values for survival based on genetic evaluation of data from the nucleus herd only would be under-disbursed by a factor of 2.4%/4.1% = 59%, relative to the expected effects in a commercial herd. This could be adjusted for by multiplying the estimated breeding values from the nucleus by 4.1%/2.4% = 1.7. However, because it is sometimes easier to manipulate economic values, an equivalent impact on a multiple trait selection index could be achieved by multiplying the economic value of survival by 1.7. For binomial traits, the variance is easily computed from the average incidence, and so the above adjustment is very easy to make, provided the assumption about heritability and genetic correlation hold. For multinomial and continuous traits, it is necessary to estimate the genetic standard deviations in both environments, and so the adjustment is less straightforward in practice, and better considered in the more general case modification discussed below.

Implications for breeding for robustness. When it is known that incidences of survival traits are lower in the nucleus where selection is undertaken than incidences in commercial herds, economic values for survival traits could be increased by the ratio of genetic standard deviations that can be inferred from incidences under the assumption of equal heritability and a genetic correlation between the two environments of one.

Different genetic parameters in the nucleus and commercial environment

The second modification deals with different heritabilities and/or a genetic correlation of less than one between the nucleus and the commercial environment. In this instance we could embed a calculation of the genetic regression of commercial (c) environment breeding values on nucleus (n) environment breeding values into the economic weight used in a selection index. The genetic regression coefficient (bg) is as follows:

$$bg_{c.n} = \frac{rg_{c,n}\sigma_{g_c}}{\sigma_{g_n}}$$

where $rg_{c,n}$ is the genetic correlation between nucleus trait performance and commercial trait performance, and σ_{g_c} and σ_{g_n} are the genetic standard deviations of the commercial and nucleus traits respectively.

Implications for breeding for robustness. When the genetic relationships between the same trait when expressed in the nucleus compared to a commercial operation are known, the economic weight for the trait under selection in the nucleus can be modified according to the genetic regression of the commercial farm trait on the corresponding nucleus trait. A more theoretically comprehensive method of dealing with genotype by environment interactions would be to develop a method of genetic evaluation based on reaction norms, which quantify the phenotypic response of a genotype to variation in environmental conditions. A more detailed consideration of how reaction norms can be included in a breeding objective has been provided above.

B. The economic value of batch consistency in an all-in, all-out pig finishing system

Introduction

While selection for performance traits such as growth rate, leanness, and feed conversion efficiency has been very successful in pigs, the resulting genotypes require improved management and also appear to have greater susceptibility to environmental fluctuations (e.g. Knap, 2005). Many studies of pig breeding objectives have identified the economic value of improvements in mean performance of growing pigs (Cameron and Crump, 2001; de Vries, 1989; de Vries and Kanis, 1994; Hermesch, 2005; Stewart et al., 1990; Stewart et al., 1988). However, the economic value of having more uniform performance across a batch of finishing pigs is less commonly quantified.

Variation in market weight is an important consideration in the Australian pig industry (Taylor and Roese, 2006) and has also been addressed in the context of the US Swine industry (Song and Miller, 2002). Market weight variation in a batch of finishing pigs can be influenced by factors such as mixtures of genotypes, disease outbreaks, variation in weaner weight and weaner age at entry to a batch. Genetic variation within a line of finishing pigs could influence within-batch variation due, for example, to genetic differences in susceptibility to disease and other environmental perturbations. Genetic variation in a maternal line of finishing pigs may also impact on within-batch variability. For example, with larger litter sizes, variability in weaning weight tends to increase because of an increased incidence of small piglets.

While continuous flow systems may mitigate this problem, there are a number of bio-security risks associated with mixing pigs. Adverse performance due to unfavourable social interactions is also likely. An alternative is to draft off heavier pigs as they reach target market weight. However, this leads to an inefficient use of the pig finishing facility, because the density of pigs in a pen steadily drops, and there is wasted finishing capacity as the lightest pigs are brought up to target weight.

The objective of this Project was to demonstrate the economic cost of batch variability in a pig finishing system whereby there is no mixing of batches, and pigs are drafted off for slaughter as they hit a target dressed carcase weight. A simple model of a pig finishing system is described and parameterised using information from the Australian pig industry.

Models

Breeding objective framework

The balancing of priorities across multiple traits of potential interest for genetic improvement is commonly and efficiently achieved through applying selection index principles. Economic weighting factors are derived for traits of interest, and these weights, along with other factors such as the amount of genetic variation in the traits, and the extent to which genetic variation in traits can be predicted accurately in selection candidates, determines the amount of genetic progress achieved in each trait of interest. In this paper, we assume that a vector of economic values ($\boldsymbol{v}$) for a unit change in a trait for a single animal expression and a vector of associated discounted genetic expressions coefficients (***d***) accounting for differences in frequency and timing of trait expressions, are already known for improvements in trait means. A model is therefore developed which identifies the impact of a reduction in within-batch variability on profitability per growing pig raised in an all-in, all-out finishing system. This allows augmentation of the conventional selection index construction as follows:

$$I = \sum_{i=1}^{n} \left(a_i \cdot d_i \left[v_i + \beta_i \cdot \alpha \right] \right)$$

where β_i gives the unit change in the raw standard deviation of batch market weights for a group of finishing pigs with respect of genetic change in the estimated breeding value (a_i) of a trait in the selection index and the constant α gives the change in profit per pig finished arising from a one unit reduction in the raw standard deviation of batch market weights. With this augmented index construction, it is likely that new breeding values could be included in the index for which the corresponding value of v_i is zero, such that their only impact on the index is through their impact on batch variability. However, other traits for example number of piglets born alive and disease traits, are likely to impact on index calculation through their average level (so they have a non-zero value for v_i), but also through their impact on batch variability. The primary purpose of this paper is to describe how α can be derived for a pig finishing system whereby pigs enter a housing unit (pen, eco-shelters) at the same time which defines a batch and then are continuously slaughtered as they reach a target slaughter weight. For the finishing system modeled, a batch is assumed to be terminated when it is no longer profitable to keep feeding the underweight pigs, and a new batch is established.

Growth model development of pigs

A simple cumulative feed intake function (*CFI*) is specified for the typical range of weights across which a batch of pigs might be slaughtered with the assumption that 4 kg of feed fresh weight is required for a finishing pig to achieve a one-kg higher carcase dressed weight at slaughter. A linear rate of daily increase in carcase dressed weight (*dwg*) is also assumed around the time of slaughter, such that dressed weight (*dw*) at time of slaughter t can be calculated as:

$$dw(t) = 35 + dwg \cdot t$$

and

$$CFI(t) = 100 + dwg \cdot t \cdot 4$$

where the constants 35 and 100 are arbitrary start and end weight of the growth trajectory, and do not impact on the results generated because a linear rate of daily increase in *dwg* is assumed during this growth period.

While the majority of pigs are slaughtered at the target dressed carcase weight finish endpoint (*T*), a residual group of pigs remaining in the batch must be slaughtered at lower weights at the time where it is no longer profitable to continue feeding them. The probability distribution (P) of weights of these remaining pigs depends on the time (*t*) of termination of the batch, the target dressed carcase weight finish endpoint, and the amount of variation among pigs within the batch. This proportion of pigs within any dressed slaughter weight band with upper and lower limits defined as u and l respectively can be defined ignoring the proportion of pigs already slaughtered because they have reached their target endpoint as:

$$P(u,l,sd,t) = \int_l^u D(x,dw(t),sd)\cdot \partial x$$

where *D* is a density function. For simplicity, we have considered only a normal distribution function for *D* with mean and raw standard deviation of dressed weight at time of termination of the batch denoted $dw(t)$ and sd , respectively.

The revenue generated from sales of residual pigs at the time *t* of batch termination depends on the extent of price penalties applied per kg of dressed carcase weight for bands of underweight pigs. Normally, price grids and contract agreements between pig farmers and processors are formulated so that there are greater step wise reductions in the price per kg paid as the carcase dressed weight reduces relative to the target slaughter dressed weight. In mathematical notation, we define carcase revenues of underweight pigs as *PV(dw),* a function which defines the sale revenue from a single pig which has a carcase dressed weight of *dw* at slaughter.

The average revenue (AR) per pig slaughtered for a termination day *t* can be computed for a given batch standard deviation *sd* and target slaughter dressed weight *T* as follows:

$$AR(t|\,sd,T) = \sum_{dw=0}^{T}\left[P(dw,dw-1,sd,t)\cdot PV(dw) + P(\infty,T,sd,t)\cdot PV(T)\right]$$

where the first part of the summed term captures the value of the residual pigs, and the second part captures the value of the pigs that have reached the specified target prior to termination time of the batch *t*.

Similarly, for a given fresh weight price of feed *FP* per tonne, the average feed costs per pig slaughtered for a termination day *t* can be computed for a given batch standard deviation *sd* and target slaughter dressed weight *T* as follows:

$$FP(t|\,sd,T) = \sum_{dw=0}^{T}\frac{FP}{1000}\left[P(dw,dw-1,sd,t)\cdot CFI(dw) + P(\infty,T,sd,t)\cdot CFI(T)\right]$$

because an allowance is also required for the opportunity cost of delaying the termination day *t* which arises because the batch facility could be better used to finish a new and full batch of pigs, we define average costs (*AC*) per pig slaughtered for a termination day *t* as:

$$AC(t|\,sd,T) = FP(t|\,sd,T) + t\cdot OC$$

where *OC* is the fixed opportunity cost expressed per piglet per day of maintaining a full batch of finishing piglets. Note that *OC* represents all costs associated with the batch that are not proportional to the number of pigs in the batch at any one time.

It is now possible to compute a net profit value (π) per pig as:

$$\pi(t|\,sd,T) = AR(t|\,sd,T) - AC(t|\,sd,T) - k$$

where k is a constant representing fixed costs per finishing pig which are not accounted for in function *AC* and which are not influenced by the choice of termination time. This function can be optimised with respect to batch-termination time t using numerical methods to obtain an optimal termination time *t**, which in turn depends on *sd* and *T* along with other model parameters and assumptions. The economic benefit per pig of α resulting from a one-unit reduction in the raw standard deviation of carcase dressed weight in pigs can then be computed allowing for re-optimisation of the termination time of the batch as follows:

$$\alpha = \pi(t^* | sd + 1, T) - \pi(t^* | sd, T)$$

such that the value of t^* for the first batch of pigs with the higher batch standard deviation (i.e. $sd + 1$) can take a different optimum value than the second batch of pigs with the lower batch standard deviation.

Growth model parameterisation

Only a modest number of parameters are required for the finishing model described above. Values used for example calculations are summarised in Table B1. A range of values for the opportunity cost of housing and facilities per pig per day are included to test the sensitivity of results to these parameters. A range of four alternative scenarios with carcase price discounts for carcases slaughtered below the target weight range were also considered. Scenarios 1 and 2 only assumed price penalties for pigs weighing less than 50 kg while scenarios 3 and 4 considered price penalties for three weight groups (Table B2).

Table B1. Parameter values used in the finishing system model

Parameter name	Parameter abbreviation	Values used
Feed price ($ fresh weight/tonne)	*FP*	230
Daily dressed carcase weight gain (kg/day)	*dwg*	0.6
Target dressed carcase weight (kg)	*T*	70
Base carcase price ($/kg *dw*)		2.85
Opportunity cost per pig per batch($/day)	*OC*	0.20, 0.50, and 0.8

Table B2. Alternative price penalties ($/kg dress weight) for carcases slaughtered below the target dressed weight

Dressed carcase weight band	Scenario 1	Scenario 2	Scenario 3	Scenario 4
60-70kg	0	0	-0.10	-0.20
50-60kg	0	0	-0.20	-0.40
<50kg	-2.85	-1.00	-0.30	-0.60

Results

Figure B1 illustrates how batch variability and price penalties interact to generate an optimum termination date for a batch of pigs that maximises profit per pig for scenarios 1 and 2. The optimum is generated because, over time, the numbers of pigs facing a price penalty is decreasing rapidly, while opportunity costs for the whole batch continue to increase linearly over time. Despite the fact that scenario 2 had a much lower price penalty for pigs under 50 kg dressed carcase weight than scenario 1 (effectively $2.85 versus $1.00 penalties), the shift in profit lines as a result of increasing the batch standard deviation was quite similar, particularly at and around the optimum termination day. Figures B2 and B3 show how the economic values for a one-kg increase in the standard deviation of dressed carcase weight of a batch tended to be less negative when the standard deviation in weight at start of a batch was quite low (i.e. a standard deviation of less than 6 kg). In Figure B2, the economic values between 8 and 18 kg of the standard deviation of dressed carcase weight of a batch fell in a similar range of -\$0.9 to -\$1.1 per kg of batch standard deviation per pig for the three pricing scenarios other than Scenario 1 which was most severe with all pigs under 50 kg generating no revenue. Results in Figure B3 suggest that the economic values are strongly influenced by the opportunity costs of the batch, with this being particularly so with the extreme penalty placed on pigs under 50 kg.

