Aspects of Selection for Economic Merit in Dairy Cattle

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ABSTRACT

Economic merit of dairy cattle is an important consideration in dairy cattle breeding. In this thesis, genetic and economic aspects were combined to quantitatively derive an aggregate genotype with the aim to improve the economic merit of New Zealand dairy cattle.

Relative economic values for production traits, liveweight and survival rate were estimated. A profit function was defined for a pasture based milk production system. The effects of changes in several genetic, biological and economic parameters on various components of farm profit were simulated with a bioeconomic computer model.

The economic value for protein yield was $ 4.64/kg and $ 4.58/kg for Holstein-Friesian and Jersey cows, followed by $ 1.84/kg and $ 1.75/kg, respectively, for milkfat yield. Liveweight had a negative economic value of $ 0.49/kg and $ 0.53/kg for Holstein-Friesian and Jersey cows. An increase in survival rate by 1% had a positive economic value of $ 9.25 and $ 9.29 for Holstein-Friesian and Jersey cows. A sensitivity analysis showed that declining returns for milk reduced economic values for all milk components and simultaneously increased economic values for liveweight.

The effects of several traits on survival rate were quantified. An increase in survival rate increases a cow's profitability as cows contribute to net farm income only during their lactation years and constitute a cost during the rearing period. After production traits, the farmer's overall opinion of the cow and the traits udder support and udder overall had the greatest impact on survival rate. These traits were used as selection criteria for survival rate in the selection indexes.

Variance and covariance components were estimated with multitrait REML procedures for all production, management and conformation traits used in the current selection index. Heritabilities were 0.25 for protein yield and 0.21 for milkfat yield for Holstein-Friesians and 0.17 for both traits in Jerseys. Generally, parameter estimates did not differ substantially from other populations.

An aggregate genotype as well as selection indexes for Holstein-Friesians and Jerseys were constructed and weighting factors calculated based on the economic values and genetic parameters estimates.

The aggregate genotype included the traits protein yield, milkfat yield, volume, liveweight and survival rate.

The selection index for Holstein-Friesians included the traits protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and udder support.
The selection index for Jerseys included the traits protein yield, milkfat yield, volume, liveweight, udder overall overall opinion, temperament, milking speed and fore udder.

These selection indexes improve the economically important trait survival rate included in the aggregate genotype through indirect selection using traits which can be measured in the first lactation. This allows the current generatio interval to be maintained when selection for survival rate i incorporated in the aggregate genotype.

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1. INTRODUCTION

Nature is a highly structured game of chaos. Man's society mirrors nature with interdependent and interwoven parts where each part is a function of and to another part. Agriculture is part of this structure.

Dairy farmers produce high value food products in the context of the prevailing economic situation. The economic situation usually forces the farmer to be a price taker. Economic theory shows that under these constraints an enterprise can be profitable under certain conditions.

The objective of most dairy farmers is to maximise net income. Net incomes or profits are increased if either output or return per unit of output is increased or input or value per unit of input is decreased. Both objectives can be achieved by combining genetic and economic parameters to rank dairy cattle according to economic merit which by definition includes genetic merit. However, most existing dairy cattle breeding schemes select for increased outputs only, thereby ignoring the improvement in net income that can result from reduction of inputs.

The main selection criterion has been milk yield in countries where fresh milk consumption is significant and milkfat yield in countries where manufacturing of dairy products is the primary concern such as New Zealand and, to a lesser extent, Australia.

Changes in the economic situation in New Zealand have stimulated a greater interest in re-evaluating and more clearly defining the selection objective for New Zealand dairy cattle. The New Zealand national dairy cattle breeding organisation, Livestock Improvement Corporation Limited, in its strategic plan stated the selection objective and the purpose for the genetic evaluation of dairy cattle in New Zealand as:

> **«to continually identify the best dairy animals in terms of their ability to improve New Zealand dairy farmers' net income»** (Livestock Improvement **Corporation Limited, 1990).**

This selection objective requires that animals are evaluated with respect to their potential to affect a number of variables. These variables are the outputs and inputs in the profit equation of a typical New Zealand dairy farm.
Since every New Zealand dairy farmer is also a shareholder in the manufacturing industry and marketing operation (New Zealand Dairy Board), this selection objective is interpreted on a national level and includes manufacturing costs and efficiencies as well as profits and losses from marketing. While a large proportion of the dairy farmer's objective to maximise net income can be achieved by optimising manufacturing and marketing practises, quality and quantity of the raw product as well as some of the farm production costs can be influenced by genetic improvement of dairy cows. The objective of the dairy farmer to maximize net income can be expressed as a function combining economic and genetic considerations.

Selection for multiple traits including economic requirements in genetic considerations ensures progression towards the breeding objective. Genetic and economic information can be combined with the selection index (Hazel, 1942; Smith, 1936). The application, however, requires genetic variances, covariances and the relative economic values of all included selection objectives and selection criteria to be known.
In this study, the parameters that have to date not been estimated for New Zealand dairy cattle populations were calculated and used in the construction of an aggregate genotype and respective selection indexes for these populations.

The objective of this thesis was to quantitatively derive a breeding objective or aggregate genotype with the aim to improve the economic merit of New Zealand dairy cattle and to develop selection indexes that can be used to rank animals according to this breeding objective. The achievement of this objective involved the following steps:

1. Estimation of economic values for traits influencing the profit function in the New Zealand dairy production system. This required the definition of a profit function and the simulation of the effects of various variables on the production system using a bioeconomic model.

2. Estimation of variance and covariance components for a range of production, management and conformation traits to allow evaluating their potential as effective selection criteria.

3. Combination of economic values and genetic parameter estimates in an aggregate genotype for New Zealand dairy cattle with the objective to increase net farm income.

4. Determination of selection indexes which maximise the correlation with the aggregate genotype and are based on population- and environment-specific genetic and phenotypic parameter estimates and economic values.

The results from this thesis are expected to assist in maximising genetic progress towards the breeding objective by ranking dairy cattle according to their ability to improve New Zealand dairy farmers' net farm income.

2. SELECTION FOR MULTIPLE TRAITS - A REVIEW

Conscious selection of certain animals as parents for the next generation has been man's opportunity of influencing animal populations for many centuries. Directed selection can change genetic and phenotypic characteristics of animal populations longterm for the benefit of man. The value of a population, breed or individual animal to mankind depends almost always on more than one character. These different characters are not likely to be all equally important nor are they always independent of each other. Babcock and Clausen (1918, cited by Lerner (1950)) state «The requirements of efficient selection, therefore, demand first an accurate method of judging the comparative worth of a series of animals with respect to certain definite characters, and second a method of weighting different characters in the same individual according to their comparative value from a breeding standpoint. It is here that science may be expected to give definitely useful contributions to practical breeding methods in the determination of mathematically accurate means of comparing data.» Thus, in animal breeding informed selection decisions which subsequently result in effective selection and genetic progress require identification of animals with the highest target value, T, the 'true worth' or aggregate breeding value. While the true aggregate breeding value of the animals is unobservable, partial information can be obtained from some observed characters and used as a basis for selection.

Several studies (Ducrocq, 1984; Van Vleck, 1986; Ahlborn-Breier et al., 1987) concluded that the achieved genetic progress in most domestic animal populations lags behind the theoretically possible level and thus selection apparently had not been as efficient as expected. These studies assumed an underlying single trait selection for the species in question. Selection for only one character implies that other traits have no economic importance. Another

interpretation of the results might be that the selection objective and the subsequent selection achieved was indeed devised to include more than one trait resulting in a lower genetic progress for the single trait analysed.
Indeed, benefits to man from a population, breed or individual breeding animal derive with very few exceptions from more than one trait. Therefore, one of the main problems in animal breeding is combining information from several traits in an optimum way when assessing candidates for selection.

2.1. Methods of selection for multiple traits

A number of procedures for selecting animals for multiple traits have been applied and described in the past. These are tandem selection, independent culling levels, selection of extremes and selection index. A short description of their characteristics is given below. It will be noted that all methods of selection for multiple traits require heritabilities, genetic correlations as well as relative economic values of the traits involved.

2.1.1. Tandem selection

Tandem selection is defined as the ranking of candidates and the selection of N individuals, a fraction p, based on only one selection criterion in any one time period, changing the selection criterion in the following time period in a cyclical way. The length of time period (generations, years) for each selection criterion depends on the importance, i.e. the relative economic value of the selection criterion (Hazel and Lush, 1942). Due to difficulties involved in calculating the length of time period for each selection criterion (Turner and Young, 1969; Nicholas, 1987) tandem selection is only rarely used in practice, especially not with dairy cattle, probably because of the relatively long generation interval.

2.1.2. Independent culling levels

With independent culling all individuals are ranked separately for each trait. Individuals are selected only if they exceed a particular performance, the minimum requirement or threshold, in all of the traits either simultaneously or at different biological stages in the one generation. The thresholds are set independently for each trait with the restriction that N individuals, a fraction p, is selected. The probability that the threshold for a trait is exceeded is $p^* = p^{1/k}$, where k is the number of selection criteria. The selection intensity for any selection criterion considered by itself is Z^*/p^*, where Z^* is the standard normal coordinate corresponding to p^*. It should be noted that selection above the threshold within a trait is at random for uncorrelated traits and depends on the genetic correlation for correlated traits.

Optimizing these selection procedures for a given overall selection objective is equivalent to finding the combination of truncation thresholds or culling levels which maximise the expected value of the overall genetic value of selected individuals. A graphical method for determining the selection differentials of the traits as well as the optimum combination of treshold levels for culling for any proportion of animals required was suggested by Young and Weiler (1960) and Williams and Weiler (1964).

Optimum truncation thresholds had also been derived algebraically (Evans, 1980; Cotterill and James, 1981; Smith and Quaas, 1982) for two variables. This restricts the objective function to an unrealistic one since usually a large number of variables is considered. Recently, Ducrocq and Colleau (1989) derived a general Newton-type algorithm to perform this maximization for n normally distributed traits for a fixed overall probability of being selected. Computing multivariate normal probability integrals they calculated the optimal truncation points when up to six correlated traits or stages of selection are considered simultaneously. The algorithm was extended to the objective of maximising annual genetic progress including all four genetic pathways. It should be noted that the application of selection using independent culling levels does require the knowledge of economic values and genetic and phenotypic parameters for the selection criteria involved.

To restrict the genetic change in one or more of the traits a general equation for a linear constraint on expected genetic change in two traits was derived by Evans (1980) for independent culling levels. The solutions specify the culling levels satisfying the constraint applied.

Selection based on independent culling levels has often been practised in breeding programs. Frequently, animals with extreme attributes are rejected (i.e. in sire selection (Short and Blake, 1988)). Also, in many cases records and genetic evaluations accumulate during the biological development of the animal with selection accordingly conducted sequentially (multistage selection). Additionally, independent culling levels can significantly reduce the cost of the breeding scheme when traits are expensive to measure. Measurements for these traits can be restricted to the proportion of the population which has passed the first stage of selection.

Van Vleck (1986) detailed that theoretical response in milk yield could be reduced by 46% when minimum selection restrictions for fat percent and type score were included in the selection decision. Short and Blake (1988) quantified these differences for commonly applied independent culling levels as a reduction of up to 1.6 standard deviations of the net present value of semen in the case of sire selection. This study showed that in practice the truncation thresholds frequently are not optimally chosen nor are their selection effects carefully evaluated.

2.1.3. Selection of extremes

A complementary method to independent culling levels was suggested by Ablanalp (1972) which he termed selection of extremes. Individuals are ranked for each trait separately and given proportions of the highest ranking individuals in each trait are selected to give the required number of parents rather than stating minimum threshold levels. When the efficiency of this modification was determined it was shown to be only more efficient than independent culling levels at low levels of selection intensity (proportion retained > 0.5) concerning two independent traits. However, this modification may be more efficient for traits with distributions for which the third moment is significantly different from zero. Selection of extremes as well as independent culling levels result in higher selection responses than tandem selection in the case of two or more independent traits or negatively correlated traits.

2.1.4. Selection index methods

The selection of animals as superior parents for the next generation of offspring requires a criterion for discriminating between them. This criterion or selection index should combine the available information into a single score reflecting the merits and demerits of various traits. One of the earliest selection indexes combining several traits, using arbitrary economic values for egg production in poultry, was reported by Pearl and Surface (1909). Smith (1936) applied Fisher's (1936) concept of the discriminant function to develop an index procedure for the selection of plant lines. Hazel (1943) extended this index procedure for the selection of individuals in animal populations by defining an aggregate genotype as a linear combination of genetic values, each weighted by the relative economic value. Hazel and Lush (1942) describe this method as «adding into one figure the credits and penalties given each animal according to the degree of its superiority or inferiority in each trait». The selection indices employed usually refer to a linear function of observable phenotypic values. The observed phenotypic value is weighted by an index coefficient.

Selection indices have been used for a number of different situations:

1. selection on a single trait combining information from the individual and its relatives (several sources) for the same trait, e.g. ancestry and progeny test information for milk yield,
2. selection on multiple traits measured on the same individual (repeated measures) e.g. information from n lactations in dairy cattle (Hill and Swanson, 1983; New Zealand Dairy Board, 1970),
3. selection on multiple traits combining information from the individual and its relatives, and
4. selection of line-crosses combining information from line-crosses and specific crosses to evaluate the 'best' crossbred combination (Henderson, 1952 cited by Henderson, 1963).

The problem of selecting animals for several traits simultaneously by combining several sources of information in an optimal way can be described as follows: from a population of n animals a fixed number of **N** candidates, a fraction p, are to be chosen as parents, e.g. bulls for artificial insemination, for the next generation of animals. Information on several traits

$$X = (X_1,\ X_2,\ .\ .\ .,\ X_n)$$

is known for each candidate. The objective is to choose candidates with a high aggregate genotype T, which cannot be observed directly, but about which partial information can be obtained from the observed information X. To maximize long-term genetic gain a criterion I is required with the properties of firstly maximising the correlation with the aggregate genotype (r_{TI}) and thus achieving the highest expected genetic response in the aggregate genotype T and secondly minimising the squared deviations of the criterion I with the aggregate genotype T, i.e. minimum variance $E(I - T)^2$. One method for computing such a criterion I is the selection index. The selection index constitutes a best linear predictor and thus is a linear function with minimum variance. Best linear prediction (BLP) requires means and variances of the joint distributions of the phenotypic predictors and the additive genetic values to be known.

The selection index I as a predictor of T has the properties to:

1. maximise the correlation between index I and aggregate genotype T (selection objective) r_{TI} (Hazel, 1943; Kempthorne, 1957; Henderson, 1963),

2. minimise the variance between index I and aggregate genotype T among all linear functions of the general form of the selection index (Tallis, 1962; Henderson, 1972),

3. maximise the probability of selecting one of the largest sample values of the aggregate genotype T by selecting the largest value of the index criteria (Williams, 1962a, 1962b; Bulmer, 1985),

4. maximise the probability of selecting the higher of a combination of aggregate genotypes (Henderson, 1963), and

5. maximise genetic progress in any one-round selection by the index (Henderson, 1963).

