Private and Public Organisational Aspects/Roles in Animal Recording & Breeding

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Executive summary

- development of livestock recording, management and improvement systems has typically involved substantial public sector investment and activity in all countries. Such investment is under increasing pressure for a range of reasons, and so there is urgent need to a) clarify beneficial or essential public roles in such systems, and b) develop approaches to management of systems involving public and private roles for often numerous groups and/or individuals
- developing a framework for such analysis from traditional political ideologies will be of little benefit: a framework is suggested here which focuses on objective program design, management and evaluation/monitoring parameters
- this framework can be applied to any livestock recording, management and improvement system, with the proviso that initial analysis and ongoing evaluation will require recognition of the full range of ways in which livestock are involved in and contribute to local ecosystems and economies
- an analogous framework can be applied to the supporting knowledge systems, and doing so will help more effective utilisation of a critical resource, namely skilled practical animal management and improvement knowledge
- from the suggested framework analysis, a clearer assessment of which goods and services are most appropriately treated as public and/or private can be made, allowing for evolution of the balance of these as management and improvement proceed
- development of an international approach to livestock resource management based on the suggested framework is clearly a potential role for FAO, and one which would assist with improving the flow and management of international aid and investment funds to livestock resources, particularly those in low-to-medium production systems which are otherwise likely to be increasingly starved of financial and knowledge inputs.

1.0 Introduction

1.1 what are public and private policy issues?

This document outlines key policy issues that arise in the course of initiating, managing and evaluating, livestock recording programs, particularly for low-to-medium input production environments (LMIP). In so doing, it explicitly assumes a value at least partly independent analysis of such programs, both to enhance internal auditing of such programs by their managers, owners and other stakeholders, and to clarify and facilitate potential roles for organisations such as FAO in assisting development of optimal management of livestock improvement programs.

It is assumed that livestock recording systems are initiated at least partly for genetic improvement purposes, and so utilises various parameters of genetic improvement programs as an objective basis for evaluating investment in livestock recording. Note that recording may begin as part of a more general "industry improvement program" (in the Western sense) or agricultural development program, and this will certainly affect decision-making about the improvement program, but for the moment, I will concentrate on the genetic improvement component of livestock performance recording.

In the wider senses, recording of performance is of enormous value simply for management decision-making, both for the individual farmer and also for the industry or country as a whole. Indeed, it is for this reason that herd recording of dairy cows has been almost universally subsidised in Western countries until recently, and hence modified the investment conditions for genetic improvement significantly. I will return to this issue of support for, and cost of, information, later in this document.

Focussing on genetic improvement in this way is built on the belief that no livestock production system (or particular breed or stock) can survive in a world of limited resources without:

1. genetic improvement in some combination of production efficiency and possibly product quality, and
2. maintenance of the ultimate resource for such improvement, namely genetic variation.

Note that this applies to all stocks, whether managed in intensive high input systems or filling a scavenger role in village ecosystems.

It is further assumed that both livestock products and knowledge of methods of genetic improvement are traded commodities with markets for both, in the broadest sense of the term "market", and that public and private policy are made and evolve in market environments. This may not be either accepted by all players, or not be explicit, but this assumption will be used here because it provides a clear and widely understood basis for thinking about situations involving management of costs and benefits.

The title of this document could suggest some comparison between private and public planning, investment and management systems: such comparisons are widespread and typically corrupted by ideological positions. They can however be avoided for this document by adopting a very pragmatic approach to developing policy, one that attempts to be simple, clear, and to recognise that almost all human activities are affected by both individual and collective concerns. Animal genetic improvement is no different: what is important is to recognise how individual and collective behaviours, rules, patterns and so on affect definition and achievement of optimal management of genetic resources.

The expertise I draw upon to develop some important questions concerning public and private policy for livestock recording and improvement is in the development and management of genetic improvement programs within a number of livestock species in one small-medium economy, namely Australia. Within that number there are species in which management is as intensive and corporate as any in the world, ranging through to others in which exchange, ownership and planning are certainly pre-modern, if not feudal in many of their properties.

Clearly, other disciplines are relevant to the topic of this discussion paper, such as policy analysis, development economics, and comparative sociology. These approaches may be beneficial for later consideration of the topic of this paper, but I contend that an initial establishment of the key policy questions will simplify any such refinement of analysis.

To summarise, the purpose of this document is to outline a framework specifically aimed at clarifying public and private roles in development and management of livestock recording and improvement programs, and for auditing the performance of such programs.

1.2 What does "private" and "public" policy mean?

A simple basis for answering this question lies in a definition of "public goods", which take several forms:

1. goods which cannot be supplied to anybody without being available to all (or at least many), and their individual users can't be made to pay for them (or pay completely) - national defence, and law and order being examples;
2. goods which can be but are not usually charged for (for instance highways, bridges, weather forecasts, and public libraries);
3. goods which can be supplied in a market way but which many governments choose to supply to their citizens free or at below cost, such as education, health services, and public transport (Stretton and Orchard, 1994).

Thus public goods are those for which there is some amount and form of collective funding, and for which planning and so on are at least in principle developed by public organisations.

Importantly, this definition includes items that provide a framework or foundation for other activities, law and order, and the existence of regulations concerning commercial transactions and the form and amount foreign investment and ownership in any commodity, being prime examples. That these are public goods, and that community and private behaviour and life is impossible without their existence has long been recognised (Smith, 1776).

From this, public policy can be defined as: "The decision-making on planning, supporting, managing, evaluating, and developing programs that deliver public goods, and the implementing of those decisions".

By contrast, private policy seems appealingly to restrict this definition to private goods - goods whose value is partly or completely retained by the person or firm producing that good (in which sense a profit is a good). More importantly, access to the goods generated by a private investment program will be restricted as much as possible to those who fund and carry out the investment program, subject of course to public constraints such as taxation.

At this point, it should be noted that some authors strongly support the view that there is no product, service or good which cannot be managed, provided or created completely in the private sector, and indeed that private sector investment will invariably deliver better results for investments of almost any kind (including scientific research and development), with the possible exception of goods that are effectively community values, such as law and order, and an integrated system of exchange. The "soft" version of this position suggests that governments or the public sector may have a role in removing market distortions or corruptions, but the "hard" version holds that even these minimal public activities are unnecessary or more likely counter-productive (Kealey, 1996).

While this position may in fact be true, the more important point is that all current livestock improvement programs throughout the world rely on public investment for at least some of their resources, so that livestock recording and improvement is everywhere a mixed system: the balance within these systems may however be changing. This balance, and whether and how that balance should or is changing is addressed here.

In this context, the question underlying this document becomes more like "how to manage public and private investments in a mixed system to ensure optimal management of genetic resources?" This will include identifying those components of livestock recording and improvement programs more likely to attract private investment and those requiring public or collective involvement, and establishing the best possible basis for evaluating the performance of the program, whatever its balance of public and private involvement.

This question in the non-animal improvement specific sense, is at the heart of political debate (and sometimes conflict) throughout the world. As such, there is an enormous literature at all levels on the subject: it is far beyond the scope of this document to address that literature. It is hoped that by focussing on well-understood aspects of animal breeding theory and practice, combined with some simple but hopefully sound assessment of the flow of resources into and out of such programs, the need to explore and review this literature will be avoided.

Genetic improvement theory assumes a sound public good framework, so that conditions are favourable for investment in genetic improvement, and that the individuals or firms making the investments will seek to maximise some parameter(s) of the investment.

For investment in any technology or process, the following conditions must be met:

- potential investors must have a clear understanding of how to adopt and use the technology,
- they must have clear information about the technology and its alternatives,
- they must have clear signals about the likelihood of achieving improved (appropriate) returns for an improved product or process,
- they must have an adequate capital base from which to fund the investment.

We can now examine the technology of livestock recording and improvement in these terms, and begin by identifying the functional elements of the technology of livestock improvement.

2.0 The technology of livestock recording and improvement

2.1 Knowledge and its application

The foundation of all animal improvement programs is the identification of genetically superior individuals or groups of animals. This has 3 essential components:

- definition of “superior”
- assessment of performance for the traits that determine superiority
- some form of prediction of genetic superiority from the observed phenotypic superiority

Note that in very simple systems, the 2nd and 3rd steps may be the same. The second step establishes the need for animal identification and recording, while the first and third are where genetic knowledge is applied.

Having identified genetically superior animals, they will then be used preferentially as parents of future generations.

In this definition, identification, measurement and control of mating can be considered as "simple" components of the knowledge system that supports genetic improvement, while the definition of superiority and the prediction of genetic superiority are more complex components. Typically in Western, "scientific" improvement programs, these components rely on trained professional input.