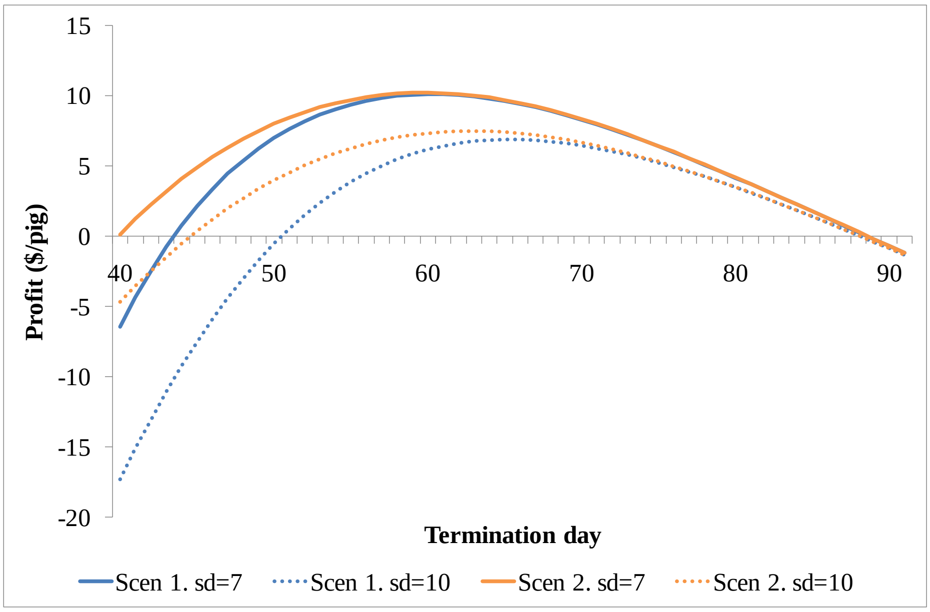


Figure B1. Reduction in profit per pig with an increase in the standard deviation of batch dressed carcase weight from 7 to 10 kg as a function of termination day under two pricing scenarios. In both pricing scenarios, only pigs with a carcase weight less than 50kg face a penalty in their price per kg of dressed carcase weight. The penalty is equal to the base pig price (i.e. pigs under 50kg are worthless with scenario 1), and pigs under 50kg face a \$1/kg penalty with scenario 2.

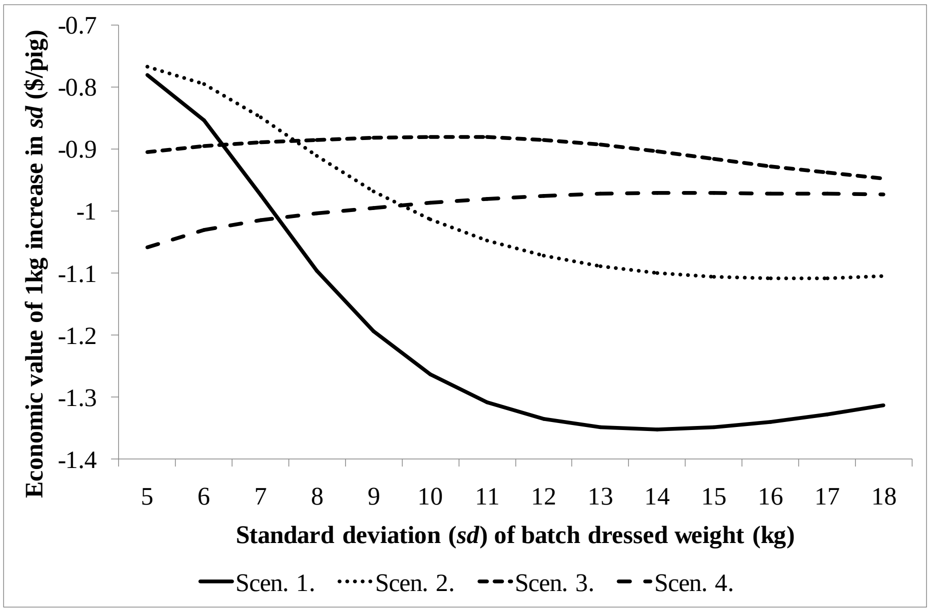


Figure B2. The economic value of a one-kg reduction in the raw standard deviation of batch dressed carcase weight under 4 different price penalty scenarios for underweight pigs and for a range of starting points for the standard deviation. Scenario's 1. and 2 have heavy and moderate penalties on pigs under 50kg dressed carcase weight respectively, while Scenario's 3 and 4 have heavy and moderate stepwise penalties on pigs in 10 kg live weight bands respectively.

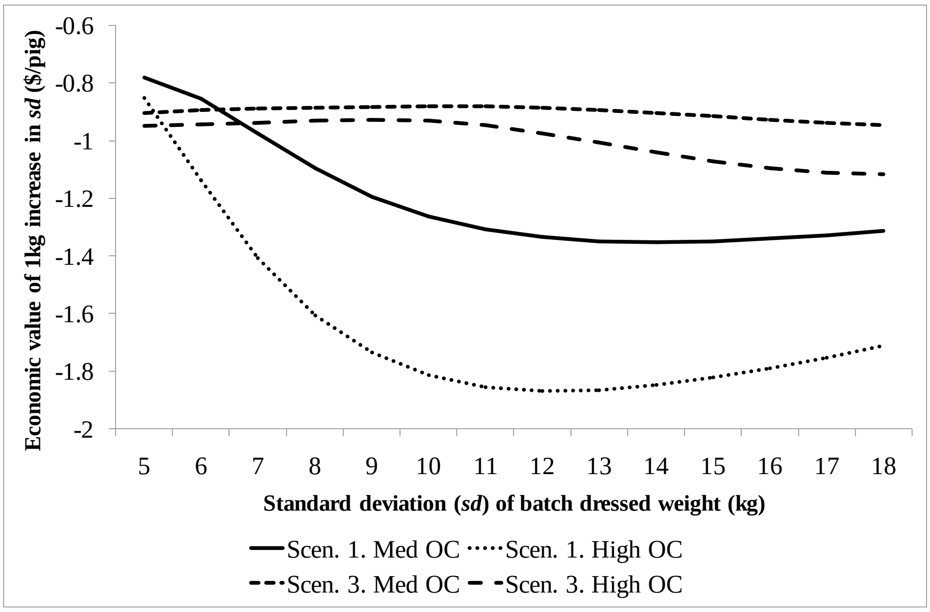


Figure B3. The economic value of a one-kg reduction in the raw standard deviation of batch dressed carcase weight under 2 different price penalty scenarios for underweight pigs and 2 levels of daily opportunity costs (OC) of finishing batch. Scenario's 1 has a heavy penalty on pigs under 50kg dressed carcase weight, scenario 3 has heavy stepwise penalties on pigs in 10 kg live weight bands, while medium and high opportunity costs were assumed to be $0.5 and $0.8 per pig per day respectively.

Economic values for a one-kg increase in the standard deviation of dressed carcase weight within a batch were found to be robust to the assumptions made about the price of feed and the base per kg carcase price (results not shown). While these parameters have a large impact on the profitability per pig, a reduction in batch standard deviation does not create much opportunity to save feed costs. Reducing variability does create the opportunity to have more pigs sold at higher weights, and this revenue translates partly into higher economic values, but the overall effect was quite modest (results not shown).
Table B3 shows the sensitivity of economic values to the different market price penalties for underweight pigs and the opportunity costs arising from delayed slaughter. Results are shown both with and without re-optimisation of the termination day. In general, economic values without re-optimisation of the termination date were only modestly overestimated, and only for some of the market price penalty scenarios. However, it can be seen from Figure B1 that finding the optimal termination date for the base standard deviation is very important, because the difference between corresponding lines in Figure B1 depends greatly on whether the comparison is made at a relative early termination date (giving an artificially high value of uniformity), or at a relatively late termination date (giving an artificially low value of uniformity).

Table B3. Economic values for a one-kg increase in the standard deviation of batch dressed carcase weight from a starting value of 10 kg under alternative model parameters with and without re-optimisation of the termination date following the increase in the standard deviation.

Underweight penalty scenario	Opportunity cost $/pig/day	Economic value with re-optimisation	Economic value without re-optimisation
Scenario 1	0.2	-0.60	-0.67
Scenario 1	0.5	-1.26	-1.35
Scenario 1	0.8	-1.81	-1.90
Scenario 2	0.2	-0.54	-0.58
Scenario 2	0.5	-1.01	-1.04
Scenario 2	0.8	-1.33	-1.35
Scenario 3	0.2	-0.53	-0.56
Scenario 3	0.5	-0.88	-0.89
Scenario 3	0.8	-0.93	-0.93
Scenario 4	0.2	-0.57	-0.61
Scenario 4	0.5	-0.99	-1.00
Scenario 4	0.8	-1.21	-1.21

Conclusions

This Project shows how batch variability can affect the profitability of a pig finishing system, and the key assumptions and parameters required to quantify the cost of an increase in batch variability by a one-kg increase in batch variability. The primary determinant of the economic impact of batch variability was the opportunity cost of delaying termination date of a batch in order to minimise the number of underweight pigs at termination. The nature of the price penalties applied for underweight carcases was also found to be important, although not as

influential as might have been expected. The economic value of improved batch variability has also been shown to depend on current levels of variability, although this was only the case where current levels of variability are unrealistically low.
In order to appropriately adjust trait weightings in a selection index to account for their effect on batch variability, it is necessary to derive partial genetic regression coefficients for each trait on batch variability. Proxies for the partial genetic regression coefficients might be obtained in practice from an analysis of data from commercial finishing systems where some extra recording has taken place. Alternatively, simulation could be used to model how changes in average and variability of performance of individual pigs translate to variability within a batch. Perhaps a limitation of simulation would be the need to account for many practical operations that may vary from farm to farm. For example, on smaller farms, there may be a need to mix batches of piglets from sows and gilts, from a wider spread of farrowing dates, and of different gender. All of these factors would increase batch variability, although additional variability within lines of similar piglets or through an increase in the numbers of smaller piglets from sows with very large litters, should be additive to the other sources of variability.

C. Economic values for performance traits of growing pigs in Australia

Introduction

Accurate estimates of economic values for traits of growing pigs describing efficient lean meat growth are an important pre-requisite to efficient overall selection indexes for pig breeding programs, and also relevant to investment decisions about the extent of the economically optimum levels of performance recording in pig breeding programs. They apply to both terminal and maternal breeding lines because one half of the genes from slaughtered pigs originate from maternal breeding lines (Smith, 1964).

Within Australia, there is a range of trait definitions used by different pig genetic improvement companies, and this range of trait definitions may have implications for the derivation of economic values to be applied to estimated breeding values. Inconsistent definitions may also lead to unrealistic assumptions about the genetic relationships between the recorded selection criteria trait, and the trait as defined in the derivation of economic values. These two issues need to be addressed, in order to have an up to date, comprehensive and robust set of economic values for the Australian pig industry.

Method

Approach

In contrast to many other studies of pig breeding objectives, we use direct equations to define the economic values for traits of interest. This approach avoids the unnecessary complexity of either specifying a profit equation and taking the partial derivative (e.g. de Vries 1989), or alternatively specifying a complex bio-economic model (Stewart et al. 1990) containing a large number of unnecessary interactions which increase the risk of double counting. The conceptual process taken involves direct consideration of the likely partial impacts on the farm system of unit profit changes. Different assumptions about the scale of the pig breeding operation can easily be accommodated, for example, we specify economic values for pig survival under the assumption either of a constant number of sows, or a constant number of pigs sold.

Economic values were estimated for traits of growing pigs based on information from the Australian pig industry. Feed traits included both feed conversion ratio (FCR) and average daily feed intake (DFI) as both of these traits are considered as selection criteria in pig breeding programs. However, only one of these traits should be considered in any single breeding objective, and the choice of which one is included has implications for how economic values for average daily gain should be computed. A post weaning survival trait and a fat depth trait were also included in the index.

Feed conversion ratio

The economic value for FCR for the lifetime of the growing pig (EV_FCR_L) was derived from the changes in feed costs over the lifetime of a growing pig per unit change in FCR, which depend on the price of feed eaten and live weight of the growing pig at slaughter. This economic value expressed in $ AU was therefore calculated using:

$$EV\_FCR_L = F_P \cdot Wt_P \qquad [1]$$

where F_P is the feed costs for piglets in $AU (kg fresh weight)$^{-1}$ ($AU0.28 (kg fresh weight)$^{-1}$) and Wt_P is the live weight of piglets at slaughter (98 kg).