The first two properties do not require the assumption of a multivariate normal distribution to hold (Kempthorne, 1957; Tallis, 1962; Henderson, 1963). In the multivariate normal case, a necessary assumption required for the latter three properties, it is assumed that **X** and **T** have a known joint probability distribution with probability density function f(**x**,t). Then the regression of T on **X** is the expected value of the conditional distribution of the observations

$$E(T|x_1,\ldots,x_n) = \int tf\,dt \;/\; \int f\,dt$$

with variance

$$\sigma^2\ (1 - r_{TI}^2).$$

For a candidate with a specific value of **X**, the regression function

$$\hat{T} = E(T|\mathbf{X})$$

is a sensible predictor of T. These properties also hold for the cases were the means are unknown (Henderson, 1963) as is usually the case in animal breeding, as well as in the case of information derived from different sources or sample sizes (Bulmer, 1985).

2.1.4.1. Optimum selection index

The information required in constructing an optimum selection index which is also termed Smith-Hazel index (Williams, 1962a) can be specified in four vectors and three matrices. The aggregate genotype or breeding value T is defined as

$$T = \mathbf{a'Y} = a_1Y_1 + a_2Y_2 + \; . \; . \; . \; . \; + a_mY_m = \Sigma \; aY$$

where **Y** is a vector of additive genetic values for the m traits included in the aggregate genotype T and **a** is a vector of constants, usually representing the relative economic values of the m traits in Y. The aggregate genotype T reflects the total economic ($) value of the genes an individual is carrying for a particular group of traits. Since T is not measurable it cannot be selected for directly. Improvement in T is achieved by selection with a selection index I which is defined as:

$$I = \mathbf{b'X} = b_1X_1 + b_2X_2 + \; . \; . \; . \; . \; + b_nX_n = \Sigma \; bX$$

where **b** is a vector of weighting factors chosen to optimize certain properties of the index I and **X** is a vector of phenotypic measures, deviations from the population averages, for the n variables or sources of information to be included in the index. The weighting factors in I are obtained by solving the following index equations and thus represent partial regression coefficients:

$$\mathbf{Pb} = \mathbf{Ga} \quad \Rightarrow \quad \mathbf{b} = \mathbf{P^{-1}Ga}$$

where **P** is a n*n matrix of phenotypic covariances between the n variables in **X**, **G** is a n*m matrix of genetic covariances between the n variables in **X** and the m traits in **Y**. The corresponding variance of the index is

$$\sigma_I{}^2 = \mathbf{b'Pb},$$

the variance of the aggregate genotype is

$$\sigma^2{}_T = \mathbf{a'Ca}$$

and the covariance of index and aggregate genotype is

$$\sigma_{TI} = b'Ga = b'Pb$$

where C is a m*m matrix of genetic covariances between the m traits in Y. The equality of the variance of the index with the covariance between index and aggregate genotype is achieved by scaling the weighting factors to give the index equations their specific form. Therefore the regression of the aggregate genotype T on the index I is unity and their correlation is:

$$r_{TI} = \sqrt{\frac{b'Pb}{a'Ca}} = \sqrt{\frac{\sigma_{TI}}{\sigma_T^2}} = \frac{\sigma_{TI}}{\sigma_T\sigma_I} = \frac{\sigma_I}{\sigma_T}.$$

An important property of the optimum index is that the weighting factors or b coefficients are chosen to correct for differences in variances, e.g. heritabilities and the phenotypic and genetic correlations, to achieve maximum efficiency of selection (Williams, 1962a).

The appropriate criterion for optimality in animal breeding is to maximize average genetic progress per year. The regression predictor $\hat{T}$ as a selection index is the optimum selection rule if maximisation of the expected value of T constitutes the desired optimum (Bulmer, 1985).

The average genetic superiority ΔT of the selected individuals over the mean of all candidates for selection is:

$$\Delta T = r_{TI}\, D\, \sigma_T$$

where D is the selection differential on a standard normal distribution (Allaire and Henderson, 1966; Cunningham, 1969;

Hayes and Hill, 1980). The genetic progress in the aggregate genotype T achieved by one round of selection on the index I is:

$$\Delta T = r_{TI}\, D\, \sigma_T = \sqrt{\frac{\sigma_{TI}}{\sigma_T^2}}\, D\, \sigma_T = \sqrt{\sigma_{TI}}\, D = \sigma_I\, D = \sqrt{\mathbf{b'Pb}}\, D.$$

This formula for ΔT is strictly true when the criteria and objective are linear or quadratic functions of normally distributed component traits and the selection is single stage. However, Harris et al. (1984) states that the principles are still relevant when more complex selection criteria are involved.

The criterion to be used in selection could also have been developed from Henderson's mixed model (1963; 1976). If least square equations are set up under the assumption that the random elements of the model are fixed with the exception of e [$\mathbf{y} = X\beta + Z\boldsymbol{\mu} + \mathbf{e}$] and the inverse of the variance-covariance matrix of the random elements is then added, the equations can be solved directly for the maximum likelihood estimators of the fixed elements of the linear model and for the criterion to be used in selection (Rönningen, 1974).

2.1.4.2. Best Linear Unbiased Prediction

Use of the conditional mean, i.e. the vector E(**T**|**X**), as a selection rule requires knowledge of the conditional distribution of T given X. However, in animal breeding the first moments of the distributions of T and X are rarely known and consequently the selection index which requires known means cannot be used. This is especially the case in dairy cattle breeding were for example each herd-year-season is unique and appropriate adjustment factors can only be estimated from the data. Henderson's mixed model methodology

(Henderson, 1963) allows to estimate random as well as fixed effects. Thus, this procedure allows to simultaneously predict breeding values and adjust for fixed effects in the case of animal breeding.

Estimates derived using this mixed model methodology are best linear unbiased predictors (BLUP) (Henderson, 1972). BLUP prediction gives an unbiased predictor, i.e. the expected value of the estimator is equal to the population quantity being estimated. In this case the expected value of the records within a given fixed effect have an expected value equal to the value of the fixed effect plus the mean (Henderson, 1972).

Both, BLUP and selection index procedures have the statistical properties of being best linear predictors (BLP), i.e. they are equivalent when the means are known, which has been proven by Goldberger (1962) and Henderson (1963). A simpler proof based on a manipulation of the basic BLUP equation was given by Henderson (1984). The selection index (BLP) can be interpreted as a special case of BLUP, representing the case were ß's are known. BLUP predictions are equivalent to selection index predictions when random genetic values are predicted from phenotypic values calculated from records adjusted by maximum likelihood estimates for fixed effects (Gianola and Goffinet, 1982). However, calculation of maximum likelihood estimates of fixed effects to ensure that selection index values are unbiased is computationally demanding (Henderson, 1972). Goffinet (1983), Bulmer (1985) and Fernando and Gianola (1986) verified that the expected value of the aggregate genotype of the selected candidates is maximised with selection based on the conditional mean of the aggregate genotype, given observations whose expected value is a linear function of a set of unknown parameters estimated by a vector of adjusted records. This holds when the expected value of the aggregate genotype is the same in all candidates as well as when it differs from candidate to candidate.

While the statistical properties are the same for both procedures, the advantages of BLUP, beside requiring only knowledge of the variance components of the joint distribution of phenotypic and genetic values, are its ability to account for a large number of specific situations frequently encountered in animal breeding like selection and culling bias, genetic trend, interactions and unequal sample sizes. Henderson's (1976) development of an algorithm based on mendelian principles to invert the numerator relationship matrix for large data sets constituted a major breakthrough in the calculation of BLUP estimates. Coupled with the use of iterative techniques and increased performance of computer hardware this has led to multiple trait BLUP applications to predict breeding values of individual animals in cattle, sheep and pigs (Blair and Pollak, 1984).

2.1.4.3. Definition of the aggregate genotype

The use of a selection index can achieve genetic progress more efficiently not only for the case where an aggregate genotype is being improved but also when selection is directed towards a single trait (Lerner, 1950; Gjedrem, 1967a). By taking into account highly correlated traits with higher heritabilities and of small or no economic importance the accuracy of identification of a genotype for the trait to be improved and thus the efficiency of the index will be increased. This is equivalent to assigning zero economic values to all traits other than the desired one in the aggregate genotype.

In practise it is common to only include the most important economic traits in the aggregate genotype. It has been shown, however, that all economic traits should be included in the aggregate genotype (Gjedrem, 1967a; 1967b).

In applied animal breeding programmes, information about important economic traits may not be available because measurements may be too costly or difficult for biological or technical reasons. In dairy cattle, for example, feed utilization is not recorded although the trait is of great economic importance. The optimum index can be used to maximise indirect genetic gains in traits which are of high economic importance but are not actually measured due to time or cost constraints. These traits may be included in the definition of the aggregate genotype with large economic values. However, since these traits are not measured they are therefore not included in the index (Binet, 1965; James, 1968; Turner and Young, 1969).

Gjedrem (1972) compared the efficiency of two types of indices which differed in the definition of aggregate genotype. The first aggregate genotype included two traits while the second one included a third correlated trait with no phenotypic information. Results showed that the aggregate genotype should include all traits of economic importance, each trait weighted by its relative economic value. Economically important traits which were not recorded should as a rule also be included in the aggregate genotype. The advantage of including unrecorded important traits was considerable in some cases and was explained by the utilization of genetic correlations between the traits in question.

2.1.4.4. Multiple-stage selection

Selection for multiple traits is not necessarily carried out simultaneously but often in a sequential manner. If information about an individual's genotype and phenotype accumulates chronologically it is usually cost effective to select individuals after each stage of information update. In dairy cattle for example potential sires are firstly selected according to their ancestry breeding value, with a second selection stage based on their performance with respect to some secondary traits like conformation during their postnatal development and a final selection decision based on their progeny test results at the age of five years. Recent advances in physiology and biochemistry have also

opened the possibility of early selection based on biochemical indicators used as indirect traits for the selection of production traits in mature individuals (Land et al., 1983; Flach et al., 1985; Ahlborn-Breier et al., 1987; Woolliams and Smith, 1988; Blair et al., 1990).
While multiple-stage selection is frequently practised it should be noted that truncating the distribution with the first act of selection reduces the genetic variance (Bulmer, 1976) and induces non-normality (Cunningham, 1975) especially at high selection intensities. An algebraic method for adjusting the effects of truncation in later stages of selection by modifying variances and covariances is given by Cunningham (1975).

The substitution index has frequently been used in the situation of multiple-stage selection when candidates for selection became available at different times (Young, 1964; Van Raden et al., 1984) with the selection rule at each stage being the appropriate index. The number of candidates is then progressively reduced until only those required for mating remain. However, when the objective of multiple-stage selection is to achieve the maximum expected response of the sum of all stages of selection, Van Raden et al. (1984) suggested to keep some less accurately evaluated animals with a lower expected mean but a larger expected variance at the first stage in order to retain greater genetic variability for selection at the following stage. They presented an index procedure considering the animal's estimated breeding value as well as the accuracy of its evaluation for the first stage of selection which achieved a slightly faster genetic gain than selection on estimated breeding values alone. Ideally, all animals should be kept until the final stage of selection but considering the costs and benefits an intermediate strategy is optimum in most cases.
The expected response for two-stage selection has been predicted using the moments of truncated multivariate normal distributions (Young and Weiler, 1960; Williams and Weiler,

1964; Young, 1964; Cotterill and James, 1981).
Multiple-stage selection will not be considered further here to limit scope and size of this thesis.

2.1.4.5. Efficiency of selection index

Regardless of the method of selection, genetic gains in individual traits will almost certainly diminish as the number of traits under selection is increased. For example, assuming uncorrelated traits of equal heritability and economic importance the gain expected in any one of n traits would only be $1/\sqrt{n}$ as great as the gain expected with selection applied to the single trait alone (Hazel and Lush, 1942; Turner and Young, 1969). However, when the genetic correlation is positive the relative efficiency of a selection index is larger than $1/\sqrt{n}$ (Gjedrem, 1967b).

When selecting for an aggregate genotype, tandem selection is the least efficient selection method compared to independent culling levels and selection index, given independent traits with the same product of economic value, heritability and phenotypic standard deviation (Hazel and Lush, 1942; Lerner, 1950). The superiority of the latter methods increases with the number of traits selected and the intensity of selection. It has been argued that the method of independent culling levels is particularly useful when estimates of the parameters are known (Young and Weiler, 1960). The threshold levels can then be fixed before the start of any selection operation, and an immediate decision can be made on each animal as it is examined, without any need for permanent labelling and re-sorting. However, current computing and communication capabilities would allow the calculation of selection indices within a very short time interval and would alleviate the need for independent culling under these circumstances. Index selection is more efficient than other methods of selection when two or more traits are involved. This has been shown by theoretical calculations (Hazel and Lush, 1942; Young and Weiler, 1960; Young, 1961; Finney, 1962). Their findings were confirmed experimentally by comparing tandem selection, independent culling levels and index selection for two bristle traits in Drosophila melanogaster (Sen and Robertson, 1964) and for the traits postweaning weight gain and litter size at birth in mice (Doolittle et al., 1972) as well as in a field experiment after five generations of selection based on individual measurements for five traits in alfalfa (Medicago sativa) (Elgin et al., 1970). The superiority of index selection over independent culling levels increases with an increasing number of traits under selection, but decreases with increasing differences between relative economic values for the traits included and with increasing selection intensity (Young, 1961).

While the selection index has repeatedly been shown to be more efficient, especially in conjunction with BLUP estimates of breeding values, the effort required to obtain sufficiently precise estimates of the parameters required for the index calculations, in particular the clear and longterm determination of relative economic values, has been a major obstacle to the use of selection index procedures in the past.

2.1.4.6. Estimated selection index

While the theory of the optimum selection index assumes the elements of the matrices G, P and C to be known exactly, in practice estimates of the required population parameters will be used and the resulting index coefficients will be estimates of the optimal index coefficients. Williams (1962) suggested this as the estimated index. However, it should be noted that due to the relatively large standard errors associated with these estimates and their high influence in the selection procedure care should be taken with respect to the accuracy of the estimates.

Criteria for the permissibility of the matrices P, G and C are that for any linear combination of aggregate genotype T the variance of T is greater zero, i.e. Var(T) > 0, and that for any predictor I the ratio between the variance of I and the variance of T lies in the parameter space, i.e. $Var(I)/Var(T) = \lambda$, $0 \leq \lambda \leq 1$. These conditions can only be satisfied if the matrix G is positive definite and the eigenvalues of $G^{-1}B$ range between 0 and 1 where B is the variance-covariance matrix for the predictors of genetic values (Foulley and Ollivier, 1986).

If estimates of population parameters are not reliable, an estimated index may actually give less response on average than a base index (Baker, 1986). This provides a strong argument against using an estimated index except for cases were the advantages of an optimum index over a base index are substantial and when reliable estimates for the genetic population parameters are available.

2.1.4.7. Substitution index

The substitution method consists of the estimation of breeding values prior to index selection. Then, these sub-indices are combined into the complete index by weighting the individual breeding values with their economic value (Henderson, 1963). This procedure is as effective as calculating the complete index initially (Moen et al., 1972 cited by Miller and Pearson, 1979) and has been shown to be algebraically equivalent by Van Vleck (1988). The use of BLUP genetic evaluations in conjunction with quadratic bioeconomic objectives is seen as most appropriate (Harris et al., 1984).

