A SEMI-STOCHASTIC SIMULATION MODEL OF THE NEW ZEALAND DAIRY CATTLE ARTIFICIAL INSEMINATION INDUSTRY

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Abstract

A univariate semi-stochastic simulation model was written with the objective of economically evaluating a range of breeding programmes from the perspective of a privately owned artificial insemination company.

To test the validity of the model four breeding programmes were evaluated. Three of the options were variants of the first which considered the progeny testing of 35 young sires sourced from the New Zealand and United States registered populations. Modifications to the initial programme centred around increasing the number of young sires sampled and the use of the New Zealand recorded, but unregistered, cow population as a source of bull dams.

Stochastic simulation was used for the male sub-populations of sires-to-breed-sires and sires-to-breed-dams, simulating each animal individually by drawing them from a univariate normal distribution. Cow populations, because of size, were simulated deterministically using expectations based on existing dairy industry structure.

Selection was imposed on the population for a single production trait with a heritability of 0.25. Selection intensities and generation intervals depended on user defined inputs such as which populations were available for selection, how many sires of sons were to be used, and how many young sires were to be sampled.

The genetic simulation was replicated ten times for each of the four options, covering a twenty year time frame. Economic analysis was undertaken by modelling two companies. One company maintained a stable breeding programme throughout the simulation so that the changing fortunes of the other could be measured as its breeding programme altered. Gross profit was estimated from semen sales and the costs associated with each programme subtracted. The resulting pre-tax profit was adjusted for tax and discounted to a net present value.

The effect of planning horizon on profitability was examined by extracting data at five year intervals, coefficients of variation were used to analyse risk and all options were contrasted with the base in percentage terms to overcome the need to account for fixed capital costs, which were assumed to remain constant across breeding programs.

For the programmes modelled it was found that cost structure played a bigger part in determining net profit than rate of genetic gain. Secondly, expanding the base population in which selection was carried out was more important than increasing the number of young sires sampled.

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CHAPTER ONE

1. INTRODUCTION

The New Zealand Artificial Insemination industry is in a state of flux. The importation of U.S.A genetics has become a recent phenomenon, milk payment systems are currently under review, and a new conformation evaluation system has recently been implemented.

Artificial Insemination (AI) of dairy cattle has been utilised in New Zealand since the early 1950s' (Edey, 1966). It has in the past, and remains today the predominant mode of bringing about genetic gain in dairy cattle in New Zealand. As early as 1950 Rendel and Robertson showed that the use of semen from bulls of proven superior genetic merit allowed the almost doubling of genetic gain over that of natural mating alone. In New Zealand the vast majority of these bulls are produced by two AI companies utilising comprehensive breeding and testing programs. Genetically superior females selected from both the registered and unregistered populations are mated to superior bulls selected from a domestic and international pool and the resultant bull calves progeny tested in commercial herds. Semen from the best progeny tested bulls is then sold on a large scale in both liquid and frozen form for use in the domestic and, to a lesser extent, global markets.

Within the traditional structure of progeny testing, many of the components of the test can be varied. Numbers of sires of sons, number of bulls to be tested, progeny test group size, and source of dams of bulls, to name just a few can all be altered. Combining these factors with the ongoing commercialisation of new biotechnology's such as embryo transfer and cloning, the scope for variation in progeny test schemes is considerable. The need for methods that can evaluate and optimise different breeding schemes becomes obvious if the farming industry is to take full advantage of new technologies as they become available. However, apart from an 'in-house' model developed by Shannon and Jackson(1987) for the, then, Livestock Improvement Division of the New Zealand Dairy Board, there has been almost no published research into the optimisation of breeding schemes for dairy cattle, genetic or otherwise, in our country.

Miller and Pearson's(1979) review pointed out that two general approaches have been used in characterising the optimality of returns from breeding programs: (1) the use of a procedure which uniquely identifies the optimum combination of factors (such as linear or dynamic programming): (2) to model the selection or production process and numerically calculate net returns from all possible combinations of resources or alternative structures of the production process. Using the first method, Skjervold and Langholz(1964) calculated the optimum progeny group size and the proportion of cows to be inseminated by young sires to maximise genetic gain. Most researchers however have tended to use the second method for three reasons. First, the variation observed about the optimum is generally more informative than the exact optimum, this is due to the incomplete representation of the real situation by any model. Second, the complexity of the modelled system often does not lend itself to using the first method and third the second method lends itself to comparing breeding programs with different structures.

With these concepts in mind it was decided that the second method was more flexible in the sense that once the system was successfully modelled the computer program could be easily modified to incorporate new breeding schemes or technologies as they become available.

This thesis reports the development of a univariate semi-stochastic simulation model of the New Zealand AI industry at the breeding company level and economically evaluates several variations of existing breeding schemes for one of the AI companies.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1. THE NEW ZEALAND DAIRY INDUSTRY - AN OVERVIEW

New Zealand is a comparatively small dairy producer by international standards, accounting for only 1.5% of the world's milk production. However, as an exporter of dairy products New Zealand, accounts for nearly 25% of all trade (Guy, 1992). Milk production is generated from approximately 2.4 million dairy cows milked in 14,700 herds (Anon, 1992) grazed almost exclusively on pasture. More than 90% of these cows calve in the months of July through September (Holmes et al, 1987) with the remainder found mainly in herds that supply the domestic fresh milk market. The average production per cow is around 116kg of protein and 152kg of milkfat over a 222 day lactation. Payment for milk products in New Zealand is based on an A+B-C system which accounts for the value of protein and fat and adjusting for the cost of transporting and processing volume.

2.1.1. BREED MIXES

The three major breeds represented in the New Zealand dairy industry are the Holstein-Friesian, Jersey, and Ayrshire. The registered cow population however, accounts for only 5% of the total population (Wickham, 1989). Beyond this division the breed composition of the population becomes difficult to assess. The use of cross-breeding as a management practice is widespread amongst breeders of grade cows (cows not registered with a breed association). This situation has arisen because of two factors, the first is the performance of the F_1 Friesian-Jersey cross which based on an analysis of 1989/90 dairy statistics out performs either parent breed for total solids produced. Second, although prior to 1960 the New Zealand cow population was predominantly Jersey, the Holstein-Friesian has, in recent times undergone a resurgence in popularity due to changes in management practices including increasing stocking rates and the increasing sales of dairy calves for beef (Guy, 1992). The primary means of increasing Holstein-Friesian numbers has been through a grading-up process involving crossbreeding. As an indication of the proportions of breeds in the population as a whole, approximately 67% of all inseminations are Holstein-Friesian, 26% Jersey and 2% Ayrshire (Anon, 1992).

2.1.2. HERD IMPROVEMENT IN NEW ZEALAND

The New Zealand Dairy Board (NZDB), an industry-owned producer board, is responsible for the marketing of New Zealand dairy produce internationally. The NZDB is in turn supplied with this product by a number of farmer-owned co-operative dairy companies that manufacture a range of commodities and value-added products.

Herd Improvement in New Zealand is also largely directed by industry through the NZDB's subsidiary the Livestock Improvement Corporation (LIC). The LIC's objectives are focused in five areas :

(1) The improvement of livestock through :

  (a) the measurement or evaluation of growth, yield of milk or milk constituents, feed conversion efficiency or any other factor relevant to decisions on breeding and management of livestock,

  (b) the development and commercial application of artificial breeding of stock and,

(c) the purchase, sale, and provision of livestock, semen, services and products of all kinds.

(2) The promotion, advancement and adoption of measures and practices designed to bring about greater efficiency. In particular, the identification of stock, elimination of unprofitable stock and the encouragement and use of genetically superior stock.

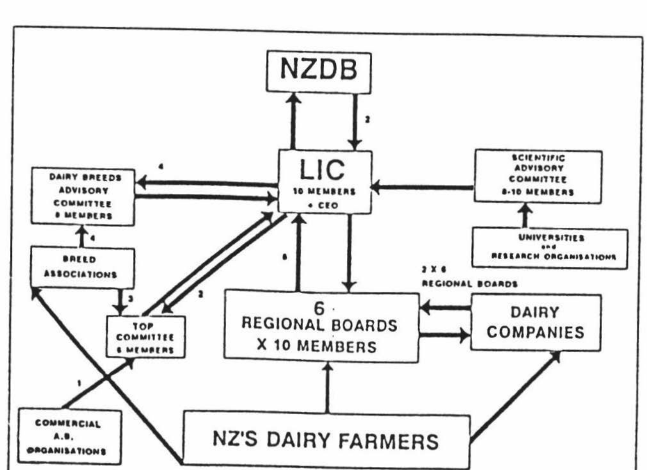
(3) Enhancement of the net income of dairy farmers through improved efficiency, management and breeding practices.

(4) Enhancement of the quality of livestock through breeding.

(5) The carrying out of any other activity in conjunction with the above objects and which may directly or indirectly assist farmers in improving the quality of their livestock and produce (Macdonald Committee report, 1992).

Consistent with these objectives, a national database is maintained to keep track of the more than 10 million animals recorded (C Linton, personal communication); milk recording of the some 1.5 million cows herd-tested is carried out; bull proofs are calculated and, an LIC-run bull stud participates in sire-proving and semen marketing. The policy setting structure for herd improvement in New Zealand is outlined in figure 1(Macdonald Committee Report, 1992).

Figure 1: Policy setting structure for herd improvement in New Zealand



2.1.3. SIRE PROVING IN NEW ZEALAND

Progeny testing, as in other countries, is utilised extensively in New Zealand to identify elite genetics. Of the six recognised semen selling organisations only two, the LIC and Ambreed NZ Ltd, are involved in progeny testing of any magnitude. As outlined in Table 1 around 103,000 cows are mated annually to young sires involved in a structured progeny test.

Table: 1 Number of cows mated to young sire semen annually

Organisation	Friesian	Jersey	Ayrshire	Total
Livestock Improvement	42,009	18,680	1,512	62,201
Ambreed	28,200	12,600	-	40,800
				103,001

Here the similarities with other countries end. Seasonality aspects mean that because young sires are almost exclusively sampled when they are one year old, the time in which young sire semen can be collected is generally condensed into a 10 week period. Thus, late born animals are rarely progeny tested and early maturity of sires is indirectly selected for. Also, it is likely that a significant proportion of young sire matings are not to straightbred cows of their own breed due to the widespread use of cross-breeding. Unlike many countries, a sire's first crop of daughters all calve within the same genetic summary period so that once a bull has his first summary, there are no new daughters added to his proof until his second crop are milked four years later. This means that a poorly-sampled sire is a costly exercise for a bull stud.

The Livestock Improvement Corporation currently samples three classes of young sires, unregistered, registered and imported while Ambreed samples only the latter two. Currently in excess of 75% of these young sires are sired by North American bulls (R. Knutson unpublished data).

The use of grade bulls in the LIC's progeny testing program began in 1972 (Guy, 1992) and arose as a result of the low numbers of registered cattle, the lack of a single selection goal in the pedigree populations and the increase in the number of 'elite' unregistered cows that were recorded and herd-tested . The use of unregistered stock has escalated such that in 1988, 70% percent of the young sires sampled in the LIC sire proving scheme were unregistered in origin (Wickham and Bishop, 1988). This should be accounted for when attempting to model the semen-sales industry.