However, when this economic value for FCR gets applied to feed intake records for the limited duration of a test period within a breeding program, there are implicit assumptions made about the genetic relationships between the test trait FCR, and FCR over other periods of the growing and finishing system. A more general formula for the economic value of FCR can be used which partitions the commercial grower period into component periods, and factoring the genetic relationship between test trait FCR, and FCR within the discrete period into the calculation. This more general formulation was calculated as:

$$EV\_FCR_L = \sum_{i=1}^{4}\left(wtend_i - wtbeg_i\right)\cdot FP_i \cdot genreg_i \qquad [2]$$

where *i* takes a value of 1 to 4 for the pre-weaning, grower, early finish and late finish periods respectively, $wtbeg$ and $wtend$ correspond to live weights of growing pigs at the beginning of the four growing pig live stages as defined above, and genetic regressions ($genreg_i$) quantifying the genetic change in FCR in a life stage with respect to a genetic change in FCR on test. These genetic regression coefficients can be derived using assumptions about the genetic correlations between FCR during the test period and FCR at various life stages for the growing pig along with the genetic standard deviations for all of the FCR traits.

In order to derive genetic regressions coefficients for test feed intake traits on lifetime feed intake traits, assumptions about genetic correlations and genetic standard deviations of traits are required i.e.

$$genreg_i = r_{G_{i.T}} \cdot \frac{\sigma_{G_i}}{\sigma_{G_T}} \qquad [3]$$

where $r_{G_{i.T}}$ is the genetic correlation between the test trait and the corresponding trait within the ith life stage of the growing pig, while σ_{G_i} and σ_{G_T} are genetic standard deviations for the test trait and ith life stage trait respectively. Assumptions about genetic correlations were informed using results reported by Shultz et al. 2003. Genetic standard deviations were specified assuming a constant heritability and coefficient of variation for feed conversion ratio expressed through the different life stages of the growing pig destined for slaughter.

Daily feed intake

The average daily gain economic value (EV_ADG) is defined as lifetime average daily gain (ADG) quantified in grams per day. The improvement in ADG is used to translate extra weight for age into savings in days at the end of the finishing period. It is assumed that change in profit is linear for an improvement in growth rate during the finishing period.

The economic value for ADG differs depending on whether FCR or DFI is part of the breeding objective. The economic value for average daily gain when FCR is also present in the breeding objective (EV_ADG_{FCR}) was calculated as a corresponding saving in no feed costs:

$$EV\_ADG_{FCR} = \left(\frac{Age_P}{Gr_P \cdot 1000}\right) \cdot C_{NF} \qquad [5]$$

where Age_P is the age of a finished pig (152 days); Gr_P is the growth rate of a finished pig just prior to slaughter (1.05kg day^{-1}); and C_{NF} is the daily non-feed costs per pig from weaning to slaughter ($AU0.609). No feed costs are considered to be saved in the economic value calculation, because any savings in feed for faster growing pigs will be reflected in their estimated breeding for FCR which is already accounted for in the breeding objective.

Daily non feed costs per pig (C_{NF}) was calculated as the difference between piglet revenue and the costs for purchasing, feeding and marketing the pig and expressed per day on feed as follows:

$$C_{NF} = \frac{\left(\left(P_P \cdot Cwt_p\right) - C_M - C_{FP} - V_W\right)}{\left(Age_P - Age_W\right)} \qquad [6]$$

where, P_P was the price of a finished pig carcass ($AU3.05 kg carcass weight^{-1}); Cwt_p was the carcass weight of the finished pig (78.70 kg carcass weight); C_M was the cost of marketing and transporting the finished pig ($AU4 pig^{-1}); C_{FP} was the cost of feed for growing pigs from post weaning to slaughter ($AU63) ; V_W was the purchase value of a weaner pig ($AU94.5 pig^{-1}); Age_P was the age of a finished pig (152 days); and, Age_W was the age of a weaned pig (23 days).

The economic value for average daily gain when DFI was also present in the breeding objective (EV_ADG_{DFI}) was calculated as:

$$EV\_ADG_{DFI} = \left(\frac{Age_P}{GrP \cdot 1000}\right) \cdot \left(C_{NF} + \left(\frac{C_{FP}}{Age_P - Age_W}\right)\right) \qquad [7]$$

which differs from the situation described above for when FCR is part of the breeding objective, because it counts the benefits of saved feed due to early slaughter.

Post-weaning survival

Survival of the growing pig after weaning is defined as a binary trait of all growing pigs with values scored as 0 for pigs that died between weaning and slaughter and 1 for pigs that survived until slaughter. Piglets that died prior to weaning have a missing value. Two approaches were considered to derive economic values for post-weaning survival including a ‘cost saving’ and a ‘lost revenue’ approach.

Cost-savings approach

The cost saving approach assumes that a predictable death rate in the finishing system is anticipated and extra finisher pigs are purchased to make up for deaths. Thus, extra survival of growing pigs reduces costs to purchase extra pigs. The economic value for post weaning survival (SG_C_EV) is based on the costs of the weaner pig, cumulative feed costs and non-feed costs from weaning until the average age of mortality, as well as costs to dispose of a pig that dies post weaning. This is represented by:

$$SG_C\_EV = V_W + \left(Feed_M \cdot F_P\right) + \left(Age_M - Age_W\right) \cdot C_{NF} + C_W \qquad [8]$$

where V_W is average value of a piglet at weaning ($AU94.50); $Feed_M$ is the mass of feed consumed by a piglet by the time it dies post weaning (80 kg fresh weight); F_P is the cost per kg of feed for piglets ($AU0.28 kg fresh weight-1); Age_M is the average age of post weaning piglet mortality (100 days); Age_W is the age of a weaned pig (23 days); C_{NF} is the non-feed costs (opportunity costs) per day from weaning to slaughter ($AU0.61); and, C_W is the cost to dispose of a pig that dies post weaning ($AU20).

Lost-revenue approach

The lost revenue approach assumes that a pig dying after weaning during the growing period results in lost revenue. In this way, the economic value for post weaning survival as a trait of the growing pig (SG_R_EV) is derived from the value of a pig at slaughter after subtraction of cumulative feed and non-feed costs from weaning until the average age of mortality, and costs of disposing dead pigs. The following equation calculates the economic value in this way:

$$SG_R\_EV = V_P - (Feed_P \cdot Feed_M) \times Wtp - (Age_P - Age_M) \cdot C_{NF} + C_W$$

[9]

where V_P is the slaughter value of a piglet ($AU240); $Feed_P$ is the cumulative weight of feed required during the finishing period of a growing pig (192 kg fresh weight); $Feed_M$ is the feed consumed by a piglet by the time it dies post weaning (80 kg fresh weight); Wtp is the slaughter live weight of piglets (98 kg); is the age of a pig when it is slaughtered (152 days); Age_P is the average age of post weaning piglet mortality (100 days); Age_M is the non-feed costs (opportunity costs) per day from weaning to slaughter ($AU0.609); and, C_W is the cost to dispose of a pig that dies post weaning ($AU20).

Carcass fat depth

Carcase fat depth (CFD) is measured at the last rib of a pig carcass approximately 6.5 cm off the dorsal mid-line at the P2 site. This measure provides high predictive power for estimating the percentage of lean in a carcass (Evans and Kempster 1979). The economic value for CFD reflects the increase in returns per pig due to a lower proportion of pigs receiving a price penalty due to high fat depths. Conceptually, it is possible to have a positive economic value for fat depth if a proportion of pigs receive a price penalty due to an extremely low fat depth. The proportion of pigs receiving a price penalty was computed as a function of the population mean and standard deviation of pigs. Therefore, changes in the mean as well as changes in the variability affect returns per pig (Hermesch, 2005). The assumption is made that the genetic regression of CFD in slaughtered pigs on estimated breeding values for fat depth is 1.

A bivariate extension of the univariate method described by Hovenier et al. (1993) is outlined here and used within the economic value framework. The equation for calculating the economic value of carcase fat depth (CFD_EV) was therefore:

$$CFD\_EV = \rho^1 \cdot \sum_{i,j} \Delta^1_{i,j} \cdot G^1_{i,j} \cdot \mu^1_{CW} + \rho^2 \cdot \sum_{i,j} \Delta^2_{i,j} \cdot G^2_{i,j} \cdot \mu^2_{CW} \qquad [10]$$

where ρ^1 and ρ^2 are the proportions of production pigs serviced by the breeding program that are processed for two pricing grids G^1 and G^2, respectively. The two pricing grids (Tables C1 and C2, respectively) are reflected by two dimensional arrays of prices per kg of carcase weight with rows with index i corresponding to carcase weight bands (i.e. for i=1 from 0 to 50kg, for i=2 from 50 to 55kg, increasing in 5kg steps until for i=11 anything greater than 95kg) and columns with index j corresponding to carcase P2 fat depth bands (i.e. for j=1 from 0 to 10mm, for j=2 from 10 to 11mm increasing in 1 mm steps until for j=12 anything greater than 20mm). Matrix elements $\Delta^{1}_{i,j}$ and $\Delta^{2}{}_{i,j}$ give the change in proportions in each carcase weight and P2 fat section of the grid out of the total slaughtered populations of pigs processed under each pricing grid when the average carcase P2 fat depth of the populations is increased by 1 mm at the same carcase weight. It is assumed that pig producers would not change their target slaughter carcase weights in response to a genetic change in CFD. These are computed as a function of the population means and standard deviations of pigs slaughtered under the respective grids as:

$$\Delta_{i,j} = \int_{lCw_i}^{hCw_i} \int_{lP2_j}^{hP2_j} B(Cw, P2, \mu Cw, \sigma Cw, \mu P2 + 1mm, \sigma P2, r) \cdot \delta Cw \cdot \delta P2 - \int_{lCw_i}^{hCw_i} \int_{lP2_j}^{hP2_j} B(Cw, P2, \mu Cw, \sigma Cw, \mu P2, \sigma P2, r) \cdot \delta Cw \cdot \delta P2 \quad [11]$$

where h and l denote upper and lower bounds within the pricing grid corresponding to sections denoted by i and j for carcase weight (Cw) and carcase P2 fat depth ($P2$) respectively. The bivariate normal distribution B is parameterised by the population means μ and standard deviations σ of Cw and $P2$ and the correlation r between them, for the population of pigs processed under the corresponding grid. For the current implementation, we assume that the correlation between Cw and $P2$ is zero.

The starting population of slaughter pigs modelled averaged 10.9 mm mean CFD for payment method 1 and 9.9 mm for payment method 2. The standard deviations of CFD for payment one and two were 2.18 mm and 1.98 mm, respectively. The average carcass price for the population pigs modelled was $AU214.28 pig-1 for payment system one and $AU206.05 pig-1 for payment system two.

Table C1. Price grid for pork meat payments in $AU per kg carcass weight based on payment method one in relation to the carcass weight and the upper bound fat depth at the P2 site of finisher carcasses

Upper bound fat depth at the P2 site on the carcass (mm)

Carcass weight (kg)	**0**	**6-11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
	50	$2.40	$2.30	$2.20	$2.10	$2.00	$1.90	$1.80	$1.70
	55	$2.40	$2.30	$2.20	$2.10	$2.00	$1.90	$1.80	$1.70
	60	$2.60	$2.60	$2.50	$2.40	$2.30	$2.20	$2.10	$2.00
	65	$2.60	$2.60	$2.50	$2.40	$2.30	$2.20	$2.10	$2.00
	70	$2.80	$2.80	$2.80	$2.70	$2.60	$2.50	$2.40	$2.30
	75	$2.80	$2.80	$2.80	$2.70	$2.60	$2.50	$2.40	$2.30
	80	$2.80	$2.80	$2.80	$2.80	$2.70	$2.60	$2.50	$2.40
	85	$2.80	$2.80	$2.80	$2.80	$2.70	$2.60	$2.50	$2.40
	90	$2.60	$2.60	$2.60	$2.50	$2.40	$2.30	$2.20	$2.10
	95	$2.60	$2.60	$2.60	$2.50	$2.40	$2.30	$2.20	$2.10
	200	$2.40	$2.40	$2.40	$2.30	$2.20	$2.10	$2.00	$1.90

Table C2: Price grid for pork meat payments in $AU•kg carcass weight based on payment method two in relation to the carcass weight and the upper bound fat depth at the P2 site of finisher carcasses

Upper bound fat depth at the P2 site on the carcass (mm)

Carcass weight (kg) **0**	**6-10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**100**
50	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60	$2.50	$2.40	$2.30
55	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60	$2.50	$2.40	$2.30
60	$3.30	$3.30	$3.20	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60
65	$3.30	$3.30	$3.20	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60
70	$3.30	$3.30	$3.30	$3.20	$3.10	$3.00	$2.90	$2.80	$2.70
75	$3.30	$3.30	$3.30	$3.20	$3.10	$3.00	$2.90	$2.80	$2.70
80	$3.10	$3.10	$3.10	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60
85	$3.10	$3.10	$3.10	$3.10	$3.00	$2.90	$2.80	$2.70	$2.60
90	$2.90	$2.90	$2.90	$2.90	$2.90	$2.80	$2.70	$2.60	$2.50
95	$2.90	$2.90	$2.90	$2.90	$2.90	$2.80	$2.70	$2.60	$2.50
200	$2.70	$2.70	$2.70	$2.70	$2.70	$2.60	$2.50	$2.40	$2.30

Discounted genetic expressions of terminal traits

Discounted genetic expressions coefficients (DGE) were used as a means of taking into account differences in frequency and timing of terminal trait expression. They are also used to translate economic values which are specified on a per growing pig basis into index weights for an index expressed on a per farrowing basis. Two different DGE were used for the terminal pig traits including for a terminal sire line piglet traits at weaning (XT_W) and at slaughter (XT_C). It was convenient to derive the DGE for a terminal sire line piglet trait at birth (XT_B) as a step towards deriving DGEs for traits expressed later although this coefficient is not directly applied in the terminal index, which does not include birth traits. All piglet birth traits are assumed to be solely under the genetic influence of the sow.

