EFECTIVENESS OF NATIONAL GENETIC IMPROVEMENT PROGRAMS - A COMPARISON OF CHALLENGES ACROSS INDUSTRIES

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SUMMARY

National improvement programs imply some industry investment in at least some components of effective breeding programs. While different industries face different challenges in terms of measurement costs, genetic evaluation, breeding program design, and management of breeding populations, there are increasing similarities of approach between the Australian dairy cattle, pig and meat sheep improvement programs. Genetic progress is increasing and becoming more reliable in each case, and there is increasingly effective cooperation between breeders, scientists, and funding agencies. These national programs have successfully blended public and private benefit. This aspect of national programs in Australia will require continually improving management as the success of these breeding programs further alters the structure of each seedstock market, and as genetic technology becomes more complex and demanding of greater inputs from trained personnel. Across-industry benchmarking of the effectiveness of industry improvement programs will be valuable for maximising the value of Australia's portfolio of livestock and plant industries.
Keywords: Genetic improvement, dairy cattle, pigs, meat sheep

INTRODUCTION

This paper is a companion to Garrick (1997), which assesses challenges to genetic improvement in some agricultural industries in New Zealand. Both papers draw on the outline presented by Clarke *et al.* (1992) in using a clear and well-accepted framework for describing the key elements of any improvement program. The current paper begins by discussing what is meant by the term "national improvement program" with examples of some different versions, then examines three Australian industries seeking to highlight progress in each, to identify particular local challenges, and to explore aspects that will require attention from the national perspective. Finally, we suggest some challenges for national programs that will be presented by new statistical and reproductive technologies, and briefly discuss the value of across-industry benchmarking.

WHAT IS A NATIONAL IMPROVEMENT PROGRAM?

Genetic improvement programs at the individual farm level are a well-understood process aimed at generating favourable genetic change in the animals or plants, usually with the aim of improving profit. In simple terms this process consists of three key decision areas: what to breed for (breeding objectives), which animals/plants to breed from (evaluation and selection), and how to mate the selected individuals (mating programs). What, if anything, changes as we adopt a "national" perspective, and hence what is meant by the term "national improvement program"?

Clearly, the major differences between a national perspective and that of the individual farm are:

- the national perspective will consider many decision-makers and the entire breeder-to-consumer chain,
- the national perspective will be less affected by cost of investment funds, short time horizon, local market vagaries, and risk of no (or negative) profit.

These differences have been summarised by Smith (1978) and can affect decision-making in all three core areas (breeding objectives, evaluation and selection, and mating programs). An additional difference is that national improvement programs have invariably enjoyed some form and amount of governmental support in response to various aspects of market failure, based on the premise that was quite valid until the introduction of BLUP, that genetic improvement programs are both very slow and quite risky, and on the fact that few individual firms could fund the necessary scientific/technical expertise and R&D programs. Responses to these are changing: firstly because attitudes to role of government are changing, and secondly because well-organised improvement programs using BLUP invariably generate proven high rates of genetic change, and these in turn stimulate more attention to optimising the entire program.

Allowing that management and funding of "national improvement programs" is changing and will likely change further, a simple definition of such programs is that they involve some collective investment from the whole industry and possibly taxpayers to meet costs, and there may be some attempt to redistribute profits, either directly through some form of dividend or indirectly through such means as regulated market access.

Brascamp (1994) identified two forms of national involvement in improvement from a simple international comparison of pig breeding programs. In one, national involvement is through collective ownership and decision-making in all three core areas (breeding objectives, evaluation and selection, and mating programs). Examples of this form are the Danish, Norwegian and Dutch Pig Herdbook systems.

In the second form, national investment supports evaluation programs independent of any breeding company or farm(s). Typically, these have been established initially in order to improve efficiency of the market for seedstock, by ensuring that commercial producers have reliable access to accurate evaluations of animals from a range of sources. In pigs, the French system is the best example of this; closer to home ADHIS, BREEDPLAN, and LAMBPLAN are all of this form (at least initially).

The important distinction is that in the second form of national program, community funds are initially less likely to be directly used in selection and mating design decisions. As will be discussed below, this distinction is becoming blurred in at least the dairy and meat sheep cases.