How are these components applied in livestock improvement programs? Almost invariably, some stratification of the population into genetically active and "commercial" sectors occur, partly because humans rely on the fact that animal populations can produce surplus offspring and so not all animals are required to be parents (and hence there can be selection). This stratification is enhanced wherever:

a) the simple (identification and recording) and complex (definition and prediction) components involve real financial costs,
b) differences in level of animal performance result in differences in market value (whatever form that market may take).

Almost invariably, some animals, families, flocks, herds or other restricted groups become the most significant source of future genes for the population - the nucleus or stud. In some circumstances this separation may not result in any difference in genetic merit: for example in some village livestock populations there may be favoured animals or families, but there may be insufficient control over mating to stop other animals or families contributing genes.

Where there is any form of nucleus, the remainder of the population may simply be harvested for its products, or may be further segregated into multiplier and commercial sectors. (Such systems will be referred to here as "nucleus-multiplier-commercial" or NMC systems.) This higher degree of organisation implies some stability of human social structure over time.

Animal breeding theory shows that such multi-tier systems offer advantages in terms of economising on recording effort, essentially by utilising potentially high (usually) male reproduction rates to produce large numbers of commercial progeny from a small nucleus, or a small nucleus plus multiplier. In these terms, stratification of this type is effectively inevitable.

More importantly for the economics of livestock improvement, having an NMC structure can allow very high levels of investment in recording and selection in the nucleus, provided that these costs can be spread over a large enough number of commercial expressions, and provided that enough of the benefits of those commercial expressions is captured so that that the investment required for successful nucleus operation can be maintained.

This structure can be evaluated through a number of simple parameters:
- numbers of parents in the nucleus (males and females) and mating ratios, and hence effective population size Ne and inbreeding rate;
- genetic selection differentials achieved in the nucleus, and hence rates of genetic gain;
- cost of recording in the nucleus, and any recording costs applied elsewhere in the system;
- lag time between tiers of the structure, and hence the rate of dissemination of genetic improvement from the nucleus into the commercial population.

More simply, the key elements that determine overall system efficiency are:
- appropriateness of objectives in the nucleus sector;
- selection intensity, accuracy of evaluation and generation length, and hence rate of genetic gain in the nucleus;
- efficiency of transmission of genetic gain deriving in the nucleus - which depends essentially on migration rates between sectors, multiplication rates within the multiplier and commercial sectors, and generation lengths in the multiplier and commercial sectors.

Design considerations for such systems have been extensively developed and discussed (Bichard, 1971, James, 1977) including systems that incorporate upward migration of genetic material (termed open nucleus systems). Since these sample a larger population, they can generate higher rates of genetic gain and reduced inbreeding, although for practical application appropriate cost-benefit evaluation must include greater costs than for closed systems.

This document is not intended to review nucleus:NMC animal breeding and production systems, rather, to highlight that they are a model of some value for thinking about investment in livestock improvement.

Such systems:
- concentrate recording effort (cost) in as small a proportion of the total population as inbreeding and reproductive constraints allow;
- use hierarchical multiplication to spread these costs over as large a commercial population as possible;
- allow differentiation of the management system appropriate to the level of the system;
- where open nucleus, allow animals to be moved to the level of the system appropriate to the predicted level of genetic merit. This point is critical; NMC systems are based on placing animals within the overall hierarchical structure where the return from the effort invested in estimating their genetic merit will be maximised. Note that this does not mean estimating all animals' genetic merit with equal accuracy

(animals compete for places in either the next tier up, or to be parents of the next generation, according to the prior expectation of their likely genetic merit and their performance within their current cohort).

What relevance does this have for the management of livestock recording and improvement systems? The relevance lies in seeing a number of analogies between the estimation and dissemination of animal genetic merit and its subsequent commercial application to produce livestock products in livestock NMC systems, and the generation, dissemination and application of animal breeding knowledge. This knowledge is a critical "raw material" of the actual livestock system, and the argument here is that its management can be developed and evaluated using the principles of NMC systems.

2.2 The Nucleus, multiplier, commercial sector of animal breeding knowledge systems

Using this model, animal breeding and production systems are backed by a complementary knowledge system, with 3 key components:

Nucleus: generation of knowledge and knowledge tools for describing and manipulating genetic variation. This includes models for describing genetic variation (additive, non-additive, molecular etc), theory and tools for variance component estimation and prediction of genetic merit, approaches to developing breeding objectives, and theory and design of breeding programs for all combinations of achieving genetic gain and maintaining/managing genetic diversity.

The "core business" of this sector is knowledge generation.

Multiplier: customisation of nucleus-derived knowledge to specific industry situations. For example, in meat-sheep breeding in Australia, this customisation includes development of breeding objectives reflecting the costs and prices associated with sheep meat products/ traits, estimation of variance components for growth, carcase, wool, reproduction and fitness traits of sheep in Australian production systems, development of prediction tools and recommendations, and breeding program design at the breed and farm level.

The "core business" of this sector is knowledge customisation.

Commercial: application of the customised knowledge through performance recording systems, breeder and commercial producer training and advisory programs, and likely integration with industry improvement programs.

The "core business" of this sector is knowledge application.

The "commercial sector" of this knowledge structure is the primary point of intersection with animal industry value chains, which typically consist of breeding, production, processing and retailing sectors, with considerable within- and between-industry and country variation in most parameters (financial constraints and structures, differentiation and integration of sectors, etc) of these value chains.

The value of this conceptual framework for evaluating the joint management of the connected genetic knowledge and livestock industry systems lies in several aspects:

- familiarity - most animal breeders are familiar with the NMC model;
- simplicity - allowing individual knowledge and actual livestock activities to be accurately placed within their respective frameworks;
- suitability for analysis of performance - the framework provides an excellent basis for understanding why particular investments (of time, people, resources etc) are made at any point in the system, and most importantly for the proposed policy document, for understanding the likely risks and returns associated with such investments, either individually or more frequently as components of overall public and\or private investment programs.

Using this framework, several features of this knowledge system can be highlighted which are specifically relevant to the aims of the policy document:

2.3 Location

- The nucleus of animal breeding knowledge systems is a dispersed one, with elements in a small number of almost entirely European and North American universities. This is certainly true for quantitative genetics theory and most of the theory of its application, and also appears to be true for the growing sub-discipline of applying molecular genetics technologies to livestock breeding.
- The customisation level (the analog of the multiplier level) is also dispersed, this time in the two dimensions of space (countries, states within countries, and sometimes organisations within those areas) and species. This level is where management and technical support of national evaluation programs are "located" (although they may involve multiple physical sites).
- The commercialisation level is the stage of actually doing genetic evaluations, indexing, advising breeding program managers and farmers and so on, is located. Clearly, this level exists for each industry for which some form of evaluation system exists, and includes the day-to-day activity of those private organisations that conduct their own internal evaluation programs.
- Nucleus breeding programs in developing countries, often located on government research stations, represent a particular form of the commercialisation level of the knowledge NMC, with some activity at

the customisation level. Alternatively, the customisation activities may take place within universities within developing countries, or through collaborative projects with developed country universities or research institutes.

- Several authors have examined the components of national evaluation/ improvement systems (Brascamp, 1994; Garrick, 1997; Banks and Kinghorn, 1997) and identified one apparent distinction that is relevant to the present discussion. Particularly in the pig industry, 2 forms of organisation are evident: the vertically integrated company which typically employs its own geneticists whose duties may include definition of breeding objectives and parameter estimation, and the alternative where separate breeding organisations, groups or farms have products evaluated via industry- or government-funded evaluation systems. Here parameter estimation and breeding objective definition (customisation activities in the NMC model) are almost invariably carried out by independent research personnel, leaving breeding program personnel to respond to the results delivered by the evaluation system.

A critical point to highlight here is that the knowledge system nucleus is essentially restricted to Western universities and research institutes is although it is dispersed within that "location". Clearly, it important to examine what resources are required to maintain this nucleus, to ask whether its physical and cultural location cause any problems, and to examine the nature and effectiveness of its integration with the customisation and commercialisation levels of the knowledge NMC.

2.4 Supply of resources

Given the knowledge NMC, there are 3 broad types (levels) of human resource

- **Theoreticians** - those involved in improving methods of parameter estimation and breeding value prediction, and in breeding program design.
- **Applied livestock improvement scientists** - people with graduate and (increasingly) post-graduate training in quantitative genetics whose work focuses on applying theory to a particular species.
- **Breeding program managers and advisers** - often with less formal quantitative genetics training (although in Western countries this is increasingly not the case), and often with more interest in practical aspects of breeding programs and animal husbandry, and typically more "people-oriented".

These 3 categories correspond to the nucleus, customisation and commercialisation components of the NMC, and will be identified as the 3 primary knowledge system roles.