The terminal sire line piglet trait at birth DGE was calculated as:

$$XT\_B = aveNBA \cdot e^{-\left(\frac{r}{365\times100}\right)\cdot GL} \quad [12]$$

where $aveNBA$ is the average number of pigs born alive (11.01); e^x denotes the exponential function with respect to x; r is the discount rate (6%); and GL is the gestation length of the sows (115 days).
The weaning trait DGE was subsequently calculated using:

$$XT\_W = XT\_B \cdot S_W \cdot e^{-\left(\frac{r}{365\times100}\right)\cdot Age_W} \quad [13]$$

where S_W is the proportion of piglet survival from birth to weaning (0.88); r is the discount rate (6%); Age_W and is the age of a weaned pig (23 days).
The slaughter trait DGE was calculated using:

$$XT\_C = XT\_B \cdot S_W \cdot S_P \cdot e^{-\left(\frac{r}{365\times100}\right)\cdot Age_P} \quad [14]$$

where S_W is the proportion of piglets that survive from birth to weaning (0.88); S_P is the proportion of piglets that survive from weaning to slaughter (0.997); r is the discount rate (6%); and Age_P is the age at slaughter for the grower pigs (152 days).

Results

Aggregate economic weights expressed per farrowing are shown in Table C3 for performance traits of growing pigs taking economic values and discounted genetic expressions into account. In addition, economic values expressed per growing pig are shown for each trait. These economic parameters quantify the change in profit when each trait is changed by one unit. A direct comparison of economic values and economic weights is difficult as the trait units differ between traits. For example, economic values and economic weights are higher for feed conversion ratio in comparison to growth rate because an improvement in feed conversion ratio of one unit (e.g. from 3.0 to 2.0) is biologically and economically considerably larger than an improvement of growth rate of one gram per day. The difference between approaches was modest, with values of $AU1739.96 and $AU1864.38 for the cost saving approach and the lost revenue approaches, respectively. The market value of a pig with 1mm greater fat depth at the P2 site was $AU-214.28 for payment system one and $AU-206.05 for payment system two. An economic weight of $AU-15.68 was calculated for the P2 fat depth of carcass trait with an economic value of $AU-1.70, a discounted genetic expression of 9.21 and an industry weighting factor of 1.0.
Aggregate economic weights were expressed per genetic standard deviation of each trait and the relative contribution of each trait based on the genetic variation available trait to the overall terminal index is shown in Table C4. Survival of pigs post weaning contributed 48% to the terminal index highlighting the importance of this trait. Feed conversion ratio contributed 26% to the terminal index which reflects the importance of feed costs to pig production. Pigs have reached low levels of fat depth which lead to low economic importance of fat depth relative to other traits in the terminal index.

Table C3: Components of aggregate economic weights for a terminal sire selection index in AU$ per farrowing taking into account economic values of unit trait changes expressed per growing pig and discounted genetic expressions coefficients.

Trait	Units	Economic value ($AU)	Discounted genetic expressions	Aggregate economic weight ($AU)
Feed conversion ratio for lifetime of growing pig	kg feed·(kg liveweight gain)$^{-1}$	-27.44	9.24	-253.56
Lifetime feed conversion ratio for the test period	kg feed·(kg liveweight gain)$^{-1}$	-23.77	9.24	-219.61
Daily feed intake for lifetime of pig	$·lifetime feed per day	-36.12	9.24	-333.76
Daily feed intake for test period of pig	$·test period feed per day	-37.02	9.24	-342.04
Average daily gain (with FCR in the breeding objective)	g·day^{-1}	0.09	9.24	0.82
Average daily gain (with DFI in the breeding objective)	g·day^{-1}	0.16	9.24	1.47
Post weaning survival (cost savings)	piglets survival·(piglet weaned)$^{-1}$	183.77	9.47	1739.96
Post weaning survival (lost revenue	piglets survival·(piglet weaned)$^{-1}$	196.91	9.47	1864.38
Carcass Fat Depth	mm	-1.70	9.24	-15.68

Table C4: Percentage contributions of each trait to the overall terminal selection index when weighted by the respective genetic standard deviation for each trait

Trait	Units	Aggregate economic weight ($AU)	Genetic standard deviation	% contribution to terminal index
Feed conversion ratio	kg feed·(kg liveweight gain)$^{-1}$	-253.56	0.15	26%
Average daily gain (with FCR in the breeding objective)	g·day^{-1}	0.82	30.00	16%
Post weaning survival (lost revenue)	piglets survival (piglet weaned)$^{-1}$	1864.38	0.038	48%
Carcass fat depth	mm	-15.68	1.00	11%

Feed intake on individual pigs is recorded over a specific test period rather than lifetime. The breeding objective trait for feed conversion ratio was based on lifetime resulting in an economic value for lifetime feed conversion ratio of $AU -27.44 which was 15% higher than the economic value of $AU -23.77 based on estimated breeding value relevant for a specific test (Table C5). The total economic value for feed conversion ratio over a specific test period is the sum of economic value components relevant for each test period. The importance of each economic value component relevant for each test period depends on their genetic association with lifetime feed conversion ratio.

Table C5: Calculation of the economic value for feed conversion ratio on test based on the sum of its projected genetic impact on feed conversion ratio at alternative life stages of the growing pig.

Period	$rg_{i,T}$	$\frac{\sigma g_i}{\sigma g_T}$	Genetic regression	FP_i (\$/kg)	$wtbeg$ (kg)	$wtend$ (kg)	Economic value component[1]
Preweaning	0	-	-	-	0kg	7kg	0
Weaner	0.7	0.6	0.42	0.28	7kg	30kg	-2.71
Grower	1.0	1	1	0.28	30kg	60kg	-8.40
Finisher	0.85	1.4	1.2	0.28	60kg	98kg	-12.66
Total							-23.77

1 Each economic value component is the product of the weight gain in the life stage (calculated as the difference between the weight at the start of the life period ($wtbeg$) and the weight at the end of the life period ($wtend$), the genetic regression (calculated as the product of the ratio of genetic standard deviations of the life stage trait and the test trait ($\frac{\sigma g_i}{\sigma g_T}$) multiplied by the genetic correlation between the life stage trait and the test trait ($rg_{i,T}$) and the feed price (FP_i).

D. Economic values for maternal pig traits in Australia motivate genetic improvement for robustness

Introduction

The application of crossbreeding in pig farming systems is fundamental to modern pig production systems and has important implications for breeding programs, including the need for separate development of maternal and terminal breeding lines of pigs (Suzanne to suggest reference here). For genetic improvement of maternal lines, both maternal traits such as litter size and sow longevity and also terminal traits such as growth rate, feed efficiency and carcass attributes are highly relevant. However, the terminal traits tend to have higher heritabilities, and are recorded earlier in the lives of selection candidates, making them much easier to improve than maternal traits. In Australia, breeding objectives and selection criteria for terminal traits have received greater emphasis than maternal traits in both research and application to breeding programs. A consequence is that opportunities to improve profitability and viability of pig production systems through improvement of maternal traits may be underutilized.

The removal of sows from a herd due to deaths, health problems or inadequate production is a major source of inefficiency in the swine industry . This leads to economic and animal welfare concerns due to higher replacement requirements and greater treatment costs. Research into the relative economic importance of maternal traits has been undertaken for a number of countries (Kristensen and Sollested, 2004; Quinton et al., 2006; Rodriguez-Zas et al., 2003), whereas for Australia, number born alive (NBA) was the only maternal trait included in the breeding objective (Cameron and Crump, 2001) in the 1990s.

The objective of this Project was to derive economic values for maternal traits in pig production including sow longevity, farrowing survival, pre-weaning survival, number of piglets born alive, age at puberty, and mature weight of sows, daily gain (maternal) and maternal weaning weight with the intention that these be included in breeding objectives for maternal lines of pigs in Australia.

Method

Approach

The economic value for a range of maternal pig traits were estimated for the Australian pig industry. Economic values were based on the change in profit per unit change in each trait expressed once and independently to other traits. Sow longevity, farrowing survival, pre-weaning survival, number of piglets born alive, age at puberty, mature weight of sows, daily gain, and weaning weight (maternal) were considered. The approach involved sub models of sow performance and profitability both before and after genetic change in each trait of interest. Two alternative approaches to derive economic values were considered for number born alive reflecting different production systems.

Key assumptions made in the calculation of the maternal economic values are included in the Appendix. These include production and price assumptions for sows, replacements and piglets (eg. the 295kg mature weight of sows) as well as those that relate to other aspects of the operation including capital value of the buildings and facilities, depreciation and discount rates.

Economic value of sow longevity

The economic value of longevity was defined as the marginal economic benefit of a sow achieving an extra parity during her lifetime. This was calculated by simulating a unit increase in inter-parity survival and dividing the average change in profit per sow across the herd by the average change in parities per sow. Parity *n* was defined as the interval from the *n*th conception to the *n*th +1 conception. The economic value for a one-parity increase in sow longevity (EV_{PAR}) was estimated as:

$$EV_{PAR} = \overline{P}\,\frac{\Delta PPP}{\Delta \overline{P}} \quad [1]$$

where $\overline{P}$ is the average number of parities per sow, ΔPPP is the change in average profit per parity for a one percentage point increase in inter-parity survival and $\Delta \overline{P}$ is the change in average parities per sow for a one percentage point increase in inter-parity survival. The multiplication by $\overline{P}$ ensures that the economic value is expressed on a per sow lifetime basis, rather than on a per parity basis. The value for the change in average number of parities, $\Delta \overline{P}$, was calculated as the difference in the average number of parities per sow lifetime before and after the 1% change in parity survival rates from the base survival rate as follows;

$$\Delta \overline{P} = \sum_{n=1}^{10} \rho S_n^{Base+1\%} \cdot n - \sum_{n=1}^{10} \rho S_n^{Base} \cdot n \quad [2]$$

where $\rho S_n^{Base+1\%}$ is the proportion of the sow herd in each parity for the scenario with a one percentage point increase in inter-parity survival rates and ρS_n^{Base} is the proportion of the sow herd in each parity for the base scenario. The symbol n indicates the parity number. Values for these inputs are shown in Table D1.

The value for the change in average profit per parity was calculated as:

$$\Delta PPP = \sum_{n=1}^{10} NR_n \left(\rho S_n^{Base+1\%} - \rho S_n^{Base}\right) + Sal^{Base+1\%} - Sal^{Base} - C_R\left(\rho S_1^{Base+1\%} - \rho S_1^{Base}\right) \quad [3]$$

such that different parities (denoted *n*) have different calculated levels of net returns (NR) per sow from weaned piglet sales after accounting for piglet and sow feed costs, Sal is the weighted average salvage returns from slaughter of cull sows in a herd with or without a one percentage point improvement in rates of survival through successive parities, C_R is the cost of a replacement gilt (AU$350), and ρS denotes the proportion of the sow herd in each of 10 possible parities which also depends on the rates of sow survival between parities. For the purposes of calculating the economic value for longevity, relative parity profitability values were used as absolute profits were unimportant.

Net returns per sow of parity n were calculated assuming that first, second and third or later-parity sows would wean 9.15, 9.86 and 9.86 live pigs worth $AU94.5, $AU97.65 and $AU99.23 on average per piglet, respectively. This gave total revenues of $AU865, $AU963 and $AU978 per litter for the first, second and third or later-parity sows respectively. Feed costs were computed using energy requirement equations from and the parameters used within these equations are presented in Table 2.