2.2. THE BUSINESS OF SELLING SEMEN

The Livestock Improvement Corporation operated bull stud acts as the supplier of semen to 70% of the AI market which consists of approximately 1.8 million cows. Another NZDB owned company Ambreed NZ Ltd supplies another 25% with the remainder being made up by semen importers and inseminations resulting from custom collections.

The New Zealand artificial insemination (AI) industry is unique compared to our traditional competitor countries. The factors that contribute to this uniqueness are discussed below.

2.2.1. SEASONALITY OF SEMEN SALES

The seasonality of dairy semen sales in New Zealand follows that of the most common milk production system. In general, the selling season begins in April with the majority of sales completed by the end of June apart from a resurgence in late October corresponding to a 'top up' by farmers after the bulk of mating is completed. The earliness of the selling season compared to the onset of mating occurs because of two reasons. First, the financial planning requirements of individual companies whose annual income is generated almost solely in the three months post-mating are such that an accurate, early assessment of total company sales is needed, and second, the competitiveness of semen selling dictates that there is a financial advantage in being first to the marketplace. Thus, the selling season starts earlier each year, with the sole restraint being the willingness of farmers to buy semen without up to date information on bulls. Mating begins earlier in the Northern provinces and progressively gets later in the Southern regions. The bulk of matings occur in the four weeks commencing 15th October.

2.2.2. COMPETITIVE ASPECTS OF SEMEN SELLING

The profit of any organisation depends on the amount of product sold, the associated selling costs and on the selling price per unit of product. It is often assumed that the selection goal that maximises the profit for the breeding company clientele will also maximise the profit of the breeding company itself. This may be the case for companies with a co-operative type structure but is unlikely to be so for privately-owned companies. The true value of genetic improvement to a privately-owned artificial breeding company is determined by its impact on saleability of the company's semen. This impact is influenced by the competitive position of the company ie. the performance of its product compared to that of its competitors (de Vries, 1989). Hill(1974) states that it seems likely that the fundamental relationship between performance and returns is sigmoid: if a company's product is much poorer than that of its competitors, its sales are likely to be small, if much superior, very large; while over the range of the competitor's performance it is likely that a large change in sales will result from a small change in performance. Of course the implicit assumption that genetic value is the only factor that impacts on competitive position and hence company profitability must be made. In the real world salesmanship, service and price are probably equally as important as performance. The LIC's use of liquid semen also has a major impact on competitive position in New Zealand.

To date, the incorporation of competitive aspects of trading genetic material into the design of animal breeding schemes have been minimal. Yet the incorporation of competitive position would seem to be a prerequisite to enable accurate modelling of any AI industry where sire selection is rarely on the basis of production breeding values alone. Alternative factors which may affect farmers choice of company and product are animal conformation, company loyalty, capital investment associated with change, service, price, past company performance and company image. To date the Anon(1978) and de Vries(1989) have been the only attempts to objectively incorporate the effects of competition into a breeding company's decision-making process. The New Zealand Dairy Board in investigating the implications of offering farmers the choice between a technician service and a do-it-yourself (DIY) approach to artificial insemination used a combination of field trials and a Markov brand-switching model to determine the impact of such a decision on market share. They also hinted that they had begun assessing intangibles such as the convenience of DIY over a technician service but no further reference could be found in the literature. The model of De Vries(1989) combines competitive aspects with traditional selection index theory and allows breeding organisations to develop a selection index based on market requirements for their products. Individual economic weights on traits are modified from their true commercial value to include the situation where, in reality, improvement of a trait with a low performance compared with competitors is more important than improvement of a trait with acceptable performance(ie the breeding stock is superior or equal to competitors for this trait).

2.2.3. LIQUID SEMEN

When a concentrated mating/calving pattern is combined with the close proximity of dairy farms in a number of regions, the opportunity to use liquid semen arises. The LIC sells the majority of its semen product in liquid format and is currently the only semen seller in New Zealand to actively market liquid semen. In the frozen semen market the LIC contributes 20% of the volume, and Ambreed 71%. This division in the market place once again poses a challenge to the modelling process. In particular the impact of liquid semen on competitive aspects of the semen selling market needs to be accounted for.

There are three primary features of liquid semen use that cause it to have a significant impact on competitive position. The number of sperm required per insemination to achieve a satisfactory conception rate is around a factor of ten less than that of frozen semen (Guy, 1992). This improvement of efficiency means that the cost of production per unit is decreased and therefore the price to the farmer can be more competitive. The capital investment required by a farmer to utilise liquid semen technology is minimal as compared to the use of frozen semen where generally a liquid nitrogen canister is required. For a company selling liquid semen the cost required for its prospective clients to change from a frozen semen regimen is minimal, thus affording it a competitive advantage over the company selling frozen semen where the costs of changing from liquid to frozen semen can often be expensive. This is in direct contrast to the US artificial insemination industry where semen from bulls of any AI stud is available to farmers nationwide and where the market size of any one bull stud is dependent upon the genetic merit of the bulls it produces as compared to the bulls produced by its competitors (Miller, 1988). The third feature of liquid semen that impacts on competitive position is that at present the lifespan of liquid semen in New Zealand is only three days. This means that bulls must be rostered so that semen will be available every day of the mating season, consequently prohibiting, in a practical sense, the individual selection of bulls by farmers if they use liquid semen. This has a polarising effect on competitive position. Farmers that have an interest in breeding and individually select their mating sires are unlikely to change from a frozen regimen to a liquid one. The use of liquid semen promotes disinterest in all but the most basic aspects of breeding and thus farmers in this category are unlikely to change unless the economic benefits are large. Even then, many would still not change because of the convenience of someone else looking after their breeding requirements.

2.3. MODELLING

The quantitative nature of animal breeding facilitates the use of computer modelling. The design of cattle breeding schemes generally requires the integration of several industry sub-systems. Modelling is a practical method of evaluating the complex interrelationships between sub-systems. It also provides an alternative or supplement to experimentation when costs are prohibitive.

2.3.1. THE EVOLUTION OF MODELLING

With the optimum breeding structure in mind the first investigations made by Dickerson and Hazel (1944) were based upon an evaluation of the genetic efficiency of alternative selection procedures. Their study also questioned the choice of criteria that should be used to judge the efficiency of breeding programs, by suggesting that it should be genetic improvement per year rather than genetic gain per generation that had, until that time, been used exclusively.

Other essential contributions were made by : Robertson and Rendel(1950), who initiated the first investigations into the value of artificial insemination as a tool for genetic improvement; Robertson(1957) and Skjervold(1963), who considered progeny group size and the optimum number of young sires to test as they impact on genetic gain, and Skjervold and Langholz(1964), who showed the relative importance of the four pathways of selection while investigating the optimum proportion of cows to be mated to young sires.

The paper of Poutous and Vissac(1962) was, however, a turning point in the evolution of modelling animal breeding processes. The realisation that economic criteria should be used wherever possible to evaluate breeding programs bridged the gap between applied science and commercial reality. This occurred such that economic criteria in general, and the concept of net present value in particular, are now the standard for evaluating breeding programs. Following this realisation, models began to appear that not only evaluated their genetic findings economically, but also resembled the complete selection process. Lindhe's(1968) investigation of optimal breeding schemes for a dual-purpose cattle breed in Scandinavia, and Brascamp's(1973a,b) papers dealing with the economic value of genetic improvement in milk yield and the effect of cost structure on the optimality of breeding programs respectively, illustrate the progression from genetic to economic criteria, and the shift from the essentially sub-system type modelling of the past to a modelling of the whole breeding scheme.

2.3.2. ASPECTS OF GENETIC MODELLING

2.3.2.1. SYSTEM OBJECTIVES

System objectives can be viewed on two levels. At the macro-level the researcher must answer the following questions: what are the goals ? What perspective should be taken ? What is to be achieved with the model ?. Failure to define objectives at this level makes the structuring of a model difficult. At the micro-level selection objectives need to be defined. Will the model select for a single trait or will allowances be made for multiple traits to be included ? What is it that the model selects for ? How often is selection carried out ?

In reality the choice of system objectives not only determines what it is that will be studied but also how it will be studied.

2.3.2.2. LINEAR OR DYNAMIC PROGRAMMING

When an organised framework is devised for carrying out selection, there may be many factors or variables to take into account. These factors have direct economic consequences, and therefore, it is necessary to know what combination of values constitutes an optimum plan. Even though an effective criterion for selection among animals is available, this does not guarantee that maximum returns will be achieved. To find this optimum combination there are two alternatives: (1) use a procedure that uniquely identifies the optimum combination (such as linear or dynamic programming) or (2) model the selection or production process and numerically calculate net returns from all possible feasible combinations of resources or alternative structures of the production process (Miller and Pearson, 1979). Models of the first kind have been used by several authors to find the optimum combination of factors for a given breeding program. Skjervold and Langholz(1964), used this type of process to determine the optimum progeny group size and proportion of cows to be mated to young sires for a conventional progeny testing scheme. Smith(1969), developed an empirical linear expression for the selection differential and used it to investigate the optimum balance of the two sexes for performance testing given that testing resources were restricted. James(1972), evaluated the optimum selection intensity that balanced the short-term and long-term objectives of a breeding scheme using the theory that the present value of future genetic improvement in a closed population was a function of the sum of the discounted changes in the population mean. More recently, Goddard and Smith(1990) used a linear programming approach to identify the optimum number of bull sires needed per generation to maximise the net response in economic merit of a breeding scheme.

Often, the complexity of the objective function makes this type of analysis impractical, most studies therefore have used the second approach. Modelling the selection/production process has the advantage of allowing sensitivity analyses, and the investigation and evaluation of risk as well as incorporating the flexibility to modify selection criteria without major model reconstruction.

2.3.2.3. DETERMINISTIC VS STOCHASTIC

Genetic improvement in dairy cattle is a stochastic process but for its simulation deterministic models have been used almost exclusively (Rendel and Robertson 1950; Hill 1974; Hopkins and James 1979). Deterministic models are based on a multivariate normal distribution of characteristics of animals in an age-sex group. Stochastic models do not require this assumption (Dekkers and Shook 1990b). Furthermore while deterministic models make a unique prediction for each set of input variables, without any associated internal variation, stochastic models contain random elements, so they not only predict the expected value of model performance variables but also their dispersion (Pomar et al, 1991). Unfortunately, stochastic simulation of large populations can be prohibitive due to computing constraints, thus it is not surprising that only one study involving the stochastic simulation of a large population could be found. Kislev's 1979 study of economic aspects of selection in the Israeli dairy herd involved simulation of up to 12000 animals.

In recent years, computing power has improved dramatically so that stochastic models are beginning to appear more frequently. Such simulation techniques are still in the main limited to small insulated production systems such as pig farming enterprises (Singh, 1986; Allen and Stewart, 1983; de Roo, 1987; Pomar et al, 1991;), or MOET nucleus schemes for dairy cattle (Juga and Maki-Tanila, 1987; Stranden and Maki-Tanila, 1990, Jeon et al, 1990).