Sub-indices can be developed for some of the traits using the information about these traits. These sub-indices then replace the respective traits in the equation for an aggregate genotype. The result is equivalent to the conventional method with linear or quadratic models of aggregate genotype and this method allows the economic values to be easily changed (Rönningen, 1978).

2.1.4.8. Indexes based on phenotypes

A number of indices based on phenotypes have been proposed to avoid the construction of the optimal index which demands solving sets of simultaneous equations and requires reliable parameter estimates. While these phenotypic indices are simple to construct and do not require specific expertise it should be carefully noted that they do not take genetic parameters into account and thus are not as efficient as more elaborate indices.

a) Base index

Williams (1962a) suggested the use of a base index defined as the sum of the products of economic values (a) and measured phenotype (P) for each trait:

$$I = a_1P_1 + a_2P_2 + \quad . \quad . \quad . \quad . \quad + a_nP_n.$$

Thus, the economic values are used directly as the index weights instead of the index being computed from the estimated parameters. This index implicitly assumes traits with equal heritabilities and zero genetic correlations, assumptions which are unlikely to hold in practise. However, for two variables the probability that the estimated index will yield a poorer response than the base index is high unless progress from the optimal index is substantially greater than that from the base index (Williams, 1962a; Harris, 1964). Williams (1962a) concluded that the base index should be used when genetic variances cannot be accurately estimated.

The base index should approach the optimum index in efficiency if correlations between traits are small, and if the variability for each trait reflects its relative importance (Harris, 1964). Also, Sales and Hill (1976b) showed for two correlated traits, of which only one was economically important that inclusion of the second trait and thus use of the optimum index developed from the variance and covariance estimates rather than the base index was only worthwhile when reliable parameter estimates were available. This shows that the efficiency of the base index is only higher than that of the optimum index when the estimates of genetic parameters are very different from their real values.

b) Primary Index

Another special case of the selection index and an extension of the base index is the primary index proposed by Andrus and McGilliard (1975) which weights the measured value (P) of each trait with the product of its heritability (h^2) and economic value (a):

$$I = a_1\, h^2{}_1\, P_1 + a_2\, h^2{}_2\, P_2 + \; . \; . \; . \; . \; + a_n\, h^2{}_n\, P_n$$

This index represents the sum of predicted breeding values of traits weighted by their economic importance but does not take correlations among traits into consideration i.e. it assumes traits to be independent. Due to the missing genetic and phenotypic correlations it is not possible to predict genetic gains from this index.

c) Elston index

A multiplicative index based on phenotypes was proposed by Elston (1963). This index uses non-parametric statistics and a log transformation to account for differences in variances and skewness. Data are transformed so that high values are desirable and distributions have similar modes. The index consists of the products of phenotypic measurements (P) adjusted by subtracting the minimum value (p) for each trait:

$$I = (P_1 - p_1)\,(P_2 - p_2) \; . \; . \; . \; . \; (P_n - p_n)$$

Subtracting the minimum value p adjusts the scale of measurement of each trait to begin at zero. This index has some characteristics of independent culling levels as individuals with the lowest measurement for a trait will have a zero index value and are thus culled without considering their measurements in any of the other traits. Elston (1963) termed his index "weight-free" because he argued that no economic values were required, however, the quantity $P_n - p_n$ acts as a de-facto weighting coefficient in this index, effectively weighting each trait approximately equally in terms of their standard deviations. Consequently, if an efficient transformation is achieved the index assumes equal importance for each trait in the selection process.

2.1.4.9. Selection indices with constraints

In the solution of simultaneous equations it is possible to place constraints on traits which are adversely correlated to other traits in the optimum index and the aggregate genotype. These constraints can prevent deterioration in the adversely correlated trait while maximum possible gains are achieved in other traits. Thus, constrained selection indices are applied when n traits are involved and the objective is to maximise genetic progress on n - r traits while imposing constraints on genetic gain in the remaining r traits.

The idea of imposing constraints on selection indices was introduced by Kempthorne and Nordskog (1959) with the aim to maximise genetic changes in the aggregate genotype while keeping genetic change in some of the traits considered at zero ("restricted selection index") and later extended to control the magnitude of such genetic changes ("proportional gains or desired gains index", Tallis, 1962; Pešek and Barker, 1969; James, 1968; Harville, 1975; Essl, 1981). There equivalence has been proven by Itoh and Yamada (1987). In the restricted selection index the genetic gains are set to zero while in the proportional gains index the constraints represent predetermined proportional gains in some traits.

Imposed constraints in the selection index can be fulfilled by incorporating Lagrange multipliers in the selection objective (Cunningham et al., 1975; Brascamp, 1984). Alternatively, Niebel and Van Vleck (1983) derived a Newton-

Raphson iterative algorithm for the solution. Lin (1985) suggested a stepwise procedure for constrained selection indices without involving Lagrange multipliers. The steps involve construction of a conventional selection index based on k unrestricted traits followed by the construction of a sub-index based on r restricted traits and solving the simultaneous equations involving the genetic variance-covariance matrices and index coefficients for r restricted and k unrestricted traits. The sub-index for the r restricted traits is developed using a retrospective approach (Allaire and Henderson, 1966; Niebel and Van Vleck, 1983). While this simplified procedure is slightly less efficient than a restricted selection index involving the Lagrange multipliers it satisfies the prespecified restrictions, can be employed with proportional, sign or linear restrictions and can be extended to multiple restrictions.

Both the restricted selection index (Kempthorne and Nordskog, 1959) and the proportional gains index (Tallis, 1962; Pešek and Barker, 1969; James, 1968) are restricted to traits being the same in the index and in the aggregate genotype. These methods were extended and generalised to allow predetermined genetic progress in the restricted characters, including situations where the index contains traits which were not included in the aggregate genotype (Harville, 1975; Sumpf, 1981; Brascamp, 1984; Tallis, 1985; Itoh and Yamada, 1986). Tallis (1985) showed that «minimising the variance of the difference between the economic merit and the selection index with respect to the coefficients of the index, and subject to the constraints, is equivalent to maximising the correlation coefficient between genetic merit and the index under the same constraints.» This simplifies calculations. Recently, Itoh and Yamada (1986; 1987) proved algebraically that the above proportional gains index methods are equivalent.

While it is sometimes claimed that the proportional gains index does not require the definition of economic values in its derivation (Mukai et al., 1989) as it implies default economic values, the decision about the proportions of genetic gain for each trait still requires some form of economic evaluation of the importance of each of the traits involved. However, genetic gains achieved with this method are independent of economic values (Harville, 1975; Tallis, 1985). In a simplified form the proportions of the standardised genetic gain of the different traits are determined by replacing the vector a of economic values with the expression $(G'P^{-1}G)^{-1}r$ where the vector r contains the desired percentage of the standardised genetic gain for each trait multiplied with the respective genetic standard deviation.

Mukai et al. (1989) compared the effect of the optimum selection index with the index for proportional genetic gains on population characteristics after long-term selection using Monte-Carlo simulation. They found no significant difference in genetic gain between the two indices. However, the optimum selection index showed a much higher variation between replicates especially for traits with a high heritability. In addition, the population structure and direction of selection varied considerably from one generation to the next. They concluded that the index for proportional genetic gains might be useful for the practical animal breeder since the objectives, i.e. stipulated proportional gains, may be easily determined as deviations of the present population mean from the defined breeding goal.

2.1.4.10. Alternatives to index selection

The general theory of canonical correlations can be applied to selection indices (Thompson, 1977). The eigenvectors of the genetic variance - covariance matrix **G** represent principal components and the eigenvalues of the variance-covariance matrix of the predictors of breeding values are the canonical correlations between the set of phenotypic variables and the set of breeding values.

Selection decisions from principal component, principal factor and maximum-likelihood factor analyses were compared to the optimum selection index by Godshalk and Timothy (1988). Their goal was to eliminate commonly encountered problems in index selection like errors in genetic parameters and difficulty in assigning relative economic values to traits. Several multivariate analysis methods were performed on phenotypic and genotypic correlation matrices with the result that principal component analysis had the highest correlation with index selection. The high correlation for principal component analysis selection with optimum selection index indicates that selection could potentially be accomplished on the basis of principal component analysis of the phenotypic correlation coefficients. This avoids the need for reliable genetic parameter estimates and consequently the disadvantages of inaccurate parameter estimates as well as eliminating costs for their estimation. Godshalk and Timothy (1988) suggest that depending on further work comparing achieved genetic gains for the different methods, principal component analysis might be a cost-effective alternative to the selection index through a reduction of the number of traits measured.

2.2. Estimation of relative economic values

All methods of selection imply a well-defined selection objective in the form of an aggregate genotype. The definition of the aggregate genotype as a linear function of the products of the breeding value for the traits included and their economic value requires specifying the relative importance of these traits. The economic values constitute a transfer of market signals into the selection objective. The relative importance or relative economic value of a trait may be empirically derived or a subjective perception of the traits influence on the selection objective.

Incorporating economic values into animal breeding plans permits clearly defined and economically based selection objectives. However, defining the selection objectives has been one of the major causes of conflict between traditional and scientific animal breeders (James, 1982).
It can be argued that any selection must be using an index of some kind since simple characters are compounds of several constituents. Thus, even single trait selection implies the use of an index in which the economic value is the same for any trait (Lush, 1961). Single trait selection for protein yield, for example, means that a kilogram of milk volume has the same importance as a kilogram of milkfat. Such implied relative economic values, however, have to be evaluated for their appropriateness.
The estimation of relative economic values is often a difficult task and methodology as well as estimates of economic values are scarce in literature. One of the difficulties in estimating relative economic values and constructing comprehensive profit functions, also called objective functions, is the scarcity of data on inputs and outputs and their variation between herds or industry sectors (e.g. commercial and pedigree breeders). This has led to different opinions about the economic values of various traits and which ones should be included in selection, subsequently resulting in substantial but probably unwarranted selection pressure for some traits (Ducrocq, 1984; Van Vleck, 1986; Ahlborn-Breier et al., 1987). The accurate estimation of economic values for traits in the aggregate genotype and the estimation of genetic parameters influencing profit such as feed intake, labour and health present a major limitation for the development of profitability indices (Blake, 1984).

The need of attention to economic factors in animal breeding and net economic values for traits has been pointed out recurrently (Harris, 1970; Miller and Pearson, 1979; White et al., 1981; Rönningen and Van Vleck, 1985). The lack of research in this area has been explained by the limited training of animal breeders in economics, difficulties in predicting future economic and technological conditions and the absence of data concerning inputs and outputs in different situations and for animals differing in breeding values for a number of traits. It should also be considered that data on inputs and outputs in an enterprise are highly specific and depend on a large number of other factors thus requiring data from a large number of enterprises to obtain reliable results and allow statistically valid inferences. However, recently there has been a surge of interest in this area following the development and routine application of genetic analyses for multiple traits.

Economic values are defined as the «amount by which profit may be expected to increase for each unit of improvement in each trait» (Hazel, 1943). In this normative approach the economic value of one unit change in a trait is determined by summing the returns and costs of all changes of inputs and outputs. This cost-budgeting approach results in marginal returns for the trait in question. This method has the advantage of simplicity and of being based on bio-economic relationships. Additionally, it is reasonably free of the variance-covariance structure in the traits in the selection objective and profit function.

Frequently the relationship between traits in a complete selection objective and the inputs and outputs in the profit function are complex and might involve non-linear functions. For example, some traits are expressed more than once and at different stages during the lifetime of an animal for example lactation yield in comparison to slaughter weight. This needs to be considered when estimating the economic values and is most easily carried out by discounting the repeated returns and costs.

2.2.1. Discount rates

Selection decisions are mating decisions and the potential revenues do not eventuate until such time when the progeny's characteristics can be evaluated. The discounting of future revenues to their present value has been frequently used to express revenues and costs occuring at different times in an equitable way (Poutous and Vissac, 1962; Soller et al., 1966; Soller and Bar-Anan, 1973; McClintock and Cunningham, 1974; Dempfle and Ponzoni, 1986). Smith (1978) concluded that the discount rate should account for inflation which may reduce the commonly applied discount rate considerably. Further, the actual interest rate (r) should be replaced with the effective annual interest rate (q) defined as

$$q = (r - i) / (100 + i)$$

where i is the inflation rate (%).

As selection decisions are longterm decisions the time frame for investments needs to be considered. A planning horizon of 10 to 15 years has been shown to be adequate for moderate discount rates (Cunningham and Ryan, 1975). In accordance, two generations of descendants for Holstein-Friesian and one generation of descendants for Jersey sires were sufficiently long planning horizons when net present values of semen were calculated based on milk income, type and a real interest rate of 3% as these had rank correlations of .99 with sire rankings from longer periods (McMahon et al., 1985).

Productive animals tend to stay longer in the herd and thus have a greater opportunity of expressing a trait which leads to non-linear economic values for the traits affected. These effects can be estimated using geneflow methodology (Bar-Anan, 1972; McClintock and Cunningham, 1974) or the more flexible matrix algebra based on Markov processes (Hill, 1974; Elsen and Mocquot, 1974). An additional complicating factor is the multiple use of animals in a production system.

In an established dairy enterprise revenues are received from the same cows for milk, their slaughter weight as well as from the sale of their male and female calves and/or heifers. A method of subindices taking into account the different economic revenues from each use and discounting future gains to their present value was presented by James (1982). The economic value also depends on the perspective taken (Soller and Bar-Anan, 1973; Harris, 1970; Moav, 1973; Miller and Pearson, 1979) and maximizing net income at the producer level does not necessarily optimize the monetary value for other sectors of the industry like the manufacturer or the consumer. In contrast, Smith et al. (1986) argue that these differences disappear when resources are efficiently used and when changes in output require proportional changes in input. In this case of rescaling which can also be interpreted as increasing efficiency, fixed costs are assumed to be expressed per unit of output rather than as fixed enterprise costs.

Economic values might also change depending on the economic situation under which the dairy enterprise operates. Pearson (1982) showed that when between 5% and 10% of pedigree animals are sold for breeding purposes, type became substantially more important for a pedigree breeder than for a commercial producer. However, he cautioned that this might be an artificial situation due to tax laws subsidising pedigree stock.

Because of the difficulties encountered in estimating economic values, methods have been suggested which apparently circumvent the need to specify economic values. This was the underlying reason for the development of constrained selection indices (Tallis, 1962; Pešek and Barker, 1969; Harville, 1975; Lin, 1985) which are calculated to give responses in individual traits proportional to "desired gains" specified by the animal breeder. However, this merely disguises the problem in a different form since even the specification of "desired gains" requires evaluation of economic potential and of the economic advantages of different proportional gains. Also, in several countries computerized mating programs (McGilliard and Clay, 1983) have become popular with farmers, animal breeders and sire analysts which generally rely upon the users more or less subjective choice of independent culling levels for traits deemed to be important (Tempelman and Burnside, 1990). It is rarely the case that the decisions on which these independent culling levels are based have evolved from a thorough investigation of their economic consequences. These situations lead to inefficient use of animal breeding plan investments by increasing costs and reducing genetic progress in economic terms.