Table D1: The percentage of the sow herd as each parity under base longevity conditions (ρS_n^{Base}) and with one percentage point greater inter-parity survival ($\rho S_n^{Base+1\%}$)

Parity number (n)	ρS_n^{Base}	$\rho S_n^{Base+1\%}$
1	24.2%	23.4%
2	18.9%	18.5%
3	14.7%	14.6%
4	11.5%	11.6%
5	9.0%	9.2%
6	7.0%	7.2%
7	5.5%	5.7%
8	4.3%	4.5%
9	2.0%	2.2%
10	2.9%	3.2%

Table 2: Energy requirement parameters used for the calculation of pig economic values

Energy requirement parameter	Units	Value
Maintenance coefficient for sows	MJME×kg liveweight^X	0.44
Maintenance exponent value for sows	liveweight^X	0.75
Weight of protein at first conception at reference mature weight	kg	45
Reference mature weight	kg	280
Energy requirements per kg of protein laid down (excl. that assoc .with water)	MJME·kg protein^{-1}	44.40
Efficiency of conversion of dietary ME to retained protein	MJME·MJME protein^{-1} (unitless)	0.54
Energy requirements per kg of fat laid down	MJME·kg fat^{-1}	52.30
Efficiency of conversion of dietary ME to retained fat	MJME·MJME kg fat^{-1}	0.74
Sow milk required for piglet to grow 1kg prior to weaning	litres	4
Energy requirement to produce 1 litre of milk	MJME·l milk^{-1}	7.70
Percent of lactation energy from mobilisation	%	0.80
Efficiency of energy use from mobilisation	MJME·litre milk^{-1}	0.85

Feed prices per unit of dry matter and per MJ of ME were assumed to be the same for growing piglets (post weaning), gilts and sows. An $AU280/tonne fresh weight cost of feed was assumed with a dry matter percentage of 90%, an energy concentration of 12.5 megajoules of metabolisable energy (MJME) per kilogram of dry matter (kg DM) leading to a cost of $AU0.03 MJME utilised^{-1}, assuming 95% feed utilisation.

The average salvage revenues to the herd per sow parity, Sal, for either the base (x=Base) or improved (x=Base+1%) survival herds were calculated as:

$$Sal^{x}=\sum_{n=1}^{9}\left(\rho S_{n+1}^{x}-\rho S_{n}^{x}\right)\cdot\left(Cwt_{S_n}\cdot P_s\cdot 0.9-C_{SD}\cdot 0.1\right)+\rho S_{10}^{x}\cdot\left(Cwt_{S_{10}}\cdot P_s\cdot 0.9-C_{SD}\cdot 0.1\right)$$

[4]

assuming that of the sows that departed from the herd, 90% were slaughtered as cull sows at a carcase weight of Cwt_{S_n} while 10% died on farm. For those slaughtered as cull sows, a carcase price (P_s) of $AU1.50 per kg carcass was used, while sows that died on farm were assumed to have a cost (C_{SD}) of $AU50 for disposal. Carcass weight of sows as a percentage of live weight at slaughter was assumed to be 75% across all parities. Carcass weights were different over the first five parities, taking values of 119, 157, 183, 199 and 215 kg, respectively. Sows older than five parities were assumed to achieve carcass weights that were the same as sows culled after their 5th parity.

Economic value of farrowing survival

Farrowing survival is a trait of the sow expressed once per parity and was defined as the proportion of live born piglets divided by the total number of piglets. The economic value of farrowing survival accounts for the opportunity cost of not having the piglet and is equal to the gestation cost of the sow associated with the stillborn piglet. In addition, the benefits of lower disposal costs of dead piglets are accounted for.

The value of the piglet itself cannot be counted because a sow with 14 piglets born alive and two piglets born dead would rank lower than a sow with 13 born alive and one piglet born dead. Both sows have 12 piglets born alive, and the value of a piglet itself is accounted for by the number of piglets born alive. The only extra costs associated with the extra dead piglet relate to feed requirements in gestation. Further, it is assumed that the lower pre-weaning survival and lighter weaning weight in the surviving piglets of the larger litter with two dead piglets are considered by including pre-weaning survival and average piglet weaning weight in the breeding objective.

The economic value of piglet survival at birth as a trait of the sow (EV_SB) was calculated as:

$$EV\_SB=\left(\frac{MEconc\times GI}{10}\right)\times\left(\frac{F_S}{Md_S\times DM_S}+C_B\right)\times aveNBA$$

[5]

where $MEconc$ is the daily energy concentration for products of conceptus (1.6 MJME day^{-1}); GI is the gestation length of the sow (115 days); F_S is the feed costs for sows (AU$0.28 kg fresh weight^{-1}); Md_S is the energy density of dry matter consumed by sows (12.5 MJME kg DM^{-1}); DM_S is the dry matter percentage of feed for sows (90%); C_B is the cost of disposing of a dead or stillborn piglet (AU$2 piglet^{-1}); and, $aveNBA$ is the number of piglets born alive averaged across all parities (11.01 piglets).

Economic value of pre-weaning survival

This trait is defined as pre-weaning survival of piglets per piglet born, rather than the total count of piglets surviving until weaning from the litter. The proportion of surviving piglets until weaning is defined as a trait of the sow expressed once per parity. The economic value is derived from the value of an extra whole piglet surviving until weaning, taking into account the costs savings due to the need to dispose of dead piglets. Most piglets die within the first few days after farrowing and average lactation feed costs for the additional surviving piglet were ignored.

Two methods for calculating the pre-weaning survival economic value were used. The pre-weaning survival economic value assuming a fixed number of piglets (EV_SW_{FP}) used: $EV\_SW_{FP} = (EV\_NBA_{FP} + CB) \times aveNBA$ [6]

where, EV_NBA_{FP} is the economic value of one extra piglet born alive assuming a fixed number of piglets, CB is the cost of disposing of a dead or stillborn piglet (AU$2 piglet^{-1}); and $aveNBA$ is the number of piglets born alive averaged across all parities (11.01 piglets).

The pre-weaning survival, assuming a fixed number of sows (EV_SW_{FS}) used:

$$EV\_SW_{FS} = (EV\_NBA_{FS} + CB) \times aveNBA \quad [7]$$

where EV_NBA_{FS} is the economic value of one extra piglet born alive assuming a fixed number of sows.

Economic value of number of piglets born alive

For a sow operation the economic value for number of piglets born alive was derived using two different assumptions about the long term constraint on the size of the farming operation. Firstly, the constraint of a fixed number of piglets generated from the sow operation was assumed (EV_NBA_{FP}) and secondly, a fixed number of sows was assumed (EV_NBA_{FS}). Both traits were defined as being expressed once per parity.

Fixed number of piglets

The economic value for an increase of one extra piglet born alive assuming a fixed number of piglets (EV_NBA_{FP}) was calculated using the ratio of total costs per sow per year divided by the number of piglets born alive per year as follows:

$$EV\_NBA_{FP} = \frac{\text{Total sow costs per year}}{\text{Total piglets born alive per year}}$$

$$= \frac{\mathrm{C_{SO}} + \mathrm{C_{SC}} + \mathrm{C_{SF}} \cdot Par + C_R}{aveNBA \cdot Par} \quad [8]$$

where $\mathrm{C_{SO}}$ is the annual operating costs per sow; $\mathrm{C_{SC}}$ is the annualised capital costs; and $\mathrm{C_{SF}}$ is the average parity feed costs for a sow operation, C_R is the cost of purchasing a replacement breeding gilt, $aveNBA$ is the number of piglets born alive per sow as an average over parities and Par is the average number of parities per sow per year. The annualised capital costs ($\mathrm{C_{SC}}$) for sows were calculated assuming a replacement capital value of the sow building and facilities

(K_s) expressed per breeding sow, an inflation free interest rate (i) and a depreciation rate (d) as follows:

$C_{SC} = K_s(i + d)$. [9]

It was assumed that no adjustment for litter size would be made when estimating breeding values for pre-weaning survival. Therefore there was no need to account for the fact that there will be higher pre-weaning mortality with larger litters in this economic value. Values of AU$130 for average annualised costs of capital (C_{SC}) per parity and AU$200 for annual sow operating costs (C_{SO}) were assumed based on information from industry experts.

Fixed number of sows

The economic value for one extra piglet born alive assuming a fixed number of sows in the long term (EV_NBA_{FS}) was based on the fact that extra piglets are generated for sale as weaners with larger litter size. A slight allowance was made for higher lactation feed requirements for sows. The economic value for NBA expressed in this way was computed as follows:

$$EV\_NBA_{FS} = V_W \cdot S_W - \frac{Gr_W}{1000} \cdot Age_W \cdot Milk \cdot MEmilk \cdot \frac{1}{Efm} \cdot \frac{F_S}{Md_s \cdot Dm_s} \quad [10]$$

where V_W is the sale price value of a weaner pig which gets adjusted for: pre-weaning survival rate (S_W), growth rate (Gr_W) in grams·day^{-1}, weaning age (Age_W), the quantity of milk ($Milk$) in litres that is required for a piglet to grow 1 kg of live weight, the megajoules of metabolisable energy (MJME) required to produce one litre of milk ($MEmilk$), the energy concentration of feed (Md_s), the dry matter proportion of feed for sows (Dm_s) and the price per tonne (fresh weight) of sow feed (F_S). All of the energy required by an extra piglet born alive was assumed to originate from mobilised fat, at an efficiency of use (Efm) of 0.85 .

Economic value of age at puberty

The economic value for age at puberty (EV_AP) is based on a one day increase in maintenance feed and operating costs for replacement gilts. The equation used to calculate these additional costs was:

$EV\_AP = C_{GO} + C_{GM}$ [11]

where C_{GO} are operating costs per gilt day^{-1} at the time of first mating and C_{GM} are the feed costs to sustain one extra day of maintenance feed energy requirements at time of first mating. The value of AU $2 ·gilt·day^{-1} for C_{GO} was based on an industry estimate, while C_{GM} was calculated as:

$C_{GM} = (Feed_{R+1day} - Feed_R) \cdot FUt_R$ [12]

where the energy requirements of a replacement in the base scenario ($Feed_R$) was 3985 MJME; the feed requirement for a replacement which takes one day longer to reach puberty ($Feed_{R+1day}$) was 4005 MJME and the cost of energy utilised by the replacements (FUt_R) was AU$0.026.

Economic value of mature weight of sows

Sow mature weight economic value (SMW) was divided into four economic value components. Sub-components for mature weight included the economic value for: extra capital investment required to accommodate the larger breeding sows (EV_SMW_C), sow cull value (EV_SMW_X), sow maintenance feed costs·parity^{-1} (EV_SMW_S), and the feed costs to rear heavier replacement gilts at age of first conception (EV_SMW_R).

Extra capital investment component

The economic value for the extra capital required to accommodate larger breeding sows (EV_SMW_C) was expressed per parity so the annual capital costs needed to be scaled back to the number of parities·year^{-1} (Par). Over the long term it was assumed the capital requirements for sows were proportional to sow mature weight to the power of an exponent (C) that takes a value between 0 and 1. This was included in:

$$EV\_SMW_C = \left(\frac{\partial a \cdot SMW^C}{\partial SMW} \right) \cdot Par^{-1} \quad [13]$$

where

$$a = \frac{K(i+d)}{SMW^C} \quad [14]$$

was treated as a constant and is the total capital value of the sow facility (K) which has been annualised and expressed per kilogram of sow mature weight (SMW) to the power C. The cost of capital was based on annualised rates of interest (*i*) and depreciation (*d*) on capital value.

Cull value component

The sub-trait for mature weight which takes into account the economic value for sow cull value (EV_SMW_X) assumed a change in sow mature weight leads to higher returns at slaughter. It was expressed only once at the end of the sows lifetime. However, the proportion of sows that do not receive higher returns (ρ_X) (because they die on farm and/or are condemned at slaughter and do not receive a higher cull value) need to be accounted for. This was shown by:

$$EV\_SMW_X = SMW \cdot (1-\rho_X) \cdot Dp_S \cdot P_S \quad [15]$$

where Dp_S is the dressing percentage expressed as sow carcass weight to slaughter weight and P_S is the cull sow price·kg carcass weight^{-1}.

Maintenance component

The economic value component which takes into account how a one-kilogram increase in sow mature weight affects maintenance feed costs·parity^{-1} (EV_SMW_S) (once per parity) was expressed as:

$$EV\_SMW_S = \left(NRG_{Base} - NRG_{Base+1kg} \right) \cdot FUt_S \quad [16]$$

where NRG_{Base} is the total energy requirements (MJME utilised) across all parities in the herd for the base sow mature weight, $NRG_{Base+1kg}$ is the total energy requirements (MJME utilised) across all parities in the herd for the base sow mature weight plus one kilogram, and FUt_S is the cost of feed energy utilised by sows in units of \$·MJME utilised^{-1}.

