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The Implications of Advanced Breeding Techniques

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PREFACE

This report was commissioned by the Australian Meat and Livestock Research and Development Corporation, with the aim of providing some guidance as to the likely impact of various biotechnologies on the Australian meat and livestock industries.

In reviewing the various biotechnologies that are already having an impact in sheep and cattle in Australia, and in attempting to predict which techniques are likely to bring most benefits to Australia in the future, we have concentrated on relatively straight-forward cost-benefit analyses.

Inevitably we have not been able to cover all possible combinations of costs and returns.

Because of these inevitable limitations we have presented the cost-benefit analyses in such a way as to enable readers to substitute their own biological, management, and financial figures, and hence to perform cost-benefit analyses that are directly relevant to their particular circumstances. In this way we hope that our report will be of direct practical use to anyone who may be contemplating the adoption of an advanced breeding technique.

F.W. Nicholas

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1 Acknowledgements

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2 Summary

This report considers some of the costs and benefits of current and potential biotechnologies on the production of meat from cattle and sheep.

Technologies such as artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) are not seen as offering quantum changes in industry efficiency. Potential improvements in these techniques are not large, but those sections of the industry that use them would welcome any small increases in efficiency. The expense of laparoscopic AI in sheep is limiting its applicability. If cervical AI in sheep with frozen semen could be used successfully, it could have some benefits. The relatively high cost of MOET, and more conservative predictions of its benefits for nucleus selection programs, limit its attractiveness.

Cloning offers considerable benefits, either as a way of producing superior natural service (NS) bulls or for more rapidly disseminating transgenic animals. Cloning in meat sheep is expected to be only marginally attractive as a way of producing superior NS sires, but it would be attractive for more rapidly disseminating transgenic rams.

Two high priority problem areas which need to be tackled before embryo cloning can be commercialised are: (1) development of culture techniques for bovine and ovine embryonic stem (ES) cells; (2) a cheap, reliable source of recipient oocytes (or embryos) to receive nuclei from the ES cells.

The development of sex control will not have an important effect on the rates of genetic gain in selection programs. Sexed semen is unlikely to be attractive in commercial situations because of the relatively high cost of synchronized AI. Embryo sexing is not likely to be cost-effective in Australia, unless the cost is reduced to a fraction of what it is currently. Any treatment for natural service sires which increased the proportion of male calves without affecting fertility could be of benefit.

Twinning offers very attractive prospects for increased efficiency, but presents new challenges to management. A current AMLRDC project will provide important insights into the practical benefits of twinning.

Research into the production of transgenic beef cattle and meat sheep should be regarded as basic research, with no immediate commercial benefits. However, this work is so potentially important, that Australia must be in a position to capitalise on major developments. This can only happen if Australia plays an active role in transgenic research. The availability of cloning will be important for rapidly testing and spreading the benefits of transgenic animals.

Research into gene mapping and the identification of gene markers should not be seen as having major short term benefits. However, such research should be seen as basic science which will greatly enhance our knowledge of, and hence our ability to manipulate, genes that affect biological and economic efficiency of meat production.

As an insurance against loss of unique genetic variation, an Australian gene bank should be established. For relatively little cost, semen and embryos, surplus to current requirements could be stored in such a bank, thereby providing substantial potential for long-term benefit to the beef and sheep meat industries in the unpredictable future.

The widespread use of certain biotechnologies may raise questions of ethical concern in some sections of society. While it is possible to provide a rational argument against these concerns, it is essential that possible public reaction be taken into account before a new biotechnology is widely adopted, and that the public be kept fully informed of developments.

The lack of a clear definition of breeding objectives in beef cattle, and to a lesser extent meat sheep, is still a major problem, and must be regarded as a major priority for research.

3 Project aims

At the outset, the aims of this project were defined as follows:-

(i) Investigate current and potential future achievements of research in advanced breeding techniques (Artificial Insemination; in vitro fertilization; embryo storage and culture; cloning; semen and embryo sexing; diagnostic screening/DNA markers; production of transgenics)

(ii) Investigate how these techniques should be applied so as to bring maximum benefit to the Australian meat and livestock industries.

(iii) Prepare discussion papers for the Australian Meat and Livestock industries, describing (a) how the above techniques should be incorporated into practical selection programs and (b) the economic and other consequences of the practical application of the above techniques.

These aims have provided a useful framework for the exploration of a new and constantly changing area. Although there has been no need to change the defined aims of the project during its course, there has been a tendency for some areas to have been seen as needing more attention than others. Only time will show whether the more rewarding areas were correctly identified.

4 Introduction

The following technologies are commercially available now: artificial insemination (AI), multiple ovulation and embryo transfer (MOET), embryo sexing, splitting and freezing. In contrast, in vitro fertilization (IVF), cloning, semen sexing, diagnostic screening using DNA markers, and production of transgenic animals are not commercially available at present. Factors such as costs, benefits, convenience and ethical considerations are important, so the mere commercial availability of a technique is not sufficient to lead to its adoption.

The wide variety of production systems and environments in Australia means that no single technology is likely to have universal applicability. Where appropriate, mention is made of production systems where particular recommendations are not valid.

It may be felt by some that a cost-benefit approach is inappropriate for planning research priorities. However, cost-benefit analysis should be seen as just one of a number of tools to aid the decision-making process. Although other factors must also be taken into account, this does not invalidate the need to investigate the economic consequences of new technologies. The lack of a clear definition of the breeding objective in both beef cattle and, to a lesser extent, meat sheep has been a problem. Generally, either the costs are well defined but the benefits are not, or the benefits are well defined but the costs are not. However, in the situations considered in this report, neither the costs nor the benefits are easy to define.

At present the relatively high costs associated with AI and MOET have restricted their use mainly to the stud herds and flocks.

Transgenic farm animals have been produced, but this technology is in its infancy and there have been few claims of creating successful transgenic farm animals. The level of success with plants, microbes and laboratory animals leads to the conclusion that transgenic farm animals will have a future, but not as rapidly as many have predicted.

DNA screening for specific genes is possible, but there are few genes which are appropriate for this procedure and with a cost of about $100 per test its application is limited at present.

Prospects for semen sexing on a commercial scale seem as remote as ever, but the prospects for partial separation in quantities large enough for use with *in vitro* fertilisation seem reasonable.

Despite the brief appearance of an Irish commercial service for embryos produced using IVF, the success rates have been too low to be of commercial use.

The maximum number of identical clones produced so far is 15. Procedures are still too expensive to be of commercial importance but prospects for cloning within five years are reasonably good.

We shall now consider each of the main technologies in detail.

5 Artificial Insemination

Beef

AI has been used on a massive scale for dairy cattle around the world, primarily because daily observation of oestrous behaviour is a routine part of the management system. With beef cattle in Australia, the situation is very different, since daily observation of oestrous behaviour is not routine. However, in the USA, many beef properties have less than 50 animals, and are part-time enterprises. For this reason AI has considerably more appeal in the USA than in commercial Australian herds where much more extensive management systems are the norm. Some Australian breeders have overcome the problems associated with AI by organizing an intensive observation season each year. Others have used synchronizing programs (e.g. prostaglandins) which are simpler and less labour intensive but are more expensive due to the drug costs.

In this section, we shall start by comparing natural service (NS) with synchronized AI. We shall then consider the use of AI in reference sire schemes, and its potential as an alternative to a multiplier herd.

Natural service versus synchronized AI

The costs associated with synchronized AI programs by comparison with natural service (NS) are discussed below. In making these comparisons, the natural service male is assumed to be mated for two to three cycles and therefore has a higher apparent success rate. This is a fair comparison because this is what would happen in practice, and it costs the same to use a NS male for 3 cycles as it costs for 1 cycle. If cows which failed to conceive on the first AI attempt are re-synchronized and re-inseminated, the cost per calf born will be the same for the first and second attempts. An added expense of the synchronized AI program would be less efficient use of a NS 'clean-up' sire, but this has not been included in the costings.

AI in beef stud herds has been seen primarily as a way of spreading new breeds or bloodlines, particularly in breeds such as Simmental which have a fairly short history in Australia. The use of AI in commercial herds has been limited to a large extent by the costs and labour involved.

In the following analysis, those items of expenditure which create differences between the costs associated with natural and artificial breeding have been combined into one overall figure: the breeding cost per calf born.

As will be seen, a primary influence on the costs associated with natural service bulls is the mating percentage. Traditionally, one bull would be allocated to about 33 cows (3% mating), but this percentage can be more than halved for those bulls which have been screened for testicle-size and soundness, and which have performed a high number of successful mounts in a serving capacity test (Blockey, 1990, pers. comm.). Several different mating percentages have been tested in the examples which follow.

Table 1

Beef Natural Service - 1 (Low breeding cost)
The bull has a low purchase price ($1500), has a 95% conception rate in 9 weeks when mated to 75 cows, and lasts for 4 breeding seasons.

Natural Service Bull	Unit cost	Units	Total Cost
Mating % (bulls needed per 100 cows)		1.5	
Years of use per bull		4	
Conception rate 9 week		95.00%	
Live calves per pregnant cow		90.00%	
Natural service bull purchase	$1500.00	1	$1500.00
Feed cost per week	$5.00	208	$1040.00
Residual value of bull	$1000.00	1	$1000.00
Total number of calves born per bull purchased		240.95	
Total cost per bull purchased			$1540.00
Breeding cost per calf born, i.e. $1540/240	$6.39		

Table 2

Beef Natural Service - 2 (Medium breeding cost)

The bull has a medium purchase price ($2000), has a 95% conception rate in 9 weeks when mated to 50 cows, and lasts for 4 breeding seasons.

Natural Service Bull	Unit cost	Units	Total Cost
Mating % (bulls needed per 100 cows)		2	
Years of use per bull		4	
Conception rate 9 week		95.00%	
Live calves per pregnant cow		90.00%	
Natural service bull purchase	$2000.00	1	$2000.00
Feed cost per week	$5.00	208	$1040.00
Residual value of bull	$1000.00	1	$1000.00
Total number of calves born per bull purchased		180.95	
Total cost per bull purchased			$2040.00
Breeding cost per calf born, i.e. $2040/180	$11.27		

Table 3

Beef Natural Service - 3 (Very high breeding cost)

The bull has a high purchase price ($4000), has a poorer conception rate when mated to few cows, and lasts for only 2 breeding seasons before being culled.

Natural Service Bull	Unit cost	Units	Total Cost
Mating % (bulls needed per 100 cows)		3	
Years of use per bull		2	
Conception rate 9 week		75.00%	
Live calves per pregnant cow		90.00%	
Natural service bull purchase	$4000.00	1	$4000.00
Feed cost per week	$5.00	104	$520.00
Residual value of bull	$1000.00	1	$1000.00
Total number of calves born per bull purchased		60.75	
Total cost per bull purchased			$3520.00
Breeding cost per calf born, i.e. $3520/60	$57.94		

For comparison with the above NS alternatives, we shall now consider the following range of synchronized AI programs.

Table 4

Beef Synchronized AI - 1 (Typical breeding cost)

In this example, prices for semen and drugs are typical of a synchronized AI program with reasonable success rates. The semen price of $10 is typical of a bull being sold without registrations.

Cost of drugs per cow		$8.50	
Cost of one insemination		$5.00	
Cost per dose of semen		$10.00	
Herd size		100.	
Cows inseminated per cow synchronized		90.00%	
Calves born per cow inseminated		65.00%	
Live calves per pregnant cow		90.00%	

Beef Synchronized AI	Unit cost	Units	Total Cost
Cows to synchronize	$8.50	100.	$850.00
Cows to inseminate	$5.00	90.	$450.00
Semen cost (commercial price)	$10.00	90.	$900.00
Cows conceiving		58.50	
Misc. costs plus labour			$500.00
Calves born		52.65	
Total breeding cost of the program			$2700.00
Breeding cost per calf born	$51.28		

Table 5

Beef Synchronized AI - 2 (Stud breeding cost)

The price for drugs is typical of a synchronized AI program with reasonable success rates. The semen price of $30 is typical of a bull being sold with no restrictions on the right to register the offspring with the breed society.

Cost of drugs per cow		$8.50	
Cost of one insemination		$5.00	
Cost per dose of semen		$30.00	
Herd size		100	
Cows inseminated per cow synchronized		90.00%	
Calves born per cow inseminated		65.00%	
Live calves per pregnant cow		90.00%	

Beef Synchronized AI	Unit cost	Units	Total Cost
Cows to synchronize	$8.50	100.	$850.00
Cows to inseminate	$5.00	90.	$450.00
Semen cost (stud price)	$30.00	90.	$2700.00
Cows conceiving		58.50	
Misc. costs plus labour			$500.00
Calves born		52.65	
Total breeding cost of the program			$4500.00
Breeding cost per calf born	$85.47		

Table 6

Beef Synchronized AI - 3 (Low breeding cost)

The price for drugs, insemination and semen has been halved. The conception rate of 80% would rarely be achieved.

Cost of drugs per cow		$4.25	
Cost of one Insemination		$2.50	
Cost per dose of semen		$5.00	
Herd size		100	
Cows inseminated per cow synchronized		90.00%	
Calves born per cow inseminated		80.00%	
Live calves per pregnant cow		90.00%	

Beef Synchronized AI	Unit cost	Units	Cost for Herd
Cows to synchronize	$4.25	100.	$425.00
Cows to inseminate	$2.50	90.	$225.00
Semen cost	$5.00	90.	$450.00
Cows conceiving		58.50	
Misc. costs plus labour			$500.00
Calves born		52.65	
Total breeding cost of the program			$1600.00
Breeding cost per calf born	$30.39		

The conclusions to be drawn these tables are:-

A. The breeding cost of a calf bred by AI using synchronizing drugs is in the order of $50 per calf born.

B. The comparable breeding cost for naturally bred calves is in the order of $10.

C. Hence the calf bred by AI has to be at least $40 (i.e., $50-$10) more valuable than the naturally bred calf to make up for the higher breeding costs associated with AI. Differences between the genetic merit of AI and NS bulls would have to be at least $80 (i.e., $40 x 2) since only half the genes are passed to the calf. Since differences between the merit of sires, as expressed in commercial beef herds, are much smaller than $80, we therefore conclude that AI is unlikely to be used extensively in commercial herds. In stud herds, the added cost of AI is not a major deterrent especially if a bull is available only through AI.

D. Table 6 shows the effect of halving the cost of semen ($5), service fee ($2.50), and drugs ($4.25), while increasing the conception rate per service to 80%. This would reduce the breeding cost per calf born from about $50 to about $30. However, the reduction is still too small to be attractive in most commercial herds.

It is suggested by some (e.g. Nicol 1990 pers. comm.) that having large groups of animals calving over a reduced time period, can lead to increased profits due to higher sale values and reduced management costs. It is further suggested that the increased profits are about equal to the cost of synchronization drugs. If the assumptions in table 4 are changed to have a zero synchronization cost, the breeding cost per calf falls from $51.28 to $35.14. Thus there is still a considerable cost associated with AI relative to natural mating. This means that AI will not be attractive as a routine practice in most commercial herds.

If semen survived in females for several weeks, it would not be necessary to synchronize mating and ovulation. Semen will not survive this long with our current technology, but if it were possible to extend the interval between mating and conception to the extent that synchronization was no longer needed, then calving spread would be as in NS, but there would be a cost associated with extending the semen life; the breeding cost would therefore be in excess of $35.14 per calf born.

If a high price is paid for a natural service sire and he leaves a relatively small number of calves, the cost of his naturally sired calves increases to that of artificially bred calves. Various possible combinations are represented in the tables below. For example, if the NS bull costs $2,800, and he leaves a total of 46 calves when mated to 25 cows in each of 2 years, then the breeding cost per calf would be the same as an AI-bred calf (semen priced at $10 per dose, as in table 4).

Table 7

Approximate break-even price for NS bulls; 2 years use per bull

2 years use per bull	**Mating percent (cows per bull per year)**		
	2 (50)	3 (33)	4 (25)
Lifetime number of calves born per bull	91	61	46
Approximate break-even price for NS bulls (above this purchase price it is cheaper to use AI)	$5,100	$3,600	$2,800

Table 8

Approximate break-even price for NS bulls; 4 years use per bull

4 years use per bull	**Mating percent (cows per bull per year)**		
	2 (50)	3 (33)	4 (25)
Lifetime number of calves born per bull	181	121	91
Approximate break-even price for NS bulls (above this purchase price it is cheaper to use AI)	$9,300	$6,200	$4,600

Sire reference schemes

The use of AI may be cost-effective if it is associated with a sire reference scheme (SRS). Under these circumstances, the added costs of AI may be justified by the benefit of seeing the published sire and herd rankings within the SRS. Competition between studs is fostered, and more intense selection is possible when animals are selected using across-herd evaluations.

Parnell (1987) simulated selection for yearling weight using deterministic and stochastic methods. He compared the results of selection using best linear unbiased prediction (BLUP) across ten herds in an SRS, with selection within a single herd. There was only a small increase in the progress which was generated during 20 years of selection; 21% in one herd, versus 24% in the SRS. In Parnell's study, selection led to inbreeding levels of 11% in single herds and an average of 2% in the SRS herds. However, a more valid comparison would be to compare the inbreeding in 10 separate herds with that in the 10 co-operating SRS herds; inbreeding could be reduced to almost zero if ten single closed herds exchanged sires at the end of 20 years of selection.

Parnell also showed that the size of the participating herds influences the effectiveness of the SRS. Where the closed herds have only 50 breeding cows, there is a more marked benefit in using an SRS. But for larger herds, with more than 200 cows, the rates of gain are not improved significantly by an SRS.

For traits with a low heritability, there is a need for larger numbers of recorded animals, and SRSs have a greater relative advantage (Blair 1989). If an SRS had to be justified purely on the grounds of increased genetic gain, then it should be considered by small herds as a method of competing with the larger herds. In practice, SRSs offer more than just slightly faster rates of gain; they help promote a breed, provide a framework for evaluating animals from other countries, and encourage breeders to define their breeding objectives.

The need for a multiplier herd

In selection programs where genetic progress is being generated in a nucleus, there are two alternative methods to disseminate this progress:-

1. Through AI directly.
2. Through the use of natural service (NS) sires bred in a multiplier herd.

There is obviously a cost advantage in using NS bulls but there is a delay of two years which, depending on the discount rate, can reduce the value of the NS option. In addition, in the early stages of the program there will be a "dilution" factor of 50% because the NS bulls will express only half the merit that the AI sire would have expressed. Once the multiplier herd has reached a 'steady state' rate of gain after about 15 years, then this 'dilution' effect will not be present because the multiplier herd would be progressing at the same rate as the nucleus but would be lagging by one generation (about 4 years).