2.2.2. Profit function - objective function

Already in the beginning of the 19th century Thaer (1809) emphasized economic aspects of actions in agriculture and gave highest possible profit priority over highest possible production as an objective for the farmer: "Nicht die möglich höchste Production, sondern der höchste reine Gewinn . . . . ist Zweck des Landwirths, . ." For this study the objective of agriculture is assumed to be the maximisation of financial gain, hereafter termed profit. However, it should be noted that in some types of farming the principle of maximisation of benefits to the household of management can be the main objective. This is not considered here. A farm in this study is defined as a local, technical and organisatorial production unit comprising the production factors which are combined for the production of goods through systematic actions by management (Steinhauser et al., 1972).

The results of actions by management can be described by a response function which identifies the relationship between factors (X_i) and products (Y), often referred to as inputs and outputs:

$$y = f\ (X_1, X_2, X_3, \ldots\ldots, X_n).$$

The response function includes direct (fertilizer) as well as indirect (land, milking machine) factors and measures the technical relationship between inputs and outputs in physical units. It comprises the basic function for economic considerations with the aim to find the optimum factor-product combination. However, an optimum factor-product combination is a necessary but not a sufficient condition for profit maximisation. This is achieved with the optimum factor-product combination at least cost. Searching for the least cost combination usually involves varying some factors while keeping others fixed resulting in a partial function:

$$y = f\ (X_1,\ X_2 \mid X_3,\ .\ .\ .\ .\ ,\ X_n).$$

This determines the relationship between factors and product with respect to a fixed or limited factor (e.g. land in dairying).

It is impossible to list all input factors involved in producing a particular livestock product and thus simplifications are used involving only the more important input factors. For most situations in livestock production the following assumptions for the response function are characteristic (Dillon, 1977):

a. continuous smooth causal relation between the inputs (X_i) and output (Y),

b. diminishing returns with respect to each input factor X, i.e. the additional output from succeeding units of input becomes less and less,

c. decreasing returns to scale, i.e. an equal, proportional increase in all inputs results in a less than proportional increase in output.

These assumptions imply that

a. the first derivatives $\partial Y/\partial X_i$ of the response function exist and

b. decrease as the input factor X_i increases, which entails that the second derivatives $\partial^2 Y/\partial X_i^2$ exist and are negative and

c. the sum of the product of the reciprocal of the average response and the marginal response is smaller than 1 ($\Sigma [X_i/Y] [\partial Y/\partial X_i] < 1 \quad \{i = 1, 2, . . ., m\}$).

The set of input quantities which best achieves the specified objective, i.e. maximisation of profit, is defined as the best operating conditions and specifies the objective function:

$$\pi = p_y Y - \Sigma p_i X_i \qquad (p_y, p_i > 0)$$

where π is profit, p_y is price per unit of output, Y is output quantity, p_i is price per unit of input and X_i is input quantity (Heady and Dillon, 1966). Maximisation of profit thus implies maximising the difference between the financial value of output and the cost of the variable inputs used. Thus, to find the maximum of the objective function for a single input variable, i.e. maximum profit, the first derivative $\partial\pi / \partial X_i$ is set to zero and solved for X_i:

$$\partial\pi / \partial X_i = p_y (\partial Y / \partial X_i) - p_i$$

Since diminishing returns are one of the assumptions of the response function it holds that the second derivative ($\partial^2\pi / \partial X^2_i < 0$) is smaller than zero. The best operating conditions with a single input variable and no constraints on the objective function occur when the marginal product (MP) of the input equals the inverse price ratio:

$$\partial Y / \partial X_i = p_i / p_y.$$

For more than one input variable the objective function is defined as

$$\pi = p_y Y - \Sigma p_i Y_i$$

and maximisation of profit π with respect to the n input variables implies simultaneous solution of the n equations

$$\partial\pi \,/\, \partial X_i = 0 \qquad (i = 1, 2, \ldots, n).$$

The solution to this system of n equations yields the set of input quantities X_i constituting the best operating conditions. Substituting these values into the response and objective function gives the level of output and profit achieved under best operating conditions. Each of the n equations can be rearranged as $MP_i = p_i \,/\, p_y$.

One of the difficulties in livestock production is the simultaneous production of several outputs, e.g. milk, calves and meat in dairying. Allocation of input factors to the various outputs is controlled by the animal at the genetic and the phenotypic level. The determination of these response functions requires detailed and sophisticated biological measurement techniques under controlled conditions and the results of these currently provide the most accurate basis for economic considerations. Note that response functions for the different outputs are most likely not independent.

Commonly, livestock production entails multiple response processes, where the overall outlay but not the individual process is limited. This requires a constrained objective function:

$$\pi = p_yY - \Sigma\, p_iX_i + \lambda\, (\Sigma p_iX_i - C)$$

where λ is a Lagrange multiplier and C is the limit of quantity of the outlay. Setting $\partial\pi \,/\, \partial X_i$ and $\partial\pi \,/\, \partial\lambda$ equal to zero gives the n + 1 equations:

$$p_y\, (\partial Y \,/\, \partial X_i) - p_i + \lambda p_i = 0,$$

$$\Sigma\, p_i X_i - C = 0.$$

The n - 1 isocline equations

$$MRS_{ij} = -p_j / p_i \quad \text{for } i \neq j$$

which, in conjunction with the constraint can be rearranged to give the iso-cost locus:

$$X_1 = C / p_1 - \Sigma\, (p_j / p_1)\, X_j \qquad (j = 2, 3, \ldots, n)$$

The iso-cost locus for X_1, X_2, ..., X_n constitutes the n equations whose simultaneous solutions gives the n input levels whose combined cost is C and which give the highest possible output and thus profit for that outlay.

Frequently the profit function is defined as a ratio to indicate production "efficiency" analog to biological efficiency measures used in livestock production. It should be noted that the definition of the profit function does affect the economic values and their sensitivity to changes in the economic conditions. When the profit function is defined as the difference between revenues $R = p_y Y$ and costs $C = p_i X_i$ the weight for X_i relative to Y is $-p_i/p_y$ and thus the relative economic value depends on the revenue and costs.

The partial derivatives of R-C are:

$$\frac{\partial}{\partial Y}\,(R-C) = p_y$$
$$\frac{\partial}{\partial X_i}\,(R-C) = -p_i$$

When the profit function is defined as the ratio C/R the partial derivatives become:

$$\frac{\partial}{\partial Y}\left(\frac{C}{R}\right) = \frac{-p_i\overline{X}_i}{p_y\overline{Y}^2}$$

$$\frac{\partial}{\partial X_i}\left(\frac{C}{R}\right) = \frac{p_i}{p_y\overline{Y}}$$

and the relative weight for X_i is $-Y/X_i$ where Y and X_i are the input and output means. Therefore, when the profit function is defined as the ratio of revenue over costs the relative economic values depend on the means and not the prices (James, 1982). This is a large and important difference between the profit functions. Another difference becomes apparent with the inclusion of overhead costs k which do not change the relative economic values for the difference R-C but do change for the ratio R/C. The relative economic value for X_i then becomes $-Y/(X_i + k/p_i)$. Thus the ratio of returns to costs is sensitive to the relative importance of fixed and variable costs whereas the difference is not (James, 1982). To avoid decisions like these, "biological" objectives have been suggested such as lean tissue feed conversion (Fowler et al., 1976; Newman et al., 1985). These objectives constitute a simplified economic model of the selection objective proposed by Dickerson (1970).

2.2.3. Methods of estimating economic values

a. Gross-revenue

A gross-revenue method assuming that the only effect of the genetic change is in the price of the final product was used to estimate economic values for traits of laying poultry (Arboleda et al., 1976a).

Nordskog (1960) attempted to estimate net economic values in poultry using a multiple regression of measures of traits as independent variables and net income as a dependent variable.

b. **Graphical methods**

A graphical method of plotting response ellipses or "profit contours" was successfully applied to identify optimum index weights by Moav and Hill (1966). They compared the efficiency of selection in specialised sire and dam lines with the efficiency of selection in both sexes of poultry and pigs, using the same criterion and with profit expressed as a reciprocal function of reproductive performance.

c. Opportunity costs

Blake et al. (1987) estimated the economic value for type score indirectly as opportunity costs of decreased milk income. They defined the opportunity costs of increasing selection intensity for type in Holstein sires as the decrease in potential net income from foregone milk. Results indicated that current selection policies using proportions of estimated annual net income exceeded the predicted proportions of milk to type by between 36 and 100 % towards type. Almost one standard deviation of net income from milk was sacrificed when a proportion of 3:1 for milk and type instead of a 1:0 proportion was used in sire selection. It should be noted that the net income from type relative to milk was most likely over-estimated in this study.

d. **Lifetime profit**

Andrus and McGilliard (1975) and Gill and Allaire (1976) developed a lifetime profit function for dairy cattle including income from milk, milkfat % and number of calvings with expenses being estimated feed costs, number of AI services, rearing cost and length of herdlife.

e. **Profit equation**

The profit equation was employed by Lin and Allaire (1977) and Lin (1985) directly to develop a different type of selection index. The aggregate genotype was equated to profit per animal per unit of time. They estimated the index weights as $b = P^{-1}g$, where P^{-1} is the inverse of the phenotypic variance-covariance matrix of the traits in the index, and g is the vector of genetic covariances between the traits in the index and profit. This approach avoids arbitrary choices of economic values required in the construction of the selection goal in the selection index methodology. The contribution of economic values to the index coefficients differs in this method, as compared to the traditional selection index approach where the goal is an explicit function of the traits. In the application of Lin and Allaire (1977) and Lin (1985), none of the traits of the index were in the profit equation. This method appears to offer alternatives for developing selection criteria.

f. Marginal profit and loss

Economic values have been estimated as the difference between the marginal profit or loss (marginal return - marginal cost) resulting from a unit increase of output over and above the output achieved with an average animal (Simm et al., 1987). Relative economic values for British beef (Simm et al., 1986) and sheep (Parratt and Simm, 1987) were derived on a national basis by estimating the national saving in costs from keeping fewer animals through genetically improved production per animal to achieve a fixed national output of lean tissue (cited by Simm et al., 1987).

g. Linear programming

McGilliard and Clay (1983) developed a linear program which selected sires for use in an enterprise with the objective of maximizing the weighted average breeding value for milk yield of sires used, while including restrictions or constraints in the form of minimum or maximum levels for the weighted average breeding values of a number of type traits and several management factors. Here the economic value was redefined as the amount by which the profit of the farm was expected to increase for each unit of improvement of a trait in a single animal. The procedure can be carried out in an iterative fashion and thus allows the selection objective to be adjusted.

Sivarajasingam (1984a; 1984b) ranked dairy sires for total economic merit by an average daughter's contribution to net farm profit using linear programming. The model included sire's breeding value for milk yield, conformation, milking speed and non-return rate, feed intake estimated from milk yield, fat % and body size, revenues from calf sales and labor cost for milking speed. The traits milk, fat percent, milking speed, body size and non-return rate had high standard partial correlations with the index of total economic merit. Parametric programming showed that many factors in dairy farm operations may restrict expansion of farm milk production.

h. Sensitivity analysis

Ladd and Gibson (1978) applied sensitivity analysis to a linear program to measure economic values. The method identified which traits were most affected by changes in the linear program.

i. Forced choice technique

Gonyon et al. (1986a; 1986b) used the forced choice technique to obtain information about the perceived contribution of milk yield, fat percentage and 15 type traits to evaluate total economic merit. Respondents were asked to rank two hypothetical cows according to their perceived total merit for these traits. The phenotypes for each trait were stochastically simulated within a defined range. This technique has the advantage that it allows a conscious assessment of the traits under consideration because other traits are assumed identical while focussing on only a few traits at a time. This technique also avoids bias from other information potentially influencing ranking decisions. The sample of perceived differences in total merit arising from the displayed phenotypes were quantified by regressing the differences on the displayed phenotypes. These regression coefficients were then used as estimates for the coefficients in a linear and quadratic total merit function. The relative economic value for the traits considered was defined as the change in total merit from a one unit increase of a particular trait.

The results gave an analysis of the perceived economic values of the traits considered based on the opinion of the sample of respondents. The concurrence between these subjective perceptions and the economic influence of the traits on the objective function in a commercial enterprise was not evaluated in detail. However, the results showed a high emphasis for udder support and a low emphasis for conformation of legs which is in agreement with other studies (Thomas et al., 1984b). Also, the ratio of milk to type was not very different from the 3:1 ratio applied in the Total Performance Index (TPI) which defines the overall type contribution in terms of a final type score trait.

j. Utility function

A utility function incorporating information on production or a selection index for production, linear type traits, timing of net revenues and accuracy (i.e. risk) showed that moderate changes in the relative weights of production versus type traits has little effect on sire rankings with rank correlations above 0.97. The effect of changing risk aversion on sire rankings was small except when risk aversion was increased to high levels (Rogers, 1990). This method is sometimes also called risk aversion since it allows to estimate the risk of a management decision by incorporating the variance of its potential monetary outcome.

2.2.4. Use of economic indices

Some economic indices have been widely used in dairy cattle in the USA. The Predicted Difference Dollars (PD$) weights breeding values for milk and fat by their market prices. The Production Type Index (PTI) weights the value for PD$ and the breeding value for type and the Total Performance Index (TPI) combines the breeding values for milk, fat % and type (Pearson and Miller, 1981). While the weights used in the rankings are not net economic values and covariances are not included, the indices appear to have a positive impact on more realistic emphasis on traits in selection (White et al. 1981). Results from a linear net merit index developed by Wilcox et al. (1984) by calculating net present values for available AI sires show low Spearman rank correlations between PD$ and the net present value of sires. This indicates that PD$ might be an unsuitable alternative for profitability rankings.

2.2.5. Non-linear economic values

The selection objective or aggregate genotype is not always a linear function of its component traits. In this case no unique economic value exists and the economic values must be changed as the mean of the population being evaluated changes. This implies that the economic gain from a certain phenotypic difference in the trait is not constant over the full range of its variation. Thus, economic values might differ between strains or breeds and geographical regions (Miller and Pearson, 1979). Non-linear economic values arise where the economic value of the product varies with the output of the product and where the economic value of a trait depends on the level of another trait (Goddard, 1983; Van Vleck, 1988).

A constant economic value for a trait implies selection for a maximum or minimum level depending on the sign of the economic value. A non-constant economic value is observed with selection for intermediate or optimum values. A curvilinear relationship between the economic value and the phenotypic level results from the law of dimishing returns as the profit curve might be a quadratic or polynomial function when prices for inputs and outputs in the response function are included. To incorporate this situation the optimum selection index has been augmented to include restrictions to keep the mean values of one or more traits unchanged (Kempthorne and Nordskog, 1959) and to confine the magnitude of genetic changes in individual traits to specified levels per unit selection intensity (Tallis, 1962; Harville, 1975; Essl, 1981) in the form of constrained selection indices.