There are in addition, 3 other types of human resource that contribute to effective improvement programs, and which will be referred to as the 3 primary implementation system roles:

- **System managers** - where this role exists, it is typically supported in some way by industry or government funds, and aims to integrate the components of the entire knowledge NMC to achieve maximum return on industry/government funds. This is not a clearly defined or necessarily recognised role, and where individuals perform this role or something closely related, they may come from a range of backgrounds.
- **Field staff** - this role may in practice overlap with that of program managers and advisers, and will typically include much farm-level coordination, data collection, inputs to animal identification and breeding. Again, this role is performed by people from a broad range of backgrounds but typically with sound animal husbandry and people liaison skills.
- **Farmers** - in most multi-owner livestock NMC's, farmers do not perform the roles identified here to breeding program managers and advisers or field staff. This is perhaps an over-categorisation, as it is clear that where appropriate rewards and training systems exist, a proportion of livestock owners will invest in developing measurement and program management skills. This tendency is enhanced where the improvement program is supported by decision-making aids, either in the form of software tools or simple rules well-extended.

The primary knowledge and implementation system roles are:

Knowledge system roles	Implementation system roles
Theory development (nucleus)	System management
Applied livestock improvement science (customisation)	Field staff - data collection
Breeding program management and advising (commercialisation)	Farmers/livestock managers

The supply system for these human resources depends heavily on the existence of education systems that support some specialisation and which are internationally linked. As with the livestock NMC, the knowledge NMC acts to spread the costs of the nucleus over as large a number of commercial operations as possible, and as with the livestock NMC, provided that the evaluation system is appropriately integrated, students with high levels of talent should be moved to the most appropriate nucleus. This has been a part of international training in animal improvement for many years.

So, for the core animal improvement knowledge skills of variance component estimation and the prediction of genetic merit, an international dispersed nucleus has existed for many years. However, unlike an animal improvement NMC, selection of candidates for the nucleus usually takes place within the culture in which the customisation and commercialisation levels exist, and there is no obvious system evaluation (see later in this section).

International links exist at the customisation level, although they are not as tight as at the nucleus but strengthening through increasing use of the world-wide web and through congresses such as the World Congresses on Genetics Applied to Livestock Production.

At the commercialisation level, links have been weaker, although progressive breeders and farmers, program managers and advisers usually have greater awareness of international developments within at least their own industry than the "average" farmer, adviser or manager.

Different cultures will differ in their retention rates of graduates to various levels of the educational system for animal improvement knowledge, but it should be possible to estimate numbers of entrants to each stage to support the NMC for its 3 primary knowledge roles and 3 primary implementation roles.

Clearly (both from practical experience and from the analogy with the livestock NMC), numbers of individuals will be smallest for the nucleus, next smallest for the customisation level, and highest for the commercialisation level. Can we estimate numbers for each?

Animal improvement systems within Australia provide an example reported in table 1.

2.5 Commentary

- This simple and approximate analysis is specifically not intended to suggest any optimality (rates of genetic improvement vary considerably between and within these industries, even within this 1 country which has a history of investing considerable public funds in animal improvement R&D).
- This analysis suggests that within Australia, there are approximately 100 animal improvement professionals servicing 5 major industries with net farm-gate value of c. $10 bn Aus (or c. $8 bn US). In addition there are some 3 000 breeding program managers/owners. Assuming a 5% recruitment rate, 5 new improvement program professionals and c. 50-60 new breeding program managers/owners are likely per year.

The foregoing provides a model for understanding and characterisation of the human resources required for sustainable livestock improvement programs. It is worth briefly noting 3 key parameters of such systems, each of which is important in diagnosis of the performance of the system, and raise some key questions before moving on to address specific policy areas.

Table 1. Animal improvement systems in Australia.

Role	Beef cattle	Dairy cattle	Wool sheep	Meat sheep	Pigs
Number of people in:					
Knowledge system:					
Nucleus			⇐ ⇐ ⇐ 10-15 ⇒ ⇒ ⇒		
Customisation	5	2	2-3	1-2	1-2
	15-25	5	5-10	3-5	3-5
Commercialisation					
Implementation system:					
System management	-	1	1	1	0.5
Field staff	-	15	-	-	-
Breeders/farmers	1,5	3*	> 1 000	600-750	15
Industry size:					
# breeding females	500	1 000 000	2 000 000	250	40
% evaluated	30-40	90	10	75	30-40
Approx. net worth	$3 bn	$1.5 bn	$4 bn	$1 bn	$1.2 bn
Approximate rate of genetic gain (δ_I/yr)**	0.1-0.15	0.15	0.05	0.15-0.3	0.1-0.25

*Australia is serviced by 1 local breeding cooperative, 2 importers who do limited progeny testing, and by direct importation.

**these estimated genetic trends include importations in some cases, and cover only the genetically active/performance recorded sector of the total breeding population

Note

- these are all estimates of net person-years. Some individuals perform mixed roles within this classification. This reflects the fact that the classification of roles developed here draws on observation of the operation of a number of industries which show some variation in how this range of roles is provided.
- the distinction between wool- and meat-sheep is cultural, somewhat arbitrary, and is breaking down.
- the estimates of net worth are approximate, and are farm-gate values.

The 3 key parameters are the integration between tiers of the knowledge NMC, the typical source and expectations behind investments into such systems, and what might be the basis of public and private evaluation of livestock improvement systems. These will be briefly discussed, before completing this section with some comment on the evaluation of the livestock and knowledge NMCs, and important philosophical questions concerning the evolution of livestock improvement systems and the possible effects of this on public and private policy.

2.6 Integration

The most successful applications of NMC systems appear to be in intensive industries, where they have accelerated inherent trends to vertical integration through ownership (or franchising). This highlights the commercial importance of very tight integration through the NMC system. By analogy, investment into the knowledge NMC will be most effective where there is very rapid and effective communication of information up and down the NMC. BLUP-based evaluation systems seem to be highlighting and accelerating this integration by information/ communication at least in western countries.

This aspect of knowledge systems has been addressed elsewhere (Blum, 1991; Blum et al, 1990; Rogers et al, 1976) with some attempt made to identify essential elements of successful agricultural knowledge/extension systems (AKS). In simple terms these comprise research, extension and utilisation. Rogers et al (1976) suggested 8 elements critical to success of AKS':

1. a critical mass of new technology;
2. a research sub-system oriented to utilisation (the nucleus and customisation components in the model presented here);
3. a high degree of user control over the research utilisation process;
4. structural linkages amongst the research utilisation system's components;
5. a high degree of client contact by the linking sub-system;
6. a "spannable" social distance across each interface between components of the system;
7. evolution as a complete system; and
8. a high degree of control by the system over its environment.

Blum et al (1990) reviewed the AKS' of Israel and the Netherlands, and suggested 8 additional critical elements:

1. the existence of specific knowledge policy to which farmers have direct input;
2. deliberate coordination of the knowledge generation and exchange process/system;
3. involvement of all media (including farmers themselves) in knowledge exchange-this includes allowing or encouraging "up and down" flow of information (an open nucleus system in the terminology of the model proposed here);
4. a higher educational level of users enhances the effectiveness of agricultural knowledge exchange;
5. informal linkages (including social ones) are as important as the formal ones;
6. linkages are most effective in small or regional systems;
7. advisers should be professionals, actors in the system should be professionally independent;
8. cooperation and involvement by all actors enhance system success.

For multi-owner public systems, many of these elements are subject to public analysis and influence.

There is considerable overlap between the "research-extension-utilisation" model of Agricultural Knowledge Systems proposed by Rogers and others and the "NMC" model proposed here: the principle difference lies in classifying knowledge activities as nucleus (theory), customisation (fine-tuning the theory for a particular species in a particular production system and environment), and commercialisation (extension, utilisation and implementation). The outstanding feature of the work of Rogers and others in the present context is the focus on integrating factors and their importance. This is the direct analog of dissemination techniques in livestock NMC's: the lag between successive tiers in a NMC is the single most controllable cost for a livestock improvement program, and in principle minimising this lag is critical to profitability.

A specific issue concerning integration that has been explicitly studied in the livestock improvement context is the genetic correlation between the nucleus environment and that of lower tiers. In simple terms, if the genetic correlation between the expression of a trait in the nucleus environment and elsewhere is not 1, then genetic improvement generated in the nucleus yields less than equivalent improvement elsewhere and there is a danger a) that the balance of improvement between traits will be wrong, and b) that investment made in the nucleus will yield sub-optimal return.