Investigation of larger populations such as those of Dekkers and Shook (1990a,b,c) overcome computing constraints by using semi-stochastic models where simulation at the animal level is reserved for age-sex groups consisting of small numbers (AI bulls, bull mothers) while deterministic procedures are used for age groups in the general cow population.

2.3.2.4. ASYMPTOTIC VS POPULATION INVENTORY

Selection is a dynamic process, spread over time. Depending on perspective, models can be of two types. Step-by-step or population inventory models describe the evolution of a population year after year and are used either for the decription of the start of a selection scheme or when fluctuations between years are important. Examples of population inventory models are: Dekkers (1989) who investigated the economic and genetic effects of changing from a conventional progeny testing breeding scheme to one involving an open nucleus, utilising embryo transfer from a competitive AI company's perspective and, Jeon et al (1990) who showed that while inbreeding slowed genetic gain in small closed nucleus cattle breeding schemes, the overall gain was still greater than that of traditional progeny test schemes.

Asymptotic models are an alternative to population inventory models that consider the long-term effects of the selection process. These models apply to populations where selection is made identically over a long period of time. Examples are: Lindhe's 1968 paper, which dealt with the impact of varying the number of frozen semen doses stored from a bull before slaughter, the effect of varying selection intensities for growth rate of sires and the economy of such schemes from a long-term industry viewpoint and, Oltenacu and Young's(1973) paper, which looked at the optimum fraction of the cow population to be bred to young bulls and the proportion of progeny tested sires selected from a genetic equilibrium stand-point.

2.3.2.5. THE FOUR PATHWAYS OF SELECTION

The description of the production system is facilitated by the use of the four pathways of selection as described by Robertson and Rendel(1950). The key concepts introduced were that there are four pathways along which genetic improvement is transmitted: sires-to-breed-sons (SS), sires-to-breed-daughters (SD), dams-to-breed-sons (DS) and dams-to-breed-daughters (DD), and that the relative importance of these paths changes depending on the characteristics of the breeding program. While the simplicity of the four pathway approach may be inappropriate in view of the complex population structures found in a modern dairy cow population it nonetheless provides a stepping stone from which further population subdivision can be accomplished. For example, within the sire-to-breed-daughter pathway the dairy bull population could be subdivided into imported and domestic sires, company product lines, or some other grouping depending on the objectives of the system.

2.3.3. ECONOMIC MODELLING

The history of modelling the economic components of breeding programs has been comprehensively reviewed elsewhere by Miller (1977) and Miller and Pearson (1979). It is therefore intended to concentrate on some of the major components of economic modelling.

2.3.3.1. GENETIC GAIN AND ECONOMIC RETURN

One of the major limitations of much of the historical research into the optimality of breeding schemes has been the fascination with genetic gain instead of the more appropriate, at least for the commercial sectors of the industry, economic gain.

Breeding programs for commercial AI companies should be chosen on economic merit. Several studies have shown that the maximisation of genetic gain does not necessarily equate with maximisation of economic return (Lindhe, 1968; Oltenacu and Young, 1974). There are obvious reasons why this disparity occurs. First, rates of genetic gain do not relate linearly to the increasing costs of breeding schemes (Smith, 1981), and second, the relative importance of the four pathways of selection are in conflict from a genetic standpoint, as compared to an economic standpoint, due to differences between paths in the time lag between creation and expression of genetic superiority (Brascamp, 1973). For example, the genetic superiority for milk production of sires of cows is expressed in the lactation's of their daughters, while that of sires-of-sires is not expressed until their grand-daughters come into lactation.

2.3.3.2. ECONOMIC PERSPECTIVE

The ability to appraise a breeding program economically depends on a knowledge of which segment of the industry profits are to be maximised for.

Economic aspects of farm profitability as a result of genetic improvement of dairy cattle have been addressed by McClintock and Cunningham (1974) who by tracing a bulls superiority, through its expression in his descendants, were able to develop a method to calculate the additional returns to the farmer of a single insemination. Likewise Everett (1975) and McGilliard (1978) used similar methods for calculating the net return to US dairy farmers of investment in frozen semen.

Researchers investigating investment from a national viewpoint are unified in their use of net income from milk as a measure of the returns to be achieved by alternative breeding schemes (Soller et al., 1966; Lindhe, 1968; Hinks, 1971; Brascamp, 1973; Petersen et al.,1974).

At the AI stud level however there has been disagreement over what is the appropriate criterion. Economic benefit per unit of genetic improvement on the farm has been used by Van Vleck (1964) and Oltenacu and Young (1974). However the implicit assumption that what benefits the farmer is what benefits the bull stud is only appropriate where the market size of the stud is static and where the stud is a farmer owned co-operative as defined by Van Vleck (1964). Privately owned bull studs are primarily interested in the profitability of the enterprise itself (Dekkers, 1989) which does not necessarily translate to maximum return to the individual farmer clients of the stud.

In principle, the economic analysis of a breeding program requires estimates of the size of the market for improved stock, the monetary value of a unit change in performance, the genetic parameters necessary to enable computation of genetic progress, the cost of alternative schemes, the planning horizon and finally the discount rate.

2.3.3.3. DISCOUNT RATE and PLANNING HORIZON

The financial discount rate (*t*) can be defined simply as the opportunity cost of money and is characterised by the relationship :

$$t = (1/(1+r))^{k}$$

where *k* is the time in years from some fixed date (usually the date of the first expense) to the end of the planning horizon while, *r* is an appropriate annual interest rate. The use of a discount rate arises in response to the fact that money in the future generally has less value than money today.

The concept of discounting is now well established in the animal breeding context. What is not well established is how it should be applied. At the centre of this conundrum is the question as to what viewpoint the project should be evaluated from. The discount rate needed for a project of national interest is considerably different to that required by a private AI stud investigating a change of breeding program. A project being implemented on a national scale need not account for risk or inflation and can therefore employ a lower discount rate than can a private company which must recognise and account for the risks placed on investors funds. Papers researching projects from a private perspective include Oltenacu and Young (1974) who used a 10% discount rate to examine several alternatives for increasing the rate of selection among progeny tested bulls, Everett (1974) who assessed the net worth of frozen semen to a dairyman using a range of discount rates from 0-14% and, Dekkers and Shook (1990a) who in comparing nucleus breeding schemes from a commercial artificial insemination firm perspective used a 5% rate.

Coupling discounting with the inherent variation in timing of expression of genetic merit through the four selection pathways, it becomes apparent that both the discount rate and the planning horizon have a major impact on the outcome of any economic analysis. High discount rates will tend to favour projects with short-term benefits while lower discount rates will favour those projects with longer term benefits. Miller and Pearson(1979) pointed out the contrasting attitudes of breeding companies and national planners toward the importance of long- and short-term goals. A firm is naturally concerned about its profit margin in the short-term future, whereas national planners are more concerned about long-term implications for balance of trade and the optimum use of natural resources.

There is a trade-off however, motivation for short-term profits may be detrimental to the achievement of long-term genetic goals and profitability, as the firm only gains a small fraction of the increased worth of improved animals through sales. Coupled with this, sales expertise and advertising can often be substituted for animal improvement reducing the need for, and competing for funds with, accelerated genetic progress.

Cunningham and Ryan (1975) clarified the question of how far into the future farmers and scientists must look to quantify the costs and benefits of artificial insemination. However, from an independent breeding company perspective where fruition of returns is delayed even further than those of an individual farmer, and where yearly profitability is imperative to survival, the importance of the planning horizon and chosen discount rate cannot be over-estimated. For example, Cunningham and Ryan (1975) stated that there is little advantage in considering a planning horizon of more than fifteen years in any situation, and not more than ten years in most. However, when the time-lag between decision making and the return on a single bulls last semen sales being 9-10 years is considered, it becomes apparent that a change in breeding scheme alters company profitability only in the medium to long- term.

2.3.3.4. FIXED VS VARIABLE COSTS

Cost structures play an integral role in determining the overall profitability of a breeding scheme. Fixed costs are defined as those costs which are invariant across schemes while variable costs are those that change between schemes. Examples of fixed and variable costs are given in table 2.

Table 2: Examples of costs for a New Zealand dairy cattle progeny testing scheme

Fixed Costs	**Variable costs**
Cost of incentives	Bull purchase price
Capital costs	Royalty rates
Cost of semen production	Housing costs

How fixed and variable costs are dealt with in an economic analysis depends on the objectives of the study. If the actual dollar superiority of one scheme over another is important rather than a simple contrast of different programs then both fixed and variable costs must be accounted for explicitly. If however, the second scenario applies then it is possible to ignore fixed costs and express returns as a percentage of some base scheme.

2.3.3.5. SEMEN PRICING

Economic returns to a bull stud accrue through the sale of semen. Therefore, any economic model dealing with the revenue of bull studs must include the relationship between genetic value and semen price. Data analyses have not yielded a clear picture of this relationship. Van Raden and Freeman (1982) used multiple regression analyses to determine the relationship between price and sire evaluations for several traits of bulls available from the Select Sires bull stud. They reported that linear, quadratic, cubic and quartic terms in the total performance index were significant in determining price. Wilder and Van Vleck (1988) were able to explain between 50-75% of the variation present in American bull stud semen prices (outliers were excluded) when functions of sire evaluations were included in normal and quadratic forms using the same type of model as Van Raden and Freeman, they also found that goodness of fit of any one model varied considerably between companies. Voelker (1984) using semen prices from bull studs in the US over a 9 year period found that total performance index had the largest correlation with price followed by predicted difference dollars, predicted difference milk, and predicted difference type. Dekkers (1989) chose a quadratic model including the single variable of a bulls genetic merit in his simulation after first examining the validity of linear, cubic, and exponential models .

There are no reports of this type of analysis being carried out in New Zealand.

2.3.3.6. RISK

The value of any investment depends on the estimate of its future cash flow. But future returns can rarely be predicted with certainty. As a result, investors rarely have very precise expectations regarding the future income that will be returned from a particular investment (Levy and Sarnat, 1988). Expectations therefore have two states, certainty and uncertainty (risk). Certainty generally refers to the case where expectations are single-valued or confined to a narrow range. Risk can be defined as that part of uncertainty which can be quantified. For deterministic models which have no chance element, risk can only be accounted for by increasing the discount rate (Brascamp,1978) or by applying sensitivity analyses. The first approach, which is in widespread use, has the confounding effect of favouring short-term projects at the expense of long-term projects and should only be used if risk grows as a geometric function of time (Bird and Mitchell, 1980). Furthermore the discount rate does not allow for the variation in magnitude of risk between programs shown by Freeman et al (1977) and Schneeberger et al (1981).

The second approach shows how much returns can vary but not what the likelihood of the variation occurring is.

Stochastic models by definition include elements of chance therefore the correct way to account for risk in these situations is to calculate the standard deviation of returns (Brascamp, 1975). This approach stops short of weighting both the expected returns and the risk component so that a choice between projects can be made.

