ECONOMICS OF LIVESTOCK IMPROVEMENT

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ABSTRACT

The economic returns from genetic improvement of farm livestock can be large on a national scale, relative to the costs involved in breeding. The main benefits go to the consumer, both in domestic and in export markets. The objective in livestock improvement is to improve the economic efficiency of production, defined as the cost per unit of product value. Economic efficiency involves many component traits and factors. Breeding work is long-term and designed to serve the whole production marketing system, rather than to meet the short term needs of individual producers with a particular set of constraints at the farm (or firm) level. Smith, James and Brascamp (1986) showed that a general long-term objective, identical with economic efficiency (Dickerson 1970), is achieved by considering all costs as variable costs, and by rescaling the size of the operation to match or discount any changes in outputs, inputs or profit.

New biotechnologies in reproduction and molecular biology will affect animal breeding in many ways; in the breeding objectives, in the methods and rates of genetic change, and in the organization and ownership of breeding stocks. These are likely to have an important impact on the economics of livestock breeding over the next decade.

INTRODUCTION

The main role of the animal geneticist is to provide effective methods for genetic change in farm livestock. Should it also be his role to determine and quantify the breeding objectives, or should this be left to breeders and economists? Largely by default, animal geneticists have found it necessary to become involved in the economics of improvement, to plan the direction of the change, as well as the means of making change. This is because practical breeders have often favoured factors such as breed type, appearance and pedigree rather than the traits of economic merit, and they are concerned with current pricing systems and subject to temporary price changes. Often the signals of economic preference and trends are not passed on by the pricing system from the consumer to the producers and breeders; the market does not always act efficiently. In these conditions the animal geneticist has adopted an interventionist role and independently derives economic weights for production traits. Co- operation of animal geneticists and economists has not been common, and then often not productive, due to difficulties in understanding each other's science and jargon, and due to different perspectives taken. Economists involved in livestock improvement have usually dealt with the individual firm (or production unit) rather than with the long-term general industry needs.

Rates of Genetic Change

The main method of genetic improvement is selection, after a fair test, of the best animals for breeding the next generation. The rates of genetic change theoretically possible range from 1 to 5 percent of the mean per year for different traits and species, as outlined in Table 1 (Smith 1984a). These rates have been obtained in experiments, so confirming selection theory, and in practice where effective selection for economic merit has been applied.

Table 1. Annual genetic change theoretically possible by selection.

Trait	Annual Genetic Change (Percent of the Mean) Poultry	Pigs	Sheep	Cattle
GROWTH/EFFICIENCY				
Normal reproduction	3.2	2.7	1.4	1.4
MOET*	—	—	2.4	2.6
LEANNESS				
Normal reproduction	2.2	1.6	0.9	0.5
MOET	—	—	1.8	1.0
SEX-LIMITED TRAITS	Egg Number	Litter Size	Litter Size	Milk Yield
Normal reproduction	2.1	4.7	2.1	1.5
MOET	—	—	3.4	2.0

*MOET - multiple ovulation and embryo transfer

Economic Benefits

Although the annual rates of genetic change by selection are not large, the improvements are cumulative and permanent. The returns from improved stock are obtained over many years, and are usually discounted to net present values, using an inflation-free discount rate (Smith 1978) of about 5 percent (Bird and Mitchell 1980). This rate includes some allowance for risk and uncertainty about future husbandry-marketing requirements.

Many authors have made prospective estimates of the benefits of future breeding schemes but there are few economic analyses of realized benefits. One well documented case is for the value of pig improvement in the UK from 1966 to 1977, by Mitchell et al. (1982), as summarized in Table 2. Genetic trends were measured using two genetic control populations. The total costs per year of improvement research and development were about $2 million. The benefits from the 1.8 percent improvement in economic merit per year, on sales of about 12 million pigs per year over a 30 year pay-off period were estimated at about $100 million, giving a cost benefit ratio of 50 to one. The value of current schemes can be estimated in a similar manner. For example, Jacques Chesnais (personal communication) has estimated that in dairy cattle in Canada the genetic improvement of milk yield of about one percent of the mean per year is worth 150 million dollars (C).

Table 2. Economic weights and economic value in genetic improvement in British pigs (1966-1977).