Assuming a discount rate of 15%, the reduction in the value per calf conceived, due to the additional time lag, is in the order of 50% to 70% (i.e., $(1.00\text{-}0.15)^4$). If we assume that an AI-bred calf costs $40 more than a naturally-bred one (see tables 2 and 4), then an annual rate of progress of about $80 per calf per year would be needed to offset the added cost of AI. The existence of an advantage which is this large is most improbable; it will, therefore, pay to have a multiplier level in the breeding pyramid, in order to avoid the need for AI.

Conclusion

It will rarely, if ever, pay to use synchronized AI to avoid the generation lag caused by introducing a multiplier level into a pyramid.

A mini-multiplier herd using AI

If commercial producers wish to avoid the cost of buying herd bulls, it is possible for them to synchronize a small number of their best cows, and inseminate them with semen from a small number of desirable bulls. This small group of elite females is really a mini-multiplier herd. From amongst the resultant male calves,the best ones can be selected for use as herd bulls. If it costs about $85 extra per calf bred by an expensive AI bull (see table 5), and we assume that six calves are needed to find one male that is selected as a herd bull, the added cost is $85 x 6 = $510 per bull.

Conclusion

If a commercial producer wants to breed a herd bull through the use of AI, it can be done for a cost of about $500 more than producing a steer. While many commercial producers would prefer to leave this breeding activity to the stud breeder from whom they normally buy bulls, a few may find this alternative system attractive.

Beef AI: general conclusion

A consequence of the relatively high cost of AI is that it will remain almost solely a tool of the stud breeder who can disseminate improved genotypes through the sale of NS bulls. There seems little prospect of dramatically reducing the cost of AI, except in reducing the costs associated with oestrus synchronization; any breakthrough in this area would also improve the efficiency of cloning in the future.

Meat sheep

Natural service versus synchronized AI

The costs of AI and NS are compared below, to find the additional breeding cost per lamb associated with AI.

Table 9

Sheep Natural Service - 1 (Expensive Ram)
A relatively high price for a commercial ram is assumed

Natural Service Ram	Unit cost	Units	Total cost
Mating %		2	
Years of use for a ram		4.00	
Live lambs per ewe joined		0.96	
Natural service ram purchase	$1500	1	$1500.00
Feed cost per week	$1.00	208	$208.00
Residual value of ram	$50.00	1	$50.00
Total number of lambs born per ram		192	
Total cost per N.S. ram purchased			$1658.00
Breeding cost per lamb born	$8.64		

Table 10

Sheep Natural Service - 2 (Cheap Ram)
A relatively modest price for a commercial ram is assumed.

Natural Service Ram	**Unit cost**	**Units**	**Total cost**
Mating %		2	
Years of use for a ram		4.00	
Live lambs per ewe joined		0.96	
Natural service ram purchase	$500.	1	$500.00
Feed cost per week	$1.00	208	$208.00
Residual value of ram	$50.00	1	$50.00
Total number of lambs born per ram		192	
Total cost per NS ram purchased			$658.00
Breeding cost per lamb born	$3.43		

Table 11

Sheep Synchronized Laparoscopic AI (Cheap AI Ram)
A relatively modest price for a commercial ram is assumed. Costs of.insemination and drugs are typical.

Cost of drugs		$4.00	
Cost of insemination		$10.00	
Cost per dose of semen		$10.00	
Flock size		100	
Ewes inseminated per ewe synchronized		0.85	
Conceptions per ewe inseminated		0.65	
Lambs born per pregnant ewe		1.20	

Sheep Synchronized Laparoscopic AI	**Unit cost**	**Units**	**Cost for flock**
Ewes to synchronize	$4.00	100	$400.00
Ewes to inseminate	$10.00	85	$850.00
Semen cost	$10.00	85	$850.00
Ewes conceiving		55.25	
Misc. costs plus labour			$500.00
Lambs born		66.30	
Total cost of the program			$2600.00
Breeding cost per lamb born	$39.22		

There are signs that a combination of drug and feeding treatments could improve the pregnancy rates (Parr *et al.* 1987). These authors found that 20% to 30% of foetuses fail to develop in sheep. Of those that die, about one third are found to have chromosome abnormalities (Nicholas 1987). Thus about 14% to 20% of all pregnancies abort for reasons other than chromosome abnormalities. (Parr *et al.* 1987) concluded.that insufficient progesterone remained in the blood stream to maintain pregnancy when ewes were 'over fed'; apparently the liver was removing progesterone as a result of increased blood flow. Administering exogenous progesterone to the 'over-fed' ewes restored their pregnancy rates to normal. Under-feeding also lowered the pregnancy rate.

Thus the losses due to early embryo mortality could perhaps be reduced by the administration of exogenous progesterone and/or controlling the diet. The highest pregnancy rates that are claimed in cattle are about 80%; if the factors which lead to this level of success could routinely be replicated in other programs, it would cause a modest improvement in the cost effectiveness of AI.

Even with current rates of conception, AI will, no doubt, play a role in the dissemination of the new breeds of sheep currently awaiting quarantine clearance (e.g. Texel or Finn Landrace).

Conclusions

A. The breeding cost of a lamb born as a result of the use of synchronized laparoscopic AI is in the order of $40 per lamb.

B. The comparable breeding cost for natural mating ranges from around $10 for a ram costing $1500, down to around $2 for a ram costing $200 (extrapolated from table 10).

C. Hence the lamb bred by AI has to be at least $30 (i.e., $40-$10) more valuable than the naturally bred lamb to make up for the higher breeding costs associated with AI. Since only half the genes are passed to the lamb, differences between the genetic merit of AI and NS rams would have to be at least $60 (i.e., $30 x 2). Differences between the merit of sires, as expressed in commercial flocks, are much smaller than $60. In stud flocks, the added cost of AI is not a major deterrent especially if a ram is available only through AI.

Cervical AI using fresh semen

The use of cervical insemination in sheep is currently possible using fresh semen. It is assumed in the calculations that follow, that cervical insemination is being carried out on a large scale (1000 ewes), and that during a 17 day cycle, roughly 60 ewes will be raddled by teaser rams. Ewes are mustered in the afternoon and are inseminated the following morning. It is assumed that as ewes are inseminated, the numbers to be mustered will decline. On the first few days of the 17 day cycle, two men would be fully occupied. Towards the end of the program, the work load would be substantially less. It is assumed that two men would be required for the equivalent of 10 days. One ram should be able to provide enough semen for up to 75 ewes per day.

Table 12

Cervical insemination of sheep

Labour cost per day for two men	$500
Teaser rams, harness, diluent	$100
Ewes conceiving per ewe joined	0.55
Days of labour per 17 day cycle	10

Sheep AI - 1000 Cervical inseminations	**Unit cost**	**Units**	**Total Cost**
Rams per 1000 ewes		1	
Years of use for a ram		4	
Ram purchase price	$1500	1	$1,500.00
Feed cost per week	$1.00	208	$208.00
Residual value of ram	$50.00	1	$50.00
Total number of lambs born per ram		2640	
Labour costs per 4 years	$500	40	$20,000.00
Total cost per ram purchased			$21,658.00
Breeding cost per lamb born	$8.20		

The breeding cost of $8.20 for cervical AI can be compared with the breeding cost of $8.64 when the same ram is used in a natural service program. (table 9). This indicates that above a certain ram purchase price (the break-even price), the use of natural service is more expensive than fresh cervical AI. In other words, an expensive ram cannot produce sufficient offspring through natural mating to keep the breeding cost per lamb at a reasonable level; by using the ram in a cervical AI program the ram leaves sufficient progeny to achieve this.

The break-even price depends on the number of years of use for the ram and on the cost which is attributed to a day spent mustering and inseminating ewes, as demonstrated in table 13.

Table 13

Break-even ram price, above which it pays to use cervical AI

Labour cost per day for cervical AI	Years of use for each ram			Breeding cost per lamb born
	2	3	4	
$250.00	$338.00	$480.00	$625.00	$4.08
$500.00	$730.00	$1,070.00	$1,410.00	$8.17

When labour costs are $250 per day and rams are used for two years, the break-even price for the ram is $338. The breeding cost per lamb born, which is attributable to the cost of buying and using the ram, is dramatically less in the cervical AI program; in this example, less than $10 by comparison with more than $40 when synchronized laparoscopic insemination is used. If the purchase price of the ram is ignored, then the breeding cost of cervical AI is about $3 to $6 per lamb born, depending on labour costs. The equivalent breeding cost of synchronized laparoscopic insemination is about $26, i.e. about five times more expensive.

The Dairy Board in New Zealand collects semen from valuable bulls all year round, bulk freezes it and then uses it fresh at high dilution rates during the short mating season. If such a system could be devised for sheep, it could increase the number of situations where it might be cost-effective to use cervical AI from expensive rams.

Conclusion

Synchronized AI is not seen as offering quantum changes in industry efficiency, and is generally too expensive to use commercially. Potential improvements in these techniques are not large, but those sections of the industry that use these techniques would welcome any small increases in efficiency. The expense of laparoscopic insemination in sheep is limiting its applicability. The use of the laparoscope increases costs both because the equipment costs several thousand dollars and also because it can only legally be used by a registered veterinarian. If cervical insemination in sheep with frozen semen could be used successfully, it could have some benefits. AI is being used by stud breeders but the cost of synchronized AI in the commercial situation is too high to be attractive.

6 Multiple ovulation and embryo transfer (MOET)

Multiple Ovulation and Embryo Transfer (MOET) is a procedure in which a female is injected with a substance (usually PMSG or FSH) and thus is stimulated to produce more eggs than would normally be the case. The female is inseminated either by AI or NS but instead of letting her start a multiple pregnancy, these fertilised eggs (embryos) are flushed from her oviducts. In the case of sheep this flushing is done laparoscopically, but with cattle it is usually done non-surgically through the cervix using special catheters. The embryos recovered in this way are then transferred into recipient females which have been synchronized but not inseminated. MOET increases the number of offspring which carry the genes of a particular female, by letting others (recipients) carry her offspring rather than their own.

The use of MOET has primarily been to increase the reproductive rate of new breeds and specific animals having special value.

Another possible use advocated by some breeders is for embryos to be taken from the 'top' cows in a herd and put into the 'worst' cows. While this might appear to be an attractive idea, it suffers from the major limitation that only a fraction of the difference between the best and worst cows is transmitted to their offspring. Two factors cause this:

(1) cows pass on only half their genes to their offspring;
(2) most traits are less than 50% heritable.

In practice, the difference between offspring from the best and worst cows is usually only 10% to 25% of the difference between the cows, depending on the heritability of the trait being considered. Given these relatively small benefits, and the current cost of MOET, this use of MOET is unrealistic.

However, MOET can be used to increase the rate of change obtainable in a selection program This application has been the subject of much recent research, and will be considered in detail below.

The term 'MOET herd' is generally used to describe a nucleus breeding program where MOET is used to increase the rate of genetic change through selection on full- and half-sibs, rather than on progeny. In the sections that follow, the cost of MOET per progeny born is documented, so that the cost can be weighed against the expected benefit.

Beef

Despite the large numbers of MOET calves obtained from certain cows, the overall average number of calves born per cow programmed in commercial MOET programs is not as great as many people believe. There are, in fact, losses throughout the procedure; a significant proportion (20%-30%) of cows fail to respond at all to superovulation drugs and only around 50% of transferred embryos survive to birth. On average, we can expect about two calves born per cow programmed. A general rule of thumb is that for each donor, 6 recipients need to be prepared. In fact, on average only 4 of these turn out to be suitable at the time of embryo transfer. However, the other 2 are a real cost to the program, and so are included in the calculations below.

Table 14

Non-surgical MOET in cattle

Number of donors to flush	100
Cost of flushing a donor (zero semen cost)	$300.00
Cost to synchronize 1 recipient and transfer suitable embryos	$105.00
Calves born per programmed cow	2.00

Non-surgical MOET	Unit cost	Units	Cost for herd
Donors to flush	$300.00	100	$30,000.00
Recipients to program and transfer	$105.00	600	$63,000.00
Misc. costs plus labour			$500.00
Calves born		200	
Total cost of the program			$93,500.00
Cost per calf born	$467.50		

The breeding cost per calf born as a result of MOET is about $470. Note that the table above does not include the cost of the semen; this will be considered below.

The disruption to the calving pattern and delayed breeding of the recipients will cause additional losses, perhaps in the order of $100 to $200 per calf born. An alternative is to purchase about 1.3 recipient heifers for every calf which is wanted; these recipients would be fed for about 10 weeks during which time they would be grown out and used as recipients once or twice. Those that conceived would be retained while those that had not, would be sold at no loss; sale costs balancing their increased weight. If we calculate agistment at $7.50 per week, and interest for each of the 10 weeks at $1.50, then the cost is ($7.5+$1.5) x 1.3 x 10 =$117.

The impact of semen cost on breeding cost per calf born in a MOET program is illustrated in table 15,. In this particular example, the semen is relatively expensive ($400 per dose). Note that two inseminations, twelve hours apart, are used for MOET but it would also be normal to split expensive semen between two cows, so on average there is one dose per cow.

Table 15

Non-surgical MOET in cattle with expensive semen

Semen cost (2 split straws used = 1 straw	$400.00
Cost of flushing a donor	$300.00
Herd size	100
Cost to synchronize 1 recipient and transfer suitable eggs	$105.00
Calves born per programmed cow	2.00

Non-surgical MOET	Unit cost	Units	Cost for herd
Donors to flush (including semen)	$700.00	100	$70,000.00
Recipients to program	$105.00	600	$63,000.00
Misc. costs plus labour			$500.00
Calves born		200	
Total cost of the program			$133,500.00
Breeding cost per calf born	$667.50		

Here we see a breeding cost of $667 per calf.

In contrast, a synchronized AI program using $400 semen has a breeding cost of $718 per calf born (calculated from table 4).

Thus, where semen costs $400 per dose, the breeding cost per calf born is actually higher using AI then MOET. In other words, MOET makes better use of expensive semen. The break-even semen cost turns out to be $370 per dose; where semen costs more than this figure, these calculations indicate that it is cheaper to use MOET than to use AI alone.

The splitting of embryos is becoming much more popular because it almost doubles the number of calves born. A fee of less than $50 is being charged for each embryo split. For the case shown in table 15, this would double the number of calves to 400, but would also double the number of recipients required. The overall result (after including the cost of the splitting) is a breeding cost of $570 per calf born, which indicates a substantial advantage of embryo splitting. If the two embryo halves are placed into the same recipient (one on each side), then the breeding cost is even less: $410. In practice, the viability of each half of a split embryo is reduced slightly so the figures ($567 and $410) are somewhat over-optimistic. In addition, not all embryos are suitable for splitting.

Conclusion

Clearly, MOET is commercially viable only where there is a peculiarly high value placed on the calf as would be found in a newly established breed or where the donor cow was perceived to have exceptional qualities. If semen from a particular sire is very expensive, the use of MOET can reduce the cost per calf born, by producing more calves from one expensive dose of semen. The splitting of suitable embryos is a viable option, even at $50 per split.

Meat sheep

The number of lambs born per ewe programmed is slightly higher than with cattle and the costs are slightly less as shown below:-

Table 16

Laparoscopic MOET in sheep

Cost of flushing a donor (zero semen cost)	$200.00
Flock size	100
Cost to synchronize 1 recipient and transfer suitable eggs	$60.00
Lambs born per programmed ewe	2.50

Sheep laparoscopic MOET	**Unit cost**	**Units**	**Cost for flock**
Donors to flush	$200.00	100	$20,000.00
Recipients to program	$60.00	600	$36,000.00
Misc. costs plus labour			$500.00
Lambs born		250	
Total cost of the program			$56,500.00
Breeding cost per lamb born	$226.00		

The cost of MOET in sheep is about $230 per lamb born even when working on a large scale. This can be compared with a cost of a few dollars for a lamb resulting from a natural service (see "Sheep Natural Service - 2"; table 10). Note that the table above does not include the cost of the semen because this can vary from zero to hundreds of dollars; only the costs of labour and drugs are represented. The disruption to the lambing pattern of the recipients will cause additional losses.

When the cost of semen is high, it may be cheaper to use MOET rather than to use laparoscopic AI; in the example below, the semen cost of $100 is chosen to illustrate this point.

Table 17

Comparison of MOET and AI in sheep, when semen is expensive

Sheep Laparoscopic MOET	**Unit cost**	**Units**	**Cost for flock**
Donors to flush	$200.00	100	$20,00.00
Recipients to program	$60.00	600	$36,000.00
Misc. costs plus labour			$500.00
Lambs born		250	
Total cost (including semen)			$66,500.00
Breeding cost per lamb born	$266.00		

Sheep Laparoscopic AI	**Unit cost**	**Units**	**Cost for flock**
Ewes to synchronize	$4.00	100	$400.00
Ewes to inseminate	$10.00	85	$850.00
Semen cost	$200.00	85	$17,000.00
Ewes conceiving		55.25	
Misc. costs plus labour			$500.00
Lambs born		66.30	
Total cost of the program			$18,750.00
Breeding cost per lamb born	$282.81		

Thus, when the cost of semen is $200 per dose, it is cheaper to use MOET rather than to use Laparoscopic AI. The break-even point turns out to be $156. Note that this break-even point will be somewhat higher if there is a significant cost associated with a disrupted lambing pattern, due to the MOET program.

Selection programs which involve MOET

MOET has also been proposed as a method for increasing rates of genetic gain by lifting the fertility of beef cattle (Land and Hill 1975), dairy cattle (Nicholas and Smith 1983) and sheep (Smith 1986a); (Smith 1986b) to the level of the pig, where sib testing has become accepted as the optimum method of selection. In the case of beef cattle, Land and Hill calculated that for traits which were measurable in both sexes, before puberty, the rate of genetic change could be doubled. The same conclusion was drawn by Smith in the case of sheep. The key elements in these MOET selection programs are short generation intervals and the use of full-sib and half-sib information (both maternal and paternal).

Pioneering work in this area tended to under-play the importance of such factors as inbreeding and reduction of genetic variance under intense selection.