The NRG_{Base} (7618 MJME) was calculated as:

$$NRG_{BASE} = \sum_{n=1}^{10} nrg \cdot \rho S_n \text{ [17]}$$

where nrg is the energy requirement for one sow in a particular parity; ρS_n denotes the proportion of the sow herd in each of 10 possible parities. Whittemore (1998) equations were used to calculate energy requirements for each sow parity (nrg) based on their production and the appropriate equation parameters (Table 2). The value for NRG_{BASE+1} (7632 MJME) was calculated using the same equations, except that sow mature weight was increased by 1 kg.

Replacements component

The economic value for additional feed costs to rear replacement gilts for a 1 kilogram increase in mature weight (EV_SMW_R) was a trait for the replacement gilt. The cost of additional feed was calculated up until age at first conception of replacement gilts. The equation for this economic value was expressed as:

$$EV\_SMW_R = (Feed_{R+1kg} - Feed_R) \cdot FUt_R \text{ [18]}$$

where $Feed_R$ (3985 MJME) is the cumulated feed energy requirements for gilts from weaning until first conception with no change in sow mature weight, $Feed_{R+1kg}$ (4292 MJME) is the cumulated feed requirements for gilts from weaning until first conception with 1 kg heavier sow mature weight, and FUt_R is the feed price·MJME utilised^{-1} (\$0.026) for gilts.

Economic values for genes of the sow affecting growth of progeny

Two approaches were developed providing economic value for maternal genetic effects of the sow and economic value for weaning weight.

Maternal genetic effects on growth rate

This trait is a trait of the sow expressed once per parity. It is based on the economic value for lifetime growth rate (ADG) with feed conversion ratio (FCR) in the breeding objective. However, when treated as a trait of the sow expressed once per parity it will have different discounted genetic expressions to the trait ADG. •There is no need to account for dilution/reduction of feed costs through faster growth rate, as long as neither FCR nor feed intake have significant maternal genetic effects. The economic value for maternal genetic effects on growth rate (EV_DGM) was:

$$EV\_DGM = EV\_ADG_{FCR} \cdot aveNba \cdot S_W \cdot S_P$$

where EV_ADGF_{FCR} is the economic value of average daily gain when feed conversion ratio is in the breeding objective as outlined in section C of this report, $aveNBA$ is the number of piglets born alive per sow averaged across parities (11.01 piglets), S_W is the piglet survival from birth to weaning, S_P is the piglet survival from weaning to slaughter.

Weaning weight

The economic value for weaning weight was estimated using:

$$EV\_WWT = EV\_ADG_{FCR} \cdot aveNBA \cdot S_W \cdot S_P \cdot \mathrm{Re}\,g_{ADG} \quad [22]$$

where EV_ADGF_{FCR} is the economic value of average daily gain when feed conversion ratio is in the breeding objective, $aveNBA$ is the number of piglets born alive per sow averaged across parities (11.01 piglets), S_W is the piglet survival from birth to weaning, S_P is the piglet survival from weaning to slaughter, and $\mathrm{Re}\,g_{ADG}$ is the regression of lifetime average daily gain on maternal weaning weight.

The regression $\mathrm{Re}\,g_{ADG}$ is difficult to define, because it effectively represents the environmental relationship between heavier weight at weaning (due to sow maternal ability) and the subsequent performance of the piglet. A regression coefficient estimate that incorporates the direct genetic relationship between weaning weight and average daily gain would be inappropriate, because maternal sow effects are operating differently, effectively as an environmental shift. Further thinking is required on how to define this coefficient in the EV_WWT definition, and a custom data analysis may be required. In the interim, we might assume that a pig that is 1 kg heavier at weaning than average due to a positive maternal effect will reach finish weight Z days earlier than average. Thus, $\mathrm{Re}\,g_{ADG}$ was calculated as:

$$\mathrm{Re}\,g_{ADG} = \left(\frac{Wtp}{Age_P - Z}\right) - \left(\frac{Wtp}{Age_P}\right) \cdot 1000 \quad [23]$$

where Wtp is the slaughter live weight of ‘grower’ pigs (98 kg), Age_P is the age of grower pig at slaughter (152 days), is the number of days earlier (14 days) a pig can be slaughtered due to it having a favourable maternal environment which allowed it to achieve a 1 kg heavier live weight at weaning.

Discounted genetic expressions of maternal traits

In order to compare the economic importance of maternal traits and to provide a means of combining the component economic values for sow mature weight, discounted genetic expressions coefficients were derived so that all maternal economic values could be compared in units per replacement gilt, accounting for the average numbers of parities per replacement gilt and discounted so that the delay between expression of replacement gilt traits and end of sow life traits is accounted for. The discounted genetic expressions coefficient for replacement gilt traits (XM_R) took the value of one.

For traits expressed once per parity, the discounted genetic expressions coefficient was calculated as:

$$XM_F = \boldsymbol{\rho}\mathbf{A}'\mathbf{q} \cdot \left(\frac{1}{1+r}\right)^{\frac{Gl}{365}} \quad [24]$$

where $\boldsymbol{\rho}\mathbf{A}$ is a vector with the nth element being the probability of a gilt surviving until parity n, $\mathbf{q}$ is a vector with the nth element being a discount coefficient corresponding to the nth parity, r is the annual discount rate of 0.06, and Gl is average gestation length in days. For traits expressed at the end of the life of the sow, the relative expressions coefficient was calculated as:

$$XM_E = \boldsymbol{\rho}\mathbf{D}'\mathbf{q} \cdot \left(\frac{1}{1+r}\right)^{\frac{Gl+Age_W}{365}} \quad [25]$$

where $\boldsymbol{\rho}\mathbf{D}$ is a vector where the nth element gives the probability of a sow dying or being culled after weaning at the end of parity n and Age_W is the age of piglets at weaning. Elements of the vector $\mathbf{q}$ are computed as

$$q_n = \left(\frac{1}{1+r\dfrac{Pi}{365}}\right)^n \quad [26]$$

where Pi is the average interval in days between parities.

Results

Energy requirements of sows

Energy requirements for each sow parity group are included in Table D3. Maintenance energy requirements increased from the first parity (3291 MJME) through to the fifth parity with 4332 MJME sow parity^{-1}. Thereafter maintenance energy requirements remained constant. All parities had the same pregnancy energy requirements (184 MJME) while lactation energy requirements peaked in the third parity (2456 MJME) and remained at this level in the subsequent parities. Energy for weight gain was greatest in the first parity (2409 MJME) and decreased to under 300 MJME after the fifth parity.

Table D3: Energy requirements (MJME) and weight gain (kg) for sows in each parity

	Sow energy requirements parity^{-1}				
Parity	Maintenance	Pregnancy	Lactation	Weight gain (loss if –ve)	Total
1	3291	184	2171	2409	8055
2	3772	184	2417	1677	8050
3	4031	184	2456	961	7633
4	4214	184	2456	509	7363
5	4332	184	2456	262	7234
6+	4332	184	2456	132 to 0	7104 to 6972

Revenue per sow

The net returns which included weaned piglet sales after accounting for feed costs and piglet disposal costs (NR_n) were \$747·sow^{-1} for the first parity, \$832·sow^{-1} for the second parity and \$845·sow^{-1} for sows in the third or older parities. Salvage revenues (which took into account the value of culled sows less any costs of disposing of sows that die on the farm) are shown in Table D4.

Table D4: Base salvage revenue from each parity in the herd (Sal^{Base}) and base salvage value revenue from each parity in the herd with one percentage point greater survival ($Sal^{Base+1\%}$) for calculation of sow parity profitability.

Parity	Sal^{Base} in \$ parity^{-1}	$Sal^{Base+1\%}$ in \$ parity^{-1}
1	39.3	38.0
2	40.2	39.4
3	36.5	36.2
4	31.0	31.1
5	26.1	26.6
6	20.3	20.9
7	15.9	16.6
8	12.5	13.2
9	5.8	6.3
10	8.4	9.2
Total	236.1	237.5

Costs of piglets and sows

Total sow feed and piglet feed costs are included in Table D5 with the greatest costs being attributed to sow costs followed by piglet feed costs. Sow feed costs were highest in the first parity (AU$211) and declined below AU$191 by the fifth parity and older. For the purposes of estimating longevity economic value it is only the relative profits per parity required. Therefore relative piglet feed costs are shown in Table 5 whereby piglets from parity 1 sows had AU$7·sow higher feed costs and piglets from parity 2 sows had AU$5·sow higher feed costs relative to piglets from parity 3 sows, based on industry estimates.

Table D3: Parity costs used in the economic value calculation for pig longevity, excluding the cost of replacement gilts.

	Total feed costs for each sow	Total piglet feed costs	Total sow costs
Parity	$	$/sow	$/sow
1	211	7	218
2	211	5	216
3	200	0	200
4	193	0	193
5	190	0	190
6+	186-183	0	186-183

Profit per parity

Key parameters applicable to the estimation of the economic value of longevity are included in Table D6. For a one unit increase in survival between parities there was a 0.8 percentage point reduction in the replacement rate required for a steady state herd structure. This contributed to the AU$2.80 lower replacement costs per parity when survival increased. Average profit per parity increased from AU$645.80·parity^{-1} to AU$646.40·parity^{-1} when survival increased 1%. After taking away the fixed replacement cost from the average profit per parity the margin was AU$3.40 higher in the scenario with higher survival and each sow was estimated to live 0.14 parities longer.

Table D4: Change in average parity per sow for a unit increase in survival between parities

Parameter	Units	Scenario	
		Base survival	+1% survival into next parity
Replacement rate of sows	% of first parity	24.2%	23.4%
Average profit per parity	$·parity^{-1}	645.8	646.4
Replacement costs	$·parity^{-1}	84.7	81.9
Average margin over fixed costs per parity	$·parity^{-1}	561.1	564.5
Average parity per sow	parity·sow^{-1}	4.13	4.27

Economic values

Table D5 includes the economic values, discounted genetic expressions, industry weighting factors and subsequent economic weights for each maternal trait. The economic value for sow longevity (number of parities) was estimated to be $AU99.00·sow lifetime^{-1} which when multiplied by the 0.88 discounted genetic expression and 1.0 industry weighting factor produced an economic weight of $AU86.90

Survival of piglets at farrowing had an economic value of $AU27.05. With a discounted genetic expression of 3.68 the economic weight for farrowing survival was $AU99.67 per piglet per parity. An economic value of $AU404.44 was estimated for every piglet that survived per parity pre-weaning with an economic weight of $AU1490.06 using the same discounted genetic expression as farrowing survival.

The economic values for number of piglets born alive using a fixed number of piglets and a fixed number of sows were $AU31.39·parity^{-1} and $AU68.64·parity^{-1} respectively. When multiplied by the 3.68 discounted genetic expression and 0.5 industry weighting factor the sub-component economic weights for piglets born alive was $AU57.82 for a fixed number of piglets and $AU126.44 for a fixed number of sows. The sum of the two sub-component traits for number of piglets born alive was $AU184.27.

Age at puberty expressed once per replacement gilt had an economic value of -$AU2.51. The economic weight for age at puberty was -$AU2.41 when the economic value was multiplied by the 0.96 discounted genetic expressions.

Mature weight had four sub-trait economic values including mature weight for gilt energy (-$AU 0.40) expressed once per replacement gilt, while sow maintenance (-$AU 0.37), and capital costs to accommodate the larger breeding sow (-$AU 1.29) were expressed once per parity. The economic value for the cull sow component of mature weight was $AU 2.66. The sub-component economic weights for: mature weight for gilt energy was -$AU0.39; for sow maintenance was $AU1.35; for capital costs was -$AU4.76; and for cull value it was $AU2.33 to give an overall economic weight for mature weight of -$AU4.17.

A $AU3.14 economic weight for a one gram per day increase in daily gain (maternal) in piglets was estimated as the product of an economic value of $AU0.85, a discounted genetic expression of 3.68 and an industry weighting factor of 1.0.

The maternal weaning weight economic value was $AU100.52 which when multiplied by the discounted genetic expression (3.68) and the 1.0 industry weighting factor gave an economic weight of $AU370.32 for a 1 kg increase in piglet weaning weight.

Table D8 provides an indication of the relative contribution each trait makes to the overall selection index by weighting each trait by its genetic standard deviation. Terminal traits from section C of this report are also included in this table for comparison. Some traits were excluded from the relative contributions and are represented by a 'not applicable (N/A). This is because they were traits that were mutually exclusive to other traits. The weaning weight maternal trait for instance would not be used if the daily gain maternal trait was included in the breeding objective. Furthermore, the daily feed intake trait would not be included in the breeding objective if an economic weight for feed conversion ratio was present. By excluding the daily feed intake and weaning weight maternal traits from the breeding objective the greatest contributor to the overall maternal index was pre-weaning mortality (33.5%) followed by post weaning survival (19.3%), feed conversion ratio (10.7%) and the number of piglets born alive (8.3%). There were fewer traits in the terminal breeding objective and the greatest contributor to this index was the post weaning survival trait (47%). Thereafter, in diminishing order of contribution to the terminal index were the feed conversion ratio (26%), average daily gain (17%) and carcass P2 fat depth (11%) traits.