EFFECTIVENESS OF THREE NATIONAL IMPROVEMENT PROGRAMS

In this section, the development and effectiveness of improvement programs in three Australian livestock industries is examined: dairy cattle, pigs, and meat sheep. The framework for analysis is common, describing:

- the approach to development and application of breeding objectives,
- the management of databases and delivery of genetic evaluations,
- the management of mating structures/programs, including use of newer reproductive technologies,
- evidence for commercial impact via market penetration and genetic trends

Dairy cattle improvement in Australia. Over the last two decades dairy cattle improvement in Australia has moved from involving a series of state-based bull-testing programs and a breeding goal focused on volume to a single national evaluation system including a selection index incorporating milk components. Further, the Australian dairy industry has become a more active participant in international improvement, forming bull-testing alliances with overseas groups, rather than simply importing genetic material for local evaluation and multiplication.

Breeding objectives for the Australian herd, and in particular the value of customisation for individual farmers, are discussed by Bowman *et al.* (1996). In response to developments in understanding breeding objectives for Australian herds, national evaluations through the Australian Dairy Herd Improvement Scheme (ADHIS) now include Australian Selection Index (ASI) values, where:

$$ASI = (3 \times \text{Protein ABV}) + \text{Fat ABV} - (0.03 \times \text{Milk ABV})$$

ABV = Australian Breeding Value
Protein = kg of protein
Fat = kg of fat
Milk = litres of milk

Demand for customised indexes is serviced by the availability of the ***Selectabull*** package, which customises bull rankings according to individual farmer selection criteria. While traits other than production may be valued by individual farmers, and markets for milk vary, Bowman *et al.* (1996) showed that correlations amongst a range of possible indexes addressing these variations are very high.

Genetic evaluation for dairy cattle in Australia is managed by ADHIS, with two components:

- herd recording and pedigree databases: the first deriving from a number of herd recording agencies coordinated through ADHIS, and existing primarily to supply management information to farmers,
- data processing carried out by the Livestock Improvement Unit within Agriculture Victoria

ABVs are produced for production traits (milk, fat and protein), workability traits (milking speed, temperament, and likability), survival, a number of type traits, and calving ease. ABVs are currently produced for approximately 75,000 sires in 10 breeds, the majority being Holstein and Jersey, and they are based on herd recording data from approximately 1 million recorded cows.

Progeny testing of young bulls is central to dairy improvement programs. Australia has one major progeny testing program, organised by the Genetics Australia Co-operative, now testing nearly 200 new young Holstein bulls per year. In addition, semen is imported from North America, and more recently from New Zealand and some European countries. Statistics on semen source for the top 0.1% of Holstein bulls (on ASI) in the May 1996 evaluations show that half were bred by Genetics Australia, a small number more by Australian importers, and the remainder were imported North American bulls. Importers are also investing in embryo-transfer (ET) programs, so far to multiply high merit sires and dams, but organised use of ET and other reproductive technologies is a major R&D area for Genetics Australia (Harford, pers comm).