More recent investigations (Keller *et al.*, 1990; Wray and Simm, 1990) have revealed the importance of these factors. For example Keller *et al.* (1990) found that in herds about the size of those used in table 14, taking account of these factors reduced the predicted rates of response by between 30% and 63%. In herds twice as large as that considered in table 14, the reduction was smaller; between 22% and 44%. Factors such as population size, planning horizon, heritability and offspring numbers in a MOET program were found to have less effect than did inbreeding. To help visualise the scale of these programs,it will be recalled that a calf, born as a result of MOET, costs roughly $500 extra, so the MOET costs alone would be about $1,000,000 a year in the 'larger' herds.

Keller *et al.* (1990) assumed a loss of 0.5% per 1% inbreeding; this may not compensate for the reductions of fertility and other fitness characteristics which are commonly seen in inbreeding programs. This is particularly true of weight of calf weaned per cow joined, where the loss will be almost 1% per 1% inbreeding (see later).

In another study (Wray and Simm 1990), it was found that genetic progress in a MOET herd was about 53% better than natural mating schemes, at the same rate of inbreeding.

A long term study of inbreeding in 48 lines of beef cattle showed that there was a big variation between herds in the effect of inbreeding (Brinks and Knapp 1975). The overall effects were greatest on weaning weight due to the effect of both direct and maternal effects being depressed.

Calves born per cow joined	-0.4% per 1% increase in F
Calves weaned per calf born	-0.3% per 1% increase in F
Weaned calf weight	-0.3% per 1% increase in F

Hence, it is calculated that on average, the weight of calf weaned per cow joined drops by about 1% per 1% increase in inbreeding coefficient (F).

The effect of inbreeding on the Final weight of individuals was much smaller (0.1% per 1% increase in F), so inbreeding will be more important in vealer systems. Inbreeding has an effect on fertility and fitness traits so the economic impact of inbreeding on *profitability* may well be larger than the 0.1% found for final weight (Brinks and Knapp 1975).

Computer models of genetic gain and inbreeding

Stochastic simulation studies of closed beef breeding herds were performed to look at the effects of BLUP selection, MOET, IVF, inbreeding depression and loss of genetic variability. At the time this work was commenced, the papers by Keller *et al.* (1990) and Wray and Simm (1990) had not been published. Their conclusions are in agreement with the results reported in Appendix 1.1 and 1.2, but the approach taken by Keller *et al.* (1990) cannot indicate the variability of response due to chance. However their method is able to predict what will happen on average. The simulation program used in Appendix 1.1 was adapted from a large FORTRAN 77 program which was originally designed to study selection and inbreeding in natural mating beef herds. The original program was written by Dr P.F Parnell as part his Ph.D. thesis, where a detailed description can be found (Parnell 1987). For the present study, sections were added to simulate MOET with the variable number of embryos which are found in practice. A section to simulate the impact of IVF was also added.

In Appendix 1.1 a small example is illustrated where we have a trait with a low heritability (4%) but the trait is economically important ($25 per genetic SD). It can be seen that BLUP selection in a small MOET herd leads to $2 per year genetic increase in profitability per calf, but there is considerable variability between herds due to chance; there is a marked increase in inbreeding (about 18% in 8 years). Selection on own performance reduces the rate of gain to about $1 per year but the increase in inbreeding is four times less than with BLUP. Details of simulated selection programs for 200-day weight are presented in Appendix 1.2, but are not central to the discussion here.

Conclusion

Early work indicated that MOET selection programs could produce twice the rate of change by comparison with conventional programs. It now appears that a 50% increase is more realistic in many cases, but for small closed herds where the effect of inbreeding is more severe, a 10% increase would be more appropriate.

A weakness of all studies like those just described is that completely closed breeding herds are rare in practice, because breeders occasionally introduce genes from other studs, sometimes with the specific aim of decreasing the level of inbreeding. Such a breeding structure is difficult to simulate without a very fast computer and so was not attempted in the present study. If such multi-herd MOET breeding structures were used to avoid inbreeding problems, it can be argued that this is really analogous to an increase in the size of a single closed nucleus. Although this increase in effective nucleus size would reduce inbreeding problems, it would obviously increase the total cost dramatically but these costs would be shared by the individual herd owners.

An example of a self-contained selection program

In the following calculations, we shall start by considering the case of a large company investing in a MOET nucleus program, and that it reaps the benefits by dispersing natural service bulls, which are used in a self-replacing female population owned by the same company. In other words, the one company owns both the nucleus and commercial herds, and derives its profit solely from the use of improved bulls in its own commercial herds; no bulls are sold to other breeders. The predicted rates of genetic progress shown below (in units of genetic standard deviation (SD) per year) have been extracted from a recent study using a deterministic model (Keller *et al.* 1990). These units are converted into more meaningful dollar terms in part (ii) of the table.

Table 18

Results of a deterministic prediction of gains in a MOET program where 8 donors are mated per sire. Selection is for a trait with a heritability of 40% and a coefficient of variability (CV) of 10%. Inbreeding depression of 0.5% per 1% inbreeding is assumed.

(i) Selection response in genetic SD units per year (From Keller *et al.* 1990; table 2).

	Transfers per generation (2 years) in a MOET nucleus				
Offspring per donor	512	1024	2048	4096	8192
4	0.170	0.218	0.245	0.259	0.266
8	0.130	0.215	0.268	0.299	0.316
12	0.083	0.184	0.256	0.300	0.325
16	0.044	0.153	0.235	0.289	0.321

(ii) Additional returns per cow joined as a result of one year of selection in a MOET nucleus herd, assuming one genetic SD is worth $10 per cow joined.

	Transfers per generation (2 years) in a MOET nucleus				
Offspring per donor	512	1024	2048	4096	8192
4	$1.70	$2.18	$2.45	$2.59	$2.66
8	$1.30	$2.15	$2.68	$2.99	$3.16
12	$0.83	$1.84	$2.56	$3.00	$3.25
16	$0.44	$1.53	$2.35	$2.89	$3.21

(iii) Total MOET costs per year.

	Transfers per generation (2 years) in a MOET nucleus				
	512	1024	2048	4096	8192
Annual MOET costs	$50,176	$100,352	$200,704	$401,408	$802,816

(Since these programs involve the large-scale use of MOET, it is assumed that the unit cost can be reduced from around $500, as calculated in table 14, to $400, which is the figure used in the present calculations.)

(iv) Number of cows which need to be joined each year in order to just cover the MOET costs.

	Transfers per generation (2 years) in a MOET nucleus				
Offspring per donor	512	1024	2048	4096	8192
4	29,515	46,033	81,920	154,984	301,811
8	38,597	46,675	74,890	134,250	254,056
12	60,453	54,539	78,400	133,803	247,020
16	114,036	65,590	85,406	138,896	250,098

It appears that such an approach would be cost-effective only when the company was joining between 30,000 and 250,000 commercial cows per year. There will not be many organizations which operate on such a large scale.

Note that there would be insufficient bulls generated as a by-product of the nucleus, so a multiplier herd using NS bulls would have to be used to produce sufficient NS bulls. The multiplier herd would progress at the same rate as the nucleus but would lag by about 5 years. Note too that Keller *et al.* (1990) assume a heritability of 0.4 and use of own, half-sib, and full-sib records.

If natural service bulls from the multiplier herd were to sire 200 offspring during an active life of 4 years, then the numbers of natural service sires required to just break-even on the MOET costs would be as shown below.

Table 19

Number of new bulls required each year to service sufficient cows in commercial herds, in order to just to cover costs associated with the MOET program.

	Transfers per generation (2 years) in a MOET nucleus				
Offspring per Donor	512	1024	2048	4096	8192
4	148	230	410	775	1509
8	193	233	374	671	1270
12	302	273	392	669	1235
16	570	328	427	694	1250

In terms of bulls required, this would be a large-scale operation.

An alternative system would be for one company to run the MOET and multiplier herds, and sell natural service bulls to commercial producers. Since the benefits would not be "within company", the numbers of bulls sold would have to increase in order for the scheme to be attractive both to the commercial producer and the breeding company.

In the above calculations, the benefits of a MOET program have been presented simply in terms of dollars per cow joined, as a result of one year of selection. In order to gain a fuller understanding of the implications of these results, it is necessary to discount these benefits.

The actual magnitude of the discount factor depends on the time scales considered in both the nucleus and commercial herds. To illustrate the effect of different time scales, we can consider the following alternatives.

In the nucleus herd, one extreme alternative is to consider just one year of selection, i.e. assume that the **nucleus herd** is dispersed in the year after the costs are incurred (time horizon is 1 year). A more realistic situation might be to consider the accumulated effect of gains made in the nucleus over, say, 10 years. These two options demonstrate the sensitivity of the scheme to financial or operational viability of the nucleus or multiplier herds.

In the commercial herd, short and long time horizons might be, say, 10 years and 85 years. A time horizon of ten years in the **commercial** herd involves taking account of all of the genetic improvement which is expressed by grand-progeny and great-grand-progeny, in the ten years following the introduction of each bull from the nucleus herd into the commercial herd. The second situation involves considering the genetic improvement arising from each new bull introduced into the commercial herd from the nucleus, as expressed in all of his descendants up to 85 years after his introduction. In fact, even with a discount rate as low as 5%, benefits accrued after 25 years count for very little. But the long time horizon of 85 years has been considered here so as to illustrate the extremes.

While it is customary to use discount rates of 5% in the evaluation of breeding schemes from a national point of view (Bird and Mitchell 1980), it is more usual to use a value of at least 15% when looking at business investment plans.

In table 20, both rates are considered together with the four possible combinations of time horizons in nucleus and commercial herds.

Table 20

The factors by which returns in table 18 may be altered depending on discount rate and time horizon in both the MOET nucleus and the commercial herds.

Nucleus herd time horizon (years)	Commercial herd time horizon (years)	Discount rate	Direct traits*	Maternal traits**	Comment
1	10	15%	0.3	0.25	Pessimistic
1	85	15%	0.3	0.28	
10	10	15%	1.8	1.38	Realistic
10	85	15%	2.2	1.86	
1	10	5%	0.5	0.47	
1	85	5%	0.6	0.62	
10	10	5%	4.5	4.08	
10	85	5%	12.2	12.33	Optimistic

* Number of discounted expressions of nucleus herd genetic gains per commercial cow joined; progeny growth or carcase traits

** Number of discounted expressions of nucleus herd genetic gains per commercial cow joined; daughter milk or fertility traits.

Row three in table 20 is labelled as "Realistic"; this is a personal judgement and may not be acceptable to everyone. It is clear that if a low discount rate is coupled with a long planning horizon, the gains are much larger (up to 9 times more) than the "realistic" situation. Conversely, a high discount rate and a short time horizon predicts returns which are up to 6 times lower than the "realistic" situation.

If the gains are 1.38 times more valuable, then the number of cows and bulls required in the commercial herds could be 1.38 times lower than those shown in tables 18(iii) and 18(iv).

The other critical figure used in quantifying the effects of MOET was the value of one SD of genetic gain. In table 18, this value was assumed to be $10. Local evidence directly relevant to this assumption has recently become available from the long-term single-trait selection program conducted by the NSW Department of Agriculture in Angus cattle at Trangie.

The interim results released at the September 1990 Open Day at Trangie suggest that for a property stocked at the optimal stocking rate, 100 unselected cows would be $4800 less profitable (per year) than 98 "High-Line" cows (see page 22 of the Open Day booklet; 98 High-Line cows give the same stocking rate as 100 unselected cows). The improvement in profitability per cow is thus $4800/100 = $48 per cow per year. The High-Line herd is the result of 14 years of selection for growth rate between birth and 12 months of age, which has increased growth rate by 2.4 standard deviations. The value of a standard deviation of realised genetic change in gross profit is thus $48/2.4 = $20 per cow per year, which is twice as great as the figure of $10 used in table 18(ii). A central assumption in these calculations is that 98 High-Line cows and their calves will eat the same as 100 of the Control-Line cows and their calves. It will be surprising to many that the stocking rates are so similar for cows which differ by 12% in mature size and by 9% in metabolic body weight. It is important that the Trangie Angus selection lines are thoroughly evaluated for feed and economic efficiency to confirm these surprising preliminary results.

From the above consideration of the effects of time horizon, discount rate, and the value of one unit of genetic improvement, it is evident that there is a wide range of possible conclusions that can be drawn concerning the effects of MOET. At the very best (long time horizon, low discount rate, and $20 per SD genetic improvement), calculations like those in tables 18 and 19 show that a scheme involving a commercial herd of as few as 1200 cows might generate sufficient profit to cover MOET costs in a small scale nucleus breeding herd. Conversely, a combination of short time horizon, high discount rates and $10 per SD genetic improvement indicates that only very large scale operations involving around 120.000 cows would break even; under such conditions MOET is unlikely to be profitable. Small scale programs carry a significant risk of not achieving expected rates of progress (genetic drift) and/or suffering very high rates of inbreeding, simply due to chance.

Conclusion

The high costs associated with MOET, and the need to have nucleus herds that are large enough to avoid the problems associated with inbreeding and genetic drift, mean that it may be difficult to recoup the costs of such schemes, unless thousands of bulls were sold. The value of MOET breeding programs is very dependant on the time horizon and discount rate that is chosen.

A better understanding of how to improve feed efficiency through selection is required before predictions of the economic consequences of MOET breeding programs can be accurately made.

7 Cloning

Limited cloning has been possible for several years (Willadsen, 1986, 1991), but is far too expensive (perhaps more than $1000 per calf born) and has such a poor success rate (Barnes *et al.* 1990) that it is not a commercial proposition. The present method of embryo cloning involves splitting a 16- to 64-cell embryo into its individual cells, and transplanting these into the cytoplasm of recipient enucleated eggs. The recipient eggs can be flushed directly from a super-ovulated cow or, more recently, produced by culturing oocytes from ovaries collected from abattoirs. Embryologists are optimistic about the prospects (Seamark, 1990 pers. comm., Herr, 1990 pers. comm.) for cheap (less than $50) clones in the near future, providing that the required resources are put into the development phase now.

A laboratory set up to produce 200,000 cloned embryos ready for transfer, might have approximate costs as follows.

Table 21

Some of the costs in producing cloned embryos.

Source of expense	Cost $
Lab rental	80,000
Media and disposables	100,000
Straws for storage of embryos	20,000
Embryologist salary and on-costs	130,000
Technicians for collecting abattoir ovaries (4 @ $20,000)	80,000
Technicians for culturing oocytes and ES lines and transferring nuclei (8@$25,000)	200,000
Other unspecified costs	200,000
Total for 200,000 cloned embryos	810,000
Cost per cloned embryos ready for transfer (810,000/200,000.)	$4.05

This table is not intended to provide accurate costings but it indicates that the cost per clone might be quite low ($4.05 each). Even if there was a pre-implantation mortality rate for these embryos as high as 90%, the cost per viable embryo would be about $40 each. This compares with hundreds of dollars for embryos flushed in the conventional way.

Research on split embryos could answer the question of how similar cloned individuals will be. At present there are two conflicting predictions. The first is based on identical twin studies where a very high degree of similarity (80%) between members of a clone family is often seen. The second arises from the fact that if the repeatability for a particular trait is known to be, say, 50%, then this should be the upper limit for the correlation between members of a clone family. A simple way to resolve this question would be to transfer cloned embryos into a variety of recipients and grow the calves out under various conditions to see what the real similarities are between clones.

Although cells can be held in tissue culture at present, it is not known whether they can be made to retain the ability to form a complete new individual (i.e. whether they can be maintained in a totipotent state). Research on media and tissue culture techniques should be aimed at the creation and maintenance of totipotent cell lines. It will be of considerable importance to find out how to prevent mutations in such cell lines should this problem arise. The leukemia inhibitory factor (LIF) discovered at the Walter and Eliza Hall Institute seems capable of assisting in this respect, but would need further research and development to extend its usefulness in mice, to sheep and cattle.

The cost of collecting ovaries from abattoirs is so low that there is no need to obtain very large numbers of embryos from one ovary. However, the ability to take an ovary from a mature elite female and generate many thousands of offspring might be of benefit to breeders. Note that this is not cloning, but the technique would be useful in the production of clones, particularly if cytoplasmic effects were important. It could also be useful if it was desired to rapidly increase the numbers of a numerically small breed. Alternatively, one might envisage female carcases being screened by staff of a breeding company for desirable characteristics (e.g. marbling) and ovaries being salvaged where appropriate.

Beef

The ability to clone cell lines cheaply (less than $50 per embryo) would be of profound importance to the cattle industry, not only in Australia but also world wide. Since the members of a clone are all identical, it should be obvious that clone transfer will normally be carried out using clones of known sex. Although the cost of cloned calves might be too high for this technology to be used in commercial herds, there may be specialist markets (e.g. Japan) where a feedlot might contract to buy cloned calves at the necessary premium (Hammond, 1990, pers. comm.). The cost of putting cloned embryos into commercial cows may be very similar to the cost of using synchronized beef AI, discussed earlier, providing the cost of the embryo is of the order of $10. In both cases the females have to be synchronized and a technician is required to deposit material near the cervix. (In the case of embryos, it may take a few minutes extra since greater care is needed to deposit the embryo.)

Apart from the advantage of buying calves that all possess the same desirable combination of genes, there would probably be advantages in the modified management systems which could be used when all animals in a group were genetically identical. Feeding and disease control could be carried out with a greater degree of certainty about how the clones would react. On the other hand, plant breeders recognise the major potential danger of monoculture, in that a successful disease organism can spread rapidly in a population where all plants are genetically identical. If cloning is to be used for cattle, then it would be wise for each farmer to use a range of clone-lines.

It must be stressed that there will still be substantial variation between cloned individuals, because most of the traits of interest have heritabilities and repeatabilities that are less than 50%.

Herd replacement using clone transfer

The table in Appendix 3.1 shows the number of cloned embryos which would be needed to replace a herd of cows. It can be seen that without twinning, the process will take two years and will probably require about twice as many embryos as there are cows. With twinning, the process could be completed in one year.

Interactions between the beef and dairy industries

If the use of cloning were taken up in the dairy sector, it is likely that the trade in surplus animals from the dairy to the beef sector would expand.

The impact of such technology would be seen particularly in the dairy industry, but it is suggested that there would be a substantial flow-on effect into the beef industry. The scenario described below, which involves the use of clones and twinning, is obviously only one of many possible future structures, but it emphasises the dramatic industry reconstruction which might take place. It should be noted that many dairy farmers would need to be convinced as to the wisdom of twinning; current AMLRDC-sponsored research into the management aspects of twinning should help to clarify the situation.