Selection Objective	
TRAIT	VALUE PER S.D. UNIT($)
Daily gain	0.64
Food efficiency	2.16
Carcass percent	1.04
Trim percent	0.53
Lean percent	1.32
Genetic Improvement	
(Genetic control herds)	$0.76 per pig per year (1.8% of mean value per year)
VALUE	
Annual costs	$2 million
Pigs marketed per year	12 million
Genetic dissemination lag	5 years
Discount rate (inflation free)	5 percent
Benefits from 1 year of selection	
20 year horizon	$77 million
30 year horizon	$104 million

These benefits, and the benefits from genetic improvement in general, accrue mainly to the consumer, rather than to the breeder or producer as indicated in Table 3. The latter benefit only from sale of stock in competition with other breeders and producers. The level of investment justified in genetic improvement is thus much larger for the nation (consumer), than for the farmer-breeder or breeding company. However, in practice it seems that it is usually the reproductive rate that limits genetic response rather than insufficient breeding resources (Smith 1981).

The rates of genetic change achieved in beef cattle and in sheep are very low relative to the rates possible with effective selection schemes. This is a serious charge on the livestock breeding industry that the methods of genetic improvement are not being used effectively. Moreover the rates of genetic change possible can be increased from 1-2 percent of the mean per year (Smith 1984a) to up to twice those rates by new technologies such as multiple ovulation and embryo transfer (Land and Hill 1975; Smith 1986). The loss in economic benefits from not exploiting available methods and new technologies is large on a national basis, and should not be tolerated.

Table 3. Perspectives in investment appraisal in livestock improvement.

	Perspective	
	Improvement in the national interest	Breeder or Company
Investment	National stock	Own stock
Time scale	Long	Short
Return to investor	Large	Small
	Increase in efficiency in whole population	Returns from extra breeding stock sold
	Permanent value	Temporary competitive value
	Cumulative value	Not cumulative
	Low risk	High risk
Investment justified	Large	Small

(After Smith 1978)

Uncertainty

Current genetic improvement systems are concerned with present economic needs.

However there will always be some uncertainty about production methods and marketing needs in the future. This uncertainty can be reduced by selecting stocks for different sets of economic or biological objectives, as an insurance against possible or even unexpected changes. For example, recent consumer demands for lean meat in sheep cannot be met because there is no large lean terminal sire breed available. It has been shown (Land 1981; Smith 1985) that there is considerable scope for developing such diverse lines, with possible increased overall benefits to society in the future. Such developments would, of course, have to be subsidized because of the uncertainty and time period involved. Some insurance is given by the range in bio-economic types available worldwide (Gregory 1986) and by conservation of rare breeds and stocks (Smith 1984b).

Another approach to uncertainty about future needs and about difficulties in developing selection criteria for economic efficiency, is to select for biological efficiency (Fowler, Bichard and Pease 1976). This might have long-term value across different husbandry- marketing systems and over time. However, unless biological efficiency is closely correlated with current economic efficiency it would not be viable in current improvement schemes (Fowler 1980) and would need to be supported.

The individual breeder faces uncertainty in the use of breeding stock if the stocks are not evaluated accurately. Schneeberger et al. (1981, 1982) and Smith and Hammond (1987) have used portfolio theory and utility theory to accommodate risk while maintaining high genetic merit. Uncertainty is greatly reduced by use of a moderate number (say 5) breeding males. Then, the main criterion for breeding use should be estimated genetic merit, rather than accuracy of evaluation (Smith 1988a).

Importation

Economic evaluation of different breeding stocks is needed so that producers can use the stocks most profitable in their production- marketing system. These comparisons should include foreign stocks, if competitive and available. Importation of genetic merit is usually an inexpensive method of genetic improvement, benefiting from investments made elsewhere, exploiting the best genetic stocks worldwide and allowing flexibility in use over time. In large farm livestock, each country tends to have its own improvement schemes for its own stock. This gives competition between countries, but also leads to duplication of effort. For example, every country in Europe has run its own dairy cattle improvement program for the last 20-30 years, favouring (as supported by several economic-genetic studies, eg. Niebel 1986) dual purpose beef-dairy cattle. Yet in recent years the dairy population has been largely replaced by the more specialized North American dairy stock. It might be argued that much of the European investment in testing and selection has been wasted. The lesson may be that unless a breeding programme is competitive internationally, investment may not be justified, and a policy of continuing importation of semen or embryos from countries with competitive schemes may be the least expensive and the best. This would apply to many developing countries, unless their husbandry- marketing conditions were sufficiently different to require their own special stocks. Of course, international competition and sale of breeding stock is well established in poultry breeding where husbandry-marketing conditions can be standardized. There are similar trends in pig breeding.