In attempting to deal with risk, Slenning and Wheeler(1989) used a simulation model to evaluate the embryo transfer strategies of non-superovulation, super-ovulation using follicle stimulating hormone, and super-ovulation using pregnant mare serum gonadotrophin. They utilised decision tree analysis to combine expectations and risk so that a definitive choice of strategy could be made. A similar approach was used by Anon(1978) in examining the implications of changing from a technician service to a do-it-yourself approach for artificial insemination of the national dairy herd. Schneeburger et al (1981) used a different approach. They showed that in evaluating the costs and risks involved in selecting bulls for AI, that increased pedigree selection followed by decreased selection among progeny tested sires could yield the same average breeding value as would decreasing pedigree selection and increasing the selection among progeny tested sires. Risk analysis revolved around the testing of a number of scenario's which would each yield the same number of sires and by plotting risk (defined as standard deviation of performance) against expected performance, the number of bulls tested, and the degree of selection on pedigree. This approach leaves the user to set their own level of risk comfort.

CHAPTER THREE

3. METHODOLOGY

3.1. GENETIC SIMULATION

3.1.1. INTRODUCTION

With the ultimate objective of this dissertation being to contrast different projects for a single profit-oriented artificial breeding company, a genetic simulation model was set up which could genetically evaluate a wide variety of options and then provide output which could be used to economically evaluate each option. Three options were chosen to be contrasted with the existing scheme. Table 3 lists each scheme with its components .

Table : 3 Characteristics of evaluated schemes.

SCHEME	NO. P.T[1] BULLS	GRADE GENETICS	AMERICAN PT'S	PROVEN AMERICAN	YEARLING HEIFERS
Existing	35	n	y	y	y
option 2	50	n	y	y	y
option 3	35	y	y	y	y
option 4	50	y	y	y	y

[1] progeny test

3.1.2. OUTLINE

A semi-stochastic model simulating genetic improvement in a single breed dairy cow population was developed with the aim of economically contrasting three alternative breeding schemes with the scheme currently in place. Stochastic simulation was used for the male sub-populations of sires-to-breed-sires and sires-to-breed-dams, simulating each animal individually by drawing them from a univariate normal distribution. The larger cow populations, also characterised by a univariate normal distribution, were simulated deterministically using expectations. The model assumes that the mean of the expected BV equals the mean of the true BV but, does not account for the reduction of genetic variance due to selection, the effects of inbreeding, or the use of liquid semen[2]. An attempt is made to account for competitive aspects of the AI industry.

Selection is for a single production trait, in this case payment BI (a composite trait of milk, protein, and milkfat), but assuming that selection index weights are not changed over time, selection could be for any individual or combination of production traits. Selection across distributions is carried out using the method of Ducrocq and Quass (1988) and is outlined in appendix 1.

The model was run ten times for each option, each run consisting of twenty iterations. Each iteration describes one year as most selection decisions occur on an annual basis in New Zealand.

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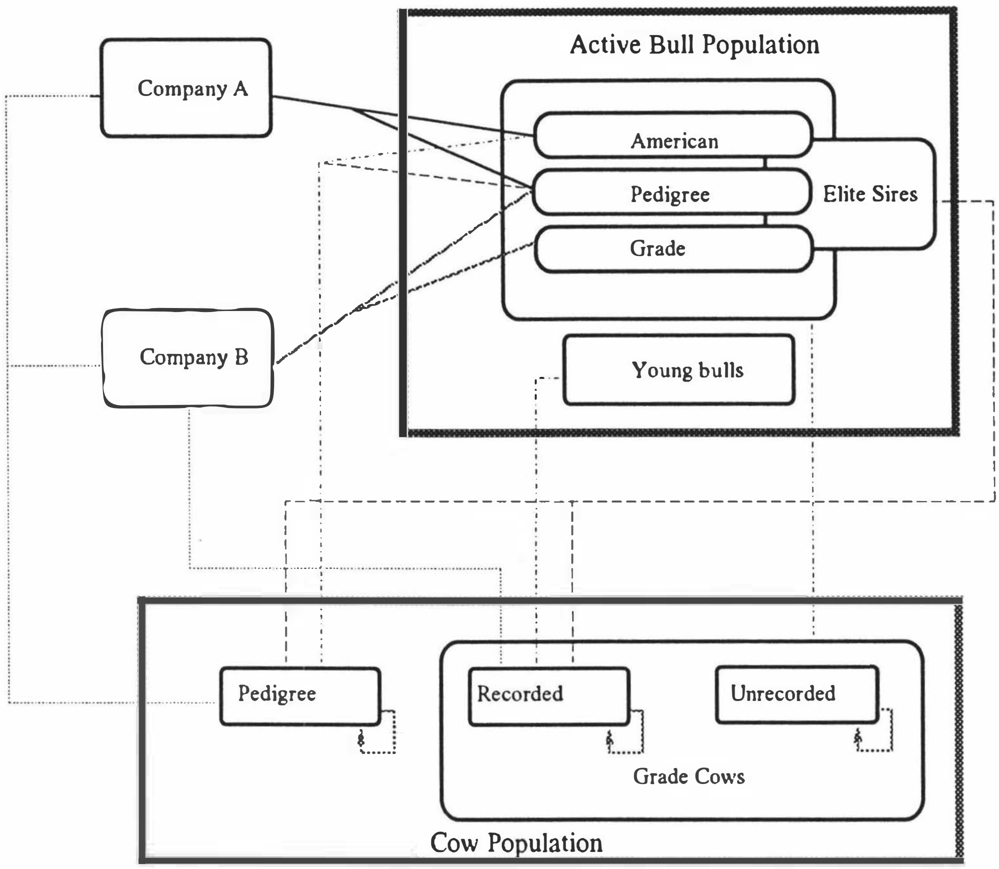
2 see market and semen allocation

3.1.3. INDUSTRY AND POPULATION STRUCTURE

Major components of the modelled (base scheme) dairy cattle artificial insemination (AI) industry are diagrammed in figure 2. Sources of genes for genetic improvement overlap between companies but are not completely shared. Company A uses imported genetics in both its proven and progeny test programs while company B uses imported genetics at the present time only as sires-to-breed-sires. Company B also uses ancestry recorded, herd-tested, grade genetics as a source of young sires and bull-dams while Company A does not.

The general cow population is divided into three sub-populations. Cows in the pedigree (ped) and recorded grade (gr) populations are herd-tested, ancestry-recorded and are eligible as bull dams depending on company breeding strategies. For simulation purposes there are 73,000 pedigree and 343,720 recorded grade cows over one year of age. The third sub-population consisting of unrecorded, untested cows makes up the rest of the 1.2 million artificially inseminated cows. This sub-population is not monitored in the simulation and is used only as a market for semen from AI bulls.

Figure 2 : Modelled components of the New Zealand AI industry



It is assumed that there is no exchange of females between sub-populations, although this does occur in reality. Young bulls are first mated for progeny testing in the recorded grade population when they reach one year of age. The remaining cows in this and the other populations are mated to the best proven bulls available across AI studs with a proportion of matings to bulls selected for traits other than production (0.05 and 0.30 for grades and pedigrees respectively). This allows for, in part, the selection criteria used by some farmers who incorporate traits other than production into their breeding goal, thereby decreasing the gain possible in the primary production traits. These other bulls are modelled deterministically and are attributed with the mean of the base group of pedigree bulls at time t .

Base populations and their characteristics are outlined in appendix 3. Bulls are mated at random within a sub-population.

It is assumed that in the marketplace, selection of commercial sires by farmers is based on payment BI and price only. Furthermore, there is no buyer allegiance to either company.

3.1.4. CREATING THE BASE POPULATIONS

3.1.4.1. FEMALE POPULATIONS

The monitored populations of pedigree- and grade-recorded cows are characterised by 11 age groups from new born calves to cows 10 years and over. Each age group is further characterised by the number of animals, the mean of the estimated BI, and the standard deviation of the estimated BI. The standard deviation of the estimated BI is given by the expression:

$$\text{Standard Dev. of estimated BI} = R_{TI} * \text{S.D of BI}$$

where R_{TI} = Correlation between true and estimated BI
and S.D of BI = The standard deviation of the true BI
(in New Zealand this = 10 BI units)

These population parameters reflect the industry situation in the 1989/90 season, except that for the purposes of simulation normality is assumed for all distributions which is probably not strictly correct (J.R. Rendel, personal communication). The number of animals in each age group remains constant over the period of the simulation as do the standard deviations of the estimated BI's. The assumption is made that the population is in a state of equilibrium with respect to numbers.

The mean of the pedigree population lags that of the recorded grade population in all age groups by 4 payment BI units. This arises due to the diverse selection criteria used by pedigree breeders being less efficient in improving the primary production traits than the breeding index only approach taken by the majority of grade breeders. The lag was estimated by a single extraction from the national database of the 1989 and 1990 born animals and then extrapolated to other age groups in the starting populations. It is likely this lag would be conservative for the older age groups, because the widespread use of high indexing USA genetics within the pedigree population, has only occurred in New Zealand since 1988 and has, as yet, had little chance to influence the genetic means of the older age-groups.

3.1.4.2. PEDIGREE AND RECORDED GRADE MALE POPULATIONS

The pedigree male population is an attempt to simulate what occurs in pedigree breeders herds, ie selection is based on more traits than production alone. The mean of this population is made up of 80% of the mean of the pedigree catalogued sires and 20% of its own mean for the previous year. This ensures that progress for production traits is less than that achieved in the recorded grade population. The original age group means for this population lag considerably behind both the catalogued and the grade male populations. The youngest age-group mean was known from actual data (R Knutson, unpublished data) and all other age-groups extrapolated from this by assuming a genetic gain equivalent to 1.5 BI units/year. Starting means for the recorded grade male population were assumed to be 4 BI units higher than the pedigree male population as was the case for pedigree and grade females.

3.1.4.3. AMERICAN PROVEN MALES AND AMERICAN BORN PROGENY TEST BULLS

A maximum of 5 American proven and 20 American unproven bulls are available to be used by Company A, for catalogue and progeny test purposes respectively, each year. The starting means were the actual available means for bulls in 1990.

3.1.4.4. INDIVIDUAL ANIMAL SIMULATION

Simulation of individual animals is based on random normal deviates obtained using a variation of the Box-Muller method (Shannon 1975) and is outlined in appendix 2.

3.1.4.5. COMPANY CATALOGUES

The starting catalogues for each company are made up of the actual 1990 catalogue bulls combined with the simulated graduates of the 1987 progeny test (PT) intakes and, in the case of Company A the simulated proven American bulls. Random involuntary culling of proven and graduate sires at the rate of 11% (Ambreed NZ Ltd, personal communication) is then carried out to allow for natural mortality rates. Bulls that are culled involuntarily are unable to be used in the company catalogues but are available to be used as sires-of-sons by the Company that progeny tested them if required. The number of required proven bulls are then selected from these groups on the basis of payment BI ranking.

In Company A's case American proven bulls are culled after 3 years of use and new intakes of these bulls cease after year 5 when the first American born progeny test sires graduate.

Catalogues are characterised by age, payment BI and a source code (table 4) for origin of bull.