In order to investigate the potential impact of cloning, we first need to establish how many calves we can expect when two cloned embryos are transplanted at a time. The necessary calculations are presented in table 22.

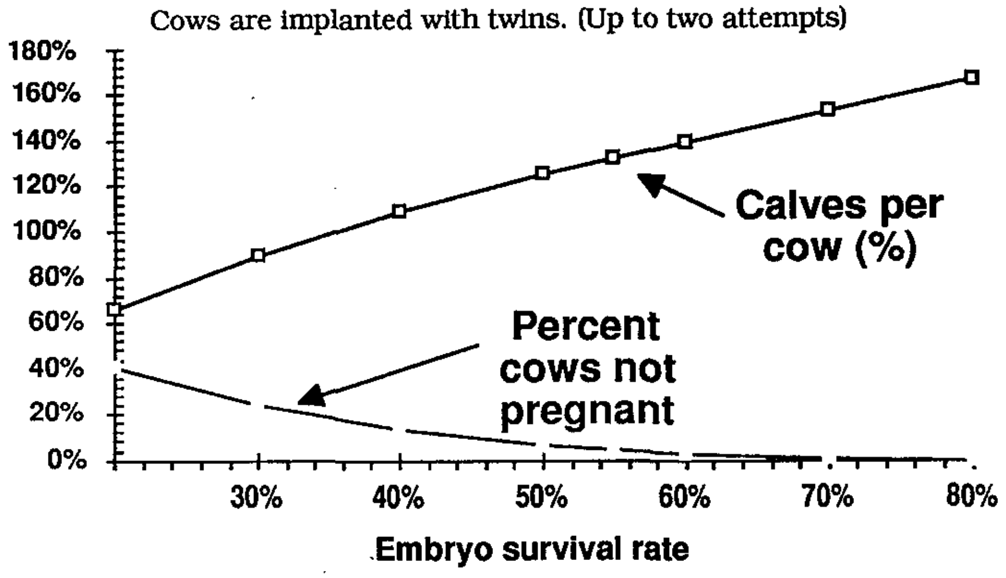
Table 22

Calculation of the expected number of calves per cow with up to three attempts to implant her with two embryos.

Percentage of embryos transferred which survive	55.0%
Percentage of cows pregnant with twins on the first attempt (a)	30.3%
Percentage of cows pregnant with one calf on the first attempt (b)	49.5%
Percentage of cows not pregnant on the first attempt	20.3%
Percentage of cows pregnant with twins on the second attempt(c)	6.1%
Percentage of cows pregnant with one calf on the second attempt (d)	10.0%
Percentage of cows not pregnant after two attempt	4.1%
Percentage of cows pregnant with twins on the third attempt(e)	1.2%
Percentage of cows pregnant with one calf on the third attempt (f)	2.0%
Percentage of cows not pregnant after three attempts	0.9%
Overall number of twins per cow (a + c + e = X)	0.376
Overall number of singles per cow (b + d + f = Y)	0.615
Total number of calves per cow (2 x X + Y)	1.367

These calculations show that if 55% of embryos survive to produce a calf, then we can expect, that after three attempts, 0.9% of cows will still not be pregnant. For those that were inembryonated at least once, we can expect 1.367 calves per cow. The percentage of embryos that survive determines the number of calves and the percentage of non-pregnant cows as shown in Figure 1.

Figure 1



We shall now consider a dairy population of 2 million cows, and suppose that 50% of them (1,000,000) become involved in the use of cloned embryos. At present, farmers mate about 30% of their dairy cows to beef bulls, and although some of those who use beef semen (or bulls) find that they do not have sufficient dairy heifers born, an industry figure of 30% beef crossing seems reasonable. This is approximately the level which balances the need for replacements against the profit which can be made from selling crossbred beef animals.

In those herds where it is anticipated that cloning might be used, 30% of beef crossing implies that 1,000,000 x (1.0-0.3) = 700,000 cows are currently required to breed replacement dairy cows.

If cloned female embryos are transferred in pairs, one might hope that each cow would produce two female calves, which is four times as many female offspring per year as at present. However, to be more realistic, we can start with the figure of 1.367 female calves per cow obtained in table 22.and divide this by 0.5 (the number expected under natural circumstances). We expect, therefore, that each cow will produce 1.367/0.5 = 2.734 times as many female calves as at present. This means that only 700,000/2.734 = 256,035 cows are needed to act as recipients of dairy embryos in order to maintain the current dairy cow population.

This leaves 743,965 out of the 1 million cows which can carry beef calves. The cheapest *alternative for these cows is to mate them* to a beef bull as is done at present. However, if cloned embryos were cheap enough relative to the value of the resulting calf, one might see the use of specialised clone lines - again implanted in pairs.

One option would be to use male beef straightbred or preferably first-cross clones, which had been chosen to limit dystocia while optimising their value as terminal beef animals. Alternatively these embryos could be members of either straightbred or first-cross terminal beef sire line clones, selected to impart particular advantages, for example a high degree of marbling (see later).

Another option would be to transfer female clones of genotypes which are most profitable as beef suckler cows, i.e. as dams of the slaughter-generation beef animals. These beef females (matrons), which would most likely be first-cross hybrids, would have to be *transported from the dairy areas to the traditional beef regions. When they reached sexual* maturity they would be mated to the most appropriate terminal sires, or they could be implanted with clones of the most appropriate slaughter-generation genotype.

It seems reasonable that the use of two sexed beef embryos will lead to at least one calf born. This assumption is not in conflict with the implied low net reproductive rate of cows used to breed dairy replacements. Remember that in order to maintain the most desirable calving pattern, some potential replacement female calves are rejected.

Remembering that there are 743,965 cows available for implantation of beef clones, and that on average, each cow produces 1.367 calves, one would therefore expect 743,965 x 1.367 = 1,017,000 female calves to be potentially available as beef suckler cow replacements each year. Assuming that only 85% of these actually survive to become beef suckler cows, and that the average productive life span of these cows is six years, it is concluded that the supply of suckler cows from the dairy industry could sustain a beef breeding cow population of 1,017,000 x 85% x 6 = 5 million.

The calculations described in the preceding paragraphs are summarised in table 23.

Table 23

Calculation of the size of suckler cow population which could be maintained by female replacements from the dairy population, when cloning and twinning are used.

Total dairy cow population	2,000,000
Percent of dairy herds using artificial (cloned) twins	50%
Dairy cow population in herds using artificial (cloned) twins	1,000,000
Present percent of cows available for beef matings in dairy herds.	30%
Present number of cows required for breeding dairy replacements	700,000
Factor by which the number of female calves born per milking cow is increased	2.734
Future number of cows needed to breed dairy replacements	256,035
Future number of cows potentially available for beef purposes	743,965
Assumed number of calves born per cow implanted with twins (up to 3 times)	1.367
Number of female calves available as suckler cow replacements	1,017,000
Percent of these calves which survive to become suckler cows	85%
Average number of years in the suckler herd	6
Size of suckler cow population which could be maintained.	5,186,700

At present one sees large numbers of dairy calves being slaughtered shortly after birth because it is not economical to rear them. Efforts to create a pink veal industry have not yet met with great enthusiasm. Unless the marketplace pays a premium for cloned calves sufficient to provide a profit after accounting for the additional costs, dairy farmers will not see a benefit in producing and rearing beef clones.

As seen in table 23, if both twinning and cloning are adopted in dairy herds, we might expect a population of over 5 million suckler cows being maintained from dairy herds. But even if twinning were not taken up as part of this scenario, there could still be substantial numbers of beef pregnancies in the dairy population, as shown in table 24. The two figures that differ in this table, compared to table 23, are the number of calves born per cow implanted (.91) and the female calf reproductive factor (1.82). The former figure is simply the result of having three attempts at achieving a pregnancy, each having a probability of 0.55, while the second arises from dividing 0.91 by 0.5, as explained for the calculations in table 23.

Table 24

Calculation of the size of suckler cow population which could be maintained by female replacements from the dairy population, when cloning, but not twinning, is used.

Total dairy cow population	2,000,000
Percent of dairy herds using cloned embryos	50%
Dairy cow population in herds using cloned embryos	1,000,000
Present percent of cows available for beef matings in dairy herds.	30%
Present number of cows required for breeding dairy replacements	700,000
Factor by which the number of female calves born per milking cow is increased	1.82
Future number of cows needed to breed dairy replacements	384,615
Future number of cows potentially available for beef purposes	615,385
Assumed number of calves born per cow implanted with clones (up to 3 times)	0.91
Number of female calves available as suckler cow replacements	560,000
Percent of these calves which survive to become suckler cows	85%
Average number of years in the suckler herd	6
Size of suckler cow population which could be maintained.	2,856,000

If cloning is used without twinning, there could still be sufficient beef pregnancies in the dairy population to maintained a suckler cow population of nearly 3,000,000.

The cost of the embryo is analogous to the cost of the semen, and the pregnancy rates are likely to be very similar for both, so the cost of cloned pregnancies will be at least as high as for AI. AI is used extensively in the dairy industry, but its use in the beef and sheep industries is limited by its cost.

Conclusion

Whatever the eventual industry structure, it is likely that the use of cloned embryos will begin in the dairy industry, where the cost of synchronization is avoided, and this will have repercussions on the beef industry in temperate areas.

Meat sheep

The cost of implanting cloned embryos into sheep is likely to remain too high for this to become a widespread practice because the cost structure will be similar to that for laparoscopic AI. Unlike cattle, the cervix of the sheep is difficult to penetrate with a catheter, so a laparoscope will be needed. However, in Australian law, the use of a laparoscope is seen as an act of Veterinary Science and therefore cannot legally be performed by a technician without supervision by a veterinarian. This is unfortunate, since a technician could implant cloned embryos into cows for less than $5 per cow (on a large scale), whereas a veterinarian would probably charge about $15 per sheep. However, the conclusions are little affected by the exact cost of laparoscopic inembryonation.

Table 25

Sheep cloning: very cheap embryos ($10) but typical costs for insemination and drugs.

Cost of drugs	$4.00
Cost of inembryonation with laparoscope	$15.00
Cost per embryos	$10.00
Flock size	100
Ewes inembryonated per ewe synchronized	0.85
Conceptions per ewe inembryonated	0.50
Lambs born per pregnant ewe	1.25

Sheep inembryonation using laparoscope	**Unit cost**	**Units**	**Cost for flock**
Ewes to synchronize	$4.00	100	$400.00
Ewes to inembryonate	$15.00	85	$1275.00
Cost of a cloned embryo	$10.00	85	$1700.00
Misc. costs plus labour			$500.00
Lambs born		106.25	
Total cost of the program			$3875.00
Breeding cost per lamb born	$36.47		

The breeding cost per lamb born is $36.47 when cloning is used. If the cost of each cloned embryo was $50 instead of $10, the breeding cost per lamb born would be about $100. If technicians were used in place of veterinarians, and the cost per ewe was $5 instead of $15, the figure of $36.47 would fall to $28.47.

There may be occasions where, for example, a clone with highly desirable carcase and wool traits is identified, and a breeder uses cloning to replicate this combination of genes rapidly; normal natural service sires would then be used to transfer these genes to the commercial population.

Norwegian sheep have a cervix which is relatively easy to penetrate, so non-surgical AI is common. One might speculate about the ease with which the anatomy of the cervix of Australian sheep might be changed by selection.

Conclusion

The cost of clone transfer in sheep will be at least $28 per lamb born, so it is not likely to be attractive in commercial herds.

Selection programs which involve cloning.

In a recent paper, Smith (1989) discussed the various roles for clones in beef selection programs - terminal clones, maternal clones and cross-line clones. A system was envisaged whereby a purebred nucleus breeding program would generate genetic change using MOET and cloning; and only the very best of the nucleus lines would be made available to commercial producers. The cloned animals would actually be better than the animals retained for breeding in the nucleus because weaker selection is required in the nucleus in order to limit inbreeding.

Smith's calculations predict a 15% to 30% initial, one-off change in genetic level due to cloning, then 2% to 3% change per year after that. However, there will need to be extensive testing of clone lines before their widespread release, to ensure there have been no undesirable correlated responses to the intense selection. Freezing is suggested as the way to retain clone lines while a clone test is performed, but if this is not possible, then it would be necessary to keep the clone lines alive in tissue culture.

Maternal lines would be likely to benefit the most from the creation of crossbred clone lines, but, in practice, this will be too expensive unless recipients are dairy cows where synchronization costs are avoided by routine daily oestrous detection.

An interesting area which could be explored as a result of the increasing success of embryonic cloning is the degree to which mitochondria differ between animals, breeds and species (Huizinga *et al.* 1986). These sub-cellular organelles contain their own DNA and are not passed from sire to progeny in the normal manner. Instead, mitochondria are passed from dam to progeny through the cytoplasm. Larger than expected variation in calf size in clones resulting from nuclear transplant has been noted by Willadsen (1991) . This could be a result of genetic variation in the DNA of the mitochondria of the recipient enucleated eggs. Specifically, there may be 'heterosis' when mitochondria derived from the donor and recipient are put into one cell.

It is possible that clone lines could be established for terminal sire breeds which conferred an additional, say, $10 profit per slaughtered cross bred offspring. Assuming that such sires left 200 calves through the use of natural service, this represents $2000 extra profit per terminal sire. These cloned terminal sires could be produced for an added cost which is much less (perhaps $50 to $500) than the additional profit of $2000. Probably the cheapest method of producing these bulls would be in dairy herds, using recipient milking cows which were not needed for breeding replacements, as described earlier. However, the organisation needed to screen a large number of clone lines for use as terminal sires would be substantial and would require a long planning horizon, as shown in table 26.

Table 26

Possible steps in a breeding program for cloned NS bulls

Year	Activity
0	Make a series (100) of male embryonic clone lines and produce, say, 5 bulls per line.
1	Rear 100 x 5 bull calves.
2.5	Test serving capacity of the lines using, say, 3 identical bulls. Cull 50 of the lines on low serving capacity test,
2.5	Use 50 x 2 bulls as natural mating sires.
3.4	Check actual fertility and ease of calving of calves. Cull 5 more lines if recording facilities are limited.
5	Record calves bred by 45 x 1 bull under feedlot conditions and measure efficiency and carcass merit.
5.5	Collate results and replicate the top 2 or 3 clone lines for release as NS sires.

The reason why this type of scheme is so cost-effective is that,

(a) once identified, a good clone line can be used for many years without much further expense, and
(b) the large number of calves from a fertility-selected NS bull helps to reduce the added cost per calf slaughtered.

The epistatic effects on the serving capacity of the bulls would be predictable even though epistatic effects in the slaughter generation would not be so predictable. The number of calves tested per line in a feedlot could be varied according to the coefficient of error variation in the feedlot. Even under the roughest of recording and management systems, a total of 70 calves per line would probably be plenty to begin with. Competition between companies testing bulls would determine the extent to which more terminal sire lines were tested, and the added degree of accuracy of these tests.

A variation of the scheme shown in table 26 would involve some culling of the clone lines in year 2, based on the mean growth performance of the clone line (own performance rather than progeny performance). This might help minimize costs of testing, while having little effect on the merit of the top few clone lines identified in year 5.5.

It has been suggested (Goddard, 1990 pers. comm.) that the mean performance of the offspring of herd bulls resulting from more conventional selection procedures would be similar to that of the bulls produced by clone-line selection. While this may be true for long-term breeding schemes, the gains to be made within the time-frame of table 26 would be greater when using clone testing. This is particularly true when carcase traits are of importance.

It has been further suggested (Goddard, 1990 pers. comm.) that where cloning of embryos is limited merely to the production of identical twins, it would be possible to castrate one of a pair of twin bull calves, and test it under feedlot conditions and then use the entire twin through AI to breed herd bulls assuming that he was the best of a team of similarly tested bulls. This sort of scheme is technically feasible even with today's technology, although it would not be such an attractive financial proposition if we could produce identical cloned herd bulls.

It is doubtful whether these types of programs would be economic for terminal sire meat sheep. It is probable that the $10 advantage which was assumed for beef animals would be only $2 in the case of meat sheep (Banks, 1990 pers. comm.); assuming 200 offspring per ram, we have $2 x 200 = $400 extra value per ram sold. The cost of producing the cloned ram would be roughly the same as for the bull (perhaps $50 to $500), so this may not be so attractive for sheep as for cattle. It is unfortunate, therefore, that most laboratories where cloning research is being conducted, still tend to favour the sheep as the preferred experimental animal, on the grounds of cost.

At present, cloned embryos cannot be made using somatic cells of adult mammals, but it seems possible that within a few years they will be generated cheaply from embryonic cell lines. In the longer term, if it becomes possible to clone adult animals, then there will be substantial additional advantages to be gained from cloning through the multiplication of animals of outstanding merit.

Conclusion

Cloning could offer substantial benefits to both beef and dairy farmers. It would be prohibitively expensive to develop cloning before a cheap, reliable (<$1) source of recipient embryos (or oocytes) can be generated. Research into oocyte and embryo culture techniques and media needs to be expanded now. Research should be aimed at how to harvest large numbers of oocytes from ovaries of slaughtered females. While there has been some success in this area, there is considerable development work needed to increase the yields of viable embryos fertilised in vitro (IVF), and to increase its cost-effectiveness. Mass-produced cloned embryos could both be cheap and have substantial benefits.

8 Sex control

Various methods are potentially available for sex control (Reed, 1985; Van Vleck, 1986). There are two major categories of methods; the first involves selection of embryos having the desired sex (Herr *et al.* 1990), either before implantation or very early in pregnancy; the second involves the use of sexed semen to pre-determine the sex of an embryo (and increase the number of them).

Embryo sexing

The first method has the disadvantage that when one sex is not wanted, half the embryos harvested have to be discarded. With present embryo harvesting costs of $300 per cow flushed and an expectation of 2 calves born, this implies a cost of more than $150 for each calf that is the wrong sex (the semen cost would lift this figure above $150).

The values used in the table below are typical. We have assumed that the calf with the less desirable sex is worth no more than a natural calf, so the question is: will the cost of the assay cover the saving to be made by not transferring unwanted embryos?

Table 27

The benefits of embryo sexing related to sexing assay price.