Conclusions

High economic values were identified for maternal traits. These traits are relatively straight forward to record and can be included in breeding objectives that will lead to more robust pigs without the need for development of complex new selection criteria.

The percentage emphasis was based on aggregate economic weight and genetic standard deviation of each trait. Results indicate a relative high importance of traits describing survival of piglets and the growing pig. However, genetic standard deviations for these traits are sparse and may vary between populations. Further work should focus on obtaining information about genetic parameters for traits describing survival of piglets and the growing pig.

Table D5: Components of aggregate economic weights for maternal traits taking into account economic values of unit trait changes per trait expression, discounted genetic expressions coefficients and industry weighting factors

Trait	Units	Economic value ($)	Discounted genetic expression	Industry weighting factor	Component economic weight ($)	Aggregated economic weight ($)
Longevity	parities	99.00	0.88	1		86.90
Piglet farrow survival	piglets per parity	27.05	3.68	1		99.67
Pre-weaning survival	piglets per parity	404.44	3.68	1		1490.06
Number of piglets born alive	piglets·parity^{-1}					184.27
fixed number of piglets		31.39	3.68	0.5	57.82	
fixed number of sows		68.64	3.68	0.5	126.44	
Gilt age at puberty	days	-2.51	0.96	1		-2.41
Mature weight overall	kg					-4.17
Sow mature weight gilt energy		-0.40	0.96	1	-0.39	
Sow mature weight sow maintenance		-0.37	3.68	1	-1.35	
Sow mature weight capital costs		-1.29	3.68	1	-4.76	
Sow mature weight cull value		2.66	0.88	1	2.33	
Average daily gain (maternal)	grams·day	0.85	3.68	1		3.14
Weaning weight (maternal)	kg·weaned weaned	100.52	3.68	1		370.32

Table 6: Percentage contributions of each trait to the overall maternal and terminal selection indices when weighted by the respective genetic standard deviation for each trait

Trait	Units	Maternal economic weight ($)	Terminal economic weight ($)	Genetic standard deviation	Maternal trait contribution %	Terminal trait contribution %
Longevity	per sow lifetime	86.90	0.00	0.70	4.6	N/A
Piglet farrow survival	piglets per parity	99.67	0.00	0.36	2.7	N/A
Pre-weaning survival	piglets per parity	1490.06	0.00	0.30	33.5	N/A
Number of piglets born alive	piglets per parity	184.27	0.00	0.60	8.3	N/A
Gilt age at puberty	days	-2.41	0.00	10.00	1.8	N/A
Mature weight overall	kg of mature live weight	-4.17	0.00	10.00	3.1	N/A
Daily gain maternal	grams per day	3.14	3.14	20.00	4.7	N/A
Weaning weight (maternal)	kg per pig weaned	370.32	370.32	0.30	N/A	N/A
Feed conversion ratio	kg feed:kg live weight gain	-950.99	-253.56	0.15	10.7	265
Daily feed intake	kg feed	-1282.87	-342.04	0.30	N/A	N/A
Average daily gain	grams per day	5.52	1.47	30.00	7.2	17
Post weaning survival	piglet survival per piglet weaned	6759.24	1802.17	0.04	20.2	47
Carcass P2 fat depth	mm P2 fat depth	-58.81	-15.68	1.00	4.6	11

Appendix Section D: Key performance and price assumptions used as the basis for the maternal pig economic value model in alphabetical order according to acronym

Acronym	Parameter	Units	Value
Age_P	Base finisher pig days of age when slaughtered	days	152
Age_W	Age of weaned pig	days	23
$aveNBA$	Average number of pigs born alive per litter weighted for parity	piglets	11.01
C_B	Disposal costs for dead or stillborn piglet	$\$\cdot piglet^{-1}$	2
C_{GO}	Daily operating costs for replacements (gilts) (excl. feed)	$\$\cdot gilt\cdot day^{-1}$	2
C_M	Cost of marketing and transport of finished pig (per slaughtered pig)	$\$\cdot pig^{-1}$	4
C_R	Cost of a replacement gilt	$\$\cdot gilt^{-1}$	350
C_{SF}	Average parity feed costs	$\$\cdot parity^{-1}$	102
C_{SO}	Annual operating costs per sow	$\$\cdot sow^{-1}\ pa^{-1}$	200
Cwt_P	Carcase weight finished pig	kg cwt	78.7
d	Depreciation rate	%	10%
Dm_S	Feed dry matter percentage for sows, as % of fresh weight	%	90%
Dp_S	Dressing percentage (culled sow live weight as carcass)	%	75%
Efm	Efficiency of energy use from mobilisation	$MJME\cdot l\ milk^{-1}$	0.85
F_S	Feed costs for sows per kg of fresh weight	$	0.28
FUt_P			
FUt_R	Feed costs for gilts per MJME utilised	$	0.03
FUt_S	Feed costs for sows per MJME utilised	$	0.03
Gl	Gestation length for sow	days	115
GrP	Live weight gain of piglet just prior to slaughter	$kg\cdot day^{-1}$	1.05
i	Inflation free interest rate	%	3%
K	Total capital value of sow facility per sow place	$	10000
Md_S	Energy density of dry matter consumed by sows	$MJME\cdot kg\ DM^{-1}$	12.5
$MEconc$	Daily energy concentration for products of conception MJME	MJME	1.6
$MEmilk$	Energy requirement to produce 1 litre of milk	MJME	7.7
$Milk$	Sow milk required for piglet to grow 1kg prior to weaning	litres	4
Par	Number of parities per year	parities	2.27
Pi	Average interval between parities	days	140
P_P	Price of finished pig carcase	$\$\cdot kg\ cwt^{-1}$	3.05
P_S	Value culled sow carcass weight	$\$\cdot kg\ cwt^{-1}$	1.50
SMW	Mature live weight of pig	kg	295
S_W	Piglet survival from birth to weaning	proportion	0.88
V_W	Parity 1 average value of piglet at weaning	$\$\cdot weaner^{-1}$	94.5

3. Application of Research

This Project has resulted in a user-friendly tool called PigEV, which can be used by producers and pig breeding companies to quantify the economic importance of traits.

Breeding companies require economic weights to set up breeding objectives. This tool enables them to construct company-specific breeding objectives. Further, breeding objectives may differ between different markets and production systems. The effects of these differences on economic values and economic weights can be evaluated using PigEV.

Producers may use PigEV to compare the economic implications of two alternative production systems. Economic values quantify the change in profitability resulting from a change in a trait by one unit independent from other traits in the economic index. Therefore, a comparison of scenarios may be achieved by setting up an economic index for an alternative scenario. This economic index quantifies the economic implications of a management or husbandry change by summing up the change in each trait multiplied by the economic value of each trait.

The list of traits is comprehensive and alternative approaches were presented for some traits that are relevant for larger versus smaller producers. In particular traits describing survival of piglets, growing pigs and sows as well as maternal genetic effects on growth and sow mature weight are important for the development of more sustainable production systems.

The approach is based on sub-models for individual traits which make potential extension or modifications of PigEV straight forward should they be required as further information becomes available.

Methodology was developed to evaluate economic importance of environmental sensitivity and batch variability. This part is more theoretical as new methodology had to be developed. Further information is required from industry to evaluate the new framework that will allow industry to account for the economic implications of reduced environmental sensitivity and lower batch variability.

Outputs to industry

The following paper shown in Appendix 1 has been presented to industry so far:

Hermesch, S., C. I. Ludemann, and P. R. Amer (2012). "PigEV - a new tool to derive economic values for pigs." In 2012 AGBU Pig Genetics Workshop Notes", edited by S. Hermesch and K. Dobos, pp45-52. Armidale: AGBU.

In addition, the application of PigEV to evaluate alternative husbandry practices has been presented to participants of the Pork CRC during the annual meeting in November 2012. A suggestion was made in regard to using a learning management tool for the adoption process.

4. Conclusions

The development of broader breeding objectives and selection indexes is now much more accessible to pig breeders and pig farmers in Australia through the development of a spreadsheet tool called PigEV.

A much broader set of economic values can now be used in pig breeding programs than the economic values that were available previously. Economic values are now available for survival and maternal traits that describe aspects of robustness.
Theoretical frameworks required to develop genetic evaluation systems for environmental sensitivity traits have been refined and developed.
A model which quantifies the impact of batch variability on finishing system profit is proposed and, with some further co-ordination with industry to appropriately parameterise the model, would provide an opportunity to further refine economic values of traits that have an impact on uniform performance within batches.

5. Limitations/Risks

The tool PigEV can be used by breeding companies and producers. Breeding companies and producers will need to take responsibility for the inputs and any alterations they make to the model. At least initially, it may make sense for these companies and producers to interact with the software developers before implementing any major changes to breeding and selection programs. The Pork CRC should provide guidance in regard to fostering the adoption process. Collaborative research is required between industry and researchers to quantify the economic implications of reduced environmental sensitivity and batch variability for specific situations. So far, limited information is available about factors that contribute to batch variability.

6. Recommendations

PigEV. The tool PigEV allows users to define breeding objectives in pigs using their own input parameters in regard to cost structures, performance and marketing information. Further this tool can be used to evaluate the economic consequences of alternative management practices. Therefore, it may be used by producers to evaluate the economic feasibility of introducing a new technology. Avenues to foster adoption of this industry tool should be explored.
Environmental sensitivity. The magnitude of economic values will depend on the difference between selection versus commercial environments as well as non-linearity of profit along the environmental trajectory. Further industry data are required to quantify the economic importance of environmental sensitivity for specific scenarios. Alternative concepts to derive economic values for measures of environmental sensitivity have been provided in this Project.
Batch variability. Batch variability in itself is not heritable and therefore not a breeding objective trait. Rather the costs of increased batch variability are economic value components for other traits associated with batch variability. For example, if progeny from gilts (or progeny from larger litters) contribute to larger batch variability, then the costs of increased batch variability would lead to a higher economic value for sow longevity (or litter size). Currently, this information is not available and further research should identify factors contributing to increased batch variability. The approach used by Jones et al. (2011) to identify group characteristics that affected the level of performance of pigs may be extended to identify factors that affect variation of performance within groups.

7. References

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Appendix 1: Output from Project

Hermesch, S., C. I. Ludemann, and P. R. Amer (2012). PigEV - a new tool to derive economic values for pigs." In 2012 AGBU Pig Genetics Workshop Notes, edited by Susanne Hermesch and Kathy Dobos, pp45-52. Armidale: AGBU, 2012.

PigEV – a new tool to derive economic values for pigs

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Greater flexibility to setup breeding objectives in pigs

The breeding objective defines the selection emphasis placed on individual traits based on the economic importance of each trait. In PIGBLUP, the $Index defines the breeding objective based on the profit function developed by Stewart et al. (1990). The profit function was based on two main equations quantifying a sow herd sub-objective (SHSO) and a growing-finishing sub-objective (GFSO). Information required in the PIGBLUP $Index module included economic inputs outlining payment details and cost structures, performance levels in key characteristics of pig production and marketing weighting as outlined by Long (1991) during an earlier AGBU Pig Genetics Workshop.

The number of traits considered in genetic evaluations has increased over time and the bio-economic model developed by de Vries (1989) was used by Cameron and Crump (1999) to derive economic weights for the main performance traits based on production and market parameters relevant for Australian conditions at the time. However, breeders require greater flexibility in the setup of company-specific breeding objectives for a wider range of traits. This need has now been met by the development of PigEV which is a tool that allows users to define breeding objectives in pigs using their own input parameters in regard to cost structures, performance and marketing information.

PigEV - concept

Bio-economic models are a common tool to derive economic values. However, often a large amount of time is invested in detailed definition of biological interactions and their associations with input and output prices, with minimal influence on the final breeding objective (Amer, 2006). Therefore, separate models for individual trait groups relevant for the growing pig and the sow were developed that capture only relevant biological interactions and their economic implications. Specific equations for individual traits can be readily modified if further refinements seem warranted.

PigEV is a spreadsheet with a number of worksheets, which capture all of the assumptions and calculations required to derive economic values for traits of the growing pig and the sow. PigEV generates a summary table of economic values as well as multiple formatted tables of intermediate calculations and assumptions. These can be readily pasted from the spreadsheet into reports and other documents as required. Inputs are divided into those that are required to customise the breeding objective to a particular situation or operation, versus those that either have minimal impact, or alternatively act as biological constants which are not expected to change over time, or across farms.