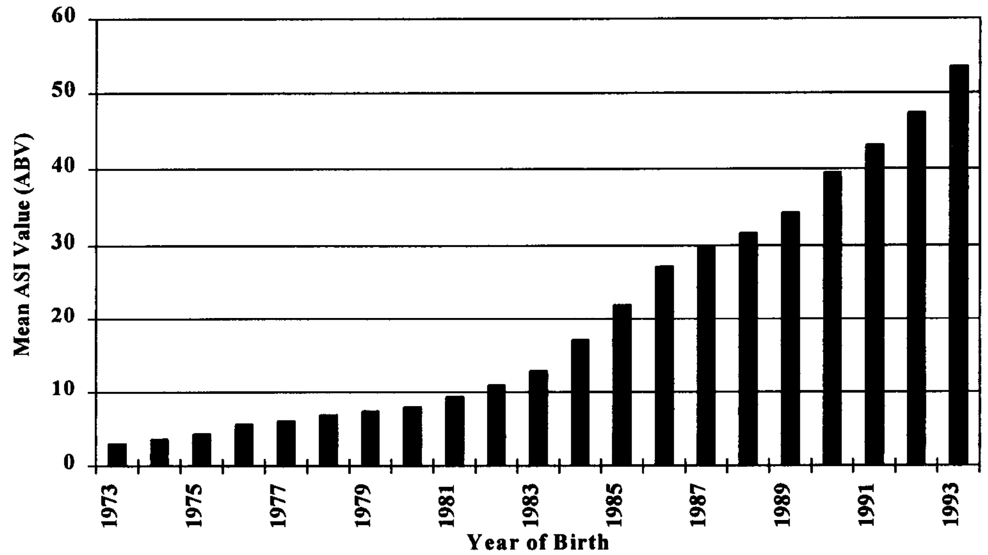

Figure 1. Genetic trend in Australian Selection Index (ASI) in Australian Holstein cows

Since the introduction of the ADHIS, numbers of heifers entering milking herds and being recorded has been fairly stable at 125,000-150,000 per year. The proportion of recorded cows that are bred by (generally) high merit AI sires has steadily increased to 90% for the 1993 drop. Total milking population is about 1 million cows, using about 250,000 replacements, so that a high proportion of cows are contributing data.

Genetic trends in the Australian recorded cow population are significantly positive and have increased since the introduction of BLUP in 1981 through ADHIS (Figure 1). While Figure 1 shows the trend in ASI for Holstein cows, a similar trend is evident in Jersey cows. In both breeds the difference in genetic merit between AI-bred and naturally-bred heifers is increasing, and is now at 30 ASI units for Holsteins and about 40 units in Jerseys. Since ADHIS began, the genetic trend for both breeds in AI-bred cows has averaged 3.75 ASI units per year (about 0.15 Index standard deviations per year).

Pig improvement in Australia. Pig breeding in Australia is conducted by two vertically integrated companies, one of which does not sell seedstock, and by a small number of small-medium operations which in most cases sell some seedstock (boars and gilts). Prior to the introduction of PigBLUP in the late 1980's, breeding operations used a variety of approaches to genetic evaluation (including none) centred on calculation of average daily gain (ADG, in g/day), and central test stations were provided by some state Departments of Agriculture.

Breeding objectives for pig breeding programs vary according to market (price effects of fat cover and meat quality), whether a crossing system is in place, and whether the program is supplying an integrated operation and/or is competing in the seedstock market. The broad components of all objectives are growth traits (eg. ADG), quality traits (eg. fat cover, drip loss, eye muscle size), reproductive traits (usually number born alive), and feed utilisation traits (eg. feed intake during a specific test period, feed conversion ratio) (Hermesch *et al.* 1995).

Recognising this diversity around a common basic direction, the PigBLUP package includes a module ($Index) which allows the user to customise an index for their particular operation. The $Index module produces index values in $/litter. Currently, these indexes are not reviewed or compared by any "industry" group.

In discussing genetic evaluation, we concentrate on users of PigBLUP (Long *et al.* 1992, Henzell, 1995). Databases for genetic evaluation are maintained by individual users of PigBLUP, who run the evaluations on their own micro-computers. Users range in herd size from <100 sows up to several thousand, so that different versions of PigBLUP are provided, depending on herd size. Evaluations are typically run weekly, as new cohorts of animals reach market weight, and selection decisions are made with the same frequency. Evaluations are all animal model based, and inbreeding analysis and genetic trend analysis are both provided.

Specific features of PigBLUP that target selection efficiency and mating program design are the Genetic Audit and Mate Allocation modules. The Mate allocation module optimises mate allocation for genetic merit and progeny inbreeding level, without at this stage addressing long-term inbreeding or dominance effects.
Thus PigBLUP has been developed to address breeding objective, genetic evaluation and mating program design issues through one self-contained suite of programs. Most of the decision-making is in the hands of the user, with support through training workshops, and formal and informal

support/consulting. An important feature of the pig industry that impacts on the design and delivery of PigBLUP is that to date there has been limited interest in across-herd evaluation, and that this is complicated by disease risks in transfer of genetic material.