Table : 4 Source codes for catalogue bulls.

Source code	Description
1	NZ born pedigree
2	NZ born grade
3	American proven
33	NZ proven, American born or bred

3.1.4.6. COMPANY PROGENY TEST TEAMS

Each Company's progeny test team has six age groups, ranging from new born to five years old, representing all sires waiting for first proofs. Each age group is defined deterministically by the number of animals in each age group, the mean payment BI of the group, the genetic standard deviation of the expected BI, and three columns defining the proportion of pedigree, grade, and American born PT's making up the age group.

As with the other sub-populations, it is assumed that each Companies breeding program has stabilised and therefore a change of breeding strategy does not affect the make-up of the progeny test teams for the previous five years. The characterisation of these distributions is based on current industry data.

It is assumed that progeny testing takes place in the recorded grade population where six hundred doses from each bull is used to yield approximately 60 herd-tested two-year old daughters. The total number of doses used by both Companies for progeny testing is deducted from the total insemination pool before catalogued sires are allocated their semen sales.

3.1.5. SELECTION AND CULLING

Selection is for an index trait with moderate heritability($h^2=0.25$) and is carried out at the end of each year. A repeatability of 0.6 between lactation's is assumed (Interbull 1986). The US proven males (Amale) and the American born unproven males (Amerpt) have a fixed genetic gain assigned to them, assumed to be comparable to the genetic gain achieved by the New Zealand population and are incremented by this amount each year. Numbers remain constant through time since, New Zealand selects a given number of bulls each year regardless of the overall pool size. The catalogued bulls are culled once a year for involuntary reasons at an assumed rate of 11% , then ranked and selected according to payment BI, and the number needed.

Female populations are also culled once a year. Numbers remain constant because the starting populations are the actual populations in the industry at the time the simulation was run, thereby accounting for involuntary culling assuming the population is in a state of equilibrium. Age-group reliability's were assumed to be the same regardless of whether the sub-population was pedigree or grade and represent those actually present in the grade population in 1991 (J.R Rendel, personal communication).

3.1.5.1. INBREEDING AND THE CHANGE IN GENETIC VARIANCE DUE TO SELECTION

For the purpose of this study it was assumed that inbreeding and a reduction of genetic variance could be ignored. This is possible because the time period over which effective selection took place was less than 15 years (3 generations) and the populations in which selection took place were large.

3.1.5.2. SIRES-OF-SONS

The number of sires used to produce future crops of progeny test sires remains constant for the duration of the simulation. For all options the number of sires-of-sons used by each Company was assumed to be five.

All catalogued bulls were available for selection by both Companies. In addition, involuntarily culled sires were available to the Company which progeny tested them during the season following their death due to a small amount of insurance semen being collected at the time of progeny testing. Selection was based solely on payment BI ranking.

The total number of inseminations carried out by both Companies is subtracted from the total insemination pool before catalogued sires are allocated semen sales.

Mating was assumed to be carried out at random with an equal number of inseminations/sire.

3.1.5.3. DAMS-OF-SONS

Selection for dams-of-sons within the female populations was carried out using Newton's method of truncating across distributions (Ducrocq and Quass(1988), and Watson et al(1981)) (appendix 1) after the relevant distributions are catenated. The number of cows required was a function of the number of young sires required for progeny testing and the number of matings required to produce those young sires. For the purposes of this simulation the function was defined as:

Number of cows selected = Number of young sires required * 4

The number of cows available for selection by each company was dependent on Company breeding philosophy (ie using/not using grades, using/not using yearling heifers as dams-of-sons) and market share[3].

3.1.5.4. SIRES-OF-DAMS

Sires-of-dams (catalogue bulls) are selected on payment BI from the existing Company catalogue and from the live progeny test graduates. In the case of Company A proven American sires are also available for selection for the first five years of the simulation, this being consistent with their current breeding program.

For the purpose of simulation it was assumed that each Company required 15 bulls to be catalogued each year.

All sires are proven with an assumed reliability of 70% and, providing they are not involuntarily culled, remain available for as long as their genetic merit dictates they be used. In the simulation very few bulls survive past 10 years of age, thus it was deemed unnecessary to account for any change in payment BI or reliability due to reproving.

Once a sire is culled (regardless of reason) he becomes unavailable for sale.

3.1.5.5. DAMS-OF-DAMS

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[3] see semen and market allocation

Literature values for selection intensity on this pathway are generally low or assumed zero (Van Tassell and Van Vleck(1991) and Brascamp(1973a)). Therefore for the purpose of this study it is assumed that there is no selection pressure applied to this path.

3.1.6. PRICE ALLOCATION

Once the bulls have been individually simulated they are ranked within Company and deviated from the lowest payment BI bull within Company. This bull is then assigned the minimum price (for all runs and years this was assumed to be $10.00). All other bulls, within company, are then assigned this minimum value plus their deviation multiplied by 0.70 cents. The seventy cents was derived from a simple regression of price on payment BI and reflects how much extra farmers had to pay in 1990 for each payment BI in their mating sires (R. Knutson, unpublished data).

3.1.7. SEMEN AND MARKET ALLOCATION

Following price allocation, the results of a multiple regression of price, payment BI, and source of bull on doses sold using actual 1990 data (R. Knutson, unpublished data) was used to determine: a) the total number of doses sold per bull in any year and, b) the total number of doses sold by a Company in any year. The regression equations used are as follows:

Doses sold = -240,560 + (1888.4 * Payment BI) + (806.15 * Price)

Or, where the bull is US proven and while buyers are still reluctant to purchase US genetics (see next section)

Doses sold = -240,560+(1888.4 * Payment BI) + (806.15 * Price)-15528

All numbers were scaled so that the total pool size remained constant throughout the simulation.

3.1.7.1. MARKET ATTITUDES TO US-PROVEN BULLS

At the present time in New Zealand, the value of American genetics is still an unknown quantity due to few bulls having proofs in both countries. Consequently, some farmers are reluctant to use American sires regardless of their potential benefits. This problem should be at least partially addressed when, by 1993, a large number of American sires will have received their first New Zealand proof. The model accounts for buyer reluctance in the intervening two years by including source of sire in the regression outlined above and subtracting 15528 from each American-proven sire's total semen sales. After 1993, it is assumed that the value of US genetics is vindicated and buyers do not differentiate between bulls of different sources.

3.1.7.2. LIQUID SEMEN

To make some allowance for the use of liquid semen the total number of doses sold by Company B was re-distributed among bulls such that the two highest bulls sold 36% of the semen, the next seven sold 51% , the lowest 2 sold 1%, and the rest 12%. This is consistent with reported sales by the Livestock Improvement Corporation for the 1987-88 season (Anon, 1988).

3.1.7.3. MARKET SHARE

Market share is determined solely on a Company's performance for payment BI, so that a Company's access to cows for contract mating is directly proportional to its sales for the previous year. It is further assumed that this access remains proportional throughout all levels of the cow population. This means that if Company A sells 48% of the total pool of semen in one year then the following year it would, in essence, have access to 48% of the best recorded grade cows in each age group.

3.1.8. NEW POPULATION MEANS

After each iteration all populations are updated for age and a new mean assigned to the youngest age group. Table 5 lists each population and associated sub-populations and gives the formula for deriving its new mean.

Table :5 Derivation of population and sub-population means

Population	Mean Derivation
American males	Constant increase of +1.7 units
American born PT's	Constant increase of +1.7 units
Pedigree females	(((ped. males*0.3)+(ped. catalogue[4] *0.7))+ped. females)/2
Grade females	(sires gr females+gr females)/2
Pedigree males	(((((ped. catalogue*0.8) +(ped. males*0.2))+ ped. females)/2)*0.25)+(ped. PT*0.25)
Grade males	((gr PT *0.85)+(((mean of all catalogue bulls+gr females)/2)*0.15)
Company A PT	(company A sires of sires+company A dams of sires)/2
Company B PT	(Company B siresof sires+Company B dams of sires)/2
Sires of Sons	depending on start-up options the average of the best available catalogue bulls
Dams of Sires	depending on start-up options and market share, the average of the best cows available to the particular Company
Pedigree catalogue	Mean of the pedigree catalogue bulls across Company
Sires of Gr Females	((((weighted mean of all catalogue and PT bulls)* 0.95)+(pedigree males * 0.05))+gr females)/2
Pedigree PT	Mean of pedigree PT's across Company
Grade PT	Mean of Grade PT's across Company

[4] Includes American proven and American born bulls

3.2. ECONOMIC EVALUATION

3.2.1. INTRODUCTION

Throughout the genetic simulation process it was assumed that Company B's breeding program remained unchanged since the objective of the simulation was to economically contrast several breeding schemes for a single commercially-oriented artificial breeding company. Thus, it is only of interest to analyse the changing fortunes of one Company in its competitive position, relative to the other Company, with respect to the effect each option has on Company profitability.

3.2.2. OUTLINE

The genetic simulation was replicated 10 times for each of the 4 options, with a twenty year time frame. The output from the genetic model, replicated for each of the ten runs, was modularised by source of bull (ie ped., American proven, Grade etc) in the following form :

Number of proven bulls in the catalogue in year t,

Number of progeny test bulls used in year t,

Number of doses sold in year t and,

Gross income in year t.

This format allows the economic analysis of performance of individual modules over time if required. Costs for the various options were then estimated and subtracted from gross profit. The resulting pre-tax profit was then adjusted for tax and discounted using standard procedures (Levy and Sarnat, 1988).

The ten replicates for each option were combined to give the average income and costs associated with each option as well as the variance of income for the particular option. This data was extracted at three times (10,15 and 20 years) so that the effect of planning horizon on option profitability could be examined.

Finally, each option was contrasted with the base in percentage terms and coefficients of variation calculated for each planning horizon to analyse risk.

3.2.3. CAPITAL COSTS AND INFLATION

The simulation assumes that Company A has already been in business long enough to have begun graduating proven sires. It also assumes that each of the options could be accommodated by the Company without additional fixed capital costs such as employing new staff or purchasing new facilities. Consequently, capital costs remain constant throughout the study and can be ignored for the economic analysis provided returns are expressed as percentage increases or decreases over the base situation.

Over the past three years inflation in the New Zealand economy has decreased from 15% to 3%. Such rapid change after a ten year period of relatively stable inflationary expectations makes predicting inflationary trends for the planning horizon of the simulation a difficult task. For the purposes of this simulation, inflation is assumed to be zero throughout the planning horizon.

3.2.4. NUMBER OF DOSES

The number of doses is defined as the sum of the doses sold from each bull. This figure reflects the company's market share and hence affects the Company's access to potential grade dams of sires by the relationship :

proportion grade dams of sires = doses sold / total pool size

Thus if the Company sells 500,000 doses and the total pool size[5] is 1,200,000 then its access to potential grade dams of sires for the next year is 41.7%. The Company's access to potential pedigree dams of sires is assumed to remain constant at 70% by virtue of its willingness to pay royalties to bull owners rather than buying the bull outright.

3.2.5. GROSS INCOME

The gross income for a Company is the number of doses sold by each bull, multiplied by the price of his semen per straw, summed across bulls, within year.