In the animal breeding case, studies suggest that the critical level of this parameter is 0.8. Clearly, there is no obvious equivalent critical point for the knowledge NMC, although cultural (and other) mismatch between individuals/firms in different tiers has clearly been recognised as a problem in implementation of improved animal breeding methods before:

- via "scientists", field staff and farmers being unable to communicate with each other,
- via these groups being socially isolated from each other,
- via the effect of Westernisation of goals and lifestyles of students moving to western countries for higher graduate and post-graduate training.

As described here, this is as much a problem of inefficient "gene flow" between tiers as of different objectives and/or environments in the different tiers: the problems are both widespread and similarly reduce the return on investment in the knowledge system.

2.7 Source/ expectation of investments

Typically investment in the knowledge NMC has relied totally on the public sector for the nucleus, most often through universities. Investment into the multiplier (customisation) and commercialisation (application) sectors has usually relied more on industry specific funds - a specific form of public funding.

This package of investments then generates value which accrues through the value chain of the specific industry for which the performance recording/genetic evaluation system has been developed. Most often, profits from livestock NMC's (and hence from the supporting knowledge NMC's) accrue at or near the consumer end of the livestock value chains. This will be through lower (in real terms) prices for livestock products - benefiting consumers, and retained or increased market share for large processing and/or retailing operations.

This overall pattern of investment reflects several beliefs (and resulting policy views):
- that the knowledge NMC and its direct application through industry performance recording and genetic improvement programs is inherently uncertain, requires long time-frames to generate detectable cultural and financial change, and produces only small and risky returns to any individual participant (Smith, 1978);
- that knowledge itself is not a commodity whose generation and application can or should be satisfactorily modelled, analysed or managed in the ways applied to more standard commodities.

Thus investment in knowledge generation and customisation, and in many circumstances in its application, have been viewed as so unlikely to attract private investment that substantial public investments have been made over considerable periods of time.

This approach has begun to alter within the last 2 decades in Western economies for a number of reasons:
- so-called economic rationalist political ideologies have been predominant, effectively questioning most forms of public ownership and investment;
- as communities have become wealthier, more attention and hence more public money, has been directed towards policy issues such as environmental degradation and maintenance of health care systems;
- increasing globalisation has placed public and private improvement systems into more competitive markets, typically identifying superior foreign product(s), forcing greater and greater local attention into the application component of the knowledge NMC and heavier reliance on the global pools of knowledge nucleus and to some extent knowledge customisation talents.

A simple example of this is provided by the simultaneous global diffusion of both North American dairy cattle genetic material and of North American-trained animal breeding graduates and post-graduates.
These changes qre affesting the ability and propensity to invest of the traditional source of much of the funding for livestock improvement systems, and bringing into clearer focus the basic reasons for such public investment, which have typically included:
- food security concerns;

- preventative health policy, aimed at ensuring consistent supplies of cheap, local food products particularly those such as milk seen as having almost strategic public health importance;
- political views regarding access to improving technology for farmers (passive public support for farmers);
- deliberate alteration of the terms of access to such technology to maintain lifestyles for farmers, rural and countryside amenity value, and clear desire to counter rationalisation of farm numbers and resultant urban unemployment, various forms of active public support for farming.

Finally, as the effectiveness of improvement programs has improved, there has been a clear modification in public expectation of breeding programs. Many (western) consumers are somewhat averse to "high-tech agriculture", and this trend is mirrored by the growing attitude that breeding companies that earn substantial profits from sale of genetic material are hardly deserving of public support.

Further questions that will be briefly discussed here are:

- Given a satisfactory method or framework for evaluation, can we suggest both appropriate individuals/groups to assess system performance, and ways of "curing" the a system diagnosed as performing sub-optimally from this model?
- Does evolution of technology and of the "livestock improvement business" affect these recruitment rates?
- What characterises a mature livestock improvement business, and is public funding/support for such necessary or appropriate?

These will be discussed in this order, since evaluation is in this case simpler than diagnosis, has a clearer basis in theory, and establishes the basis for addressing both other questions identified here, and those addressed in the remainder of this document.

2.7.1 Analysis and Evaluation of a) The Livestock Improvement NMC

Evaluation of investment into a livestock NMC is straightforward and routine. The primary measure of success is rate of genetic gain, expressed either in index units (ideally currency units), or to facilitate comparison across species and industries, in units of index standard deviations.

Clearly, this component of the evaluation can use the simple expression for genetic gain:

$$\text{Rate of gain R (index units/yr)} = \frac{(\Sigma\, i_i \,.\, r_{IT}\,)\,.\;\sigma_I}{\Sigma\, l_i}$$

where: i=standardised selection intensity
rIT=correlation between Index and True Breeding Value
L=generation interval
sI=standard deviation of Index

Breeding program managers, advisers and research scientists typically investigate the "settings" of each of the components of this response formula and their joint optimisation in both theoretical studies and increasingly in year-to-year management of breeding programs under their control or influence.

Secondary evaluation measures several parameters affecting commercial returns and sustainability:

- Rate of expression in commercial animals. This is a compound parameter, comprising genetic lag between nucleus and other tiers in the livestock NMC (which in turn comprises time lag to commercial expressions and number of commercial expressions per recorded/evaluated animal), and market penetration in the breeding sector (usually the nucleus of the livestock NMC). The latter is typically expressed as the proportion of dams of sires undergoing evaluation, or the proportion of commercial sires (sires delivered/sold to the commercial sector) undergoing genetic evaluation.
- Numbers of new sires entering the population and their relatedness. These are the primary determinants of effective population size and hence of the rate of inbreeding. For populations either closed or unlikely to be open to importation, this affects capacity to maintain rates of improvement into the medium- and long-term.
- Rate of financial return to the nucleus sector. This does not directly affect company/community return from the improvement program, but may be a limiting factor, either through insufficient funds to support the costs of high-performing programs, and/or insufficient incentive for personnel involved in managing the program to pursue improvements.
- Appropriateness of breeding objectives is also critical to sustainability of the improvement program. It is not really however a diagnostic (except in the sense that one can check that the Index being applied is the one that maximises correlation between Index and True Breeding Value for the known objective). Rather, it requires that economic analysis of the industry be as rigorous and comprehensive as possible. Determining whether this is/has been the case is somewhat subjective. Attempts have been made to develop theory for establishing multiple lines with multiple objectives (Smith, 1978, Howarth and Goddard, 1997): these however are both incomplete and are based on using a diverse portfolio approach to counter uncertainty regarding the future, rather than "real-time" or a posteriori evaluation of objective(s) being applied.

  In this area then, as with the area of predicting growth of new core knowledge, we are left with no obvious way of dealing with uncertainty about the future. Perhaps the diverse portfolio approach warrants further investigation in both areas.

In addition, program cost parameters which should be considered include:

- cost of obtaining each performance record(s) for individual animals;

- cost of processing data to produce breeding value estimates (per estimate), this should include reporting costs;
- amount and cost of advisory input to both data collection and selection and mating decisions;
- total number of performance records and breeding value estimates per year;
- where possible, any public support for any of these costs should be identified.

A series of specific diagnoses can therefore be suggested:
- Rate of gain, in index standard deviation units, either as estimated (where BLUP methods are used) or predicted (from selection, accuracy and generation length parameters, where population is non-pedigreed).
- Design parameters: selection intensity, accuracy and generation length for each pathway (where pedigreed records are maintained in a database, each of these can be directly calculated).
- Rate of expression in commercial population: the diffusion rate or rate at which genes of new animals are expressed in the commercial population (where separate).
- Numbers of new sires entering nucleus: this is easy to determine whether the population is pedigreed or not, but where pedigree records are kept in a database, more precise measures of the rate of inbreeding can be calculated.
- Return to the nucleus: average prices for seedstock animals, and relationship between estimated merit and price received.
- Appropriateness of breeding objectives: the primary evaluation here can only be checking current (or recent) prices for all traits/units in the objective with those used in the actual breeding objective. Also, current population statistics should be used to check realised discounted expressions per sire (or breeding female, or whichever livestock unit is used) for cases where there are distinct cohorts of animals contributing to total discounted expressions, and these differ in their expressions of traits in the objective.
- Net investment in the program, and net return. In most circumstances these will be over a specific period of time in order that the flow of returns from individual selection decisions can be fully accounted. Where costs are broken down to publicly-, privately-, individually-and collectively-funded, both the net investment and the net returns can then be apportioned accordingly.

The suggested overall framework for the evaluation of livestock improvement programs including some diagnostic steps is reported in table 2.

Table 2. Framework for evaluation and diagnosis of Livestock Improvement Programs.