Organization

The reproductive rate of different species and the costs of running a breeding scheme affect the breeding system used. In poultry breeding, stocks of adequate size can be kept at reasonable cost, and breeding and selection are now effected largely by breeding companies in international competition. The same trend is occurring in pig breeding, though in most countries artificial insemination (AI) stations and farmer-breeders compete in the sale of breeding stock. In dairy cattle the artificial insemination co-operatives and companies play a dominant role, while in beef cattle and sheep, breed improvement is still largely the province of the farmer-breeder. Increased female reproductive rates in cattle and sheep through multiple ovulation and embryo transfer (MOET) allow faster rates of genetic change than through progeny testing and other conventional systems. Thus, selection in elite nucleus herds may be favoured, altering the breeding systems, organizations and the economics of improvement.

ECONOMIC OBJECTIVES

The objective in animal breeding is to improve economic efficiency of production. Economic efficiency, however, is determined by many component traits in a complex algebraic function. However, Goddard (1983) pointed out that if the component traits are inherited additively genetic progress in profit based on linear selection indices is always greater than that based on non-linear indices. The economic value (or weight) of a trait is the marginal change in economic efficiency or net profit per unit change in the trait (Hazel 1943; James 1980; Smith et al. 1986). McArthur (1987b) points out that this should apply at the optimal policy of production. Traits of economic value are included in the aggregate breeding value, the selection objective. Traits which are measured are included in the selection index, the selection criterion.

There has been wide variation in the interpretation of Hazel's original definition of economic weight. These range from simple methods (eg. Mitchell et al. 1982), linear programming methods (Wilton 1986), use of bio-economic efficiency models (Tess et al. 1983), to taking account of the number of discounted expressions in the economic weights rather than in the evaluation (Moll and Kropf 1987). The situation was confused by Moav (1973) who showed that economic weights calculated from profit equations depended on the perspective taken, and differed for breeder, producer, processor, investor and consumer, with their competing interests. Yet the same breeding stock has to serve all the interests and do so equitably so as to allow efficient operation of the production-marketing system.

Rescaling

A resolution of Moav's problem was given by Smith et al. (1986). They argued, first that animal breeding improvements are long-term, so that all costs should be treated as variable costs, and second that any changes in output, input or profit incurred by the genetic changes than can be matched by rescaling the size of the production enterprise, should not be counted, since they can be achieved without any genetic change. With these conditions they showed that the relative economic weights among traits are the same for all the perspectives listed above. They are also the same as those derived for economic efficiency (Dickerson 1970), representing the ratio of the value of all products to the cost of all inputs, or the cost per unit of product value. These results remove the logical anomalies in estimating economic weights. But, since net profit is usually small relative to total costs, they will have only moderate effects on the economic weights derived.

The economic weights are general and long-term. In the shorter term, or for the individual breeder or producer with a given stock and production facilities, or where there are artificial distortions of markets, other objectives may be preferred (James 1986). But these shorter term and individual objectives will impose an opportunity cost of selection for economic efficiency.

The rescaling procedure has been criticized by McArthur (1987a, 1987b). He suggests that the prices of different products (and inputs) were not considered in Smith et al. (1986), yet they were. Another point made is that the production system should be optimized to maximize profit. Smith et al. (1986) dealt with this by showing that genetic improvement should not be used to correct inefficiencies in the system. A more serious point is that with an optimum system and profit maximization, changing the size of the operation (rescaling) and earning more profit would not be possible, else the producer (as a profit maximizer) would have already done so. The profit maximization is usually with regard to a given set of constraints, such as a fixed quota on output or a fixed input (say of land) for the particular enterprise. These constraints can be removed for example by buying more quota or more land, so rescaling is always possible. The situation has been well summarized by James (1986) who shows that in the longer term what is important on an industry wide basis is economic efficiency and only genetic changes in economic efficiency can be regarded as genetic improvement. Economic Weights Derived

Some of these points are illustrated by Gibson (1988a) in estimating economic weights in dairy cattle. In a recent review he found that many previous studies suffered from several inadequacies; 1) they failed to include the majority of the costs, 2) they were based on payment systems without demonstrating long-term price stability, 3) they used average, not marginal, costs and returns, and 4) they used no rescaling to allow for alternative methods of increasing outputs or effective limits to production (quotas). He showed the effects of these deficiencies in estimating economic weights for carrier, fat, protein and lactose in selecting for milk yield and composition in Canadian dairy cattle, as outlined in Table 4. Current pricing systems gave positive value for carrier (water). A proposed price system, based on total solids, gave a moderate economic weight to lactose, which is in surplus and of low value. Currently, protein too is in surplus and has low marginal value, but in the long-term, with new processing systems and products, protein is expected to have a higher marginal value. Use of inappropriate economic weights could lead to reductions in economic response by up to 30% (Gibson 1988b). More recent studies on estimating economic weights are aware of many of the problems and pitfalls (Elsen et al. 1986), and provide more realistic estimates (Tess et al. 1983; Ponzoni 1986; Simm et al. 1987; Van Arendonk 1988; Groen 1988).