3.2.6. TOTAL COSTS

Grouped together under this category are all the variable costs involved with an option, including progeny test costs, royalties, housing costs above normal progeny testing, semen production costs, and selling costs. Costs not included are administration costs, expansion costs, and salaries as these are either fixed or, as is the case with expansion costs, assumed zero .

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[5] total pool size= total inseminations (1,200,000)- number of doses inseminated with progeny test semen - number of doses used for contract mating

An advantage of the modularised format adopted for the project is the ability to assign costs depending on their source. This becomes apparent when, for example, assigning the costs of extra housing. If a progeny test bull is a grade or an American sourced P.T then he has to be housed at Company cost while awaiting the outcome of his progeny test. If however, he is a New Zealand born pedigree then he is returned to his owner immediately after semen is collected until his first proof results are known thus, housing costs are not incurred in the intervening period. Differences in royalty payments between sources of bulls are also accounted for in the same manner.

3.2.7. DISCOUNT RATE AND NET PRESENT VALUE

An assumed discount rate of 10% was used throughout the simulation. In keeping with literature values (Smith, 1978; Bird and Mitchell, 1980; Oltenacu and Young, 1974; Everett, 1975) and industry advice, this figure represents a reasonable return on investment for a profit-oriented, private sector company such as the one simulated in this study.

Present values (PV) were calculated for each year's returns using the formula:

$$PV = \text{net income} * 1/(1 + k)^t$$

where; k= discount rate, and t= time period

and then summed for the three planning horizons (ten, fifteen, and twenty years) to yield net present values.

3.2.8. VARIANCES OF RETURNS

Variability of returns were calculated as the standard deviation of returns over the ten runs, and allowed risk to be monitored. The coefficient of variation ($c = \sigma / E$) defined as the standard deviation normalised by the expected return (Levy and Sarnat, 1988) was used as the final criteria for choice of project. This figure was calculated for each of the three planning horizons on each of the options.

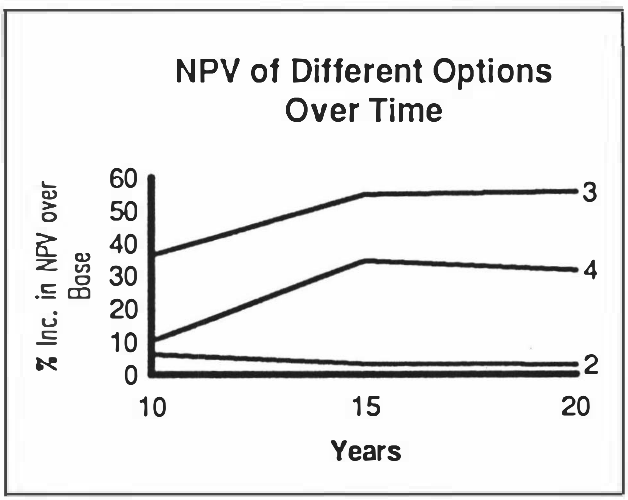
CHAPTER FOUR

4. RESULTS

Simulation results for total sales and average genetic gain are graphed in figures 5 through 12, costs in figure 4, net present value in figure 3 and co-efficients of variation in table 6. The following trends have been extracted :

1. As can be seen from figure 3 all options are profitable relative to the base. Option 3 (Company A's current breeding scheme except for the utilisation of grade genetics) is clearly the most profitable, incurring less costs throughout the study than the other options and returning a 1.23% average increase in sales relative to the base.

Figure 3: Variation in Net Present Value of the Three modelled schemes contrasted with the base scheme.



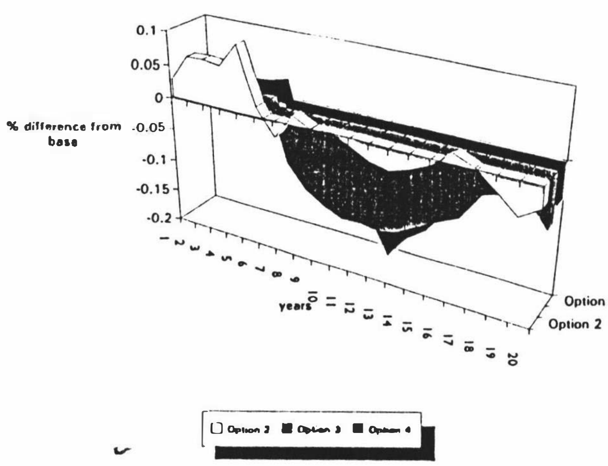
Not only does it return the largest NPV for all three planning horizons but, it also has the lowest coefficient of variation for two out of the three time periods (table 6). Option 4, which only differs from option 3 in that the number of progeny test sires was increased to fifty, also returned a very profitable return on investment.

Table 6: Coefficients of variation across planning horizons

Option	**Coefficients of variation for each planning horizon**		
	10 year	**15 year**	**20 year**
1. 35 PT	0.103	0.082	0.080
2. 50 PT	0.114	0.076	0.056
3. 35 PT & Grades	0.078	0.067	0.061
4. 50 PT & Grades	0.157	0.091	0.097

2. All options were more expensive than the base option during the setting up period of years 1 through 5 but option 3 and 4 were considerably cheaper throughout the rest of the study (figure 4). Thus, it appears that cost structure rather than genetic gain or increased sales was the primary determinant of profitability. This is confirmed by figure 13 which shows that there is little difference in the rates of genetic gain achieved by any of the plans. An expected result given the similarity of the options.

Figure 4: % total costs of modelled schemes relative to base option



3. Figures 6,8,10 and 12 all show that the use of USA genetics makes up for the smaller progeny test size of Company A providing the assumption that US genetics will perform as expected holds. The abrupt change in sales between year 3 and 4 for all schemes is due to buyer reluctance to using American genetics being removed. This also shows the impact US genetics has on the total sales of Company A.

4. Figure 6 also shows that based on genetics alone, even when Company A continues with the base option, there should be little difference in the sales of the two Companies after the settling in period of US genetics. This is in contrast to the case in reality where in NZ one Company has a 70% market share and the other only 30%.

6. An analysis of price yielded no significant difference in average semen sale price over the twenty year period for any of the options with the average sale price varying from $12.23 for option 4 to $12.47 for option 2.

7. Genetically, there was little variation in the proposed options therefore large differences in the genetic parameters between options was not expected. It is noteworthy however, that the average genetic gain (as defined by the change in average catalogue payment BI proportional to genetic standard deviation) for both options involving the use of grade genetics exceeded the other options by between 0.5-2.0%. This difference was due to the application of increased selection intensity as the generation intervals for all pathways remained stable throughout the simulation. The average genetic gains achieved by all options ranged between 0.14-0.18 genetic standard deviations.

Figure 5: Company sales when Company A continues with the base option, 35 young sires, no unregistered sires.

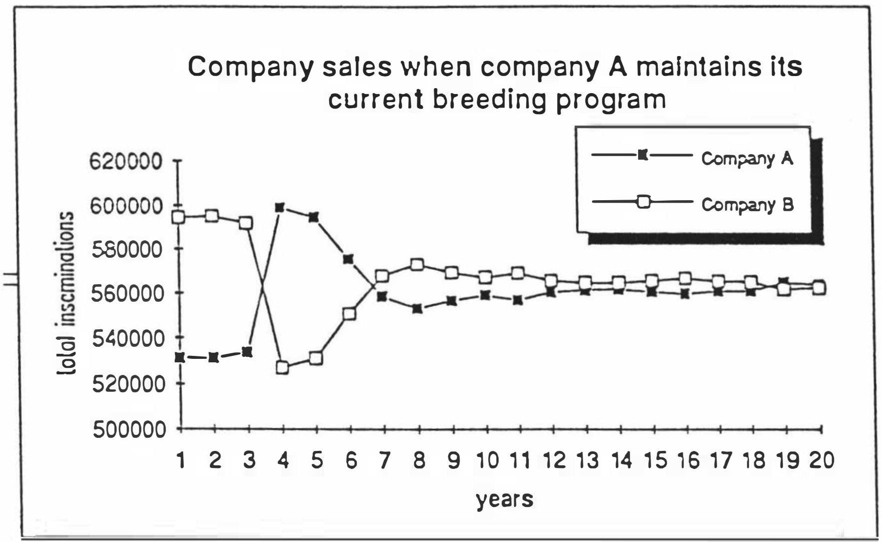


Figure 6: Company genetic gains when Company A continues with the base option, 35 young sires, no unregistered sires.

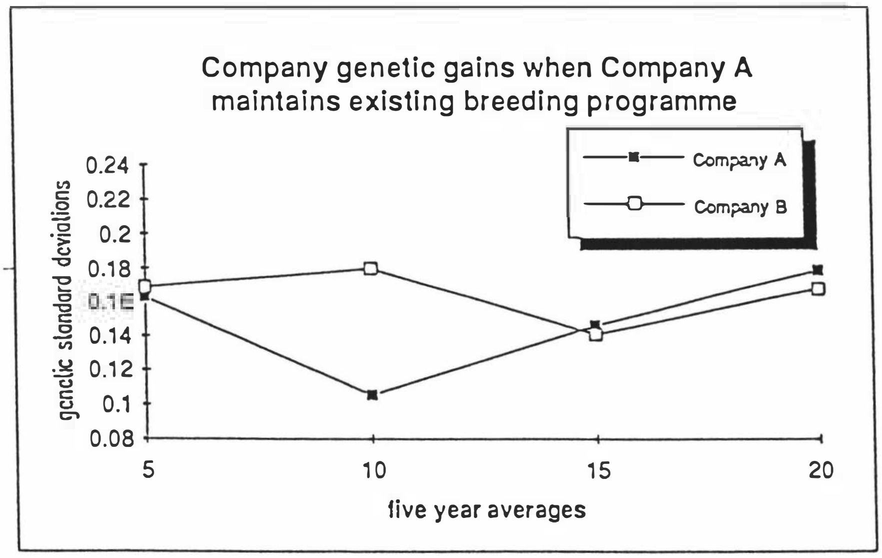


Figure 7: Company sales when Company A adopts option 2, 50 young sires, no unregistered sires.

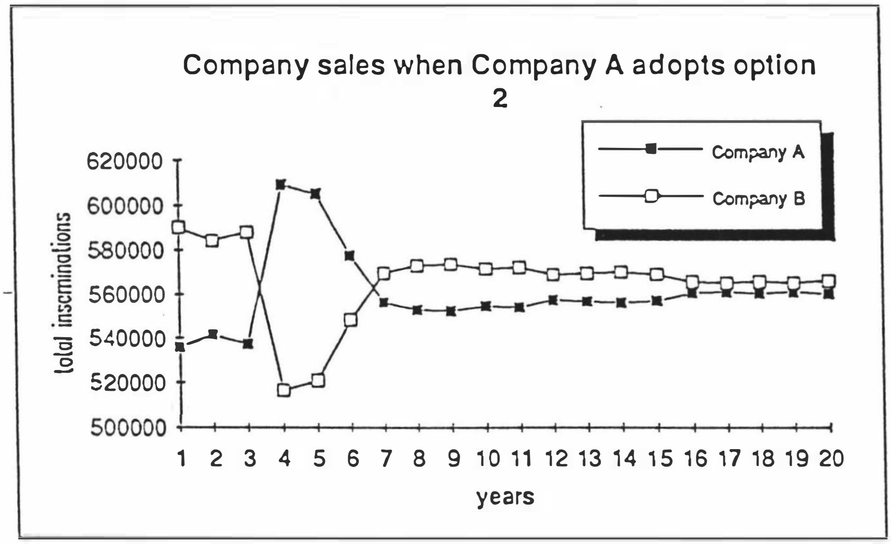


Figure 8: Company genetic gains when Company A adopts option 2, 50 young sires, no unregistered sires.