Current estimates are that 30-40% of sows in breeding programs in Australia are in herds using PigBLUP (the largest single operation and seller of seedstock uses its own evaluation program and does not provide genetic information in seedstock advertising or sale). No combined industry estimate of genetic trend is possible, but an excellent example of the impact of PigBLUP is provided by genetic trends for ADG from one medium-herd size operation (Figure. 2).

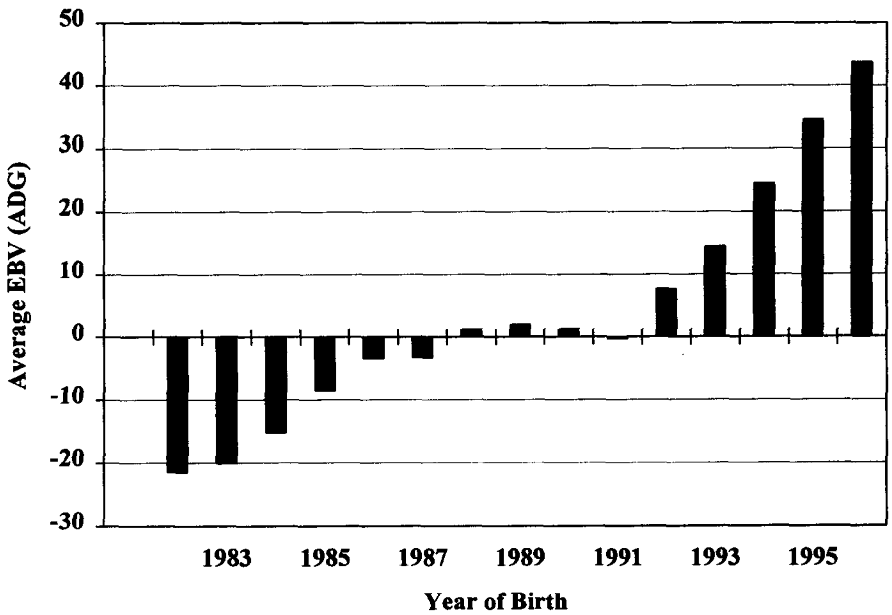

Figure 2. Genetic trend in Average Daily Gain (ADG, g/day) in a breeding program that uses PigBLUP.

(Similar trends are available for other traits, including $Index). PigBLUP was introduced to this program in 1993, and since then the annual rate of improvement has more than trebled from c. + 2.5 g/day in ADG to + 10 g/day, and is still increasing (the recent trend represents 0.2-0.25 genetic standard deviations per year).
An important feature of this graph is the clear evidence of favourable genetic trends prior to use of PigBLUP - pig breeders have been using performance records effectively for some time. The data show that these trends have increased, and that annual improvement has become more reliable -.

there is less variation around the trend line. Note also that the selection emphasis placed on ADG has almost certainly changed over the time period covered.

Overall, there is evidence of favourable genetic trends for PigBLUP. Benefit-cost analyses for PigBLUP have been highly favourable, even when previous favourable genetic trends are accounted for. Major issues for decision across the pig industry breeding sector seem to now be in the value (and method) of across-herd evaluation, and/or the value of industry-wide investigation of breeding objectives.

The pig industry has developed genetic improvement approaches and tools quite differently from the dairy industry. There is neither a formal national evaluation system nor a large cooperative breeding group (following Scandinavian practice). To date, uniformity exists only in the evaluation models and definitions of traits in PigBLUP and in the approach to index definition through $Index. At the same time, industry funding supports R&D for PigBLUP and pig improvement generally: this appears to be a workable response to the mix of public and private benefit accruing from genetic improvement in pigs in Australia. There are however, some potential strains within this system, which will be addressed in concluding remarks.

Meat-sheep improvement in Australia. Prior to the mid-1980's the sheep meat/lamb industry in Australia was effectively moribund, both economically and in terms of uptake of R&D and improvement generally. Since that time, genetic improvement has been encouraged and supported through LAMBPLAN, and there has been an integrated program of industry development covering production methods, trading systems, and improved marketing both domestically and overseas.