Economic values quantify the change in profit for a trait while keeping other traits in the breeding objective constant. PigEV includes sub-models for each trait of the growing pig and the sow that quantify profit both before and after changing each trait by one unit. Input parameters include production and price assumptions for growing pigs, sows, replacements and piglets as well as operational costs including costs of facilities, depreciation and discount rates. The general assumptions relevant for each trait of the growing pig and the sow are outlined below.

PigEV- traits of the growing pig

The main traits of the growing pig affecting profitability are feed conversion ratio or feed intake, growth rate, survival rate and carcase characteristics that affect the market value of pig carcases. The traits of the growing pig described below are direct traits of all growing pigs including those destined for slaughter and replacement gilts.

1. Accounting for feed costs of the growing pig

Feed costs until age at slaughter can be accounted for by considering feed conversion ratio (FCR) or feed intake (FI) in the breeding objective. The economic values for these traits assume that average daily gain, or age at slaughter, are part of the breeding objective when evaluating the economic value of FCR or FI. It is further assumed that feed eaten from birth to slaughter is measured in kg. The price of feed eaten by growing pigs must have units which correspond to the measure in the FCR or FI trait definition (e.g. kg dry feed or kg wet feed). This should be a weighted average price for feed over the entire life of the pig. Slaughter age is assumed to be the range across which FCR and FI apply.

The estimated breeding value is available for FCR or FI in the test period (FCR_T, FI_T). Therefore, FCR_T or FI_T need to be adjusted for the fact that they have a genetic relationship with FCR or FI through the lifetime of the pig. Adjustments are made using genetic regressions, based on the assumption that no trait other than FCR_T or FI_T has a predictive genetic correlation with FCR or FI other than indirectly via their correlations with FCR_T or FI_T. Note that this conceptual approach could be used to help determine the optimal time during the growth phase to test pigs for FCR or FI.

The economic value for FCR is derived from the changes in feed costs over the lifetime of a growing pig per unit change in FCR, which correspond to the price of feed eaten and live weight of the growing pig at slaughter.

The economic value for FI is based on the number of days until slaughter and price of feed eaten.

2. Computing of daily non-feed costs per pig from weaning to slaughter

Daily non-feed costs are used in economic values for average daily gain, weaning weight and post-weaning survival of growing pigs. It is assumed that all finishing costs excluding feed costs and grower pig price, plus a normal profit margin on finished pigs are all proportional to number of days from weaning to slaughter. Non-feed costs per day in the growing period from weaning to slaughter were derived from the revenue of the pig at slaughter minus marketing and feed costs, and the price of the weaner pig divided by the number of days of the growing period.

3. Economic value for average daily gain

Average daily gain is defined as lifetime average daily gain quantified in grams per day. The improvement in lifetime growth rate is used to translate extra weight for age into savings in days at the end of the finishing period. It is assumed that change in profit is linear for an improvement in growth rate during the finishing period.

The economic value for average daily gain differs depending on whether FCR or FI is part of the breeding objective. The economic value for FCR captures the reduction in feed costs due to higher average daily gain. This reduction in feed costs due to higher growth rate is not implicitly captured in the economic value for FI.

The breeding objective includes FCR. The economic value for average daily gain when FCR is part of the breeding objective is defined as the reduction in non-feed costs per pig due to savings in days until slaughter with higher growth rate.

The breeding objective includes FI. In comparison, the economic value for lifetime growth rate when FI is part of the breeding objective is higher because it accounts for both, the dilution of non-feed and reduction in feed costs with faster average daily gain.

4. Economic value for carcase fat depth

The economic value for carcase fat depth reflects the increase in returns per pig due to a lower proportion of pigs receiving a price penalty due to high fat depths. Conceptually it is possible to have a positive economic value for fat depth if a proportion of pigs receive a price penalty due to an extremely low fat depth. The proportion of pigs receiving a price penalty was computed as a function of the population mean and standard deviation of pigs. Therefore, changes in the mean as well as changes in the variability affect returns per pig (Hermesch, 2005).

PigEV – traits describing survival of pigs and sows

Survival of piglets, growing pig and sows are not only an important aspect of animal welfare but also affect profitability of pig enterprises. The traits considered include still born piglets, pre-weaning survival of piglets, post-weaning survival of growing pigs and sow longevity.

1. Economic value of farrowing survival

Farrowing survival is a trait of the sow expressed once per parity and defined as the proportion of live born piglets divided by the total number of piglets. The economic value of farrowing survival accounts for the opportunity cost of not having the piglet which is equal to the gestation cost of the sow associated with the stillborn piglet. In addition, the benefits of lower disposal costs of dead piglets are accounted for.

The value of the piglet itself cannot be counted because a sow with 14 piglets born alive and two piglets born dead would rank lower than a sow with 13 born alive and one piglet born dead. Both sows have 12 piglets born alive, and the value of a piglet itself is accounted for by the number of piglets born alive. The only extra costs associated with the extra dead piglet relate to feed requirements in gestation. Further, it is assumed that the lower pre-weaning survival and lighter weaning weight in the surviving piglets of the larger litter with two dead piglets are considered by including pre-weaning survival and average piglet weaning weight in the breeding objective.

2. Economic value of pre-weaning survival

The trait is defined as pre-weaning survival of piglets per piglet born, rather than the total count of piglets surviving until weaning from the litter. The proportion of surviving piglets until weaning is defined as a trait of the sow expressed once per parity. The economic value is derived from the value of an extra whole piglet surviving until weaning taking into account the costs savings due to the need to dispose of dead piglets. Most piglets die within the first few days after farrowing and average lactation feed costs for the additional surviving piglet can be ignored.

3. Economic value of post-weaning survival

Survival of the growing pig after weaning is defined as a binary trait of all growing pigs with values scored as 0 for pigs that died between weaning and slaughter and 1 for pigs that survived until slaughter. Piglets that died prior to weaning have a missing value. Two approaches were considered to derive economic values for post-weaning survival.

The cost saving approach assumes that a predictable death rate in the finishing system is anticipated and extra finisher pigs are purchased to make up for deaths. Thus, extra survival of growing pigs results in a savings in costs to purchase extra pigs. The economic value is based on the costs of the weaner pig, cumulative feed costs and non-feed costs from weaning until the average age of mortality and costs to dispose of a pig that dies post weaning.

The lost revenue approach assumes that a pig dying after weaning during the growing period results in lost revenue. Otherwise, the principle to derive economic values is the same as for the cost saving approach. The economic value is derived from the value of a pig at slaughter subtracting cumulative feed and non-feed costs from weaning until the average age of mortality and costs of disposing dead pigs.

4. Sow longevity

The economic value of longevity was defined as the marginal economic benefit of a sow achieving an extra parity during her lifetime. The trait is expressed on a per-sow lifetime basis, rather than a per parity basis. The economic value for a one-parity increase in sow longevity was estimated from the change in average profit per parity for a unit change in parities per sow when inter-parity survival of sows increased one percentage point. The calculation included a multiplication with the average number of parities per sow which ensures that the trait is expressed on a per sow lifetime basis.

The change in average profit per parity resulting from superior sow longevity is based on the cost of replacement gilts offset partly by average salvage returns from slaughter of cull sows and increased net returns per sow that arise through having an older sow herd on average (i.e. less lower performing young sows which wean less piglets in a herd with better survival), .

PigEV – traits of the sow

The main traits of the sow profitability are maternal genetic effect of average daily gain, number of piglets born alive, age at puberty and sow mature weight. All traits of the sow are expressed once per parity unless otherwise stated.

1. Economic value for the genes of the sow affecting lifetime average daily gain

The genes of sows affect the growth performance of their progeny and as such estimates of these genetic effects represent a trait of the sow. Two approaches were considered to derive economic values for traits quantifying the genetic effects of the sow on average daily gain of the growing pigs.

The maternal genetic effect of growth rate has the same economic value as growth rate when FCR is part of the breeding objective multiplied by the number of slaughter pigs per litter. There is no need to account for dilution of feed costs through faster growth rate, as neither FCR, nor FI have significant maternal genetic effects.

Weaning weight as a trait of the sow should only be fitted if maternal genetic effects of growth rate are not included in the breeding objective. The economic value is based on the change in growth rate resulting from a change in weaning weight of the sow multiplied by the economic value for growth rate, litter size at birth and survival until weaning and during the post-weaning growth period.

However, the change in growth rate of the progeny resulting from a change in weaning weight of sows is difficult to define, because it effectively represents the environmental relationship between heavier weight at weaning due to maternal ability and the subsequent performance of progeny. Therefore, a phenotypic regression coefficient that incorporates the direct genetic relationship between weaning weight and average daily gain would be inappropriate, because maternal sow effects are operating differently, effectively as an environmental shift. Further thinking is required on how to define the regression coefficient to obtain the economic value for weaning weight of the sow and a custom data analysis may be required.

2. Economic value for number of piglets born alive

For a sow operation the economic value for number of piglets born alive was derived using two different assumptions about the long-term constraint on the size of the farming operation. Firstly, the constraint of a fixed number of piglets generated from the sow operation was assumed and secondly, a fixed number of sows were assumed. Both traits were defined as being expressed once per parity.

Fixed number of piglets. The economic value for an increase of one extra piglet born alive assuming a fixed number of piglets was calculated using the ratio of total costs per sow per year divided by the number of piglets born alive per year. The costs per sow per year included annual operating costs, annual capital costs, average parity feed costs and costs to purchase a replacement breeding gilt. It was assumed that no adjustment for litter size would be made when estimating breeding values for pre-weaning survival. Therefore there was no need to account for the fact that there will be higher pre-weaning mortality with larger litters in this economic value.

Fixed number of sows in the long term. The economic value is based on the assumption that extra piglets are generated for sale as weaners with larger litter size. Further, a slight allowance was made for higher lactation feed requirements for sows.

3. Economic value for age at puberty

The economic value for age at puberty measured in days is based on a one-day increase in feed costs for maintenance and non-feed costs per day for replacement gilts. Age at puberty is a trait of the replacement gilt.

4. Economic value for sow mature weight

The economic value of a one-kilogram increase in sow mature weight was based on four sub traits including extra capital required to accommodate the larger breeding sows, the cull value of the sow, sow maintenance feed costs per parity and the feed costs to rear heavier replacement gilts at age of first conception.

Capital investment for housing heavier sows. The economic value for the extra capital required to accommodate larger breeding sows was expressed per parity. Over the long term it was assumed that the capital requirements for sows were proportional to sow mature weight to the power of an exponent that takes a value between 0 and 1. Annualised capital costs for sows are computed assuming a full capital value of the sow facility, an inflation-free annual interest rate and an annual depreciation rate.

Cull value of sows. The economic benefit from heavier sows results from a higher cull value at slaughter expressed by sows once at slaughter. The proportion of sows that die on farm or are condemned at slaughter needs to be taken into account. The revenue obtained for the proportion of sows sent to slaughter is derived from the weight of sows at slaughter, dressing percentage and price per kg weight of cull sows.

Feed maintenance costs per parity. The economic cost of a one-kilogram increase in sow mature weight due to higher feed costs for maintaining larger sows was derived per parity and was based on the increase in energy requirements across all parities in the herd multiplied by the cost of feed energy utilised by sows.

Feed costs to rear larger replacement gilts. The economic value for additional feed costs to rear replacement gilts for a one-kilogram increase in mature weight was a trait for the replacement gilt. The cost of additional feed was calculated up until age at first conception of replacement gilts. The equation for this economic value included the change in cumulative feed requirements for gilts from weaning until first conception with a change in sow mature weight and the price per kilogram of feed.

Discounted expressions

The model accounts for difference in timing and frequency of types of traits. For example, the genes of a sire line boar mated to maternal sows are expressed early in the progeny for traits expressed in the growing pig. In comparison the genes of a maternal line boar are expressed later as only a proportion of his daughters become replacements, which go on to express genes for a number of maternal traits during their lifetime encompassing multiple parities. Finally genes affecting sow longevity are expressed with a substantial delay once daughters had the chance to express differences in sow longevity.

Uses of PigEV

The tool provides greater flexibility for pig breeders to setup specific breeding objectives for pig breeding programs. The number of traits has been extended to include multiple traits describing survival of pigs during the growing period as well as sow longevity. Further, methodology has been outlined to consider the effects of the genes of the sows on growth rate of their progeny. The approach is based on developing sub-models for individual traits, which is beneficial for the modification and extension of models should it be required in the future. Research into new traits used in pig breeding is continuing and further extensions of breeding objectives are likely.

The tool can also be used to evaluate the economic outcomes of implementing other, non-genetic products. The economic benefits of a superior husbandry practice may be evaluated by multiplying the improvement in each trait with its economic value. The sum of these products will have to be compared with the additional cost of the new technology to quantify the overall change in profitability resulting from adopting an alternative husbandry practice.

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