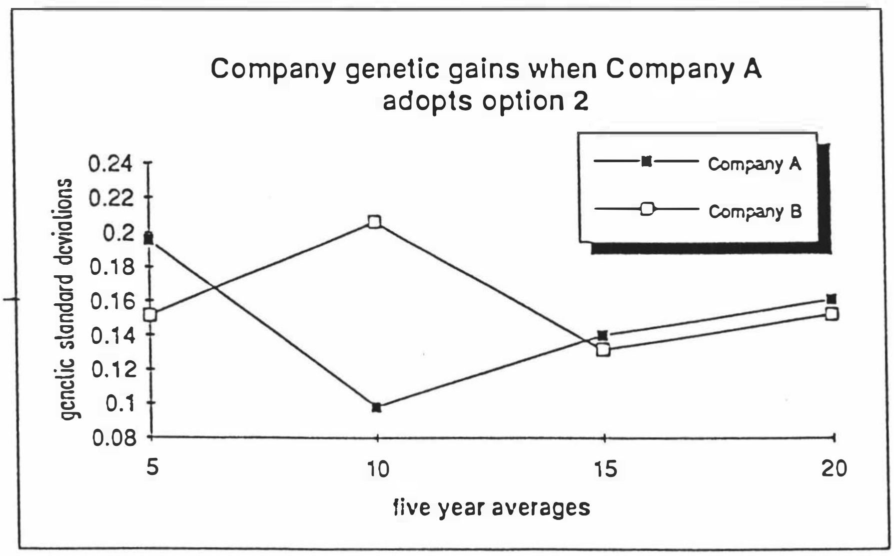


Figure 9: Company sales when Company A adopts option 3, 35 young sires, unregistered sires allowed.

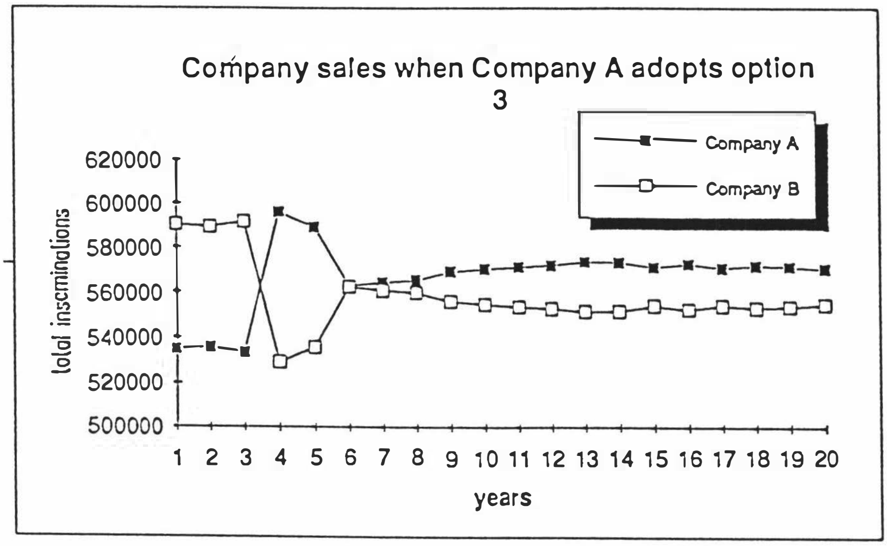


Figure 10: Company genetic gains when Company A adopts option 3, 35 young sires, unregistered sires allowed.

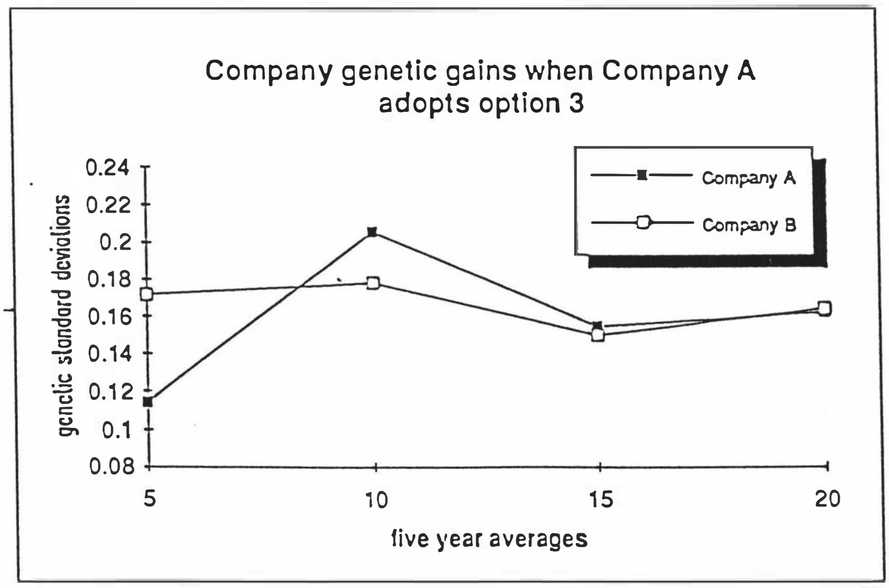


Figure 11: Company sales when Company A adopts option 4, 50 young sires, unregistered sires allowed.

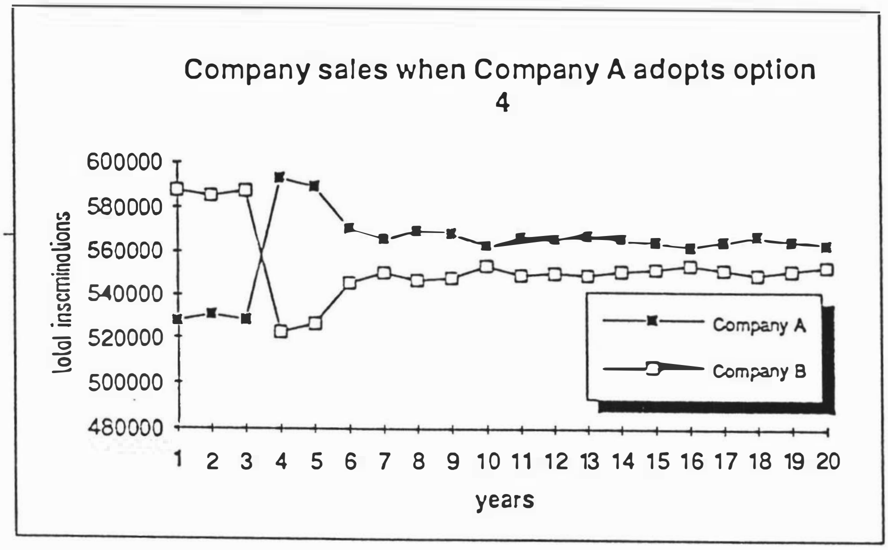


Figure 12: Company genetic gains when Company A adopts option 4, 50 young sires, unregistered sires allowed.

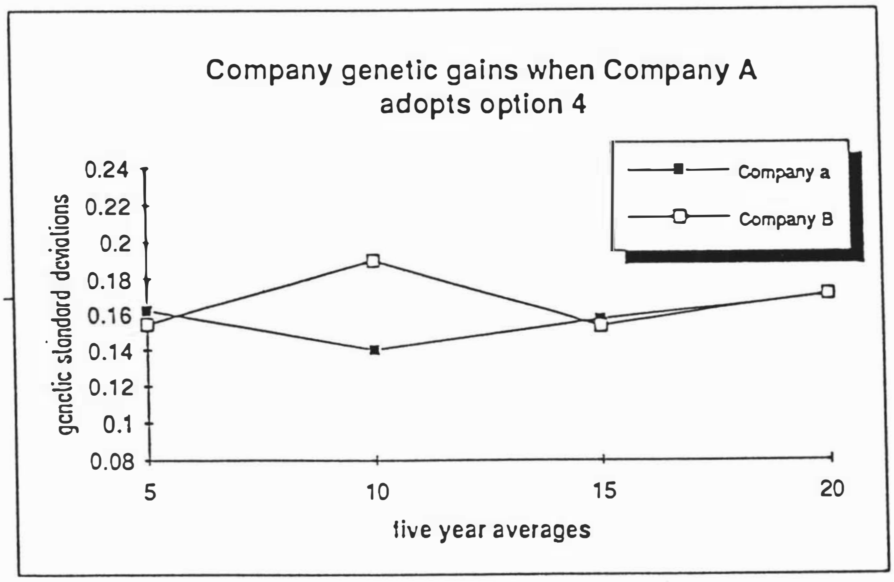
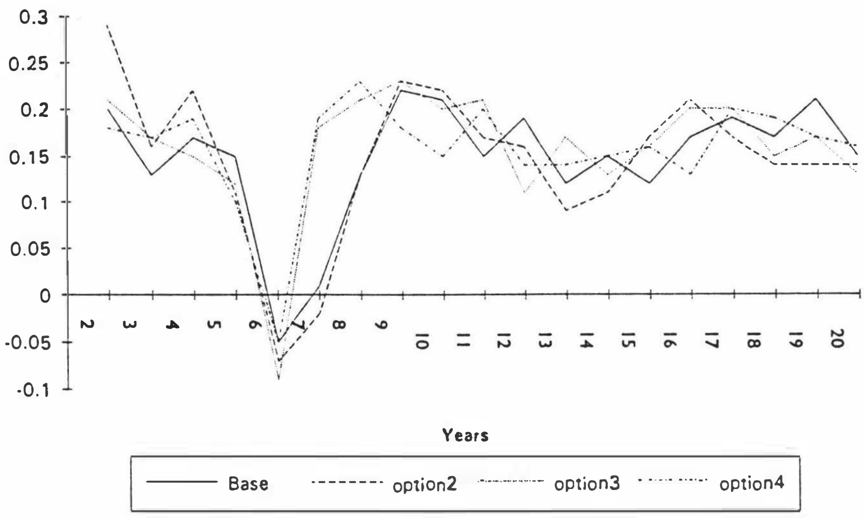


Figure 13: The yearly genetic gains of Company A for each of the four options.



CHAPTER FIVE

5. DISCUSSION

It was the purpose of this thesis, to develop a simulation model which could be used, in conjunction with other decision making tools, to evaluate the increasing number of breeding scheme options available to a commercially-oriented artificial breeding company. Within this framework it was decided that aspects of planning horizon, cost structure, competition and risk analysis should be given particular emphasis. Bearing this in mind, three breeding schemes were chosen which were similar in their characteristics but, which could portray the relative importance of each of these aspects.