By contrast with the dairy and pig industries, the lamb industry has:

- very clear separation of ownership between the breeding and commercial production sectors
- a very high number of "breeding program managers" - over 2,000 registered studs with c. 500 having more than 100 breeding ewes
- distinct breeds recognised as terminal sire or crossing/dual-purpose

Breed identities, and formal breeding objectives studies (eg. Atkins 1987; Fogarty 1987) support separate breeding objectives for different breeds (or groups of breeds). LAMBPLAN has recognised this by providing different indexes for different breeds, with initial focus on growth phase traits and hence on terminal sire breeds. There has been only very limited provision of customised indexes to individual breeders or breeds, with most such activity being since the introduction of across-flock evaluations in 1995.

During the period 1989-1995, genetic evaluations within LAMBPLAN were predominantly within-flock, within-year using sire models. Since 1995, evaluations have moved to being animal model, across-year and across-flock, with across-breed analyses now being trialed for terminal sire breeds. This has necessitated development of a national pedigree and performance database, and steadily increasing activity in data networking. Data collection is now a joint effort of accredited LAMBPLAN Operators, who measure carcase traits on live animals and may assist in collection of weight, reproduction, wool and other traits, and the breeders themselves. More recently, protocols have been developed for collection and use of data on cross-bred progeny from commercial flocks.

Specific mating structures/programs have existed in the lamb industry in the form of nucleus breeding programs, either solely to increase genetic gain (Eppleston and Banks, 1997), or to jointly increase genetic gain and evaluate new measurement technology (Banks, 1997). With increasing impact of across-flock evaluations, use of reproductive technologies in cooperative mating programs has accelerated, both through nucleus:multiplier systems and through wide-scale progeny testing of teams of elite young sires. These seem likely to evolve towards organised use of embryo transfer (ET) technology.

Numbers tested through LAMBPLAN have grown steadily since 1989, to the point where c. 70% of young terminal sires and c. 25% of young maternal breed sires are being tested. Genetic trend across all users over that period is shown in Figure 3.

Note that this trend is across all LAMBPLAN users, in 13 breeds. The trend averages 0.95 Index points per year, or 0.1 Index standard deviations. There is some evidence of increasing trends in recent years, and some flocks/groups have exploited across-flock information and AI technology to average 6-8 index points per year (0.6-0.8 Index standard deviations per year).

A final point of comparison with the dairy and pig industries is that genetic change has acted as a catalyst to other changes in the lamb industry, rather than developing in conjunction with (or after) basic management and marketing improvements were in place. Thus the environment for genetic improvement in meat sheep is still improving, which together with increasing interest in use of across-flock (and breed) evaluations and advanced reproductive technologies, suggests that rates of genetic gain should increase steadily across the lamb industry.

COMMON DEVELOPMENTS AND CHALLENGES

Reviewing the dairy, pig and meat sheep improvement programs in Australia, it is clear that the introduction of national, BLUP-based systems has coincided with increases in genetic trends, with increases in performance recording, and with increasing reliability and directional control of genetic gain at both the individual and industry level. Further, there has been in each case effort in developing breeding objectives with some scope for customisation, and towards improvement of mating designs.