Another situation where non-constant economic values occur is with selection for a lowest acceptable value which can be described by a stepwise function in relation to the phenotypic value. Such thresholds imply a non-linear economic value: above the threshold for acceptability, an increase in the trait may have only a relatively small economic value per unit, but falling below the threshold is reason for culling despite the redeeming qualities of other traits. Recognition of this type of non-linearity of economic values is embodied in the method of independent culling levels. In this procedure animals which fall below a certain threshold for traits such as fertility, disease resistance or temperament are likely to be culled more or less independently of their potential genetic values for traits with more clearly defined economic values (Van Vleck et al., 1987). Also, tandem selection is a useful method when the economic weight of some traits is non-linear as its occasional use is a simple method of preventing certain traits to fall below defined thresholds (Turner and Young, 1969).

The question of non-linearity in models for the aggregate genotype or total merit was treated by Wilson et al. (1968) in a statistical context. Especially when considering traits related to fitness, the assumption of linearity may be questioned. To circumvent this situation the substitution method was proposed where subindices for each trait are developed using information on all traits, and these subindices replace each trait in the aggregate genotype equation. This method gives the same result as the conventional method for linear or quadratic models of total merit (Wilton et al., 1968; Rönningen, 1971; Goddard, 1983) but has the advantage that the economic values can be varied easily (Rönningen, 1978). An extension of the algorithm to maximize genetic progress including all genetic pathways subject to non-linear constraints has recently been presented (Ducrocq and Colleau, 1989) with an example in dairy cattle breeding.

2.3. Effects of errors in parameters on expected genetic gain

2.3.1. Errors in genetic parameters

The accuracy of the prediction of response in index selection experiments is mainly dependent on the accuracy in the estimation of the parameters involved in the construction of the index (Sales and Hill, 1976b). When estimates are far from the true values, the index looses effectiveness as a predictor of the underlying aggregate genotype. In that situation, the observed response will be smaller than expected, the deficit depending on the magnitude of the error committed. Harris (1964) studied the influence of the magnitude of sampling error of heritability and genetic correlation estimates on the accuracy of the prediction of response. He concluded that losses in efficiency can be important when sample sizes are small. These losses increase when heritabilities are low and genetic correlations are negative. Alternatively, the use of the base index has been proposed (Williams, 1962). The precision of long-term predictions in selection experiments with multiple objectives can be low even in the absense of incorrect estimates.

In many practical situations of breeding domestic animals distortions of normality due to selection might be sufficiently slow to have little impact due to low heritabilities and selection intensities. Finney (1962), however, cautions that any selection applied in one generation will destroy normality at its first application and potentially reduce genetic variances of all traits correlated with the function used as selection criterion as well as their covariances (Bulmer, 1971).

Bohren et al. (1966) theoretically demonstrated that changes in gene frequencies due to selection affect genetic covariances to a greater extent than genetic variances. Thus, prediction of correlated responses would be valid over a smaller number of generations than prediction of direct response. That genetic covariances can even change sign as a result of selection has been pointed out by Lerner (1958). Hence, concordance between realized and predicted response will not only decrease when poor parameter estimates were used, but also when the magnitude of these estimates changes as selection proceeds, due to genetic drift and/or to selection itself (Caballero, 1989). Several authors have tried to overcome such problems by using indices re-calculated in each generation from parameters obtained in the previous ones.

The efficiency of restricted indices is also affected by errors of estimation, and the response of the restricted trait can be rather different from that predicted, especially when its heritability is low (Hill and Meyer, 1984). Additionally, simulation studies by Mortimer and James (1987) have shown that response to selection using this type of index is particularly sensitive to temporal changes in the genetic parameters. This occurred to such an extent that restriction is only possible if genetic covariance and genetic variance of the restricted trait do not change. Thus, re-estimation of parameters has also been suggested for constrained selection indices as a way to improve genetic response.

Caballero (1989) calculated the differences between expected and observed responses (1 - ($R_{exp.}$ - $R_{obs.}$) / $R_{exp.}$) in a large number of selection experiments using Drosophila, Tribolium and mouse strains to measure the relative importance of possible causes of inaccuracies in predicting the response. He reported that re-calculated indices have the highest efficiency of 90% whereas classic or base indices achieve an average efficiency of 54 and 46% and constrained indices are the most inefficient. High losses in efficiency occur with constrained indices when traits have low heritabilites (Hill and Meyer, 1984). These type of selection experiments were not even included in the analysis by Caballero (1989). In his comparison constrained selection indices were completely successful in only one selection experiment and only partly effective or wholly ineffective in the remaining cases. In general, efficiency decreased from 50% to 37% as a consequence of errors committed in the estimation of the parameters used to construct the index. Temporal changes experienced by the parameters resulted in a much more pronounced reduction of the efficiency, from 67% to 37%. He concluded that of those factors which can be shown to decrease the expected selection response, temporal changes of genetic parameters were found to be the most important one, and the use of indices re-calculated every generation from selection data appears to be the best way to optimize selection gain.

While populations are significantly larger in dairy cattle breeding these results still show that serious consideration should be given to the use of a re-calculated selection index.

From the above it appears that errors in the heritability estimates reduce the efficiency of the selection index to a lesser extent than do errors in the correlations.

Hayes and Hill (1980) used a canonical transformation to reparameterize the phenotypic covariance matrix to allow an easy computation of the sampling variances of the index. The index was likely to be least stable when the transformed variables had a low heritability with high economic values. The weights had the largest sampling variance when these heritabilities were near equal.

Canonical correlations can be employed to check the validity of the parameters used in the selection index. The coherence or permissibility of the parameters is assured when the matrix **G** describing relationships among breeding values is positive definite and the eigenvalues of $\mathbf{G}^{-1}\mathbf{V}'\mathbf{P}^{-1}\mathbf{V}$ range between 0 and 1 (Foulley and Ollivier, 1986). The risk of incoherence is high when the true genetic correlations are close to -1 or +1.

In a selection experiment with Tribolium castaneum an unrestricted, optimum and proportional gains index of two traits were compared in their sensitivity to errors in the genetic correlations (Campo and Velasco, 1989). Underestimation of the genetic correlation affected the efficiency of the proportional gains index significantly more than the optimum or the restricted index.

A method to improve the efficiency of index selection has recently been proposed by Tai (1989). The noise associated with the estimates of the parameters is rounded off via a canonical variate analysis on the phenotypic and genotypic variances of a group of traits. Based on a χ^2 test the first k significant eigenvalues are chosen for the improved index since the non-significant eigenvalue are expected to represent variability due to non-genetical factors. It is hypothesized that this procedure improves the precision of the index and that this outweighs the loss in genetic gain due to a small proportion of lost genetic variability.

The genetic progress in the genetic index g defined as the linear combination of the genetic component of each phenotype weighted by the respective index coefficients b_i achieved by one round of selection on the index I is:

$$\Delta g = \frac{\sigma_g^2}{\sigma_I^2} D_1 \, \sigma_I = \frac{b'GB}{b'Pb} D_1 \, \sigma_I = h_I^2 \, D_1 \, \sigma_I$$

where g is the genetic index and D_1 is the selection intensity of the index or the selection differential for the population with variance equal to 1 (Lin and Allaire, 1977). This represents the genetic progress in the selection criterion.

2.3.2. Errors in economic values

Economic values should be estimated as precisely as possible. However, the efficiency of the index does not suffer much from relatively large errors in the economic values (Rönningen, 1971; Fowler et al., 1976; Vandepitte and Hazel, 1977). The efficiency of the index was reduced by less than 2% with errors in the economic value in the order of ± 50% (Fowler et al., 1976). A comparison of a two-trait index with economic values ranging from 5:1 to 75:1 resulted in different expected genetic response for the component traits but did not change the genetic response of the aggregate genotype and its economic value much (Allan et al., 1985). However, Smith (1983) cautioned that large losses in efficiency can occur if important traits are omitted or unimportant traits receive a high economic value or when the direction of selection is reversed for an important trait. He points out that the selection objective should be well defined so as to consider all important traits affecting economic production.

2.4. The current breeding objective for New Zealand dairy cattle

2.4.1. Selection objective

The objective for most dairy farmers is to maximise net income from their enterprise. This could be most easily achieved by increasing the prices received for the output. However, the single dairy farmer is a pricetaker and the influence over prices received is limited even for the industry as a single seller. About 90% of dairy products manufactured in New Zealand are exported but New Zealand's international dairy market represents less than 5% of total world dairy production. Import prohibition or protection is applied in most markets of developed countries. This is essentially supported by the manufacturing industries in these countries thereby creating considerable price differentials for dairy products between various domestic markets. The international market for dairy products consequently has developed into a dumping ground for excess production resulting in a very competitive pricing structure, forcing traders to often sell dairy products at or below production cost. This scenario forces New Zealand dairy producers firstly to produce milk at a very low absolute cost level, utilizing the advantages of a favourable climate most effectively, and secondly to anticipate long-term world trends in consumption and use of dairy products. However, predicting longterm trends is difficult. The lack of stability in the international dairy market also creates wide fluctuations in the prices received for dairy products and thus raw milk.

This economic situation stimulates an awareness for a clearly defined and periodically re-evaluated selection objective in both the farming community as well as the dairy industry. Livestock Improvement Corporation Limited (1990) operates according to the following selection objective set out in its strategic plan:

"The statement of purpose for the genetic evaluation of dairy animals in New Zealand is to continually

identify the best dairy animals in terms of their ability to improve New Zealand dairy farmers' net income."

This selection objective requires that animals are evaluated according to their potential for increasing the outcome of a function of several variables combining economic and genetic considerations. Economic theory shows that under these constraints profit functions exist for an enterprise given a priori assumptions. The profit function (P) defined as the difference between output or revenue (R) and input or costs (C)

$$P = R - C$$

can be maximised by either increasing quantity or value per unit of output R or by decreasing quantity or value per unit of input (I). Both strategies require that genetic and economic parameters are combined to rank dairy cattle according to their expected economic merit.

Dairy farms have an extraordinary dependance on one product and are almost single purpose enterprises with 85% of their revenue achieved from milk sales. The biggest expense items are overheads (which includes interest on debts) while feed comprises about 50% of the non-overhead expenses. This clearly shows the need for an efficient feeding policy.

New Zealand dairy farmers are effectively shareholders in their own manufacturing company and marketing and trading company. Therefore the returns for their product are a mixture of raw material value and a share of the marketing profit. Consequently, the selection objective needs to be interpreted on a national level and should be based on manufacturing costs and efficiencies as well as profits and losses from marketing. While a large part of the dairy farmer's objective to maximise net income can be achieved by optimising manufacturing and trading practices, quality and quantity of the raw product (milk) as well as some of the farm production and manufacturing costs can be influenced by genetic improvement of the dairy cows.

2.4.2. Current selection criteria

To realize a selection objective selection criteria need to be objectively and rationally chosen according to which animals are evaluated and selected. The selection criteria currently used for New Zealand Holstein-Friesians, Jerseys, Ayrshires and Milking Shorthorns are detailed in several publications (Ahlborn-Breier, 1988a and 1988b; Ahlborn-Breier and Wickham, 1990a; Ahlborn-Breier et al., 1990). The latter two publications include a list of all selection criteria and their economic values and are presented in the appendix for ease of reference. For this reason only a brief background on the genetic paraemeters and economic values used for the current twenty selection criteria for New Zealand dairy cattle for which breeding values are currently calculated will be given here.

a) Production traits

Protein and milkfat production are the most important measures of profitability for the New Zealand dairy farmer. Heritability estimates for milk, milkfat and protein yield average .26, .29 and .20, respectively, with high and positive genetic correlations between these traits (Lin et al., 1985; Lin et al., 1987; Norman et al., 1988). Economic values are currently 1 kg protein : 0.65 kg milkfat : - 0.01 l milk (Livestock Improvement Corporation Limited, 1989).

b) Adaptability to milking

The seasonal milk production system results in all cows in a herd calving and starting to lactate over a short time period. This requires heifers which can easily adapt to the milking routine to avoid compounding the stress experienced by the farmer during this time of the year.

Heritability estimates for adaptability were not available when the decision about this selection criterion was made. However, heritability is expected to be similar to the heritability for temperament in the order of .10 - .15. Although genetic correlations between adaptability and other traits have not been estimated, a high phenotypic correlation between shed behaviour, a closely related trait, and temperament exists (Ahlborn-Breier, unpublished). The economic value for the closely related trait shed behaviour is very small (Ahlborn-Breier and Wickham, 1985) and it is expected that adaptability to milking might have a slightly higher economic value due to its more accurate definition.

c) Shed temperament

Temperament has been shown to affect the milking routine. A continuous flow of cows through the milking parlour is required to ensure a smooth milking operation particularly in large herds. Nervous cows disturb the milking routine and represent a potential source of danger to the farmer. Concern about shed temperament increases with increasing herdsize.

Heritability estimates for temperament range between 0.11 and 0.18 (Wickham, 1979; Jensen, 1983; Lawstuen et al., 1988; Foster et al., 1988) for first lactation cows. These estimates are likely to be deflated values as they are calculated from multinomial scores. A high genetic correlation between first and second lactation of 0.76 (Jensen, 1983) indicates a strong correlated response between lactations. Therefore it is feasible to restrict measurement of this trait to the first lactation avoiding an extended generation interval.

The genetic correlation between temperament and production is moderately high (0.39 with milk yield, Mäntysaari et al., 1983; -0.15 with milkfat yield and reversed coding, Wickham, 1979). This implies that selection for higher milk or milkfat yield indirectly improves the temperament of cows in the next generation. Genetic correlations between temperament and most other traits are small and close to zero except for traits related to milking (i.e. milk let down, putting cups on, cups staying on, milking speed) which are in the order of

0.20 to 0.38 (Wickham, 1979). A small positive (favourable) correlation between temperament and mastitis incidence is reported by Lindstrom and Syväjärvi (1978) indicating correlated responses for a reduced incidence of mastitis with selection for temperament. Farmer's overall opinion of the heifer is strongly influenced by its temperament (Ahlborn-Breier and Wickham, 1985). Temperament is also phenotypically correlated, albeit to a lesser extent, with shed behaviour, ease of putting cups on and cups staying on. The economic value of temperament is high under New Zealand production conditions (Wickham, 1979). In contrast, in Scandinavian countries temperament has the lowest economic values of all traits considered (Mäntysaari et al., 1983; Christensen, 1984). The economic value of temperament in Finland has been estimated as $ 0.44 per standard deviation or 0.15 kg milkfat (Mäntysaari et al., 1983).

d) **Milking** Speed

Harvesting milk is probably the most important task on every dairy farm. Milking speed of the individual cow influences the time spent on harvesting milk and gains importance as yield per cow and/or the number of cows per herd increase. Although milk yield per cow is low in pasture based production systems, milking speed is of economic consideration in New Zealand because of the large average herd size of presently 157 cows (Livestock Improvement Corporation Limited, 1990). Slow milkers can disrupt and prolong the milking routine especially in milking parlors which handle large groups of cows at a time which are common in New Zealand.