5.1. MODEL VALIDATION

Model validation was assessed by comparing the average genetic gains achieved by the model with literature values. Although in a strict sense this action would not validate the model due to the absence of reported values for New Zealand breeding schemes it none the less provides a check for gross inaccuracies. Model results were typically in the 0.14-0.18 genetic standard deviation range, or 1% of the mean, once equilibrium was approached. In comparison Dekkers(1989) found that for a population of 2 million cows, served by two AI studs using conventional progeny testing schemes, sampling 100 young sires each per annum an equilibrium rate of 0.200σ could be achieved. Allowing for the fact that the population size was larger, more young sires were being sampled, and no account was taken of the sub-optimal sire selection decisions that farmers often make, Dekkers results correlate well with the results of our model. Hunt et al(1971) found, using a deterministic model, that gains of between 1-1.3% could be achieved in the Canadian Holstein population if selection criteria approached optimality. The cow population in this study was smaller than that of our study but once again no allowance was made for the sub-optimality of selection decisions made by many farmers. Closer to home, Anon(1983) showed that manipulation of the bull numbers proven or the number of daughters in a bulls proof in the New Zealand Holstein population could yield increases in breeding index of 0.6-0.73. Given that this study dealt with a population similar to the one modelled in our study and that, like our study, the changes modelled were of a fine tuning nature, the gains achieved were agreeable with those of our study. Ahlborn-Breier et al(1987) investigated the actual rates of gain achieved by one of the major AI studs in New Zealand and found that over a three year period gains of 0.203 standard deviations had been achieved. While in general modelled results are usually higher than those actually achieved in reality the difference between Ahlborn-Breier's study and ours could be attributed to aberrations caused by the short time frame over which they carried out their investigation or to the fact that they were looking at only one part of the whole AI industry in New Zealand. In any case once again differences were small.

5.2. PLANNING HORIZON

In any discussion of the economics of breeding schemes, time considerations are of major importance (Wickham et al, 1977). In conjunction with the discount rate, the planning horizon in effect determines, based on net present value criterion, which project is chosen. Short planning horizons and high discount rates favour those projects which incur low setting up costs and produce returns promptly. Breeding schemes that don't deviate markedly from the status quo such as option 3 in this study are typically suited to this type of evaluation. On the other hand, long planning horizons and low discount rates favour more ambitious projects where the payback period is longer. Breeding schemes which benefit from this type of evaluation are those that may have large set-up costs such as schemes 2 and 4 which both involve increasing the number of bulls progeny tested .

The problems in evaluating what the correct planning horizon is for commercial AI companies are twofold. First, ignoring the intangibles such as marketing strategy and service, if it is assumed that the genetic merit of breeding stock largely determines market share, then the timing of expression of genetic merit is of major importance. A commercial AI company which changes its breeding program today will have to wait a minimum of seven years before the results of this decision will begin to be seen in the balance sheet. Several more years will be required before there is any significant impact, that is, before the first bulls proven resulting from contract matings today go into widespread use, thus the impact on cash flows for the first seven years will only be one of costs. Second, and coupled with the first, is the requirement of a commercial AI company to remain viable. Any scheme which causes the company to incur losses for any length of time is unlikely to be chosen because of the company's need to post a profit. This profit motive often rules out projects which may maximise long-term returns.

It is, therefore, suggested that new breeding schemes should be evaluated over a range of planning horizons and that the resultant economic data should be used in conjunction with decision and risk analyses to arrive at a choice of project. This should also take into account the specific economic criteria of the individual company concerned. For this process to be most efficient the correct choice of discount rate is imperative and should represent the risk-free private sector rate of return.

5.3. COST STRUCTURE

Cost structure is probably of more economic importance to the commercial AI company than outright genetic gain. There would obviously be no point in embarking on a scheme which would generate record profits for the company in fifteen years time if, after the first five years the company is declared bankrupt because of losses sustained in the setting-up period. Thus the decision on whether a project will be undertaken or not is influenced by the immediate set-up costs of the new project and the ability of the old scheme to sustain the company through the setting-up period. It must be noted however, that in many cases the option exists to stagger entry into a new scheme over a number of years so that set-up costs are incurred at a manageable rate.

5.4. COMPETITION

While competitive aspects were only dealt with by the model in a rudimentary fashion through adjustments to pricing, distribution and, the restriction of US proven semen sales until they were proven under New Zealand conditions, comment is still possible.

First and most important, it appears that in New Zealand, market share, which is influenced by both frozen and liquid semen and the associated disparity in pricing, semen availability and mode of use is not easily determined. This is in contrast to the US where market share is largely determined by the overall genetic merit of the bulls being marketed

(Miller, 1988). Therefore for any model to accurately reflect economic reality, competition must be accounted for explicitly. To date, only two reports have attempted to objectively incorporate the effects of competition into a breeding Companies decision-making process (Anon, 1978; de Vries, 1989). The New Zealand Dairy Board's operations research model dealt with the specifics of the liquid semen/frozen semen issue but not with the effect of other intangibles effecting market share. The de Vries method accounted for performance of competitor company's genetics relative to the base company but was unable to account for the effect of marketing strategies such as the use of liquid semen. More research is required in this area.

5.5. RISK

Risk has been treated superficially in this thesis, as has been the case generally in breeding scheme research. In retrospect, Slenning and Wheeler's (1988) paper provided valuable insight into a more definitive method for evaluating risk than has been used here. Instead of combining runs into averages and calculating standard deviations, runs could have been grouped into classes based upon their net return and, probabilities assigned to each class depending on the proportion of runs falling within the boundaries of each class. Decision tree analysis could then have been applied to results by multiplying the net return for each class by its probability and summing across class within strategy to yield an expected return. In future, this should become the method of choice for evaluating risk because it accounts for the likelihood of a particular return occurring and does not involve loading the discount rate with a risk premium which would have the effect of favouring short-term projects.

5.6. GENERAL

Increasing the number of young sires progeny tested is often regarded as being the easiest way to increase genetic gain and thus market share. In fact this may not necessarily be the case. The breeding schemes contrasted in this thesis show that better genetic gains and, more importantly, better profit margins can be made by breeding companies simply by optimising selection intensities. That is, by broadening the base from which sires-of-sons, and dams-of-sons are selected, whether that be by expanding the base within a country (in this case using grade genetics) or expanding the base internationally (in this case sampling young sires from the US). Quite apart from increasing the genetic gain, base expansion by Company A (using grade genetics) would help to negate some of the competitive advantage afforded to Company B, who at present has a monopoly on grade genetics. That is, Company A's gain is also Company B's loss. A third advantage of base expansion is that diversifying the source of genetics also diversifies risk ie. the risk of disease or of selection objectives changing is decreased by diversifying the sources from which genetics are obtained, especially if they are separated geographically. This is especially so if the source of genetics are different countries.

CHAPTER SIX

6. CONCLUSIONS

Artificial insemination became available soon after the second world war yet animal geneticists did not begin to fully analyse the benefits of the progeny test until the 1960's. Consequently rates of genetic gain world-wide have generally been below their potential up until the last ten years. To avoid repetition of this type of mistake, animal breeders must be constantly speculating about, and then testing, alternative breeding plans that take advantage of new technologies before they become commercially available. Only in this way will current rates of genetic progress be enhanced in the livestock industries.

Modelling is one method of testing breeding plans for industry useability. It is particularly suited to cases where live animal experimentation is too expensive and/or takes to long to carry out. Models are not only a prediction tool but also a management tool; information supplied by the user is used by the model to predict responses of the simulated system to the given parameters. Choices can then be made based on the model's response to different sets of parameters. In this sense then, simulation models represent an interface between scientific principles and decision making theory, with the outcome of this interfacing being the discovery of new efficient, and often optimal, strategies.

Breeding scheme modelling has become more sophisticated as computing power has improved such that the number of random elements able to be fitted into models has increased. This has resulted in simulated breeding schemes that are better equipped to characterise the commercial setting and to identify genetic or economic optimums more accurately.

Modelling theory has also evolved rapidly, asymptotic genetic gain has been replaced with population inventory, deterministic models by stochastic processes, and genetic gain with net present value. However, much of the historical research has, understandably enough, centred on genetic aspects of the modelling process with, in many cases only minimal attention paid to economics, such that genetic aspects, of at least macro-system modelling are now well understood by animal breeders and improvements will be of a fine-tuning rather than of a landmark nature. What is not so well understood are aspects of economics specifically, competition and risk analysis. It is in these areas that economic principles need to be cross-credited to applied genetics research.

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8. APPENDIX 1

Truncating Across Distributions

Given that we have several populations all normally distributed but with different means and variances ($N(\mu_i, r_i^2)$) and given that from these populations we want to select a certain fraction (α) then the function for which we are trying to find the root (ie f(k)=0) is given by the following formula :

$$f(k) = \left[\sum_i w_i \Phi\left(\tfrac{k_1 + (\mu_1 - \mu_i)}{r_i} \right) - \alpha \right]$$

where w_i is the proportion of animals available for selection from each distribution, k_1 is the truncation point to be identified and Φ is the cumulative density function for the normal distribution $N(0,1)$.

The only unknown is therefore k_1 and we want to find k_1=k such that f(k)=0, this can be done using Newtons Method as follows :

$$k_{(n)} = k_{(n-1)} - \frac{f\left(k_{(n-1)}\right)}{f'\left(k_{(n-1)}\right)} \quad \text{where} f'(k) = -\sum_i \frac{w_i}{r_i} . \phi \left(\frac{k_1 + (\mu_1 - \mu_i)}{r_i} \right)$$

ϕ is the probability density function for the normal distribution with mean 0 and standard deviation 1

Newtons method works on the principle that if a line is drawn at a tangent to the function at the point of first guess then the line intercepts the x-axis at a point closer to the root than the first guess, this point can then be used as a 'new' first guess and Newtons method applied again. Repeating the process enough times will bring the solution arbitrarily close to the root k_1.

9. APPENDIX 2

Random Normal Number Generation

Symmetrical about its mean value and characterised by its mean value μ and standard deviation σ the use of the normal distribution in an animal breeding context is widespread. The Marsaglia and Bray method of generating normally distributed pseudo random numbers is a computationally faster and easier variation of the exact inverse method proposed by Box and Muller (Shannon, 1975). The methodology used is as follows :

1. Generate two random numbers r_1 and r_2

2. Then setting $V_1 = -1 + 2r_1$ and $V_2 = -1 + 2r_2$, we compute $S = V_1^2 + V_2^2$.

   If $S \geq 1$, we start over again. If $S \prec 1$,

3. $X_1 = V_1\sqrt{\frac{-2 \text{ In } S}{S}}$ and $X_2 = V_2\sqrt{\frac{-2 \text{ In } S}{S}}$

The Marsaglia-Bray variation avoids having to calculate sines and cosines (necessary in the Box-Muller method). An estimated 127 pairs of random numbers will be needed to generate 100 pairs of random normal numbers(Shannon, 1975)