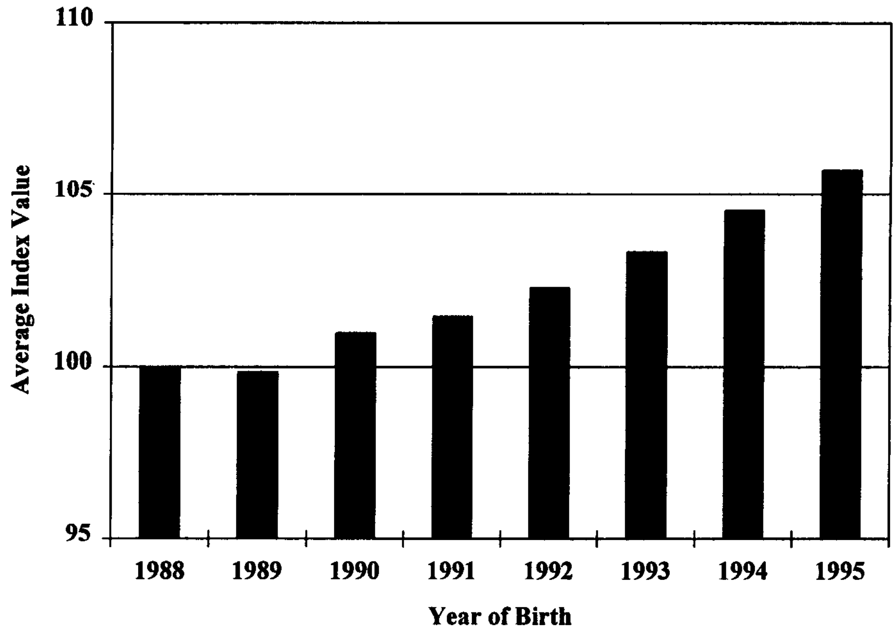

Figure 3. Genetic trend in Index value across all LAMBPLAN users.

In the pig industry this has largely been through independent use of a self-contained breeding decision package, while in dairy cattle and meat sheep it has been through more generic and public advisory work and consulting. In all cases however, a trend is apparent towards industry-supported consulting for breeding program management and the development of informal or formal alliances for continuing technical input:

- Genetics Australia (GA) runs the largest young bull-testing program in the Australian dairy industry, is developing formal alliances with Holland Genetics and Livestock Improvement (NZ), makes formal use of specialist genetic advice, and contributes to quality control of herd recording data - the latter being in the interests of both GA and ADHIS. This situation then is becoming more similar to the Danish/Norwegian/Dutch model of national pig programs, and generates a high mutual dependency between ADHIS and GA.
- one of the larger users of PigBLUP contributes both financial and data support to pig genetics R&D programs (Hermesch *et al.* 1995), while some smaller users are advocating and assisting across-herd evaluations.
- close (albeit at present informal) consulting links exist between LAMBPLAN and the 5 major breeding groups (as groups of breeders) within the lamb industry, and address issues of data

structure, selection criteria and mating programs. Thus LAMBPLAN began as a "French pig evaluation" form of national program, and is moving to add elements of the Danish/Norwegian/Dutch pig model.

So, while national programs may begin by providing only one specific component of the total portfolio of decision tools, there seems a trend towards increasing involvement of non-owners in overall management of genetic improvement programs even at the individual farm level.

There are good reasons for believing that this trend will continue as techniques for reproductive manipulation and for more precise description and utlitisation of genetic variation improve. New technologies such as *juvenile in vitro fertilization*, QTL detection, Marker Assisted Selection and mate selection to drive progressive breeding designs are on the horizon now. However, these could result in extension disasters arising from information complexity. Most probably, breeding program management will involve more and more direct involvement by trained personnel and with it a transfer of decision-making away from the individual breeder towards groups with control of economically viable numbers of breeding females. Given the small scale (by international standards) of breeding populations in all three species reviewed here, this seems likely to strengthen the "national" character of dairy, pig and meat sheep improvement in Australia.

In all three cases, distinguishing R&D from routine measurement, evaluation and mating is becoming more difficult, to the point where "R&D" is a "run-time" activity and incurs only a marginal cost on top of the normal selection and multiplication costs (Bichard, 1971). As this trend continues, it will require increasingly good understanding of the innovation process within each industry, and will probably force changes in the mechanisms and responsibilities of collecting and managing R&D funds.

Finally, this paper has used a common framework for summarising developments in these three Australian industries, and has used standard elements for that framework. This raises the issue of the value - to AAABG, to the funding agencies, and to the country as a whole - of developing a simple but standard benchmarking system for such national programs. This could address both costs and returns (fixed and variable dollars invested per breeding female, average rate of gain per breeding female, etc) as well as less tangible elements (availability and relevance of breeding objectives, target rates of gain, overheads due to R&D, etc). While in the short term there might be some embarrassments, the medium- to long-term benefits of maximising national returns to the total investment in genetic knowledge and improvement systems will mean maximising the value of the portfolio of alternative enterprises for land, water and feed use. This ultimately means achieving the highest rates of well-directed genetic improvement across all livestock and plant industries: for this a universal and objective benchmarking system is essential.

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