	Assay cost			
	$120	**$100**	**$53**	**$40**
Value of a normal calf at birth	$100	$100	$100	$100
Value of a MOET calf of the desired sex at birth	$1,000	$1,000	$1,000	$1,000
Value of a MOET calf of the less desired sex at birth	$100	$100	$100	$100
Number of embryos per flush suitable for transfer	4.0	4.0	4.0	4.0
Percentage of calves born per transfer	50%	50%	50%	50%
Cost of flushing a donor	$300	$300	$300	$300
Cost of synchronizing a recipient and transferring an embryo	$105	$105	$105	$105
Semen cost	$30	$30	$30	$30
Alternative 1. Keep all embryos. **Do not use assay**				
Flush	$300	$300	$300	$300
Transfers - 4 @$105	$420	$420	$420	$420
Semen	$30	$30	$30	$30
Total costs	$750	$750	$750	$750
Sale of desired sex calf	$1,000	$1,000	$1,000	$1,000
Added profit from sale of less desired sex calf	$0	$0	$0	$0
Total Returns	$1,000	$1,000	$1,000	$1,000
Benefit (1)	$250	$250	$250	$250
Alternative 2. **Do assay.** Discard the wrong sex embryos				
Flush	$300	$300	$300	$300
Transfers - 2 @$105	$210	$210	$210	$210
Semen	$30	$30	$30	$30
Sexing assay cost - 4 embryos / donor	$480	$400	$210	$160
Total costs	$1,020	$940	$750	$700
Sale of desired sex calf	$1,000	$1,000	$1,000	$1,000
Total Returns	$1,000	$1,000	$1,000	$1,000
Benefit (2)	($20)	$60	$250	$300
Added earning due to sexing assay (2) - (1)	**($270)**	**($190)**	**$0**	**$50**

It can be seen that the sexing assay is too expensive if it costs more than $53 per assay. It might be argued that splitting of embryos is normally performed at the same time as a biopsy is taken, but this will have little effect on the results because it increases the returns from both options at the same rate. The value of the desirable sex calf and the cost of flushing has no effect on the advantage (or otherwise) of the sexing assay.

Frequently, however, both male and female calves from an elite mating have values well above the natural calf from the recipient, which means that both sexes *are* wanted. If the value of the less desirable calf is $310, then even if the sexing assay costs nothing, there is no financial advantage in using the sexing assay.

Also, often the cost per transfer is reduced when more than 10 transfers are performed on a property; if we modify the table and drop the costs from $105 to $50, then the break-even assay price would drop from $53 to $25. If the cost of the transfer were $200, then the break-even price for the assay is $100.

Conclusion

The cost of the sexing assay is critical in deciding whether it is better to transfer all embryos without knowing their sex. The cost of a sexing assay needs to fall well below $50 before there is a marked advantage in its use. The other critical factor is the value of the additional 'unwanted' calves, which, if more than about $300, removes any advantage of sexing even if it were free.

Semen sexing

Semen sexing would have a distinct advantage if it increased the number of embryos of the desired sex. However, none of the numerous attempts to sex semen have been successful to date. Fluorescence Activated Cell Sorting (FACS) (Ericsson *et al.* 1973; Reed 1985; Amann 1989) has some potential as a semen-sexing system (Reed 1985), but the very low number of sperm sorted per day and the high capital cost ($700,000) means that the technology will be used in limited circumstances (e.g. IVF). It is estimated that perhaps one dose of semen could be processed per day, but the interest cost alone would be $300 per day, and there are also doubts concerning mutagenic effects of the process. Development of this technique for animals has not progressed to the point where a commercial service is operating.

Amann (1989) has defined 'success' of semen separation as: ". . . no reduction in fertility, a high probability of achieving offspring of the desired sex, minimal loss of sperm during the processing, a simple procedure applicable to numerous samples in a given day, at low cost."

Immunological methods have been proposed whereby a male would produce sperm cells of only one sex but so far, no success has been claimed. An immunological method in which a vaccinated female rejects pre-implantation embryos of the "wrong" sex, would probably not be widely accepted; the loss of embryos and disrupted calving pattern would cause greater economic losses than the advantage of having the right sex.

The economic pressures for one sex versus another would probably vary with time and the changing perception of the prospects for the industry. When growers are optimistic, the female calf will be seen as a more desirable commodity because of its reproductive potential. When prospects are bleak, the male calf will be preferred because of its slightly faster (6%) growth than females. Control of sex would enable growers to adjust the numbers of breeding females more rapidly in response to the prevailing industry outlook. Although superficially this might seem attractive, it may have a destabilising effect on prices. Modelling such a complex situation could be done using the Econometric Model of Australian Broadacre Agriculture (EMABA) (Dewbre *et al.* 1985) but such a study would cost at least $10,000 (Corra, 1989, pers. comm). It might be wise, therefore, to defer this type of modelling until such time as it seems more likely that sex control will be cost-effective in extensive beef and sheep industries.

With the recent discovery of the gene on the Y-chromosome which triggers embryonic differentiation into the male phenotype, there are now some possible transgenic manipulations which might produce 100% male offspring (Goddard, 1990, pers. comm.). For example, a male clone-line might be produced which carried the male gene on both its X and Y chromosomes, thus producing 100% male offspring. These bulls would be sold for use as natural service terminal sires. They could be replicated cheaply within the dairy herd using milking cows not needed for replacements.

Conclusion

The prospects for producing sexed semen in quantities sufficient for general AI use have not improved significantly, despite considerable research. Transgenic manipulation of the expression of the male sex gene and the use of natural service male clones may hold the best prospects.

Selection programs involving sex ratio control

As part of the present study, the effect of altering the sex ratio in a natural service breeding herd of 100 females was investigated, using Parnell's (1987) deterministic model of a selection program. As shown in table 28, the predicted rates of gain were almost unaffected by sex ratio; drastic alterations to the sex ratio produced at the most only an extra 500-491 = 9 kg of response, compared to the response obtained with the natural sex ratio. The main reason for this insignificant effect is that, with a trait which is expressed by both males and females, the gains to be made by more intense selection of males are offset by lowered selection pressure in females (and vice versa).

Table 28

The effect of altered sex ratio on expected genetic change over 50 years of selection in a closed breeding program, starting with a mean yearling weight of 320 kg in the first year.

	60% Male calves born	**50% Male calves born**	**25% Male calves born**
Predicted averageyearling weights at the end of 50 years (kg)	500	491	498
Increase in inbreeding (dF%)	21.8	21.7	21.3
Mean generation interval (years)	2.99	2.98	2.95

Note that if more than about 65% male calves are born, there will be insufficient female replacements.

Beef

The use of AI with sexed semen to produce male calves in commercial beef herds is unlikely to be cost-effective since the added growth potential (about 6%) of male calves would be insufficient, especially if much of this additional 6% were dissipated through larger feed requirements of males. Recall that the estimated cost of AI was about $50 per calf born (see table 4). If the additional profit to be gained from male slaughter stock is assumed to be $10, and a natural service bull capable of generating 100 more male calves and 100 fewer female calves during its lifetime could be produced, the value of such a bull would be $1000 more than a bull leaving a 50:50 sex ratio. This size of benefit is large enough to justify considerable effort towards controlling sex ratio in a natural service sire. However, if the bull with the altered sex ratio caused a fall in herd fertility (e.g. female foetuses abort), then the cost would have to be weighed against the benefits.

Meat sheep

In the case of meat sheep, it is clear that the terminal-cross sire breeds would be best exploited by the use of a sexing method which generated more male lambs. However, for the same reasons as above, the probability of sexed semen from terminal sires being used in commercial flocks seems remote.

9 Twinning

There has been considerable interest in twinning, with much of the Australian work being centred on CSIRO's facility at Armidale. Some of the research in this area has been summarised recently by Piper and Bindon (1989) and Bindon (1989).

Barlow (1989b) has calculated that the net benefit of twinning in a vealer operation would be about $32 to $55 per cow mated. This assumes that about 45 extra calves would be sold per 100 cows mated, and that costs such as feed, labour and veterinary supervision were accounted for.

Barlow highlighted the danger of the inappropriate use of an anti-Inhibin vaccine where adequate feeding, labour and veterinary supervision are not available. It was recommended that management strategies need to be thoroughly tested before the technology is promoted. It was anticipated that twinning through the use of MOET and IVF would be of primary interest to stud breeders only if there was sex control too (to avoid freemartins). Anti-Inhibin vaccine would be of particular interest to those involved in vealer production.

Various methods have been discussed (Seidel 1985) for inducing twinning, including MOET, hormone injection, and more recently, vaccination with an anti-Inhibin vaccine (now under development). Although the use of PMSG can induce twins (Bindon 1989), there are disadvantages; more than 2 calves can be born (poor survival and growth); cows need to be synchronized first (an additional cost); 40% of the herd over-respond but have lowered pregnancy rates (10%-13%), and of those that are pregnant, only about 9% have twins. The cost of PMSG and prostaglandin combined with unpredictable results mean that this is not a viable option. The proposed use of the anti-Inhibin vaccine would probably be cheaper than PMSG,particularly since it is expected that the vaccination would last for several cycles (Bindon 1989). The only drawback is that the date of calving would not be known, as it would be in the PMSG/prostaglandin system.

Genetic means for increasing twinning in sheep are available (Morris 1990), and despite a fairly low heritability (13%) for twinning rate, the average realised response to selection has been 1.3% per year.

Proponents of twinning have been aware that cross-mixing of foetal blood from twins of opposite sex usually result in heifers being sterile (free-martins), thus reducing the desirability of the concept. Three new techniques which, in theory, could prevent this are:-

i. Splitting embryos into two, and placing both halves in the same cow. Even if this were done on a large scale, it would not be economically attractive in the commercial industry because of the high cost of MOET.
ii. Applying a sexing assay to the embryos at the time of transfer and transferring pairs of the desired sex only. This would be far too expensive ($120 per assay).
iii. Transferring two members of a clone of known sex (if infinite embryo splitting - juvenile cloning - were a reality).

Biological efficiency

In biological terms, the efficiency of a meat producing enterprise is at its greatest when there is a rapid turnover of the female breeding herd (Taylor *et al.* 1985). This seemingly extraordinary situation is due mainly to the fact that growing animals use food more efficiently than mature cows. Taylor *et al.* (1985) suggested that where it was possible to determine the sex of a calf, the ideal system (in biological terms) would be where almost all calves were heifers, and once the young female had weaned her first calf, she would be slaughtered (the "once-bred heifer").

In economic terms this system is not attractive. The economic forces that would favour the "once-bred heifer" system would also favour systems where there is a rapid turnover of the female herd. In practice, however, most beef producers tend to keep their cows for as long as possible. Using a complex simulation, Marshall and Stewart (1990) showed that the best *economic* efficiency is obtained when females are not culled until later in life. In contrast to Taylor's study, reproductive rate for heifers was assumed to be lower than that of cows; this, and the relative economic values for cow and heifer beef, were the main reasons for their conclusions.

There are good theoretical reasons to expect twinning to improve the biological efficiency of a meat producing enterprise; the maintenance of the cow in a cow/calf system accounts for about 60% of the energy consumed. If this overhead can be spread over two offspring, then a larger proportion of the total energy consumed is directed towards producing meat and less towards mere maintenance. A deterministic model based on the work at ABRO in Scotland (Taylor *et al.* 1985) suggests that a 28% increase in biological efficiency could be achieved by causing cows to produce double the normal number of offspring per year (see Appendices 2.1, 2.2 and 2.3). It will also be seen from Appendix 2.3 that a 48% increase in biological efficiency is predicted where a "once-bred heifer" system is combined with twinning.

The primary reason why these systems are unattractive to Australian cattle producers is that the meat value of the first calf female after she has reared a calf is of the order of $350 to $400, while her value as a pregnant breeding cow is perhaps $450. For Taylor's system to be really efficient, the calf must be artificially reared so that its dam can be prepared for slaughter shortly after calving. In Taylor's calculations, the energy consumption of the calf was calculated separate from its dam; it was as though the milk production of the dam was not relevant. In other words, the fact that calves out of heifers are lighter than average, at weaning, was ignored. However, even if this had been modelled correctly, their lower weight would have been exactly offset by a lower food requirement.

From the biological stand-point, twinning is very attractive. But the economic consequences of twinning may not be as attractive. As part of the present study, four scenarios were simulated using the EMABA (Econometric model of Australian Broadacre Agriculture) simulation system, which models the inter-relationships between sheep, beef and wool output (Dewbre *et al.* 1985). Both immediate and longer term influences are modelled, involving 5 livestock and 6 cropping commodities. In each of the four scenarios studied here, the assumption was that reproduction rates were increased by 30% without any increase in inputs. Full details of the results of these simulations are presented in Appendices 5.1 to 5.4. In summary, the main results were:

1 **Twinning in dairy cattle.** In the short term beef prices were depressed by 5% but had stabilised within 4 years. The long term effects were almost negligible.

2 **Twinning in dairy and beef cattle.** In this extreme case, production of beef increased by about 25% and prices fell by 20% in the first 3 years. In the long term, a fall in beef price of 4.1% coupled with an increase in output of 4.7% were predicted. Thus, a pessimistic view of the value of twinning would be that the technology would lead to almost no net benefit in the long term.

3 **Twinning in sheep.** This scenario produced a complex set of interrelated changes in the broadacre industries. In the first three years, beef production fell slightly (-2%) but this was balanced by a slight rise in prices (+2%); wool and lamb production increased by 12% with a similar fall in prices; mutton prices fell by 27% while production increased by 16%. In the long term, beef production stabilised at +13% but this was balanced by a fall in prices (-12%); lamb production increased by 11% with a similar fall in prices; wool production increased by 35% with a 16% fall in prices; and mutton prices fell by 51% while production increased by 47%.

4 **Twinning in sheep and cattle.** This scenario also produced a complex set of interrelated changes. In the first three years, beef production increased (22%) but this was balanced by a fall in prices (-20%); lamb production increased by 11% with a 13% fall in prices; wool production increased by 13% with a 13% fall in prices; mutton prices fell by 17% while production increased by 4%. In the long term, beef production stabilised at +18% but this was balanced by a fall in prices (-16%); lamb production increased by 11% with a similar fall in prices; wool production increased by 36% with a 17% fall in prices; mutton prices fell by 51% while production increased by 46%.

The overall conclusion is that the net long-term effect of twinning in sheep and cattle is predicted to be a dramatic increase in production of, and earnings from, wool. The 46% increase in mutton production would be coupled with a fall in earnings.

It should be noted that the EMABA system reacts to the initial increase in reproduction by dropping prices: farmers are then expected to react to the slump in such a way as to maximise their profits.

As with most other changes which increase biological efficiency, the long-term effect of twinning is not predicted to be a bonanza for meat producers. The increased efficiency merely increases the competitiveness of the industry with respect to other vying industries.

The current twinning research which is being financed by AMLRDC should make an important contribution to our understanding of the practical problems associated with managing herds and flocks with a high level of twinning. However, in the light of the economic consequences predicted above, the long-term benefits need to be given further careful consideration.

Conclusion

The prospects for increased biological efficiency through the use of twinning are potentially very good; solving the management problems is a current AMLRDC project which will provide important insights into the practical benefits of twinning.

10 Transgenics

"Transgenesis is controlled mutagenesis; with both its advantages and disadvantages." (Robertson, 1986, pers. comm.)

The processes involved in producing and evaluating transgenic animals have been reviewed by Smith *et al.* (1987). This is an area in which the new biotechnology might appear to offer a way to replace existing animal breeding techniques. However, many animal geneticists believe that this is most unlikely in reality (Franklin 1988).

In his review Franklin makes a number of points concerning transgenics which would be supported by many other geneticists. For example,". . Our greatest limitation, now and in the future, is to identify desirable genetic changes that can be achieved by the transfer of a small number of genes. This can be overcome only by an intense research effort in two areas, namely into developing genetic maps for our livestock, and into understanding the rules for translating genetic differences to phenotypic differences."

As anticipated by Robertson (1986), many of the transgenics produced to date which express the transgene, show undesirable traits like diabetes, female sterility and premature ageing. However, some exceptional transgenic pigs have proved this trend need not always be the case (Seamark, 1990, pers. comm.).

The control of gene expression is an area requiring extensive research, either to control the creation of mRNA (transcription) or to produce anti-sense mRNA which can interfere with the expression of another gene. Franklin emphasised the multi-genic control of many of the traits of interest in domestic animals; this will make it difficult to find genes which can be manipulated to produce a desirable phenotype. There has been a tendency for genetic engineers to set their sights too high; Franklin suggests that inserting additional copies of a gene without attempting to modify it, may have merit at least until we understand the feed-back control systems. Our ignorance in the development of animals at the level of genetic control is profound. The very basic questions of developmental biology need to be asked using laboratory species which are cheaper than sheep and cattle. It is not normal to find one particular enzyme in a biochemical pathway being the critical rate-limiting step. For this reason, it is not surprising to find that complex metabolic processes are under multi-genic control.

It is unusual to find genes with large desirable effects, and where they do exist, they will often have undesirable side-effects. Following the creation of a transgenic animal, 5 to 10 years would be needed to check that there was indeed a net economic benefit to be gained; that the transgene's inheritance was stable, and that there were no unacceptable side-effects. This process would be faster in sheep with earlier puberty and shorter gestation.

Extravagant claims about quantum leaps in productivity have not been realised and have tended to cause disenchantment within funding agencies. Franklin (1988) was in no doubt that genetic engineering will enhance traditional breeding technology rather than replace it. Benefits due to an investment in creating a useful, new gene-construct can be spread throughout a number of breeds by the use of natural service males, but the ability to produce these males using cloning would be an advantage.

Conclusion

Research into the production of transgenic beef cattle or meat sheep should be regarded as being basic research, with no immediate commercial benefits. However, the research is so potentially important that Australia must be in a position to capitalise on major developments; this can happen only if Australia continues to maintain an active role in transgenic research. The availability of cloning is seen as being of importance for rapidly testing and spreading the benefits of novel gene constructs.

11 Gene mapping

AMLRDC has recently funded a gene mapping project based at CSIRO Rockhampton. Family and in situ hybridization studies have as their aim the production of a gene map for cattle with a minimum distance between markers of 40 centiMorgans (Hetzel *et al.* 1989). Other industries have also instigated research in this area.

It would be over-optimistic to expect immediate benefits from this type of research; as emphasised above, in most situations we expect many genes to be involved in the control of traits of interest. However, the new techniques ultimately will let us know that a particular animal carries particular genes. The extent to which this information is used in on-going breeding programs will be determined by whether the value of the additional genetic gain from using the marker(s) exceeds the cost of including the marker(s) in the selection criteria. Alternatively, markers could be used in an *ad hoc* manner, e.g. to identify rare animals which carry economically important combinations of genes. AI companies might use such markers to select candidates for AI, having screened several hundred animals. However, the value of the genetic merit of top (+2 genetic standard deviations) beef bulls may be of the order of $5 to $10 (see table 29). Since only half of this superiority is transmitted to the next generation, the benefits are likely to be low relative to the costs. A trait which might assume sufficient economic importance in the near future, is the ability to produce a carcass with the type of marbling that is desired in Japan.