Parameter:	Measure
Rate of gain:	
primary measure:	Predicted/estimated gain
secondary measures	Selection intensities in nucleus Accuracy of selection in nucleus Generation length in nucleus
Appropriateness of breeding objectives:	
	Current/recent prices for traits in objective function
Sustainability (genetic sustainability):	
Inbreeding accumulation	Numbers of new sires per year/calculated rate of inbreeding
Measures of financial performance:	
Variable costs	Cost of recording for each trait Cost of processing per breeding value estimate Cost of advisory inputs, to recording Cost of advisory inputs, to selection and mating
Fixed costs	Net investment in design, parameter estimation, system management, and training
Net performance	Net investment, total fixed costs Net investment, total variable/recording and processing costs, and total advisory costs
Financial return - to nucleus	Real price trends for seedstock Relationship between seedstock estimated genetic merit and price
Financial return - to system	Discounted commercial expressions per nucleus animal (number) Price trends for commercial traits
Net return:	
	Net present value of gain over 5, 10, & 25 years Net present value of program over 5, 10 & 25 years

This technical and financial evaluation of livestock improvement programs is in principle straightforward, and there is no reason why any improvement program in any species could not be evaluated following this simple outline. Most features of the evaluation will be common, but with some scope for recognising aspects unique to particular species and industry structures.

In this latter context, it is appropriate to note that financial evaluation may well be more difficult in practise where it is hoped to compare public and private programs (and indeed, some private programs may resist any disclosure of program performance at all).

Differences and similarities across species will be highlighted by use of rate of gain in index standard deviation units as the primary technical evaluation. Clearly, average price for nucleus animals, net investment and net return will be heavily influenced by the value of the product(s) of the particular species and hence the value of individual animals.

2.7.2 Analysis and Evaluation of b) The Knowledge NMC

Similar analysis of investment into the knowledge NMC is not so straightforward, and even where carried out may be confused by competing and conflicting attitudes to valuing knowledge and varying reasons for public and private investments into such systems.

As with the technical and financial evaluation of public and private livestock improvement programs, it will often be difficult to obtain accurate information on investment in human resources within the private entities in the knowledge NMC. This really approaches the crux of the public:private policy issues regarding investment in livestock improvement: eventually public support for such programs must be justified, and to be justified it must have measurable livestock improvement results and quantifiable investment in human resources.

I have attempted a human resource assessment for a number of Australian livestock industries: this is however only the first step in managing that particular total investment portfolio. Allowing that there are in some cases no obvious analogies with the livestock NMC, we can nevertheless move through the main evaluation stages suggested above:

2.7.2.1 Rate of gain

There is no clear analogy here, whereas rate of genetic change can be quantified and valued (in both prediction and estimation phases), it is not so immediately obvious how rate of generation of new knowledge can be similarly handled. This is not to say that qualified observers cannot judge whether a particular method (for variance component estimation or breeding value prediction), result (for a particular parameter for a particular trait), or design innovation (in breeding program design) is really new and genuinely adds new knowledge. Indeed, this is the basis of use of citation indexes and (with almost certainly less value and accuracy) in assessment for career progression via simple paper counting. The main concern with use of citation indexes would be that appropriate stratification by subject was included, so that the rate of generation of new knowledge within a particular subject area could be assessed.

One aspect of the knowledge NMC which is simple to assess and which is analogous to the "Accuracy of selection" measure in the livestock NMC, is that it should be defined whether breeding value estimates (where used) are within-unit, within-year or across-unit and across-year. The capacity to allow across-unit comparisons significantly adds to the power and effectiveness of a livestock improvement program, but brings specific requirements of the recording and data processing systems.

More generally, there is not such a clear relationship between new knowledge about genetic improvement and genetic improvement itself, as there is for example between changing genetic merit and changing phenotypic merit. So, whereas high rates of change in estimated genetic merit translate readily into high rates of change in observed phenotypic merit, it has not been the case to date that rates of knowledge generation for animal improvement, and rates of animal improvement themself, have been particularly closely related. Indeed, one of the key issues for this paper is really how to improve that translation of knowledge into practical effect.

Part of the problem with including "rate of gain" in knowledge as a component of evaluation of the knowledge NMC is that livestock improvement has a substantial store of "knowledge capital" which has been accumulated through the 20th century, and in particular since World War II, almost as if there had been a protected nucleus operation, which has only really begun to be harvested since the 1960's.

A possible argument here is that in fact further investment in the knowledge nucleus (core knowledge and core knowledge workers) is not justified, since well-managed improvement programs are reliably predicted to continue improving for the indefinite future, and that sufficient knowledge and software tools exist for the customisation process to be successfully applied to any species of livestock.

The other problem is that whereas genetic theory provides means to estimate duration of genetic progress, and we can confidently expect improvement to continue in most species for at least several decades, we have no corresponding theory for the generation of new knowledge. It should be stressed that this applies more specifically to the knowledge nucleus areas of study: in customisation it is essentially easy to specify how much effort (money and time) will be required to obtain what number of genetic parameter estimates and breeding objective definitions, and in application, relatively little new knowledge is ever required.

A clear distinction can therefore be drawn for evaluation purposes between:

- "harvesting" of existing knowledge, which is fairly simply evaluated both via its results, rates of genetic gain in a particular population, and via measurement of activity such as parameter estimation, breeding objective definition and so on, and
- generation of genuinely new "core" or nucleus knowledge.

For the moment we will note the problems in this component of evaluation of knowledge NMC's, and move on to examine prospects for other aspects of that evaluation.

2.7.2.2 Numbers of new "knowledge workers" entering the population

As with actual animals, there are 2 components to this. Firstly, each individual can only do so much "knowledge work", with different limits in different tiers of the knowledge NMC. Advisers can only satisfactorily "service" a finite number of farmers in the course of a year, research scientists can only generate so many genetic parameters estimates, and so on. Thus, depending on the number of owners or animals, and of animals, it is possible to estimate required numbers of "application workers", and given normal rates of attrition, ideal numbers of new trainees per industry per year.

Secondly, the influx of new knowledge workers brings revitalisation, slightly (and occasionally radically) new approaches, and continuing capacity to train further new workers. This latter aspect is more akin to the inbreeding aspect of recruitment rates in livestock improvement programs. Typically, this is addressed by a combination of scholarships and/or subsidised training for junior workers, together with the incentives provided by whatever employment prospects exist within the knowledge NMC.

This evaluation should usually be straightforward, (numbers of students in various forms of agricultural and/or technical training can be determined, as can recruitment rates to public and private sector livestock improvement programs and organisations).

2.7.2.3 Rate of financial return to the nucleus

As with the evaluation rate of gain in the knowledge vs the livestock NMC, this is not straightforward for the knowledge NMC, and again this is based on difficulties with valuing knowledge. In this case, the specific problem is that different cultures vary in both their capacity to identify, and then their readiness to specifically reward, knowledge innovators. Again, this reflects the lack of a simple and reliable theory of knowledge generation and valuation (by contrast with the existence of such theory for generating and valuing genetic change).

Even in cultures where good/great teaching has been valued, this has not necessarily meant rewarding the source of new knowledge, but rather its transmission, and further it is certainly the case that social and financial rewards even for teaching have diminished in many countries during the last 3-5 decades.

The problem here is however not one of evaluation: it is straightforward to identify returns to personnel working in the knowledge nucleus. It is harder to know whether these rewards are in fact sufficient or appropriate to ensure satisfactory rates of generation of core knowledge into the future, again because of the absence of any satisfactory theory of knowledge and growth.

Clearly there are problems with direct evaluation of the performance of the knowledge NMC itself. Does this present serious problems? The main reason for wanting such evaluation is to improve diagnosis and cure of under-performing livestock improvement systems. Given that a simple approach to their diagnosis has been presented, clearly much can be done before detailed objective analysis of the knowledge NMC becomes necessary, and even then it is relatively straightforward to assess human resource investment and to identify shortcomings in the customisation and application sectors of the knowledge NMC.

Extending this point, a comprehensive survey of the performance of livestock recording and improvement programs as outlined here will very rapidly identify those sectors where limited or ineffective access to the knowledge nucleus is hindering performance.

3.0 The technology of livestock recording and improvement

3.1 Summary and recommendations

- The first step in optimising public and private investment in recording and improvement systems is sensible evaluation of the amount, type and location, and result(s) of such investment.
- A simple framework for evaluation of livestock improvement programs across species has been suggested. FAO should establish a database for those programs with which it is involved, recording the parameters outlined here for both the livestock system, and as far as possible, the supporting knowledge system.
- Wherever possible, other systems/programs should be included in the database, which will both expand the bases of comparison and highlight any systematic differences (both qualitative and quantitative) between the different classes of program: FAO-involved, independent but with governmental involvement, independent but with industry involvement, and private.
- Performance of the livestock system is the primary measure of performance of the supporting knowledge system, and if the approach suggested here is followed, it will be straightforward to identify deficiencies in the knowledge system that are limiting performance of the livestock program.