Milking speed is moderately heritable with heritability estimates in the order of 0.25 for two-minute yield (Sharaby, 1977; Moore, 1980; Williams, 1980; Schneeberger and Hagger, 1985) and ranging between 0.11 and 0.20 for total milking time (Moore, 1980; Williams, 1980; McClelland et al., 1983; Lawstuen et al., 1988). Thus, milking speed can be increased efficiently through genetic improvement. Genetic correlations between milking speed and milkfat production range from -0.18 to 0.31 for total milking time (Moore, 1980; Williams, 1980) and from -0.23 to 0.22 for two-minute yield (Sharaby, 1977; Moore, 1980; Williams, 1980). A genetic correlation between milking speed and temperament of 0.36 has been estimated (Lawstuen et al., 1988).

Milking speed is considered to be an important trait (McClelland, 1983; Schneeberger and Hagger, 1985). Commercial dairy farmers in New Zealand allocated a relatively high economic value to milking speed (Ahlborn-Breier and Wickham, 1985).

e) Overall opinion

The owner's overall opinion of a heifer is expected to indicate the heifer's suitability for the dairy enterprise. Besides milk production, management and conformation traits, the suitability might include any other trait of importance to the dairy farmer. Thus, this trait might serve as an indicator of the comprehensiveness of the evaluation system used.

Genetic parameters for overall opinion were not known, however, the heritability is expected to be low to moderate. By definition, overall opinion is expected to be at least phenotypically highly correlated with a number of, most likely important, traits like production traits.

f) Liveweight

Liveweight can be used to allow more accurate estimates of feed intake. Implementing this information might lead to a higher production efficiency per cow and/or per farm.

Liveweight in dairy cattle has a moderate heritability with estimates ranging from 0.20 to 0.44 (McDaniel and Legates, 1965; Lin et al., 1985; Meyer et al., 1985; Colleau et al., 1989). Genetic correlations between liveweight and milk production are moderate to strong and positive (McDaniel and Legates, 1965, Norman and Van Vleck, 1972; Lin et al., 1985). Phenotypic correlations between liveweight and milk production vary widely but are generally positive (Norman and Van Vleck, 1972; Lin et al.,1985; Sieber et al., 1988; Foster et al., 1988).

Dempfle (1986) estimated the economic value for liveweight using a profit function and found a negative economic value of \$ -0.23/kg liveweight for Holstein-Friesians and \$ -0.31/kg liveweight for Jerseys.

g) Stature

Stature measures the skeletal frame and hence is easier to assess and distinguish than liveweight resulting in higher repeatabilities of evaluations by trained evaluators (Ahlborn and Dempfle, 1990).

Heritability estimates are slightly higher than for liveweight ranging from 0.27 to 0.44 when subjectively scored (Schaeffer, 1983; Meyer et al., 1985; Lin et al., 1987; Norman et al., 1988; Colleau et al., 1989). Genetic correlations between stature and milk and milkfat yield are close to zero (Foster et al., 1988; Norman et al., 1988).

h) Capacity

Capacity is difficult to define accurately and presumably represents an unconsciously constructed index of body depth, stature, chest and rump width, rump and diagonal body length and body volume.

Heritability estimates for capacity range from 0.23 to 0.35 (Schaeffer, 1983; Meyer et al., 1985; Sorensen and Kennedy, 1985). Schwark and Fahr (1989) report a heritability of 0.27 for a height and width index, .36 for a rump volume index and .34 for a body volume index. Strong positive genetic correlations exist between capacity and most measures of body size, general appearance and udder conformation (Meyer et al., 1985). Since capacity does not affect farm profitability directly it is very difficult to arrive at estimates for its economic value. Due to the lack of any objective data the economic value for capacity is set to be zero.

i) Leg conformation

The heritability of leg conformation is low. Numerous published estimates average at about 0.12 with a slightly higher value of 0.15 for measures based on linear scoring. The genetic correlation between leg conformation and production is small but positive (Blanchard et al., 1983; Petersen et al., 1986). This indicates that leg conformation would not deteriorate with selection for higher milkfat even if leg conformation would not be included as a selection criterion. Blanchard et al. (1983) reported a small positive correlation with stayability.

The economic value of leg conformation is very low for commercial dairy producers (Ahlborn-Breier and Wickham, 1986).

j) Rump width and rump angle

Heritabilities estimates for different traits of rump conformation vary between zero and 0.25 (Norman et al., 1983; Schaeffer et al., 1985; Smith et al., 1985; Thomas et al., 1985). Rump width and rump angle are the traits with the consistently highest heritabilities of around 0.20 across datasets and authors. Heritability estimates increase with age of cow (Thompson et al., 1980; Smith et al., 1985). Genetic correlations between rump conformation and production are small but not antagonistic (Van Vleck et al., 1980; Blanchard et al., 1983). A small favourable genetic correlation between rump conformation and calving ease of 0.28 was reported by Dadati et al. (1985). High genetic correlations between rump conformation and final score, general appearance and stature ranging from 0.60 to 0.85 (Van Vleck et al., 1980; Blanchard et al., 1983; Norman et al., 1983; Schaeffer et al., 1983) show that a large proportion of the general appearance is determined by rump conformation. Genetic correlations of rump conformation with fore udder, rear udder, feet and legs are moderate (0.20 - 0.55) and favourable (Thompson et al., 1981; Blanchard et al., 1983; Norman et al., 1983). Rump width is genetically moderately

correlated with the width of the rear udder (Thompson et al., 1981; Norman et al., 1983; Schaeffer et al., 1985).
The economic value of rump conformation is very low for commercial dairy produceers (Ahlborn-Breier and Wickham, 1986) but is seen as being fairly high by pedigree breeders.

k) Udder support

Udder support, also called udder cleft, segmentation or suspensory ligament, is moderately heritable with heritabilities ranging from 0.09 to 0.20 for subjective scores depending on the method of estimation (Schaeffer et al., 1985; Smith et al., 1985; Thomas et al., 1985; Magid et al., 1986; Meyer et al., 1987; Colleau et al., 1989; Monardes et al., 1990). Genetic correlations of udder support with milk and milkfat yield are small with estimates of 0.11 and 0.14 (Blanchard et al., 1983). Udder support has a moderately high genetic correlation with dairyness (0.41), fore udder attachment (0.31), rear udder height (0.31) and rear udder width (0.47) (Thompson et al., 1981; Norman et al., 1983; Schaeffer et al., 1985). A high favourable genetic correlation (0.75 - 0.92) exists between udder support and teat placement (Thompson et al., 1981; Schaeffer et al., 1985; Meyer et al., 1985; Colleau et al., 1989).
The economic value for udder support has been reported as high (Ahlborn-Breier and Wickham, 1986) under New Zealand conditions.

e) Fore udder

Heritability estimates for fore udder are small ranging from 0.11 to 0.24 (Blanchard et al., 1985; Meyer et al., 1985; Schaeffer et al., 1985; Smith et al., 1985; Foster et al., 1988; Klei et al., 1988; Monardes et al., 1990). Genetic correlations between fore udder and milk and milk fat yield are close to zero (Blanchard et al., 1983; Klei et al., 1988). High positive genetic correlations (> 0.53) exist between the conformation of the fore udder and final score or style, rear udder width, rear udder height, rear udder attachment, fore udder attachment, median suspensory ligament, teat placement and milk out (Blanchard et al., 1983; Norman et al., 1983; Schaeffer et al., 1985; Smith et al., 1985; Foster et al., 1988). Fore udder attachment is favourably genetically correlated with udder depth (Schaeffer et al., 1985).

Fore udder has a low economic value (Ahlborn-Breier and Wickham, 1986).

m) Rear udder

The heritability for rear udder is low with a range from 0.14 to 0.29 (Van Vleck et al., 1981; Blanchard et al., 1983; Hay et al., 1983; Dadati et al., 1985; Meyer et al., 1985; Schaeffer et al., 1985; Monardes et al., 1990). The genetic correlation between the conformation and production traits is close to zero or slightly antagonistic for milk yield and milkfat yield (Blanchard et al., 1983; Foster et al., 1988). High positive genetic correlations exist between rear udder and final score, general appearance, back, rump and tail, legs, fore udder, fore udder attachment, rear udder attachment, suspensory ligament and front and rear teat placement (Thompson et al., 1980; Van Vleck et al., 1981; Blanchard et al., 1983; Schaeffer et al., 1983; Meyer et al., 1985; Meyer et al., 1987; Klei et al., 1988).

The economic value of the conformation trait rear udder is low (Ahlborn-Breier and Wickham, 1986).

n) Front and rear teat placement

In most studies angle and placement of teats were scored as teat placement as both traits are highly related. This approach will be adopted here. Teat placement is moderately to highly heritable. Petersen et al. (1985) measuring the distance between the four teats reported estimates for all four teats of > 0.51 before and > 0.43 after milking. Heritability estimates for subjective scores for teat placement range from 0.12 to 0.32 (Schaeffer, 1985; Smith et al., 1985; Thomas et al., 1985; Colleau et al., 1989).

Estimates for front teat placement are about 40% higher than estimates for rear teat placement (Meyer et al., 1985; Monardes et al., 1990). Genetic correlations between production traits and teat placements are close to zero (Foster et al., 1988). Smith et al. (1985) published a genetic correlation of 0.73 between teat placement and edema. Placements of front and rear teats are genetically highly correlated (Petersen et al., 1985; Schaeffer et al., 1985; Smith et al., 1985; Meyer et al., 1985). High genetic correlations are also encountered with other udder traits e.g. rear udder width (Schaeffer et al., 1985; Smith et al., 1985; Klei et al., 1988), fore and rear udder attachment and udder support (Schaeffer, 1983; Schaeffer et al., 1985; Meyer et al., 1985; Klei et al., 1988).

A high economic value is placed on teat placement by farmers presumably because it directly interferes with milking (Ahlborn-Breier and Wickham, 1986).

o) Udder overall

Heritability estimates for udder overall vary from .12 to .33 (Schaeffer, 1983; Meyer et al., 1985; Sorensen and Kennedy, 1985; Colleau et al., 1989; Monardes et al., 1990). High positve genetic correlations between udder overall and most udder traits have been observed (Meyer et al., 1985; Colleau et al., 1989).

The economic value for udder overall is high because of its direct influence on the milking routine.

p) Dairy conformation

Dairy conformation is frequently broken down into the traits dairy character, dairyness or general appearance. All of these traits have moderately high heritabilities ranging from 0.15 to 0.42 (Blanchard et al., 1983; Schaefer, 1983; Mao, 1984, cited in Dohy, 1984; Dadati et al., 1985; Meyer et al., 1985; Schaeffer et al., 1985; Thomas et al., 1985; Foster et al., 1988; Klei et al., 1988). Dairy conformation improves with selection for milk and milkfat yield due to a strong positive genetic correlation (Petersen et al., 1986; Foster et al., 1988). Moderate to high genetic correlations exist between dairy conformation and most other conformation traits (Meyer et al., 1985; Schaeffer et al., 1985; Foster et al., 1988) with the highest correlations for traits describing udder conformation. The genetic correlation between dairy conformation and calving ease is moderate but unfavourable (-0.33; Dadati et al., 1985).

Dairy conformation has a high economic value in New Zealand (Ahlborn-Breier and Wickham, 1986). In the U.S.A. the retrospectively estimated relative emphasis on milk yield and final score of surviving cows was 5:1 and 7:1 for sale price of registered Holsteins (Ruff et al., 1983) and 4:1 for profit per day of life for Jerseys (Norman et al., 1981).

3. A BIOECONOMIC MODEL

3.1. Introduction

The quantitative definition of the selection objective describing the aggregate genotype is fundamental to genetic advances and thus improvement of economic performance within a production system and to the success of a breeding programme. This quantification requires the estimation of relative economic values for the traits affecting the profit of the production system and the determination of those biological and economical components which offer the greatest opportunities for genetic improvement leading to increased efficiency of production.

The need for a quantitative definition of the aggregate genotype and the subsequent formulation of selection indices has led to approaches which combine genetic as well as economic aspects of changes in the mean of a trait. A recently developed approach has been termed the bioeconomic model. These models are based on a production unit in which changes in certain traits are being simulated by linear or dynamic programming techniques to evaluate their effects on input and output variables of the production unit. This method was used by Harris et al. (1984) and Newman et al. (1985a; 1985b; 1987) for the evaluation of breeds and strain crosses. The importance of different components of a pork production system on their economic and biological efficiency was estimated by Tess et al. (1983a; 1983b; 1983c) by simulating genetic changes in the life cycle. A preliminary bioeconomic model for dairy cattle in New Zealand was proposed by Dempfle (1986). The procedure of using bioeconomic models to estimate economic values for traits was generalized by Ponzoni and Newman (1989).

3.2. A bioeconomic model for a pasture based milk production system

The objective of this study was the estimation of relative economic values of milk production and non-production traits for a solely pasture based milk production system with unlimited output in a competitive marketing system. A bioeconomic computer model of the animal's life cycle in a dairy production unit simulating the effects of changes in genetic, biological and economic parameters on various components of farm income was constructed. As experiments testing all these parameters simultaneously and with a proper experimental design do not exist the necessity arose to integrate experimental results and statistical data from the areas of nutrition, physiology, genetics and economics during the development of the model. This integration allowed to answer questions beyond the scope of animal experimentation in each of these separate disciplines.

The model accounts for the biological and economic input and output variables in a dairy cattle pasture production system producing under world market conditions for milk solids and is based on the model described by Dempfle (1986) and Munoz-Luna, Yadav and Dempfle (1988). Relative economic values for milk production and liveweight were estimated from the bioeconomic model and the relative economic values for secondary traits were estimated from their effects on survival rates and thus profitability of the enterprise.

The approach used in constructing the model was to account as accurately as possible for biological and economic inputs and outputs in order to sustain a predetermined genetic level of performance. One of the crucial assumptions made was that feed is one of the main limiting factors, as 95% of dairy farmers in New Zealand exclusively use pasture as feed, and thus the production of milk solids is restricted by dry matter production of the farmed area. This is in contrast to dairy production systems in most other developed countries and also most production systems using non-ruminant domestic species where either the number of animals or labour are the main limiting factors. For example, unlimited feed supply was assumed in the model developed by Tess et al. (1983a) for pigs.

This model used energy requirements to generate production output information, since the amount of available metabolisable energy (ME) was a constrained input variable. In contrast, protein is seldom a limiting factor for milk production from ryegrass-clover pasture (Wallace, 1961; Geenty and Rattray, 1987; Holmes et al., 1987). It was assumed that the supply of protein, vitamins and minerals is adequate. To calculate the utilization of available ME through harvesting by the animals, physical factors of rumen degradation and digestability and metabolic conversion efficiencies were taken into account.