Conclusion

Research into gene mapping and the identification of gene markers should not be seen as having major short-term benefits; it should be seen as basic science which will greatly enhance our knowledge of, and hence ability to manipulate, genes that affect biological and economic efficiency of meat production. Much more needs to be known about the physiology of animals before promises of commercialisation of genetic markers can hope to be fulfilled.

12 Australian genetic bank

A potential danger of cloning is that if the majority of the animals in an area are of identical genetic make-up, there is a possibility of a disease epidemic occurring which none of the animals can combat. This problem has arisen in plant industries, where monoculture with cloned varieties is common. This danger may be minimised by ensuring that not all animals in an area are from the same clone-line.

In the event of unforeseen changes in the environment, marketplace or disease situations, it would be useful to be able to access genetic variation from the past, which could be lost if cloning gained widespread acceptance.

Since the keeping of frozen embryos and semen in large storage facilities has a very low marginal cost, the "banking" of samples of genes in deep frozen storage can be very inexpensive. Artificial breeding companies would no doubt cooperate with AMLRDC in establishing such a repository. Rather than deliberately selecting random samples of bulls for semen collection, it would be more practicable to save semen from bulls which were already being sampled. Not only is the marginal cost of an additional dose of semen very low, but the fact that the semen can be left in storage for long periods without disturbance will limit the cost of storage.

Where research flocks or herds include control lines, these could be preserved by freezing semen and embryos. Frozen storage could completely replace live animal controls or could merely augment them and act as an insurance against a disease outbreak.

For perhaps an initial cost of $5000 and an annual administration and running cost of perhaps $1000, AMLRDC could instigate a modest gene bank which might prove invaluable in the next millenium. All that is needed is a mechanism for approving the removal of semen from the bank; a committee consisting of representatives of farmer organisations, breed societies and AB organizations, together with a genetic adviser, might serve this purpose.

The committee would have to decide which types of animals were sufficiently represented by semen and embryos; it would be necessary to limit the size of the bank. For other types of animals, it would be necessary to identify gaps in the bank and take steps to fill these gaps. The owner of a male who donated semen to the bank could have access to half the straws for a period of 10 years; beyond that time the committee would be free to decide on the use of all remaining doses.

In the case of embryos, the value of commercially collected embryos is likely to be too high for many donations to be forthcoming. However, research facilities, veterinary schools and technician training courses might provide a useful source of donated embryos from a range of breeds. At present, considerable numbers of embryos are frozen because there is an inadequate number of recipients available on the day; no doubt some of these eventually will be considered "surplus to requirements" and will be discarded. If the owners of such embryos were aware of the gene bank, no doubt some of these surplus embryos would be donated.

13 Ethics

When AI was first introduced as a commercial service in the 1950s,many felt that it should be avoided for ethical reasons. Others felt it would lead to "weak" calves because they were not naturally bred. Today we do not hear serious objections to AI, and the suggestion of "weak" calves is seen as having arisen from ignorance and fear. Will the newer technologies such as cloning and gene transfer be seen in the same way 40 years from now? Critics of inter-species gene transfer feel that not enough is known yet about the consequences of creating novel animals. Their opponents argue that inter-species gene transfer has happened frequently during evolution and is still occurring naturally today (Skjervold, 1986); they would argue that the increased risk of a relatively small number of artificially induced gene transfers would be outweighed by the potential benefits.
Distinctions can be made between procedures which:-

1. Cause animals undue pain. ***(Pain)***
2. Cause alteration in the DNA of animals. ***(Genetic Engineering)***
3. Alter the reproductive rate or sex ratio without inflicting undue pain or directly manipulating DNA. ***(Controlling Reproduction)***
4. Produce additional desirable animals using embryo manipulation without inflicting undue pain or directly manipulating DNA ***(Cloning)***

1 Pain

Animal liberationists are likely to find support from a wide section of the community if it were demonstrated that animals were having to suffer undue pain as a result of the introduction of new techniques.

2 Genetic Engineering

A distinction is sometimes made between procedures which modify some of the body tissues of an animal, without changing the germ line, and those that modify the animal so that its offspring also carry the same genetic alteration. The distinction is important where there is a possibility that the genetically altered animal could escape and cause environmental damage. In the case of animals which have no changes to the germ line, the potential for damage would be only temporary since their offspring would not show the modifications.
In the guide-lines laid down by the Victorian Law Reform Commission for Genetic engineering (Anon. 1989), it was recommended that there should be controls on the release of genetically-altered organisms. Fifteen recommendations were made. Those relating to animals can be summarised as follows:-

1 Genetic manipulation should not be limited in any general way.

3 Legislation should be enacted to provide that anyone proposing to undertake certain types of potentially hazardous scientific work should be required to notify the Department of Labour at least 30 days before work begins.

4 The categories of work requiring notification should be defined by Genetic Manipulation Advisory Committee (GMAC; a federal monitoring body).

5 The legislation should empower the Department of Labour to prohibit or impose conditions on proposed projects.

6 The Minister for Labour should adopt the Recombinant DNA Monitoring committee/GMAC Guide-lines, as revised from to time, as a Code of Practice for all genetic manipulation work.

11 & 12 There should be no special remedy for people injured, or who suffer property damage, as a result of genetically altered organisms.. They should have the same common law remedies as people who are injured or suffer property in other ways.

13 New legislation should:

- make it mandatory to inform GMAC and relevant government departments if it is proposed to release a genetically altered organism into the environment;
- require that the supervising government agency should conduct an environmental assessment before any experimental recombinant organisms are released;

- require the supervising government agency to advertise any proposed release, and to ensure that interested individuals are able to obtain information and to participate in the decision-making process before the proposal is approved;
- enable supervising government agencies to impose conditions when approving a release proposal.

14 Federal involvement is recommended.

15 Biological products resulting from recombinant DNA technology should be subject to the same quality controls as other biological products on the basis of their intended use.

The guide-lines have not yet been accepted by the Victorian Government, but an enquiry by the Federal Government is in progress. Critics of the guide-lines feel that the make-up of the advisory committee (GMAC) could cause it to take a too lenient attitude towards approval of doubtful situations. The other concern is that companies under financial pressures may be tempted to take short-cuts to circumvent the inevitable delays inherent in the proposed procedures. Such short-cuts could lead to the illegal release of genetically engineered organisms before it was shown that they had no harmful side effects.

The potential dangers associated with the general release of genetically altered cattle or sheep are far less than those associated with micro-organisms. If a new breed of sheep were found to be damaging the environment, the situation could be corrected by mustering and slaughtering them, whereas micro-organisms are hard to detect and hard to control outside the laboratory.

If Federal Parliament decides that it is not appropriate to grant any patents for novel gene constructs, it is most unlikely that commercial companies will invest in DNA manipulation of cattle or sheep. In these circumstances, the only pressure to proceed with genetic engineering would be that from instrumentalities such as universities or CSIRO. It might be argued that research instigated for the public good is likely to be conducted in a more responsible way. Under these circumstances it will be more important to find funds to support public research for the benefit of producers and consumers.

3 Controlling Reproduction

Procedures such as hormone treatments which increase the frequency of twins without causing undue pain to animals, seem to present few ethical problems, providing that the treatment is not causing undesirable side effects. Such procedures should be subject to the same testing protocols that are currently applied to any new drug or treatment. Non-surgical introduction of twin embryos should not cause ethical problems either, but laparoscopic introduction of embryos or semen could attract criticism.

4 Cloning

A common reaction to the concept of cloning animals is that it is the most extreme form of interference, and will inevitably lead to its use with humans. The logic of this fear could be challenged in that although meat animals finish up on the butcher's display, humans are not subjected to the same treatment. In fact, there would be no public pressure for cloning to be extended to humans. And ever since the second world war, there have been no indications that governments have wanted to set up institutional breeding centres for humans. In the absence of such pressures, there seems little likelihood of institutionalised human cloning becoming a desirable goal.

Providing that the procedures for generating clones do not cause undue pain to animals or cause mutations, there seem to be few ethical problems, other than perhaps those based on religious scruples.

14 Breeding objectives

Introduction

In the past 10 years there has been an increase in the sophistication of the information systems available to breeders. BREEDPLAN has provided more accurate estimated breeding values (EBVs) and for a wider range of traits than was the case a decade ago. There also has been an increase in awareness of the importance of producing carcases which suit particular market niches through schemes like AUSMEAT.

There is a natural temptation for both breeders and scientists to concentrate on traits that are easy to measure, rather than those that provide the greatest real economic benefits. The most obvious reason for avoiding traits which are difficult to record is the expense involved. However, it should not be assumed that because a trait is relatively simple to record, profits will increase when breeding animals are selected for that trait. Nor should it be assumed that continued selection in one particular direction will always increase profit; there may be an optimum level for the trait itself, and there may be correlated changes in other traits which create problems.

Selection Index theory distinguishes between:-

1 **The Objective.** A weighted combination of traits which contribute to profit and which may or may not be directly recorded. The weightings represent the dollar value of a unit change in each trait.
2 **The Index.** A combination of measurements, optimally weighted, to maximise the chance of ranking animals according to profitability.

In ideal circumstances, the logical first step in a breeding program would be to calculate the extent to which the objective varies, i.e. how much more profitable do we expect best animals to be by comparison with average ones. To make this calculation we need to know not only the major components of profitability but also the extent to which they vary (variance), and how they tend to change together (covariance). For example, we know that there is variation for mature size, but how much extra food do larger breeds eat?

Having defined the objective and how rewarding it will be to increase the number of desirable animals, the next step is to find the most cost-effective design of breeding program and genetic evaluation system. This will involve optimizing the combination of:-

(a) Measurements to be made, on which animals, at what age, and with what accuracy (ultrasonics, subjective scores, BLUP);

(b) Selection intensities (SI) for which animals, and at what age (SI can be increased by AI, MOET, and scale of operation, but will be limited by consideration of inbreeding and expense);

(c) Systems for marketing the genetic improvement or using it profitably 'in-house' (sale of NS bulls, semen, embryos, females).

This process of optimization is usually done by 'trial and error', but if any component is ignored the consequences can be very serious. For example, we could produce an elegant method for evaluation which was inadequately correlated with the breeding objective, or we might achieve superior rates of genetic gain but have a marketing system which was unable to recover the cost of the program.

Clearly therefore, the definition of the breeding objective is central to the process of optimization. Without a clear objective, either of the above scenarios can easily be the result. In reality, there is a constant process of development as our perceptions change.

In cases where there are desirable covariances between all the components of the objective, there is little to be gained from very accurately knowing the covariances, since selection on an index that improves one trait will tend to improve the others. However, where some of the components of profit are unfavourably related to the rest, it becomes very important to know the complete pattern of variances and covariances.

Unfortunately, meat-producing mammals probably epitomise this latter situation, because many of the traits that are desirable in the slaughter generation (fast growth and muscling) are not particularly desirable in reproducing females, where ideally we want reasonable fertility, easy calving and low lifetime feed requirements. This is unlike the situation in dairy cows where selection for milk proteins appears to be correlated with few undesirable traits.

Our understanding of the components of profitability (their variance and covariance) in meat animals is far from perfect, and in the case of the complex of traits which includes appetite, growth-rate and grazing-behavior, there is much to be learned. This is particularly true when complicating factors like temperature, disease exposure, and protein content, protein quantity, and energy-density of feed are considered.

Without a clear definition of what constitutes 'genetic improvement', the simulation of improvement schemes is of doubtful relevance. In the absence of this knowledge, one is forced to make informed guesses, or to test a variety of hypothetical possibilities. In considering breeding objectives for Australian beef herds, Ponzoni and Newman (1989) identified four steps:-

1. Identify the breeding/production/marketing system
2. Identify the sources of income and expense
3. Determine the biological traits which influence income and expense.
4. Derive the economic value of each trait using discounted gene flow methods (McClintock and Cunningham 1974).

They examined the income and expenses for a self-replacing herd of 1000 cows used for weaner production; the following were included as components of their breeding objective:-

CD	Calving date
9CWd	Carcass weight at 9 months - direct
9CWm	Carcass weight at 9 months - maternal
hCW	Carcass weight for surplus heifers
cCW	Carcass weight for cull cows
hFD	Fat depth for surplus heifers
9FI	Feed intake to 9 months of age
hFI	Feed intake for surplus heifers
cFI	Feed intake for cows
US	Ultrasonic Fat depth

Their breeding objective had a genetic standard deviation (SD) of about $25. The measurements included in their most comprehensive index were calving date (corrected for date of oestrus relative to joining), yearling weight and ultrasonic backfat measurement. The individual and 32 half-sibs were included in the index, together with sire and dam records; this index had an accuracy of 0.22 and a SD of about $2.50. A less accurate index in which CD was left out, had an accuracy of 0.1; CD requires oestrous detection so is not an attractive proposition. For completeness, these calculations are shown in Appendices 4.1 to 4.5(.

In a recent paper (Goddard and Economou 1989), estimates were given for the economic variation between animals for a range of traits, each treated in isolation; the table below is based on this work and shows the degree of variation for various possible breeding objectives ($ value per genetic standard deviation).

Table 29

Breeding objectives and their variability in dollar terms.

Trait	$ value per genetic SD	Average EBVs of top 2% sires (+2SD)	Notes
Pregnancy percent in heifers	$9.60	$5.00	a
Cow culling percent	$11.20	$4.56	b
Bull fertility (cows mated per bull per year)	$5.00	$4.00	c
Heifer dystocia (direct)	$6.00	$7.62	d
Percent meat in carcass	$9.60	$8.44	e
Index of growth and carcass and female fertility traits	$25.00	$5.00	f, g

Notes relating to the calculation of the EBVs:

(a) Using calving date records on 30 half-sisters as an indirect measurement
(b) Using conformation as an indirect measure
(c) Using a fertility index
(d) Using calving ease records on 30 half-sisters as an indirect measurement
(e) Indirect selection for eye muscle area and fat thickness.
(f) 'Simple' index from Ponzoni and Newman (1988). Accuracy 10%.
(g) Discounted returns were calculated with a 5% discount rate.

The average EBV of the top 2% of bulls represents the average potential value, for a particular trait, of the best two young bulls, in a drop of 100 bull calves. The extent to which the potential of one of these bulls is actually expressed, depends mainly on the number of progeny which he produces. However, the discount rate and the time horizon also have an influence. The concept of "number of discounted expressions per cow joined" was introduced in table 20; it was seen that, depending on our choice of parameters, we can expect between 0.25 and 12.33 discounted expressions per cow joined. With such a wide range of possible values for the numbers of discounted expressions, let us simply assume a value of one discounted expression per cow joined. This means that if a bull which is in the top 2% for "Pregnancy percent in heifers" is mated to 150 cows, we can expect 150 x \$5 = \$750 to be the added genetic benefit relative to the average bull for this trait.

The first five rows of table 29 suggest that the variation of estimated breeding values expressed in dollar terms may be fairly similar for a wide range of traits. The last row of the table is included for comparison with Ponzoni and Newman (1988). Their objective did not include dystocia or sire fertility so the genetic standard deviation (SD) in dollars becomes $(25^2+5^2+6^2)^{-2}$ or \$26.19 when these factors are added to their objective (assuming that they are all uncorrelated). The relatively high value of the top 2% of bulls on EBV for percent meat is based on a calculation which ignores the unfavourable associations between muscling and traits such as dystocia, so the average EBV of the top 2% of sires for percent meat is likely to be much less than the \$8.44 shown in the table.

With differences between bulls on a per progeny basis as small as those suggested in table 29, it is most unlikely that the use of AI sires could be justified in commercial herds, when synchronized AI costs about \$50 per calf born (see table 4).

Note that the low dollar value associated with bull fertility does not mean that the phenotypic selection of bulls with high serving capacity is a waste of time. A bull with a serving capacity score of 9 can be joined to 35% more cows than one with a score of 5 (Blockey, 1990, pers. comm.).

In a brief review of the current situation, Barlow (1989a) stressed the importance of specifying and validating a complete profit function including feed-inputs, and recommended that this would best be done by an economist. Customising of the breeding objective for each producer has been proposed (Upton *et al.* 1988), but it is recognised (Barlow, 1989a; Hammond, 1989) that this will require more extensive advisory services. The B-Object program, briefly described by Upton *et al* (1988), holds great promise in this regard, but it is not yet available, nor is a detailed specification of its method.

The simulation model (TAMU) developed at Texas A&M University (Cartwright 1982) has shown that an interaction should be expected between level of nutrition (energy and energy density) and the production traits. The model shows that when nutrition is limiting, smaller animals with lowered milk production are best for herd productivity. .The contrary is true for better conditions. The TAMU model simulated the lowered herd fertility associated with the females of larger breeds being underfed. Breeds like the Hereford were found to be at an intermediate point which means that although they do not excel when under very harsh or very good conditions, they are likely to be "good all-rounders" especially when nutrition level varies.

The lack of well documented breeding objectives for the major categories of Australian production systems has been (and still is) a major problem. It will be clear from this section that there can be no simple solutions to our lack of knowledge in this area. A systematic, all-embracing attempt to gain a full understand would be a huge and expensive task; all that can be hoped for is a gradual build up of the required information. A most important area where our knowledge is sadly lacking is the degree to which efficiency varies between animals within breeds. Without this knowledge and the means to estimate it cheaply, we probably will not make any real improvements in growth efficiency of animals.

A clear definition of the breeding objective for individual breeders and for the more common situations is still an area for priority research. To develop techniques for genetic improvement without defining these objectives, is to tackle the problem in the wrong order.

15 Allocation of research resources

Twinning

The practical management problems involved in twinning, as well as the mechanisms to induce twinning artificially, need to be fully understood. The work already being funded in this area should help considerably in this respect.

Cloning

In the dairy industry, embryo cloning could have an enormous effect on increasing efficiency. In the beef industry, cloning would be too expensive for the production of the slaughter generation unless the calf had some special value. For example, a cloned calf could be transgenic for a gene construct which conferred a special economic advantage. Cloned males with special merit could be used as natural sires with considerable advantage.