Table 4. Estimated economic weights for milk components in Canada (Gibson 1988a) ($ per standard deviation change).

	Carrier	Fat	Protein	Lactose
Standard deviation (kg)	939	40.2	34.2	54.0
Unscaled				
Current price (volume and fat yield)				
Costs ignored	161	260	4	6
Costs included	130	217	-15	-15
Rescaled to constant fat output: costs included				
Current price	130	110	-15	-15
Proposed price (fat and solids not fat)	-20	92	48	83
Average current value	-45	110	155	-16
Marginal current value	-21	124	12	-13
Marginal future value	-45	124	58	-16

Biotechnologies

The economics and organization of animal breeding may change appreciably over the next decade with the application of new biotechnologies in livestock improvement (Gibson and Smith 1988). These involve changes in the rates and processes of reproduction and in the application of molecular genetics in the production of biologicals, such as growth hormone, and in the creation of transgenic stocks.

- **Reproduction.** As already discussed, multiple ovulation and embryo transfer (MOET) allow faster rates of genetic change in sheep and cattle. Breeding schemes organized around elite nucleus stocks may be favoured with MOET, compared with the current field population testing in dispersed farmer-breeder units. Thus there may be developments in co-operative breeding schemes, or formation of breeding companies, as in pigs and poultry, to take advantage of these innovations. The breeding work will be more technical, expensive (per individual tested) and will be more detailed and controlled, and new techniques such as embryo sexing, splitting and cloning, can be applied more quickly. Cloning will lead to substantial lifts in genetic merit, by selection and use of the best clones for widespread commercial use, and to further increased rates of genetic change (Smith 1988b). It will also require further specialization of selection stocks, as terminal and maternal clones with different sets of breeding objectives, and lead to selecting clones for special husbandry-marketing niches. These developments will change breeding systems and the organization of breeding and marketing of improved stocks.

- **Biologicals.** Another development is the production by molecular genetic processes, of a range of biologicals, animal hormones and factors, which when given exogenously, may affect animal performance. For example, somatotropin produced by engineered micro- organisms can increase yield and efficiency of milk production by 15-25 percent (Bauman et al. 1985) and is being used in pig production as a repartitioning agent to produce leaner pork. Slow release systems are being developed to avoid the need for frequent treatments. These products could affect breeding objectives, the stocks used and even the whole justification for animal breeding if large changes in economic efficiency can be achieved readily by physiological means. However there may be public concern about the use of such products in food production, and naturally bred animals may be preferred.

- **Transgenes.** Transgenic stocks of farm livestock, with exogenous DNA in the germline, are being developed and may soon be of practical use (Smith, Meuwissen and Gibson 1987). Development of transgenes involves molecular genetics, identifying the DNA for a target protein, developing a construct (or fusion gene) with a promotor (to initiate and control the expression of the gene) and transferring it into genome. Large laboratory and testing and evaluation effort will be needed before practical use, but already some dramatic results have been obtained. Pigs with the growth hormone gene, with a heavy metal promoter, are very lean, with only 3% of chemical fat compared with 25% of fat in normal pigs of the same age (T.E. Wagner, personal communication). Again these developments will alter the breeding methods and systems, and change the organization and economics of animal breeding. The granting of patent rights to a genetically engineered mouse (Ezzell 1988) suggests a profitable arena for useful transgenic livestock. It is important that livestock breeders, co-operative groups and companies get involved in these developments if they are to retain their share of the breeding market, nationally and worldwide.

DISCUSSION

Animal breeders have adopted a fairly pragmatic approach to the economics of livestock improvement, yet appreciable improvements in economic merit have been achieved, especially in poultry and pigs, and more recently in dairy cattle. In sheep and beef cattle there is still much concern with perceived indicators of merit, such as sale price or favoured type, rather than direct measures of economic merit, and improvements have been limited. It is important to keep the breeding objectives simple, so that breeders understand them, and that the geneticists-economists are not misled by their own elaborations. In many countries, quotas have been placed on the levels of production. This may have only modest effects on breeding goals, whose objective is economic efficiency whatever the level of input or output.

Most of the economics of animal breeding deals with the details of improving current production systems and deals little with the broader issues. There is need and scope for an outward looking perspective to consider the development of new production systems, with new markets and new products. One fillip to the current systems will be the development of new biotechnologies, and the further incursion of science and research and development into animal production systems. Studies of the best long-term use of our scientific, animal and land resources in the common interest, should be included in the economics of livestock improvement.

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