The remainder of this document links this simple and essentially technical "functional analysis and evaluation framework" with a series of policy issues.

This approach has been taken in the view that policy decisions for livestock recording and improvement must be grounded in objective evaluation of those programs first, and choices about access, funding, support and so on, second. This is clearly a value judgement, and one that is prevalent within the community of western animal breeding scientists in particular, and particularly recently, western economists and other technocrats. I believe it is relevant to discussion of animal improvement systems fundamentally because such systems have always relied on valuing of animals and animal products by individuals and communities. Such valuing assumes differences in performance, and more importantly differences in the results of different selection decisions: differences that individuals and groups attempt to predict and capture.

Accordingly, an underlying market-based model is acceptable: the public and private issues arising are not those concerning effectiveness of the recording and improvement system itself so much as those concerning access to the system, funding for it, and access to/distribution of its products and profits.

4.0 Specific policy issues arising from the functional analysis and evaluation framework

4.1 What are the consequences of focussing on "Low-to-medium input production environments (LMIP's)?

It can be initially tempting to ascribe to livestock production systems in LMIPs characteristics that inhibit analysis using a simple framework as described here:

- animals may (appear) not to be traded in any cash economy and so are hard to value;
- surpluses of livestock or livestock products may be rare or intermittent;
- ownership may be highly communal;
- animals may function as part of a waste-management or recycling system rather than a surplus generation and harvesting system, and so on.

These and other characteristics that apparently differentiate such systems from those in which livestock improvement technology has been successfully applied are however analogous to the features of ecosystems different from those first studied by western ecologists: the nodes and channels of energy flow may be quite different in say a tropical rainforest from those of a temperate grassland. These differences may lead to the initial conclusion that no common principles apply: there is still however energy input, flux, dissipation and so on, and the underlying principles of analysis that support analysis and understanding of an ecosystem will still be valid.

In the same way, while the specific features of recording and improvement in an LMIP may be unique, the underlying principles will still include:
- differences in performance with some genetic component and differing value for some decision-maker(s);
- selection amongst the animals and resulting manipulation of mating and reproduction;
- some cultural process for supporting this human activity and ensuring that it continues.

If this view is accepted, then the main challenge in developing and evaluating policy for recording and improvement systems in LMIPs lies in careful and accurate analysis of the system, rather than in the simplistic response that the fact of operating in an LMIP means that broad-target, western-style systems will be necessary and must be funded and managed from outside the LMIP and the people who live within it.

Another aspect for consideration here is whether agency response to an LMIP (and agency may be either local government and/or foreign aid agency) is to encourage/support modification of the physical environment. This may change the underlying conditions of the livestock system, and mean that the basis for valuing livestock changes. Such modification of the environment is of course often one of the results of successful management of such systems: as farmers accumulate some form of profit from their livestock or other activities, some of that profit may be invested in improving feed supplies, disease control or whatever. This invariably changes the demands placed on the livestock and hence both the breeding objectives and the favoured breeds/strains or individual animals.

This type of change has already meant the disappearance or decline of many breeds within western agriculture and there is no reason to suppose any different result elsewhere. This raises in itself a fundamental policy issue: is the current low-to-medium input accepted as inevitable or will some way be sought of modifying the bio-economic ecosystem? If the latter, then should anyone be concerned with the fate of breeds/strains suited to the existing system? Further, is there a real likelihood that humans will tend to leave the LMIP system if they have any choice?

There is a high likelihood that this issue will become more and more relevant in the next few decades as food supply and security become more and more central to world trade and political debate. It seems highly likely that there will be more and more international investment in food production, and this will certainly not be restricted to working within the constraints that apply to local farmers and/or traditional farming systems.

Given that in this sense LMIP livestock systems are often integral to traditional cultural systems, the real issue for public policy debate here (both nationally and internationally) may rapidly become "whether and how traditional lifestyles should be preserved?"

Thus the suggested answer to this first question is a two-fold “no”:
• the same framework for analysis and evaluation of livestock recording and improvement can be used for LMIPs and for higher input systems; what may change are the specifics of how valuing is done, how selection decisions are supported, and how results are distributed (for example), but rates of gain and rates of inbreeding can still be estimated;
• answering “yes” would imply that inputs cannot and/or will not change, but while the farmers/people within an LMIP livestock system may be unable to modify the inputs there is now very little chance that the system will remain isolated from the rest of the world. While internal profits may not be sufficient to modify the system, external ones almost certainly will. This prospect raises far wider social questions than those which simply focus on livestock production.

The approach taken to answering this question quite simply broadens the arena for the public policy question to something like “should governments attempt to change the conditions of access to markets for individuals\groups where most players are relatively poor (in capital)”. Typically, the answer has been “yes”, and various forms of assistance have been developed, which have been widely applied within western agricultural systems over a long period of time. Incidentally, state funding of research stations and cooperative/nucleus breeding programs should be recognised as methods of changing the conditions of access to both knowledge and seedstock markets.

The difficulty that arises sooner or later if this approach is taken is to decide the point at which the assisted group is no longer sufficiently relatively poor. A further difficulty often highlighted by supporters of less interventionist approaches, is that such modification of market access does not seem to help individuals or companies survive or compete when conditions change: for these individuals or groups to remain involved requires a new set of modifications to market access conditions.

4.2 What are the consequences of different forms of ownership: public (through government), cooperative and private on investment in livestock production systems?

I suggest that the answer here is again two-fold:
• different forms of ownership have no effect on the applicability of the functional analysis and evaluation framework outlined here;
• different forms of ownership may however have real and important effects on propensity to invest in innovation, marketing and other aspects of managing the livestock system, and will clearly almost certainly have different effects on the distribution of any profits.

The most obvious effect of various forms of public/collective involvement in livestock production (indeed, in agricultural production) has been to maintain more individuals physically involved in the production process itself than where private ownership has operated. This has not necessarily meant higher or lower rates of genetic gain or better or worse preservation of genetic material.

In some cases it is argued that this result is in itself desirable (by for instance reducing urban unemployment rates). Becoming too deeply involved in this debate is beyond the scope of this document, but two simple observations can be made:

- the analysis and evaluation framework suggested here encourages a focus on the primary livestock (and in particular, genetic) aspects; rate of gain in commercial traits and preservation of the capacity to make such gain and to respond to changing circumstances. If public policy decisions are made which affect these adversely but maintain employment/involvement, then the capacity to support employment within the livestock system will suffer. To avoid this, decision-making will often become as centralised as in any private conglomerate, with almost as damaging a set of social consequences;
- livestock recording and improvement are only unrelated to innovation in a world of constant environment and population; normally they inevitably mean change in the circumstances of the humans involved, and this typically means reduced direct employment.

In general then, the functional analysis and evaluation of livestock systems are not changed by their form of ownership. What is likely to change is the degree of management complexity as more owners' interests must be explicitly addressed, and the means and availability of investment funds, particularly to support innovations in areas such as new measurement technologies (although there is no strong evidence suggesting that either private companies or public institutions are necessarily more or less likely to make such investments successfully).

This conclusion is probably also true for different political systems. As with the suggested effects of different forms of ownership, the basic functional analysis is not changed whether capitalist or socialist systems are being considered: what certainly may change is the environment for investment, the skill etc with which this investment is carried out and managed, and the way in which returns from investment are handled. Genetic improvement has been successfully implemented in a range of political cultures but has been most clearly documented and has accelerated most rapidly since the introduction of BLUP systems in countries and industries with access to large breeding populations and reasonably effective markets for seedstock/genetic products. Importantly, the effectiveness of such markets has often been enhanced by public investment in independent genetic evaluation systems, although some authors have suggested that such independence is only necessary to support genetic improvement until a significant proportion of production is managed within vertical and horizantal alliances.

4.3 Does the purpose of the Recording/ Breeding system affect the public and private organisational roles - genetic improvement or genetic conservation?

There has been a tendency for greater public investment to be necessary for programs aimed at genetic resource conservation. In general this reflects either lack of private sector interest (ownership, development etc) in breeds no longer viewed as commercially competitive, or more general lack of development activity in a livestock sector which particularly when coupled with increasing pressure of land and feed resources for livestock production inevitably fragments and reduces livestock breeding populations.

These problems clearly underpin the global livestock genetic diversity program, the question here is more specific. Given that private sector involvement in livestock populations will require return on investment and usually aims to maximise that in the short to medium term, then we can expect less private investment in programs solely aimed at preservation/conservation.

This highlights the question of purpose for such programs, and supports the pragmatic position in which populations are selected for conservation effort that are already locally economically important, or have sufficient numbers such that appropriate genetic improvement will make increasingly attractive for private involvement in management and development.