Development of cost-effective cloning is seen as being of strategic importance to the long-term development of the beef industry and possibly to the meat-sheep industry. It could play an important part in the testing and dissemination of transgenic animals.

Transgenics

If patenting of novel gene constructs is not sanctioned by Parliament, then little if any development work will take place in the private sector. If this is the case, public sector funds (e.g. from RIRFs) would be needed to support transgenic research. If it is decided to continue funding of transgenic research, it should be seen as a long-term investment and should not be done at the expense of research and development into cloning. Both the development of embryonic stem cells and in vitro maturation/in vitro fertilization are worthy of consideration. The choice of genes to be manipulated and how they interact with an animal under farm conditions is an area of considerable ignorance.

Gene mapping

This should be seen as medium-to-long-term basic research rather than having an immediate practical benefit. However, the pay-off is potentially large enough that continued research is warranted

Breeding objectives

Inputs as well as outputs

The pioneering work in the use of chromium dioxide-controlled release devices has opened new avenues of research into the real values of different genotypes under grazing conditions. The complexity of selection for efficiency is such that it is most unlikely to be done at present. If physiological screening tests could be devised which gave an indication of efficiency then this would bring a new meaning to BREEDPLAN data. At present BREEDPLAN is a statement of outputs with no mention of inputs.

Fitness Traits

The genetics of disease resistance and its relationship with growth and reproduction has been studied at Rockhampton (Mackinnon *et al.* 1989) but many questions remain unanswered e.g. will the apparent negative relationships between parasite resistance and growth have an adverse effect on the long term progress of selection programs?

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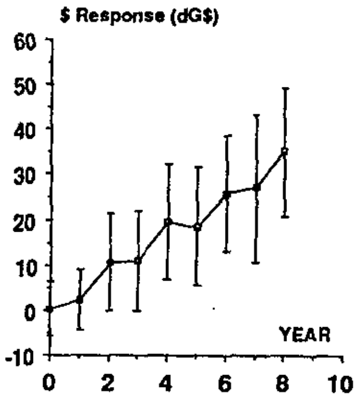
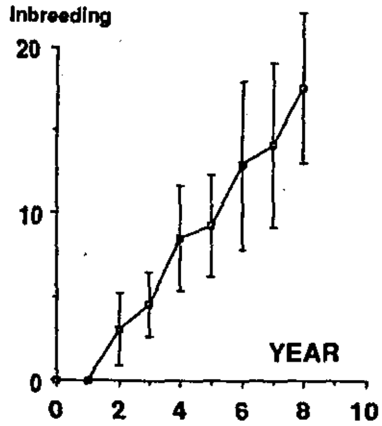
Appendix 1.1

MOET SIMULATIONS

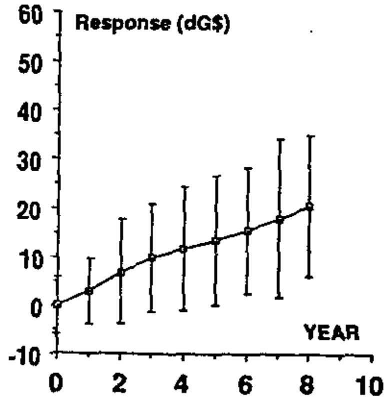
Summary of stochastic simulation of closed breeding herds which produce an average of 75 calves per year using MOET from the best cows. For details of the simulation model see Parnell (1987). Two scenarios were tested, both with 40 herds, each herd was run for 8 years. In the first scenario, selection was based on a BLUP evaluation of all animals in the herd, using all relationships to increase accuracy; in the second scenario, animals were selected on their own performance (expressed as a comparison with contemporaries). Genetic changes are shown in dollars, for a trait with a heritability of 4% and a genetic standard deviation of $25. Cows were selected on merit and were available for use for up to 5 calvings. Sires were used for one year when selected on their own performance, but were available for use for up to 5 years when BLUP was used. The trends shown are not adjusted for inbreeding, so will overestimate the real response. The vertical bars represent one standard deviation on either side of the trend lines.



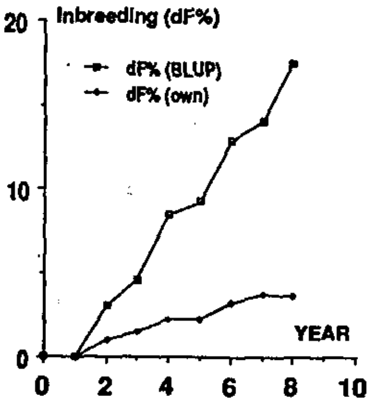
Here we see a response of about $4 per year, using BLUP selection. Note that some herds did not make much progress; 17% made less than $20 progress during the 8 years.



Inbreeding increases rapidly when a MOET herd uses BLUP to select parents of the next generation. Within 8 years, 17% of herds were more than 25% inbred.



Here we see a response of about $2 per year, using selection on own performance. Note that some herds did not make much progress; 17% made less than $10 progress during the 8 years.



Here we see a large difference between the rate of inbreeding using BLUP versus using selection on own performance. If this inbreeding is associated with lowered profit, then the advantage of using BLUP willbe much less than that indicated by the response graphs.

Appendix 1.2

Computer simulations of MOET Selection programs.

Using the same FORTRAN program as was used for Appendix 1.1 (Parnell 1987), selection for 200-day weight was simulated for a 15-year period. Each donor was flushed to give an average of 3.8 pregnancies, and replacement sires and donors were selected on the basis of their own performance.

The results from a series of simulated MOET nucleus selection programs are expressed in terms of percent genetic change, and are shown in Appendix 1.3. Each row in Appendix 1.3 represents the summarised results of 40 herds, each of which was selected for 15 years for a trait having a heritability of 30% and a coefficient of genetic variation (CV) of 12%. For a trait with a CV of 6 %, the response would be halved. The conception and calf survival rates were such that, with the natural mating herds, 100 breeding cows were needed to produce the 75 calves surviving to breeding age. In the case of MOET models, sufficient pregnancies were simulated to produce an average of 75 surviving calves per year. Cows were selected on merit and were available for use for up to 5 calvings. Sires were used for one year when selected for own performance but were available for use for up to 5 years when BLUP was used. In the cases where IVF is used, each litter-mate is by a randomly selected sire, whereas with MOET, all calves from a particular donor were by only one sire.

The simulated total response in 200-day weight was +69±13 kg while inbreeding rose by 9±2%. After allowing a depression of 1% in 200-day weight per 1% increase in inbreeding,the net gain would be 51 kg. This represents a 57% increase in genetic change by comparison with a herd of similar size in which natural reproduction is used. Similar stochastic simulation results have been reported by Wrayand Simm (1990).

The effect of selection using Best Linear Unbiassed Prediction (BLUP) was also tested using the same simulation model The simulated change in 200-day weight was +81±11 kg while inbreeding rose by 21±6%. After allowing a depression of 1% in 200-day weight per 1% increase in inbreeding, the net gain would be 38 kg This represents a 15% increase in genetic change by comparison with natural reproduction.

It is important to note that the effect of inbreeding depression would be removed if the inbred animals were used in a crossbreeding program. Bearing this in mind, it is evident that BLUP would be most useful where a breed was being selected for traits to be expressed by crossbred offspring (e.g. in the creation of a terminal sire breed).

Models involving BLUP selection and MOET (e.g. Model 6) gave the highest rates of inbreeding and genetic response. However traits like 200-day weight gave the lowest net response ($dG\%_{1.0}$ = 5.4%) because a 1% depression in 200-day weight per cow joined can be expected. For traits other than 200-day weight, the final column is more realistic if one regards the results from Miles City (Brinks and Knapp 1975) as being applicable in Australia

Where the primary use of a breed is in a crossing situation, the most appropriate column to consider is the one where no account is taken of inbreeding depression ($dG\%_{0.0}$)

MOET SIMULATIONS

Summary of stochastic simulation of breeding herds where cows are retained for 5 calvings; the herd is closed and produces 75 calves per year. For details of the simulation model see Parnell (1987). Each row represents the summarised results of 40 herds, each has run for 15 years. Genetic changes are shown in percentage units for a trait with a heritability of 30%.

Model	Use of MOET	Use of IVF	MAX No of Pregnancies per donor per year	Select animals on Own Performance or BLUP	Number of sires used per year	Increase in Inbreeding	Standard Error of Increase in Inbreeding	Genetic Change when Inbreeding depression is ignored	Standar. Error of Genetic Change	Net Gain% when Inbreeding Loss is 1.0% per 1%dF	Net Gain% when Inbreeding Loss is 0.5% per 1%dF
						dF%	SE dF%	$dG\%_{0.0}$	SE dG%	$dG\%_{1.0}$	$dG\%_{0.5}$
1	NO	NO	1	OWN PERF	5	5%	1%	21.8	5.3	16.4	19.1
2	NO	NO	1	BLUP	5	13%	2%	25.9	5.6	13.4	19.6
3	YES	NO	5	OWN PERF	5	9%	2%	34.4	6.3	25.7	30.0
4	YES	YES	5	OWN PERF	20	5%	1%	24.9	3.6	20.3	22.6
5	YES	NO	9	OWN PERF	20	7%	2%	28.2	3.7	21.4	24.8
6	YES	NO	9	BLUP	5	39%	11%	44.0	9.3	5.4	24.7
7	YES	NO	5	BLUP	10	21%	6%	40.3	6.0	18.9	29.6
8	YES	NO	9	BLUP	20	19%	5%	36.7	6.0	17.7	27.2
9	YES	YES	5	BLUP	5	15%	3%	36.5	6.4	21.1	28.8
10	YES	YES	5	BLUP	20	9%	2%	30.3	5.6	21.2	25.8
11	YES	YES	5	OWN PERF	5	9%	2%	32.8	5.8	23.7	28.3
12	YES	YES	9	BLUP	5	30%	6%	42.2	6.9	12.2	27.2
13	YES	YES	9	OWN PERF	5	10%	2%	34.8	4.9	24.6	29.7

Appendix 1.3

Appendix 2.1

Model to predict biological efficiency

Prediction of Biological efficiency using the model described by Taylor et al. (1985)						
Energy equations for twinning taken fron the appendix of their paper.						
	Input values	Calculations				
Body wt (W)		330.00				
Mature Body wt (A)	440					
Input degree of maturity at slaughter (u)	0.75	0.75				
Mature wt of sltr males relative to females	1.2					
Food from Birth to degree of maturity u (Fs)		57.10				
Cost per MJ food relative to that given to heifers (c)	1.00					
Food Units for pregnancy (∂p)	4.00					
Food Units for dams between calvings (Fdn - Fd1)	46.00					
	2	3.00				
Mature Weight of progeny relative to their dam (t)	1	1.00				
Reproductive rate (r); Greater than 1 means twins	**1.55**					
Number of potential calvings per dam (n)	6	0.65				
(n-1)		5.00				
Number of surviving males for slaughter (nsm)		4.65				
Number of surviving females for slaughter; less 1 female repl (nsf)		3.65				
Degree of maturity of dam at slaughter at parity n ud(n)	0.9					
Males Price per Kg relative to female slaughter prog (psm)	1	$ per Kg drops with age at slaughter				
Dams Price per Kg relative to female slaughter prog (pdn)	$0.92		$0.96	$0.94	$0.92	.
Lean tissue as a proportion of LW at slaughter (v)	0.333					
Food consumed by dams (size scaled units) to 1st calving (Fd1)	46					
The cost of the conception event (B)	1	$5.28				
Outputs slaughered progeny (grams of lean meat per Kg Mature Wt)		2305.19				
Outputs slaughered dams (grams of lean meat per Kg Mature Wt)		229.77				
Total Outputs (grams of lean meat per Kg Mature Wt)		2534.96				
Inputs - slaughter progeny (MJ Energy per Kg Mature Wt)		527.03				
BREEDING FEMALE						
Inputs to 1st calving		52.20				
Inputs to nth calving		267.00				
Total Inputs		846.23				
EFFICIENCY gms lean per MJ energy (E)		**3.00**				
Notes: Lactation is assumed to cost nothing since calf intake is accounted for						
Cost of pregnancy has little effect						
Food Cost beef c/MJ	$1.20					
Feed costs ($ per 'feed unit')	$5.28					

Model to predict biological efficiency

Prediction of Biological efficiency using the model described by Taylor et al. (1985)						
Energy equations for twinning taken fron the appendix of their paper.						
	Input values	Calculations				
Body wt (W)		330.00				
Mature Body wt (A)	440					
Input degree of maturity at slaughter (u)	0.75	0.75				
Mature wt of sltr males relative to females	1.2					
Food from Birth to degree of maturity u (Fs)		57.10				
Cost per MJ food relative to that given to heifers (c)	1.00					
Food Units for pregnancy (∂p)	4.00					
Food Units for dams between calvings (Fdn - Fd1)	46.00					
	2	3.00				
Mature Weight of progeny relative to their dam (t)	1	1.00				
Reproductive rate (r); Greater than 1 means twins	**0.77**					
Number of potential calvings per dam (n)	6	1.30				
(n-1)		5.00				
Number of surviving males for slaughter (nsm)		2.31				
Number of surviving females for slaughter; less 1 female repl (nsf)		1.31				
Degree of maturity of dam at slaughter at parity n ud(n)	0.9					
Males Price per Kg relative to female slaughter prog (psm)	1	$ per Kg drops with age at slaughter				
Dams Price per Kg relative to female slaughter prog (pdn)	$0.92		$0.96	$0.94	$0.92	.
Lean tissue as a proportion of LW at slaughter (v)	0.333					
Food consumed by dams (size scaled units) to 1st calving (Fd1)	46					
The cost of the conception event (B)	1	$5.28				
Outputs slaughered progeny (grams of lean meat per Kg Mature Wt)		1019.48				
Outputs slaughered dams (grams of lean meat per Kg Mature Wt)		229.77				
Total Outputs (grams of lean meat per Kg Mature Wt)		1249.25				
Inputs - slaughter progeny (MJ Energy per Kg Mature Wt)		233.08				
BREEDING FEMALE						
Inputs to 1st calving		49.08				
Inputs to nth calving		251.40				
Total Inputs		533.56				
EFFICIENCY gms lean per MJ energy (E)		**2.34**				
Notes: Lactation is assumed to cost nothing since calf intake is accounted for						
Cost of pregnancy has little effect						
Food Cost beef c/MJ	$1.20					
Feed costs ($ per 'feed unit')	$5.28					

Appendix 2.2

Appendix 2.3

Details of Model

Prediction of Biological efficiency using the model described by Taylor et			
Energy equations for twinning taken fron the appendix of their paper.			
	Input values	Calculations	
Body wt (W)		=B6*B7	
Mature Body wt (A)	440		
Input degree of maturity at slaughter (u)	0.75	=C5/B6	
Mature wt of sltr males relative to females	1.2		
Food from Birth to degree of maturity u (Fs)		=(1/0.023)*(-(LN(1-C7)+0.073))	
Cost per MJ food relative to that given to heifers (c)	1		
Food Units for pregnancy (∂p)	4		
Food Units for dams between calvings (Fdn - Fd1)	46		
	2	3	
Mature Weight of progeny relative to their dam (t)	1	1	
Reproductive rate (r); Greater than 1 means twins	**0.77**		
Number of potential calvings per dam (n)	6	=1/B16	
(n-1)		=B17-1	
Number of surviving males for slaughter (nsm)		=(0.5)*(B16*B17)	
Number of surviving females for slaughter; less 1 female repl (nsf)		=((0.5)*(B16*B17)-1)	
Degree of maturity of dam at slaughter at parity n ud(n)	0.9		
Males Price per Kg relative to female slaughter prog (psm)	1		
Dams Price per Kg relative to female slaughter prog (pdn)	0.92		0.96
Lean tissue as a proportion of LW at slaughter (v)	0.333		
Food consumed by dams (size scaled units) to 1st calving (Fd1)	46		
The cost of the conception event (B)	1	=B27*B41	
Outputs slaughered progeny (grams of lean meat per Kg Mature Wt)		=1000*(B9*(C19*B23*B25)+(C20*B23*B25))*(C15*B7)	
Outputs slaughered dams (grams of lean meat per Kg Mature Wt)		=1000*B24*B25*C7	
Total Outputs (grams of lean meat per Kg Mature Wt)		=C29+C28	
Inputs - slaughter progeny (MJ Energy per Kg Mature Wt)		=((B9*C19*B11)+(C20*B11))*B15*C10	
BREEDING FEMALE			
Inputs to 1st calving		=B11*(B26+(B12*B16))	
Inputs to nth calving		=B11*((B17-1)*(B13+(B12*B16)))+(B17*B27)	
Total Inputs		=C35+C34+C32	
EFFICIENCY gms lean per MJ energy (E)		**=C30/C36**	
Notes: Lactation is assumed to cost nothing since calf intake is accounte			
Cost of pregnancy has little effect			
Food Cost beef c/MJ	1.2		
Feed costs ($ per 'feed unit')	=B6*B40/10		

Number of Clones required to completely replace an existing herd of cows with calves bred from cloned embryos

Herd substitution using Clone Transfer (CT)												
First year												
Assumed herd size	100	100	100	100	100	100	100	100	100		100	100
Assumed % of Recipients which calve to 1 CT	50%	55%	60%	65%	70%	75%	80%	85%	90%		50%	55%
Assumed % of calves born which enter the herd	80%	80%	80%	80%	80%	80%	80%	80%	80%		70%	70%
Number of successful CT in cycle 1	50	55	60	65	70	75	80	85	90		50	55
Number of successful CT in cycle 2	25	24	24	22	21	18	16	12	9		25	24
Number of successful CT in cycle 3	12	11	9	8	6	5	3	2	0		12	11
Number of successful CT in cycle 4	6	5	4	3	2	1	0	0	0		6	5
Total number of CTs	186	172	161	150	141	132	123	116	110		186	172
Total number of successful CTs	93	95	97	98	99	99	99	99	99		93	95
Number of female calves born which will enter herd	74.4	76	77.6	78.4	79.2	79.2	79.2	79.2	79.2		65.1	66.5
Next year more CTs needed												
Number of CTs needed	64	55	48	42	38	35	33	31	29		100	88
Number of successful CT in first and only cycle	32	30	29	27	27	26	26	26	26		50	48
Number of female calves born which will enter herd	26	24	23	22	21	21	21	21	21		35	34
Total Number of Replacements by CT	100	100	100	100	100	100	100	100	100		100	100
Assumed Calving rate to 1 CT	50%	55%	60%	65%	70%	75%	80%	85%	90%	#	50%	55%
Total number of CTs required	250	227	209	192	179	167	156	147	139		286	260