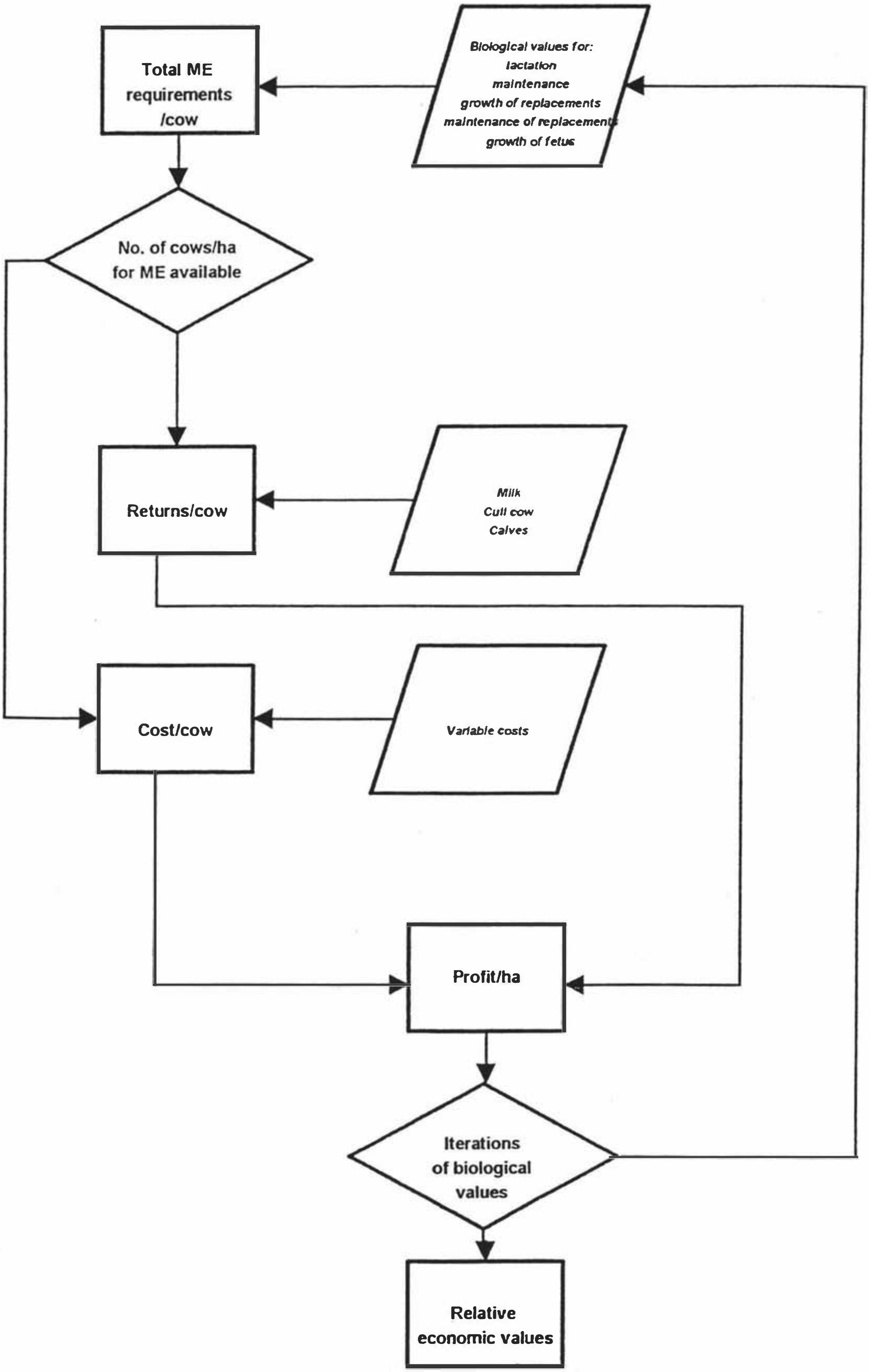
The bioeconomic model developed was then used to estimate relative economic values for the traits protein, milkfat and lactose yield, milk volume, body weight, replacement rate and indirectly management and type traits. A flowchart of the bioeconomic model is shown in Figure 3.1.

3.3. Baseline parameters and variables

Baseline levels of performance were chosen to represent a seasonal supply dairy farm with average pasture production where replacements are reared on the farm. The objective was to maximise net income under unrestricted output and constant price conditions. The effect of an increase in total milk production on a national scale on the price structure for milk components was considered by simulating over a range of prices paid for milk components.

Parameters and relationships used within the model were estimated from available industry data and from experimental results obtained from scientific literature. When required functions were not directly obtainable, they were either derived from related data or assumptions were made that were biologically reasonable and compatible with results from

Fig. 3.1.: Flowchart of bioeconomic model



related systems.

To evaluate genetic differences unconfounded by other effects, herds of different genetic performance levels were compared in an equilibrium state. This was achieved by accounting for all inputs and outputs required for a set of cows of a given genetic merit, their replacements and calves born that could be supported by a fixed level of metabolisable energy available. A profit function was defined which related inputs and outputs as the difference between revenues and costs.

The biological variables used in the model and their derivations as well as base levels and standard deviations are detailed in the following.

3.3.1. Dairy farm production system parameters

Data from the New Zealand dairy industry cow census 1989/90 were analysed to evaluate point and dispersion parameters to be used as base parameters for New Zealand dairy farms (Table 3.1.). These estimates were based on information received

Table 3.1.: Dairy farm production system parameters employed in the bioeconomic model ($\hat{\mu}$ = mean, $\hat{\sigma}$ = standard deviation).

	Owner-Operator n = 8,688		Sharemilker n = 1,597	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
Effective area (ha)	67.5	31.9	78.4	33.7
Herdsize (no. cows)	163.7	77.1	192.4	71.4
No. cows/effective area	2.5	0.6	2.6	0.6
Milkfat/cow (kg)	145.1	23.9	146.5	21.3
Milkfat/herd (kg)	23,708.9	11,472.5	28,093.9	10,819.5
Milkfat/ha (kg/ha)	363.4	106.9	378.1	68.5

from 10,285 seasonal supply farms representing 77% of all 13,357 (Livestock Improvement, 1990a) dairy farms in New Zealand. Of these farms 84% were owner-operated. Dairy farms with a sharemilking contract had slightly different production system parameters and these are also shown in Table 3.1. As sharemilkers operate only a small percentage of dairy farms and only for a limited time period the parameters for owner-operators were used in the model.

3.3.2. Metabolisable energy available

The metabolisable energy (ME) available is the limiting factor in a dairy production system restricted to pasture. The annual amount of ME per ha, produced in the form of pasture dry matter (DM), can vary quite markedly depending on soil and climatic conditions and varies considerably between years. In addition, the measurement of dry matter grown has a relatively large standard error. Annual production of dry matter for different sites throughout New Zealand varies between 10,853 kg/ha and 18,483 kg/ha with an average of 13,443 kg/ha and a standard deviation of 2080 kg/ha (Holmes and Macmillan, 1982; Bartlett, 1984). A figure of 13,500 kg DM/ha was chosen as a baseline.

3.3.3. Utilization/requirements of metabolisable energy

The utilization of metabolisable energy (ME) or dry matter grown depends on the percentage of energy harvested by the animal, the digestability of the dry matter and the partial utilisation efficiencies for maintenance, prenatal and postnatal growth and the milk components milkfat, protein and lactose. Additionally, the extent of catabolic and anabolic processes influences the utilization of energy.

Pastoral systems for milk production are essentially dependent upon the utilisation of pasture in situ. The utilisation of pasture is one of the most variable factors in

pasture based dairying and is directly influenced by management decisions such as stocking rate, grazing frequency and grazing intensity. Utilisation of pasture is strongly effected by stocking rate (Holmes and Macmillan, 1982) and ranges from 50% on farms with low per ha production to 80% and 90% on efficient and highly stocked farms (Holmes et al., 1987). This bioeconomic model was based on the assumption that feed supply is limited and a pasture utilisation of 80% representing efficient, highly stocked farms, utilising the majority of the ME grown, was used as a baseline.
The apparent digestability of energy in pasture varies seasonally with a maximum of 80% in spring and a minimum of 60% in late summer (Bryant and Trigg, 1982). Accordingly the energy content of a kg of dry matter (DM) of grazed pasture herbage ranges between 9.8 and 11.8 MJ ME/kg DM (Bryant and Trigg, 1982). From these published results a mean of 10.93 MJ ME/kg DM with a standard deviation of .83 MJ ME/kg DM was calculated and chosen as a baseline. Seasonality is the main factor influencing organic matter digestability, and thus ME content. Experimental results have shown that the effect of changes in variables such as stocking rate, irrigation etc. on ME content is mininmal (Bryant, 1981). Therefore a standard deviation of .83 MJ ME/kg DM is expected to cover a wide range of situations of milk production from pasture.

A change in any of these variables represents an increase or decrease in ME available for the production of biological components. It is important to note that the utilisation of pasture has by far the highest influence on the amount of ME available and shows the largest variation. Second is the amount of dry matter grown annually. Digestability has the smallest effect. However, data on pasture utilisation (Bryant and Holmes, 1985) and digestability are limited and restricted to experimental conditions and so the influence of these two variables under practical conditions may be underestimated. Combining the estimated variation of these variables an average of 118,000 MJ ME/ha are available for the production of biological components varying between 57,000 MJ ME/ha in the worst case and 168,000 MJ ME/ha in the optimal case. Using the average as a baseline in combination with the average farm size of 68 ha then 8,024,000 MJ ME are available per farm per year and calculations with the bioeconomic model were based on this figure.

3.3.3. a) Maintenance

The ME for maintenance is defined as the ME oxidised to provide energy to support essential body functions like maintaining a dynamic equilibrium of fat and protein turnover, a constant body temperature and a normal level of locomotor activity (Chwalibog, 1991a). This energy is dissipated as heat when the animal is in energy equilibrium and describes the dietary ME used to replace body tissue lost through catabolism in animals fed at zero energy gain. ME required for maintenance depends on the animal's body weight, age, diet and its activity (Geenty and Rattray, 1987; National Research Council, 1988). Cows of similar size and breed may vary in their maintenance requirements due to differences in efficiency, even under controlled activity conditions by as much as 8 to 10 percent (Van Es, 1961, cited by National Research Council, 1988).

Metabolism at fasting is more closely related to a fractional power of an animals liveweight than the absolute liveweight since the ME requirement is related to surface area rather than to bodyweight per se. The general convention of expressing ME requirements per kg liveweight to the power of 0.75 (Chwalibog, 1991a) is used here to account for this. However, there are some indications that the exponent of liveweight might be closer to 1 during growth and production (Geenty and Rattray, 1987).

The efficiency of utilisation of feed ME increases and, consequently, the amount of ME for maintenance decreases with increasing digestability of the feed (Blaxter, 1962). For feeds with an average gross energy content of 18.4 MJ ME/kg

DM the k_{maint} of 0.52 MJ ME/kg DM was suggested (Standing Committee on Agriculture, Subcommittee on Ruminants, 1991). This value can also be applied for feeds with a ME content of around 10 MJ ME/kg DM which are reported for different pasture types (Geenty and Rattray, 1987) and ryegrass-clover pasture (Waghorn and Barry, 1987).

These values give a mean of 0.719 for maintenance efficiency (k_{maint}) ranging from 0.696 to 0.736 resulting in a standard deviation of 0.02 which is slightly lower than the values given by Agricultural Research Council (1980). Chwalibog (1991a) recently reported a value for k_{maint} of 0.68 estimated from 18 Jersey cows in early lactation.

For the activity of grazing an allowance of a 15% higher ME requirement was added to support the energy requirements for the additional muscular activity compared to the closed confinement conditions used during energy balance experiments. A value of 20 to 30% has been suggested by Holmes et al. (1987). The slightly lower allowance of 15% was chosen as the value cited by Holmes et al. (1987) appeared to be based on experimental data from sheep which have a higher grazing activity per kg of liveweight than dairy cows.

Temperature changes also lower efficiency in a pasture based dairy farming system like in New Zealand and these have been taken into account in the energetic efficiency for lactation.

Additionally, the physiological state of the animal has an effect on the efficiency of ME. Lactating cows have a 10% higher ME requirement than non-lactating cows to account for the increases in metabolic activity of tissues and organs (Holmes et al., 1987).

Summarising the above considerations and values for the efficiency of ME for maintenance a mean for k_{maint} of 0.625

ranging between 0.592 and 0.725 for lactating cows and a mean for k_{maint} of 0.539 ranging between 0.522 and 0.552 for non-lactating cows (assuming a 15% higher ME requirement for grazing activity and a 10% higher ME requirement for the physiological state of the cow) was used in the bioeconomic model. Assuming a lactation length of 260 days the cow's annual ME requirement for maintenance can then be derived as

$$\begin{aligned} \mathbf{ME_{maint}} &= (260 * 0.6250 * \text{liveweight}^{0.75}) \\ &\quad + (105 * 0.5390 * \text{liveweight}^{0.75}) \\ &= 365 * 0.6002 * \text{liveweight}^{0.75} \end{aligned}$$

The value of 0.6002 for k_{maint} has been used as a baseline in this study. The respectively derived range of k_{maint} was 0.572 to 0.675.

For replacements a maintenance efficiency (k_{maint}) of 0.65 was used which represents a 10% lower efficiency to account for temperature changes (Holmes et al., 1987) experienced in the New Zealand pasture based dairy farming system.

3.3.3. b) Lactation

In ruminants, the conversion of metabolisable energy into fat and protein in milk is considerably more efficient than synthesis of tissue fat and protein. The reasons for this are that primary synthesis of short chain fatty acids in milk is more efficient than synthesis of body fat, the highly efficient conversion of blood glucose to lactose and the higher efficiency of protein synthesis in the mammary gland when compared to protein deposition in non-lactating animals (Moe, Tyrell and Flatt, 1970). More than half the cost of milk synthesis is attributable to biosynthetic costs (Baldwin et al., 1987).

Variation in the net energy requirement of individual cows to produce one unit of milk or to maintain one unit of metabolic body weight is relatively small and the net energy efficiency for maintenance has a low heritability (Buttazoni and Mao, 1989). Also, variations in the physiological capacity to convert feed to milk or milk solids as a result of lesser or greater nitrogen and energy uptake or utilization of energy are small within breeds (Trigg and Parr, 1981; Davey et al., 1983) as well as between breeds (Bauman et al., 1985; Blake et al., 1986). Estimates for the energetic efficiency for lactation (k_{lact}) range from 0.52 to 0.72 (Agricultural Research Council, 1980; Moe et al., 1970; National Research Council, 1988) with a mean value of 0.62 for k_{lact} (Agricultural Research Council, 1980) and is to some extent dependent on the diet. For concentrate ratios Chwalibog (1991a) recently estimated an energy efficiency of 0.68 for Jersey cows which agrees well with a value of 0.705 derived from a mechanistic biochemical model based on biochemical, stoichiometric and tissue level data (Baldwin et al., 1987). For diets with a lower energy content, as encountered in pasture, slightly lower efficiencies are suggested.

An additional aspect to be considered with respect to the efficiency of utilisation of ME for lactation is the occurence of catabolic processes during periods of negative energy balance. A higher percentage of milk produced indirectly from body reserves rather than directly from the ME contained in feed will decrease the overall efficiency of utilization for lactation. During early lactation ME requirements for maintenance and lactation cannot be met due to the restrictions on dry matter intake placed by the physical limits of the digestive system and then a percentage of milk is produced through the catabolism of body reserves. This indirect use of feed ME which reduces the energy efficiency of milk production has been taken into account by allowing for: the amount of milk derived from catabolic processes using body reserves as estimated from the average lactation curve, the average grass growth curve for New Zealand climatic conditions and the maximum feed intake.