In this view, public involvement can aim to "save" endangered populations, establish the basis for their continuing improvement, and aim for increasing private involvement (farmer, cooperative, company) in the medium to long term.

Successful management of such populations will then depend on exactly the same performance parameters as any other:
- the rate of genetic improvement in the breeding objective, properly defined;
- the management of inbreeding and of access to new sources of genetic variation.

In such cases, public roles become clearer:
- identification of candidate stocks;
- assessing the existing genetic structure so that initial sampling can be optimised;
- initiating some form of recording in order to support selection;
- and having some input to the mating program such that inbreeding is minimised.

Once this has been implemented, the challenge remaining is to decide at what point, and how rapidly to reduce public support for and involvement in the program. This is addressed in a later question. The conclusion here is that all livestock management and improvement programs should be seen as having "conservation" and "improvement" components, that simple measures are available with which to assess performance for both, and that as such programs develop the likely involvement required from the public sector will change. In short, the distinction between "conservation" and "improvement" programs is blurred and the balance of the two aspects will change as a livestock population management program proceeds.

4.4 Should performance recording and livestock improvement programs have a clearly stated objective?

Framed this way, there can only be 1 answer to this question. Given the time, resources and modification of livestock populations that can be expected from all sound recording and improvement programs, it is essential to have both objectives and performance targets objectively defined.

Having objectives and targets clearly defined and assessed maximises the chance that successful programs will make the transition to economic self-sufficiency, and that under-performing programs will be rapidly diagnosed and targeted for intervention.

From the functional analysis that is used in this document, the objectives should include:

- clear definition of the breeding objective for the population;
- definition of initial set of traits for recording;
- definition of models and methods for initiation of reporting for management and genetic evaluation;
- definition of targets for numbers of recorded animals, numbers of selected animals, and hence targets for rates of genetic improvement and for maintenance/increase in effective population size (and hence stabilisation or reduction of rate of inbreeding);
- definition of targets for numbers of commercial animals expressing genetic improvement, where there is a distinction between "nucleus" and "commercial" animals;
- statement of method and audience for reporting of a) genetic evaluations and b) performance against stated objectives/targets.

Establishing this framework for evaluation, and in many cases maintaining it, will require some disinterested public input. Given that this framework defines the starting conditions for livestock recording and improvement, and a solid basis for continuing monitoring and evaluation of such programs, this points to the value of public activity as establishing a platform for recording and improvement and an independent structure for monitoring continuing performance.

4.5 Who is responsible for development and maintenance of the genetic technologies used in the performance recording system, and what does this responsibility imply in terms of amounts and duration of public support?

The most useful starting point for answering this question is the definition of public goods given earlier. Where an effective market exists for livestock or their products, then performance recording is almost invariably justifiable on the basis of management diagnosis and animal improvement. If so, then recording costs themselves should not require public support.

Expert advisory inputs, large scale research, and overall program monitoring and management will remain more as public goods, until such time as individual business units have grown in scale to the point where annual revenue is in excess of 20-50 times the cost of these R&D and management items. (As an example, net farm gate income of the Australian meat sheep industry is some 600m$Au, and for this industry expert advisory input, technical support and program management cost c. $0.5 m or 0.1% of turnover). If this estimate of core system costs is valid elsewhere (other than simply Australia), then industries or livestock populations that cannot generate in excess of $500m income will require some public intervention.

This discussion suggests different categories of program costs, in line with the functional analysis outlined earlier (the NMC system for supporting knowledge). At this time in the Australian meat sheep industry, all direct program costs are met by industry (so in strict terms entirely privately), with a distinction between fixed costs (program management, expert advisory input and research support) being met by industry levies and more recently by membership costs which are relatively similar for all breeders and commercial producers, and recording and delivery costs, which are essentially per animal.

This model aims for complete industry ownership, totally private funding, but with a mix of overhead (management, technical and advisory support etc) and variable (recording and reporting) costs. The Australian meat sheep industry and its the evolution in funding method is reported in table 2.

The model outlined addresses the direct costs of livestock population recording and improvement programs. The major indirect cost not included is the education and training of operatives at different levels of the knowledge NMC. Here there is the clearest case for continuing public involvement, whether through investment in education generally or through more specific measures such as scholarship programs for all levels of training. Even within the knowledge NMC, it is possible to view the Nucleus costs as being public goods, and the skills/knowledge requirements of the Multiplication and Commercialisation sectors as being more private. Within the model examined above (the Australian meat sheep industry), the Knowledge Multiplier (customisation) costs (program management and supporting research) have been met through generic

Table 2. The Australian meat sheep industry and its the evolution in funding method

Item	Period/phase	
	Establishment	Direct ownership
Period/duration	1989-1996 (7 years)	1996 - ?
Funding for Overheads *(Management, technical support, research)*	Industry levies - largely from commercial production plus government R&D matching (up to 2.5% of turnover)	Direct membership of industry owned company
Funding for delivery: *(Recording, data processing and reporting)*	User pays - breeders pay per animal evaluated	User pays; breeders pay per animal evaluated
Triggers for phase change:	a) proportion of nucleus recorded (75% for terminal sires, 33% for maternal breed animals) b) maturity of system information (across-flock and year evaluations for all breeds, breed specific indexes, structural traits evaluated) c) premiums for recorded seedstock (25-33% margin for each Index standard deviation superiority) d) legislative (R&D Act) requirements	

levies on production and are now being met through membership of an industry company, while Commercialisation costs (delivery) have been and remain on a direct user pays basis.

The challenge that remains within this model is for industries\countries\livestock populations to be aware of, and maintain effective knowledge nuclei and effective links between those nuclei and the Multiplication and Commercialisation sectors.

Summarising this point, for both the livestock and knowledge NMCs, nucleus costs are most readily identified as public, commercialisation as private, and Multiplication costs as moving through a transition from typically initially public or at least collectively funded to more direct industry/farmer/private ownership.

4.6 Who is responsible for collection, analysis and dissemination of the information products of the performance recording system?

The simple answer for this is that this responsibility lies with the program/ system management, and is indeed an integral component of the design of the system, and should be continuously monitored for effectiveness (cost, accuracy, speed, simplicity, relevance and so on being critical).

Similarly, reporting system/program performance should be an explicit responsibility of the program management.

The exact methods used for collection, analysis and dissemination will depend on the traits involved, the culture and geography of the country and industry involved, the educational level of farmers and advisors, and is obviously a central “design” issue for the program.

In terms of public/private roles, the initial design and management of these aspects of the program will be within the Multiplication (customisation) sector of the knowledge NMC, and hence likely to at least initially involve public/collective funding. As the system develops, there is no reason why these design issues cannot be more and more directly included in delivery, and hence more and more directly funded by the users (farmers and producers).

4.7 Where (as is usually the case) multiple agencies (public and private) are involved, what are the stated/ effective reasons for that involvement?

The answers to questions 5 & 6, together with earlier discussion, suggest that the following reasons will be important:

- public agencies will often be involved where farmers do not have, or are believed not to have, sufficient skills and or funds to support the decision-making required particularly for the livestock nucleus;
- public agencies may be involved to help small farmers remain in the breeding and/or production business, by reducing the cost of technical knowledge and/or recording and/or genetic evaluation;
- public agencies may be involved for national strategic reasons, food security, regional employment, general development and so on;

- private agencies will almost invariably be involved in order to profit; this does not mean such agencies are not contributing to the public goals such as those suggested above (indeed much public policy discussion throughout the world is now concerned with using the profit motive to improve delivery of previously public services.

The latter point highlights the 2 key issues about private involvement in community development issues (which is what livestock recording and improvement have typically been viewed as):

- private investment will seek private goods and services ie those where individuals or firms can capture value from their supply, and this has classically been the argument for public involvement in areas such as basic research, expensive research, general extension and so on;
- there is widespread political argument in favour of the view that private sector delivery is almost invariably more effective and/or efficient than public sector. As privatisation has proceeded and begun to be analysed, more attention has been paid to the characteristics of the market for the goods or services whose delivery privatised (for example, Tittenbrun, 1996).

These studies point to the value of preserving a public role for analysing market characteristics, identifying approaches to enhancing market efficiency, and in particular questioning the existence of supposed “natural monopolies”.

In terms of the issue of livestock recording and improvement, the analysis presented here suggests that nucleus knowledge may be the clearest example of a public good, and that as one moves towards to commercial end of the “knowledge chain”, knowledge and system/program design become more and more private goods and services.