Appendix 3.1

Breeding Objective derived by Ponzoni and Newman (1988)

C-Matrix

CD	32.00		4.05		-0.88	-0.88				-397.66
9CWd		76.80	-6.27	88.68	3.39	2.72	106.58	543.17	698.36	2053.52
9CWm	4.05	-6.27	51.20		2.77	2.22				670.68
hCW		88.68		160.00	3.92	4.90	165.67	672.00	1176.00	3260.40
cCW	-0.88	3.39	2.77	3.92	2.40	1.92	2.90	27.44	30.87	72.62
9FD	-0.88	2.72	2.22	4.90	1.92	2.40	2.90	20.58	41.16	72.62
hFD		106.58		165.67	2.90	2.90	350.07	828.33	1366.74	6137.91
9FI		543.17		672.00	27.44	20.58	828.33	7840.00	9408.00	26972.38
hFI		698.36		1176.00	30.87	41.16	1366.74	9408.00	17640.00	43570.78
cFI	-397.66	2053.52	670.68	3260.40	72.62	72.62	6137.91	26972.38	43570.78	219632.25

V
-1449.6
606.323
454.048
359.425
79.582
-1243.7
-1198.1
-9.819
-9.819
-17.103

	CD	9CWd	9CWm	hCW	cCW	9FD	hFD	9FI	hFI	cFI
V' here	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10
V' in P & N	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10

v'Cv = VAR(T)	618857401.76128	
SD of T in $	24876.84	per 1000 animals
SD of T in $	24.87684	per 1 animal

WHEN		THEN		
Rti	0.22	SD of I in $	5472.9058	per 1000 animals
(Where CD is recorded)		SD of I in $	**$5.47**	per animal
Rti	0.10	SD of I in $	2487.6845	per 1000 animals
(Where CD is not recorded)		SD of I in $	**$2.49**	per animal

Code	**Meaning**
CD	Calving Day (Oestrus detection in the paddock required for correction of data.)
9CWd	Carcass Wt Maternal
9CWm	Carcass Wt Direct
hCW	Carcass Wt - young stock
cCW	Carcass Wt - cull cows
9FD	Fat depth - surplus females
hFD	Fat depth - surplus males
9FI	Food Intake - surplus females
hFI	Food Intake - surplus males
cFI	Food Intake - Cull Cows

Appendix 4.1

Breeding Objective derived by Ponzoni and Newman (1988)

C-Matrix

CD	32.00		4.05		-0.88	-0.88				-397.66
9CWd		76.80	-6.27	88.68	3.39	2.72	106.58	543.17	698.36	2053.52
9CWm	4.05	-6.27	51.20		2.77	2.22				670.68
hCW		88.68		160.00	3.92	4.90	165.67	672.00	1176.00	3260.40
cCW	-0.88	3.39	2.77	3.92	2.40	1.92	2.90	27.44	30.87	72.62
9FD	-0.88	2.72	2.22	4.90	1.92	2.40	2.90	20.58	41.16	72.62
hFD		106.58		165.67	2.90	2.90	350.07	828.33	1366.74	6137.91
9FI		543.17		672.00	27.44	20.58	828.33	7840.00	9408.00	26972.38
hFI		698.36		1176.00	30.87	41.16	1366.74	9408.00	17640.00	43570.78
cFI	-397.66	2053.52	670.68	3260.40	72.62	72.62	6137.91	26972.38	43570.78	219632.25

V
-1449.6
606.323
454.048
359.425
79.582
-1243.7
-1198.1
-9.819
-9.819
-17.103

	CD	9CWd	9CWm	hCW	cCW	9FD	hFD	9FI	hFI	cFI
V' here		606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10
V' in P & N	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10

v'Cv = VAR(T)	565614464.94997	
SD of T in $	23782.65	per 1000 animals
SD of T in $	23.78265	per 1 animal

WHEN		THEN		
Rti	0.22	SD of I in $	5232.1831	per 1000 animals
(Where CD is recorded)		SD of I in $	**$5.23**	per animal
Rti	0.10	SD of I in $	2378.2651	per 1000 animals
(Where CD is not recorded)		SD of I in $	**$2.38**	per animal

Code	**Meaning**
CD	Calving Day (Oestrus detection in the paddock required for correction of data.)
9CWd	Carcass Wt Maternal
9CWm	Carcass Wt Direct
hCW	Carcass Wt - young stock
cCW	Carcass Wt - cull cows
9FD	Fat depth - surplus females
hFD	Fat depth - surplus males
9FI	Food Intake - surplus females
hFI	Food Intake - surplus males
cFI	Food Intake - Cull Cows

Appendix 4.2

Appendix 4.3

Breeding Objective derived by Ponzoni and Newman (1988)

C-Matrix

CD	32.00		4.05		-0.88	-0.88				-397.66
9CWd		76.80	-6.27	88.68	3.39	2.72	106.58	543.17	698.36	2053.52
9CWm	4.05	-6.27	51.20		2.77	2.22				670.68
hCW		88.68		160.00	3.92	4.90	165.67	672.00	1176.00	3260.40
cCW	-0.88	3.39	2.77	3.92	2.40	1.92	2.90	27.44	30.87	72.62
9FD	-0.88	2.72	2.22	4.90	1.92	2.40	2.90	20.58	41.16	72.62
hFD		106.58		165.67	2.90	2.90	350.07	828.33	1366.74	6137.91
9FI		543.17		672.00	27.44	20.58	828.33	7840.00	9408.00	26972.38
hFI		698.36		1176.00	30.87	41.16	1366.74	9408.00	17640.00	43570.78
cFI	-397.66	2053.52	670.68	3260.40	72.62	72.62	6137.91	26972.38	43570.78	219632.25

V
-1449.6
606.323
454.048
359.425
79.582
-1243.7
-1198.1
-9.819
-9.819
-17.103

	CD	9CWd	9CWm	hCW	cCW	9FD	hFD	9FI	hFI	cFI
V' here	-1449.63					-1243.74	-1198.08	-9.82	-9.82	-17.10
V' in P & N	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10

v'Cv = VAR(T)	741315357.13714	
SD of T in $	27227.11	per 1000 animals
SD of T in $	27.22711	per 1 animal

WHEN		THEN		
Rti	0.22	SD of I in $	5989.9635	per 1000 animals
(Where CD is recorded)		SD of I in $	$5.99	per animal
Rti	0.10	SD of I in $	2722.7107	per 1000 animals
(Where CD is not recorded)		SD of I in $	$2.72	per animal

Code	**Meaning**
CD	Calving Day (Oestrus detection in the paddock required for correction of data.)
9CWd	Carcass Wt Maternal
9CWm	Carcass Wt Direct
hCW	Carcass Wt - young stock
cCW	Carcass Wt - cull cows
9FD	Fat depth - surplus females
hFD	Fat depth - surplus males
9FI	Food Intake - surplus females
hFI	Food Intake - surplus males
cFI	Food Intake - Cull Cows

Appendix 4.4

Breeding Objective derived by Ponzoni and Newman (1988)

C-Matrix

CD	32.00		4.05		-0.88	-0.88				-397.66
9CWd		76.80	-6.27	88.68	3.39	2.72	106.58	543.17	698.36	2053.52
9CWm	4.05	-6.27	51.20		2.77	2.22				670.68
hCW		88.68		160.00	3.92	4.90	165.67	672.00	1176.00	3260.40
cCW	-0.88	3.39	2.77	3.92	2.40	1.92	2.90	27.44	30.87	72.62
9FD	-0.88	2.72	2.22	4.90	1.92	2.40	2.90	20.58	41.16	72.62
hFD		106.58		165.67	2.90	2.90	350.07	828.33	1366.74	6137.91
9FI		543.17		672.00	27.44	20.58	828.33	7840.00	9408.00	26972.38
hFI		698.36		1176.00	30.87	41.16	1366.74	9408.00	17640.00	43570.78
cFI	-397.66	2053.52	670.68	3260.40	72.62	72.62	6137.91	26972.38	43570.78	219632.25

	V
CD	-1449.6
9CWd	606.323
9CWm	454.048
hCW	359.425
cCW	79.582
9FD	-1243.7
hFD	-1198.1
9FI	-9.819
hFI	-9.819
cFI	-17.103

	CD	9CWd	9CWm	hCW	cCW	9FD	hFD	9FI	hFI	cFI
V' here	-1449.63	606.32	454.05	359.43	79.58			-9.82	-9.82	-17.10
V' in P & N	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10

v'Cv = VAR(T)	106423737.52542	
SD of T in $	10316.19	per 1000 animals
SD of T in $	10.31619	per 1 animal

WHEN		THEN		
Rti	0.22	SD of I in $	2269.5614	per 1000 animals
(Where CD is recorded)		SD of I in $	$2.27	per animal
Rti	0.10	SD of I in $	1031.6188	per 1000 animals
(Where CD is not recorded)		SD of I in $	$1.03	per animal

Code	Meaning
CD	Calving Day (Oestrus detection in the paddock required for correction of data.)
9CWd	Carcass Wt Maternal
9CWm	Carcass Wt Direct
hCW	Carcass Wt - young stock
cCW	Carcass Wt - cull cows
9FD	Fat depth - surplus females
hFD	Fat depth - surplus males
9FI	Food Intake - surplus females
hFI	Food Intake - surplus males
cFI	Food Intake - Cull Cows

Breeding Objective derived by Ponzoni and Newman (1988)

C-Matrix

											V
CD	32.00		4.05		-0.88	-0.88				-397.66	-1449.6
9CWd		76.80	-6.27	88.68	3.39	2.72	106.58	543.17	698.36	2053.52	606.323
9CWm	4.05	-6.27	51.20		2.77	2.22				670.68	454.048
hCW		88.68		160.00	3.92	4.90	165.67	672.00	1176.00	3260.40	359.425
cCW	-0.88	3.39	2.77	3.92	2.40	1.92	2.90	27.44	30.87	72.62	79.582
9FD	-0.88	2.72	2.22	4.90	1.92	2.40	2.90	20.58	41.16	72.62	-1243.7
hFD		106.58		165.67	2.90	2.90	350.07	828.33	1366.74	6137.91	-1198.1
9FI		543.17		672.00	27.44	20.58	828.33	7840.00	9408.00	26972.38	-9.819
hFI		698.36		1176.00	30.87	41.16	1366.74	9408.00	17640.00	43570.78	-9.819
cFI	-397.66	2053.52	670.68	3260.40	72.62	72.62	6137.91	26972.38	43570.78	219632.25	-17.103

	CD	9CWd	9CWm	hCW	cCW	9FD	hFD	9FI	hFI	cFI
V' here	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08			
V' in P & N	-1449.63	606.32	454.05	359.43	79.58	-1243.74	-1198.08	-9.82	-9.82	-17.10

v'Cv = VAR(T)	443218645.67133	
SD of T in $	21052.76	per 1000 animals
SD of T in $	21.05276	per 1 animal

WHEN		THEN		
Rti	0.22	SD of I in $	4631.6069	per 1000 animals
(Where CD is recorded)		SD of I in $	**$4.63**	per animal
Rti	0.10	SD of I in $	2105.2759	per 1000 animals
(Where CD is not recorded)		SD of I in $	**$2.11**	per animal

Code	**Meaning**
CD	Calving Day (Oestrus detection in the paddock required for correction of data.)
9CWd	Carcass Wt Maternal
9CWm	Carcass Wt Direct
hCW	Carcass Wt - young stock
cCW	Carcass Wt - cull cows
9FD	Fat depth - surplus females
hFD	Fat depth - surplus males
9FI	Food Intake - surplus females
hFI	Food Intake - surplus males
cFI	Food Intake - Cull Cows

Appendix 5.1

EMABA Model Results

Dairy industries uses twinning. (1)

Table 1 : PERCENTAGE IMPACTS FROM THE ADOPTION OF TWINNING - SCENARIO I (1)

	YEARS										
	1	2	3	4	5	6	7	8	9	10	LR
AUSTRALIA (2)											
Beef Production	2.8	3.4	3.3	2.4	1.8	1.2	1.0	0.7	0.6	0.4	0.7
Lamb Production	0.0	-0.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0
Mutton Production	-0.8	-1.0	-1.5	-0.7	-0.6	-0.2	-0.2	0.0	0.0	0.2	-0.1
Wool Production (greasy)	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Beef Price (3)	-5.0	-2.2	-3.3	-1.2	-1.9	-0.9	-1.3	-0.6	-0.7	-0.1	-0.6
Lamb Price (4)	-0.8	0.2	-0.3	0.0	-0.2	-0.1	-0.2	0.0	-0.1	0.0	0.0
Mutton Price (5)	-0.4	1.9	2.0	1.1	0.3	-0.1	-0.3	-0.3	-0.3	-0.4	0.0
Wool Price (6)	0.0	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1

(1) Increase in offspring numbers applies to dairy animals only. (2) Year ended June 30.
(3) Weighted average saleyard price of beef, est dressed weight basis. (4) Weighted average saleyard price of lamb, est dressed weight basis (5) Weighted average saleyard price of mutton, est dressed weight basis. (6) Auction level greasy wool price.

EMABRA Model Results

Dairy and beef industries use twinning. (2)

Table 1 : PERCENTAGE IMPACTS FROM THE ADOPTION OF TWINNING - SCENARIO 2 (1)

	YEARS										
	1	2	3	4	5	6	7	8	9	10	LR
AUSTRALIA (2)											
Beef Production	20.9	25.0	24.6	17.0	12.5	8.3	6.9	5.2	4.4	3.3	4.7
Lamb Production	0.0	-1.7	-0.7	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	-0.2	-0.1
Mutton Production	-4.7	-6.7	-9.7	-4.9	-4.0	-1.2	-1.6	-0.2	-0.2	0.9	-0.6
Wool Production (greasy)	0.0	0.4	0.8	1.2	1.4	1.5	1.5	1.5	1.4	1.3	0.7
Beef Price (3)	-29.4	-14.1	-20.9	-7.2	-12.3	-5.9	-9.1	-4.3	-4.6	-1.3	-4.1
Lamb Price (4)	-6.0	1.3	-2.3	-0.1	-1.7	-0.7	-1.4	-0.4	-0.6	0.0	-0.4
Mutton Price (5)	-4.0	12.7	15.5	8.7	2.4	-0.9	-1.4	-1.7	-2.0	-2.8	-0.1
Wool Price (6)	-0.1	-0.8	-1.2	-1.5	-1.3	-1.2	-1.0	-1.0	-0.8	-0.7	-0.4

(1) Increase in offspring numbers applies to dairy and beef animals only. (2) Year ended June 30.
(3) Weighted average saleyard price of beef, est dressed weight basis. (4) Weighted average saleyard price of lamb, est dressed weight basis. (5) Weighted average saleyard price of mutton, est dressed weight basis. (6) Auction level greasy wool price.

EMABA Model Results

Sheep industryuse twinning. (3)

Table 1 : PERCENTAGE IMPACTS FROM THE ADOPTION OF TWINNING - SCENARIO 3 (1)

	YEARS										
	1	2	3	4	5	6	7	8	9	10	LR
AUSTRALIA (2)											
Beef Production	-0.8	-1.6	-2.0	-0.9	1.2	3.7	5.9	7.6	8.8	9.6	13.0
Lamb Production	0.0	13.2	11.3	9.6	10.8	10.1	9.9	10.2	10.2	10.2	10.5
Mutton Production	2.7	6.5	15.7	21.2	24.3	26.4	28.1	29.7	31.4	33.1	47.2
Wool Production (greasy)	3.9	8.6	12.3	15.3	17.7	19.7	21.6	23.2	24.8	26.1	35.4
Beef Price (3)	1.3	1.4	1.5	-1.0	-3.3	-5.4	-6.7	-8.0	-8.9	-9.7	-11.9
Lamb Price (4)	0.1	-15.4	-11.2	-8.8	-10.3	-9.4	-9.3	-9.8	-9.9	-10.1	-10.8
Mutton Price (5)	-5.3	-14.5	-27.7	-32.9	-35.3	-36.8	-38.0	-39.4	-40.9	-42.2	-51.5
Wool Price (6)	-8.0	-11.3	-11.6	-11.9	-12.2	-12.4	-12.8	-13.2	-13.6	-14.0	-16.3

(1) Increase in offspring numbers applies to sheep only. (2) Year ended June 30.
(3) Weighted average saleyard price of beef, est dressed weight basis. (4) Weighted average saleyard price of lamb,
est dressed weight basis. (5) Weighted average saleyard price of mutton, est dressed weight basis. (6) Auction level greasy wool price.

Appendix 5.4

302.91

EMABA Model Results

Dairy and beef and sheep industries use twinning. (4)

Table 1 : PERCENTAGE IMPACTS FROM THE ADOPTION OF TWINNING - SCENARIO 4 (1)

	YEARS										
	1	2	3	4	5	6	7	8	9	10	LR
AUSTRALIA (2)											
Beef Production	20.2	23.3	22.5	17.2	15.5	13.8	14.1	13.5	13.5	13.0	18.0
Lamb Production	0.0	11.2	10.5	9.4	10.3	9.6	9.4	9.8	9.8	10.0	10.5
Mutton Production	-2.2	-0.7	4.3	14.7	18.5	24.1	25.6	29.2	31.2	34 4	46.4
Wool Production (greasy)	3.9	9.0	13.2	16.7	19.4	21.5	23.4	25.1	26.5	27.7	36.4
Beef Price (3)	-28.7	-12.9	-20.0	-9.5	-16.3	-12.1	-15.7	-12.2	-13.1	-10.8	-15.6
Lamb Price (4)	-5.9	-14.2	-12 8	-9.2	-11.9	-10.1	-10.6	-10.3	-10.5	-10.2	-11.0
Mutton Price (5)	-9.1	-3.0	-16.7	-27.0	-33.1	-36.8	-38.5	-40.4	-42.1	-44.1	-51.6
Wool Price (6)	-8.1	-11.9	-12.6	-13.1	-13.3	-13.6	-13.9	-14.3	-14.5	-14.8	-16.7

(1) Increase in offspring numbers applies to sheep and cattle. (2) Year ended June 30.
(3) Weighted average saleyard price of beef, est dressed weight basis. (4) Weighted average saleyard price of lamb, est dressed weight basis. (5) Weighted average saleyard price of mutton, est dressed weight basis. (6) Auction level greasy wool price.