This points to specific and valuable public roles in livestock recording and improvement:

- identifying sources of, and perhaps assisting with access to, appropriate knowledge nucleus workers or teams and products (i.e. software);
- working with farmers/industry to establish the framework for knowledge customisation;
- developing with farmers/industry a suitable framework for evaluating performance of the recording and improvement system;
- applying independent analysis to the markets for livestock seedstock, animals and products and the corresponding knowledge products and services to identify market distortions and inefficiencies;
- from the basis of such analysis, working with farmers/industry to remove such distortions and inefficiencies.

4.8 (a) What training structures/systems are in place for personnel within the knowledge and livestock NMCs? How are these funded and evaluated?

This is not so much a question for discussion here, so much as an important component of the public analysis role suggested under 7. This discussion paper is pointing to development and management of the basic knowledge generation and dissemination systems as being a “public” role in most circumstances.

This does not mean that the public sector should be seen as the permanent provider/manager of this component of recording and improvement systems, but that initial evaluation of the knowledge NMC should be independent of individual sectors and/or firms. Such analysis can then highlight alternative ways of funding continuing research, training and knowledge dissemination with the suggested aim being to move to such knowledge management being treated as being a standard component of the “business” of that industry or livestock population.

As with the livestock NMC, evaluation of the knowledge NMC is critical, certainly initially this will be an important public role.

4.8 (b) How and on what terms do elements within the knowledge and livestock NMCs have access to capital?

This is really a financial version of 8 (a), and is an area that has been explored widely and for a number of decades within the discipline of development economics and elsewhere. Again, the point is not to develop answers (or analysis) here, but to stress the importance of analysis of terms of access to capital for the development and management of both the knowledge and livestock NMCs.

This analysis should include identification of alternative strategies for modifying access both knowledge and financial capital: cooperatives are a widespread and potentially highly successful way of reducing costs of entry to numbers of small players such as farmers.

In this context, existing laws governing cooperatives and other financial and legal structures can affect the ease of establishment and likelihood of success of alternative forms of operation within both the knowledge and livestock NMCs. Initial analysis and planning for recording and improvement systems should take this into account.

4.9 What processes of system evaluation are available, and how can they be used most effectively in continuing system management?

One of the key messages of this discussion document is that a simple framework exists for the evaluation of livestock recording and improvement systems and their associated knowledge NMCs. The elements of this framework are standard within the breeding program design literature: what is perhaps new is the suggestions that:

- The framework should be routinely applied to all livestock recording and improvement systems.
- It forms a simple model for developing analogous evaluation of the knowledge systems that support livestock recording and improvement.

- It can be applied to LMIP systems including those where some/much of the value of livestock and their products are outside any obvious cash economy (including for example scavenger animals, which may not be traded but which have a clear and definable role within for example a village ecosystem).
- It is robust to evolution of both the livestock and knowledge NMCs and is applicable to systems initially devoted to conservation or improvement separately.

The framework is sufficiently simple that it could be readily applied to either national or international databases monitoring both livestock programs and the supporting knowledge NMCs. As with other forms of evaluation, this would improve allocation of resources within both systems and particularly help international aid and development agencies diagnose and respond to problems within both systems.

4.10 When is a livestock recording and improvement system mature, and what effect(s) does this have?

Two indicators of system/program maturity can be suggested:

- The system has become self-supporting; it is generating sufficient income to fund its own management and has the appropriate internal mechanisms in place and operating to do that.
- Rates of innovation, within both the livestock and knowledge NMCs, have stabilised (note: not that they have stopped).

The effects of such maturing will probably include:

- Reduced or zero need for public involvement, in the sense of support\input from taxpayers outside the livestock industry/system (note that cooperative or collective involvement may be integral).
- Under current trends of globalisation, almost certainly horizontal and vertical alliances across national borders.
- Larger effective scale for most operations in all sectors of both the livestock and knowledge NMCs; however it is achieved, maximising the number of animals expressing each new unit of both knowledge gain and genetic gain is one of the two ultimate determinants of livestock population/industry success.
- Unfortunately for many circumstances, this usually means a period of contraction of employment prior to growth in both livestock and knowledge work being dependent on income from the livestock system\program.

4.11 Does the public role ever disappear?

The answer to 10 above suggests that in strictly functional terms, the public role (suggested as initial analysis, development of the basic framework for livestock recording and for continuing evaluation of the performance of the livestock and knowledge NMCs) could indeed decline as livestock systems/programs approached maturity. This is probably generally unlikely for 2 reasons:

- True maturity probably requires a truly perfect market for all components of both livestock and knowledge NMCs; this situation has not been reached even in highly integrated poultry and pig industries in Western countries which still rely on the public sector at least for a supply of both trained graduates and access to developments in core knowledge.
- There is a continuing tension between the desire for economic efficiency (as expressed in the desire for cheaper and higher quality food) and the desire for food safety, environmental safety, and the increasing world-wide concern about the availability of employment.

At the very least, these latter point to a continuing public role (both within and increasingly across national borders) in modifying the environment and conditions for private operations.

On this basis, it seems likely that both public and private roles will continue and have to coexist within livestock and knowledge NMCs.

4.12 Is there a role for agencies such as FAO?

At best, such agencies are an international version of traditional public service organisations within countries, providing disinterested analysis, modifying conditions of access to suit particular community expectations, providing otherwise limiting resources, and so on.

Given this view, there is clearly a role for FAO such areas as:
- Collating basic information (the DAD-IS Global Database).
- Suggesting a framework for development, evaluation and management of livestock NMCs, and initiating a database for this purpose.
- Conducting assessment of global livestock recording and improvement knowledge resources, and particularly in helping match global aid and investment funds with such resources and the areas requiring their application.
- Disseminating the continuing evaluations of recording and improvement systems (this could be in conjunction with agencies such as INTERBULL).

These roles might simply be summarised as providing at least the beginnings of a global livestock recording and improvement system with integrated supporting knowledge NMC.

5.0 Conclusions

Discussion of public and private roles in livestock recording and improvement systems addresses issues common to the much wider issues of the roles of public and private sector activity generally. In livestock industries, there have typically been the specific issues of concern for the viability of small farmers and of public availability of scientific knowledge of animal production and improvement, and to these have been more recently added concern for genetic viability of many locally and internationally important livestock populations.

Rather than work through the potential minefield of ideological differences concerning public and private policy generally, management of mixed systems, and so on, this discussion document provides a simple functional analysis of the critical elements of livestock recording and improvement systems and their associated knowledge generation and dissemination systems.

The underlying message is that there are many simple analogies between the two, and that we can draw on animal breeding program design models to suggest a simple and logical framework for developing, managing and evaluating both the livestock and knowledge systems.

Without such a framework, discussion of public and private roles is effectively meaningless: with such a framework it is relatively simple to assess the state and performance of any potential or existing recording and improvement system.

This framework can be applied to LMIP systems: what may be special about these is the exact role(s) played by a particular breed or strain in a particular system. What will not change are the basic parameters of what traits contribute value and are amenable to genetic improvement, what information or records will allow effective genetic selection and improved management diagnosis, and who makes what decisions about mating structure and so determines medium- to long-term genetic viability.

It is suggested here that the clearest public role is to establish this framework for each individual situation, and following this is minimise distortions and inefficiencies in the markets for livestock, their products and the knowledge required for their management and improvement. Public involvement beyond this is problematic, not so much because it may not be of value but because it may be increasingly hard to reduce reliance on public support despite reducing availability.

This problem will likely be minimised by having a clear framework for evaluation of the livestock and knowledge systems, which will highlight both problems with either system, or just as importantly successes such as improvement in average animal performance, increases in rate of genetic gain, increase in effective population size, or improvement in rates of dissemination of knowledge and skills.

The discussion here is unavoidably simple; many issues are raised in passing and it is possible that the need for skilled and sensitive local and global analysis and understanding has not been stressed sufficiently. This is probably the second area where high quality public involvement will be of great value, and points to a critical facilitating role for FAO and related agencies. Establishing an international framework for, and system of, analysing and evaluating livestock and knowledge recording and improvement systems will almost certainly improve access to and allocation of knowledge resources for managing livestock recording and improvement.

Such a framework will reduce the chance local breeding populations will be unnecessarily swamped or replaced by imported stocks, and improve the chances for effective international utilisation of livestock recording, management and improvement skills.

Without that framework, many systems will not be managed to the level necessary to maintain and enhance livestock production in a range of environments, and will lose the base of genetic variability with which to respond to both changing circumstances and the need for constant improvement which all livestock production systems will increasingly face.

Clear, simple and practical information is essential in improving livestock production in all environments and political systems. Applying that principle to the development and evaluation of livestock recording and improvement systems themselves will most simply allow public and private roles to be identified and to evolve to suit the animals, the production systems and the communities in which they exist.

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