This showed that for a cow with average production 50% of the milk produced during the first and second month of lactation is derived from body reserves. For the utilization of stored body energy for lactation a mean value of 0.84 for k_{lact} (Agricultural Research Council, 1980; National Research Council, 1988) with a range from 0.81 to 0.90 was used. Production in the first and second month comprises 16% and 17% of the annual milk yield, respectively, and thus the overall efficiency of energy utilization for lactation is reduced by 3.2% resulting in a k_{lact} of 0.60. The magnitude of this reduction in energy utilization for lactation depends on the level of milk production and on liveweight. However, an average increase in production and a 100 kg difference in liveweight results in a decrease of the overall utilization efficiency of only 0.0038% which is a negligible difference compared to the overall variation investigated. Therefore the k_{lact} value of 0.60 has been used as the base level for the energy efficiency for milk production.

Recent simulations investigating interactions between forage degradation characteristics, rumen processes and liveweight showed that the maximum intake of metabolisable energy is proportional to $LW^{0.87}$ which is greater than the scaling of $LW^{0.75}$ used for maintenance (Illius and Gordon, 1991). The study was based on ruminant species ranging in liveweight from 3.7 kg to 1000 kg and showed that maximum intake can be predicted with surprising accuracy from generalised specifications of animal characteristics derived from allometric equations. It showed that large ruminants have a superior capacity for processing feeds relative to their maintenance requirements. The superiority of large ruminants is greater on feeds with residues of low digestability and slow cell wall digestion. While this study concludes that large ruminants can obtain a greater proportion of their energy requirements from abundant poor-quality feeds than small ruminants, the effect of the slightly larger scaling factor is small for the weight ranges considered here i.e.

300 kg - 500 kg. The slightly larger scaling factor converts into a lower amount of energy derived from catabolic processes and thus a slightly higher efficiency of ME utilisation for lactation for larger cows, especially on ryegrass-clover pasture with its lower digestibility. The difference in maximum intake between a 400 kg and a 500 kg cow with the larger scaling factor is about 2%. This converts to an increase of efficiency through the reduced percentage of ME derived from catabolic processes of only 0.26% and therefore this difference is ignored in the calculations of the bioeconomic model. These estimations assume the between species relationship to hold within a species. However, it was considered unlikely that the within breed variation would be larger than the between species variation and these estimations gave an indication of the extent of this factor.

The energy content of milk is determined by the three organic components: milkfat, protein and lactose with a zero contribution from the ash (Tyrell and Reid, 1965; Blaxter, 1962). Differences in published estimates for the energy content of milk components (Tyrell and Reid, 1965; Crovetto and Van der Honing, 1984; Chwalibog, 1991a; Sjaunja et al., 1991) are relatively small compared to differences arising from variations in energy efficiency (k_{lact}) estimates. Tyrell and Reid (1965) state that lactose has little significance with respect to the prediction of the energy content of a kg of milk. However, the energy contained in the different components of a cow's annual milk yield varies considerably between breeds of widely differing composition such as the Holstein-Friesians and Jerseys. This results in different annual energy requirements per cow and therefore the energy requirements for lactose were included in this study. A lactose percentage of 4.60% for Holstein-Friesian and 4.69% for Jerseys (Ahlborn and Bryant, 1992) with a standard deviation of 0.124% was used as a base level.

The recent study by Chwalibog (1991b) is the first study which estimates utilization of ME for milkfat, protein and carbohydrates and indicates different partial efficiencies of ME utilization for the different milk components. These were derived from metabolic studies using detailed feed intake measures and from the regression equations of ME requirements on the different components. To distinguish between energy from protein, milkfat and carbohydrates the relationship between energy deposition in milk, nitrogen, milkfat and carbohydrate content was estimated by means of a multiple regression analysis. The resulting equation showed a high degree of fit between data and the applied statistical model. Partial energy efficiencies of 0.54 for protein and carbohydrates when compared with an energy efficiency of 0.82 for milkfat indicate a much greater efficiency in the utilisation of ME for energy deposition in the form of milkfat compared to other milk solids. Table 3.2. below compares the ME requirements per kg milk (Chwalibog, 1991a) with a constant k_{lact} and the ME requirements per kg milk using these partial efficiencies for the different milk components (Chwalibog, 1991b). The different partial energy efficiencies result in a 18% higher ME requirement per kg of average Jersey milk (5.97 MJ ME/kg for milk with 5.6% milkfat, 4.1% protein and 4.7% lactose) compared to a kg of average Holstein-Friesian milk (5.10 MJ ME/kg for milk with 4.4% milkfat, 3.4% protein and 4.6% lactose). If the same ME efficiency for all components is assumed this difference is 20%. The prediction equation given by Tyrell and Reid (1965) of

$$\text{MJ ME/kg milk} = -\,0.108 + 0.223\%\,P + 0.384\%\,F + 0.199\%\,L$$

gave intermediate results and was therefore used in this model since it is not known which values are correct (P = protein, F = milkfat, L = lactose).

It should be noted that while the energy content per kg milk from an average Jersey cow is 18% higher than in Holstein-

Table 3.2.: Estimates for ME requirement for milk components (ME = metabolisable energy required for production of milk component, k_{lact} = coefficient of energy for lactation).

	Energy Content in milk MJ/kg	Constant k_{lact}		Partial efficiencies	
		k_{lact} /kg	MJ ME /kg	k_{lact}	MJ ME
Protein	2.38	0.68	3.500	0.54	4.407
Milkfat	3.89	0.68	5.721	0.82	4.764
Carbohydrates	1.63	0.68	2.397	0.54	3.019

Friesian milk and both breeds produce the same yield of milkfat (Ahlborn and Dempfle, 1992), the total annual milk energy output of a Jersey cow was only 10% lower than the total annual milk energy output of the average Holstein-Friesian cow. This is due to the lower lactose yield produced by Jersey cows.

3.3.3.c) Prenatal growth

A low efficiency of the metabolisable energy utilisation for the anabolism process during pregnancy and simultaneous energy requirements for body tissue has repeatedly been observed. The utilisation of metabolisable energy for the growth of the foetus (k_{preg}) varies little from 0.13. A number of studies report a mean energy efficiency for k_{preg} of 0.133 with estimates ranging from 0.120 to 0.142 (Agricultural Research Council, 1980). These figures were used as a baseline, resulting in between 7.04 and 8.33 joules per joule deposited in the form of the foetus per unit time with a mean of 7.5 joules. The efficiency of energy utilisation for the growth of foetus does not seem to change with stage of pregnancy (Holmes et al., 1987) or quality of diet (Standing

Committee on Agriculture, Ruminant Subcommittee, 1990).
The estimated energy content of the gravid uterus and a foetus of 40 kg is given by Agricultural Research Council (1980) as 288 MJ. These values are slightly higher than those given by Moe and Tyrell (1967). Assuming a mean energy efficiency (k_{preg}) of 0.1333 this gives a ME requirement of 54.14 MJ ME/kg liveweight of the calf at parturition. In this bioeconomic model the liveweight of the calf at parturition is expressed as a fraction of the cow's mature liveweight thus the ME requirements for prenatal growth can be predicted as follows:

$$\mathbf{ME_{preg}} = \mathbf{54.14\ MJ\ ME/kg * ratio\ of\ calf\ to\ mature\ liveweight * cow\ liveweight}$$

Expressing ME requirements for prenatal growth as a function of the mature liveweight of the cow allows variations in the cows' liveweight to be reflected.

3.3.3.d) Postnatal growth and weight gain

The efficiency of utilization of ME for postnatal growth and weight gain in ruminants (k_{gain}) is well below that observed in non-ruminants and varies from less than 0.2 to over 0.7 (Agricultural Research Council, 1980). Fat deposition is more efficient than protein deposition especially in ruminants (0.67 - 0.73 versus 0.10 - 0.35). Efficiency of utilization is negatively related to the metabolisability (metabolisable energy/gross energy) and fibre content of the diet (Black, 1990). However, even with feeds having similar metabolisability, values ranging from 0.33 to 0.51 for white clover and perennial ryegrass (Rattray and Joyce, 1974) have been estimated.
Values for k_{gain} range from 0.2 to 0.5 (Moe et al., 1970; Agricultural Research Council, 1980). A gain efficiency (k_{gain}) of 0.45 was used in the model to allow for the activity of grazing and to take account of temperature changes

experienced in the pasture based dairy system of New Zealand (Agricultural Research Council, 1980; Holmes et al., 1987; National Research Council, 1988; Standing Committee on Agriculture, Ruminant Subcommittee, 1990). Holmes et al. (1987) report a figure of 14 MJ energy contained in each kg of body tissue gain for heifers and this value was used as a baseline in the model.

ME requirements for gain were estimated as net energy/kg gain

$$\mathbf{ME_{gain} = 14\ MJ/kg\ body\ tissue\ gain * 0.45\ k_{gain} * kg\ gain}$$

where k_{gain} is the efficiency of utilisation of ME above maintenance for body tissue gain.

The mean age at first calving is 24 months with a standard deviation of 20 days (Ahlborn-Breier and Hohenboken, 1991; Ahlborn and Dempfle, 1992) and it was assumed that this point coincides with maturity of liveweight. Therefore the growth of replacements was calculated over a period of 730 days.

3.3.4. Biological animal variables

3.3.4.a) Milk production

Statistical parameters for milk volume, protein and milkfat yield were estimated from current industry data reported in a number of analyses (Ahlborn-Breier, 1989; Ahlborn-Breier and Hohenboken, 1991; Ahlborn and Dempfle, 1992; Ahlborn and Bryant, 1992). Unpublished estimates for the 1990/91 season which were used as a baseline are given in Table 3.3. These values were used to allow a realistic sensitivity analysis which represented the current state of the dairy industry.

Data for the concentration of lactose of 4.60% for Holstein-Friesian and 4.69% for Jersey with a standard deviation of 0.124% (Ahlborn and Bryant, 1992) were used as a baseline level.

Table 3.3.: Milk production statistics for 1990/91 season for Holstein-Friesians and Jerseys ($\hat{\mu}$ = mean, $\hat{\sigma}$ = standard deviation).

	Holstein-Friesian n = 496,090		Jersey n = 238,863	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
Lactation length(days)	221	38	225	35
Milk (kg)	3,466	961	2,672	670
Protein (kg)	120	34	110	28
Milkfat (kg)	155	43	154	41
Lactose (kg)	159	44	125	31
Protein %	3.47	0.29	4.12	0.31
Milkfat %	4.47	0.57	5.75	0.67
Lactose %	4.60	0.12	4.69	0.12

3.3.4.b) Liveweight

The baseline for liveweight was found by measuring the weight of 420 cows of various ages in three commercial herds (Ahlborn-Breier and Dempfle, 1990) and four experimental herds (Ahlborn and Bryant, 1992). The average liveweight used as baseline in the model was 440 kg for Holstein-Friesian and 360 kg for Jersey cows with standard deviations of 74 kg and 40 kg, respectively. For mixed age Holstein-Friesian*Jersey crossbred cows similar mean values have recently been published (Thomson et al., 1991). However, the phenotypic standard deviation for liveweight of two-year-old cows has been reported as 35 kg for Holstein-Friesians and 27 kg for Jerseys (Ahlborn and Dempfle, 1992). The smaller variation in this large dataset might have been due to the measurement being a subjective assessment of trained inspectors between 2 and 28 weeks after calving and the restriction of the dataset to two-year-old cows.

3.3.4.c) Replacement rate

An early survey of herds in the North Island reported an annual replacement rate of 19.2% (New Zealand Dairy Board, 1957). From a more recent study based on records from 384 herds with different breeds during the 1985/86 season (Harris, 1989b) a replacement rate of 20.96% was calculated. An analysis of 6,107 dairy herds showed a mean replacement rate of 22.7% with a standard deviation of 6.25% during the 1989/90 season (Ahlborn, unpublished). Replacement rates are significantly influenced by the prices received for cull cows and the cost of replacements in each year (Ahlborn-Breier and Wickham, 1986) which might explain the difference in the estimates. A replacement rate of 22% was used as a baseline for both breeds since detailed published breed specific estimates were unavailable.

3.3.4.d) Age distribution of herd

Differences in the age distribution of a herd have been recognized as a factor influencing efficiency estimates of farm production systems (Cartwright et al., 1975; Greer et al., 1980). Estimates of the age distribution and average age of culled cows are essential in economic analyses of farm production systems as the biological inputs and outputs depend on the age distribution of the cows in the system (Azzam et al., 1990a and 1990b; Kristensen, 1992). The age distribution of the herd directly influences the replacement rate. A reduced average herdlife means increasing the replacement rate and requires a higher number of young stock to be reared and leads to a smaller percentage of mature cows. Cow's milk production changes in a curvilinear fashion with age increasing until maturity and decreasing thereafter as shown in Table 3.4. These results for the 1990/91 season agree closely with published figures from the two preceeding seasons (Ahlborn-Breier, 1989; Livestock Improvement, 1990a). Due to age-related changes in milk production the realized milk production of the herd and its corresponding energy requirement depend on the age distribution and percentage of mature cows in the herd. Table 3.4. shows that the numerically largest age group in the herd, the two-year-olds, produced up to 22% less than mature cows. A change in average herdlife and thus replacement rate with its relatively larger effect on the number of two-year-olds therefore will change the total milk production of the herd. Table 3.4. also shows slight differences in milk production at different ages between breeds.

The amount of energy required for maintenance and rearing of young stock, one of the main input costs, changes with the age distribution of the herd due to a different number of young stock reared as replacements.

To account for these effects of different age distributions with different replacement rates an "age-production factor" (F) was included in the model. This age-production factor F represents the proportion of the expected realized production estimated from the age distribution resulting from a given average herdlife and replacement rate in comparison with the production achieved at the baseline level with 4.5 year herdlife and a 22% replacement rate. The age-production factor F was calculated for each breed from an analysis of production figures from the 1990/91 season shown in Table 3.4. The age-production factor was calculated as the product of the age distribution of the herd (3.3.4. da) and the proportional milk production of each group (3.3.4. db).

3.3.4.da) Estimation of age distribution in herd

The age distribution in the herd was estimated using survival rates for each age group from the 1990/91 season. These are shown for the Holstein-Friesian and Jersey breeds in Table 3.5. In a study estimating the heritability of survival rate Harris (1989a) published slightly different survival rates for an average across breeds. However, Table 3.5. indicates that relatively large differences exist between breeds. These could be caused by genetic differences or management

Table 3.4.: Statistical parameters for production per cow by age for Holstein-Friesians and Jerseys (1990/91 season, 100 % = yield of five-year old cows).

Age		2	3	4	5	6	7	8	9	10+
Holstein-Friesian (n = 469,090)										
	n	85,367	75,086	71,727	64,459	56,520	53,348	36,382	21,955	31,306
Milk kg	μ	2,866	3,247	3,570	3,672	3,754	3,763	3,754	3,646	3,473
	σ	750	844	903	950	971	970	978	969	976
	%	78.1	88.4	97.2	100	102.2	102.5	102.2	99.3	94.6
Protein kg	μ	97	111	124	128	131	132	131	128	121
	σ	25	29	31	33	28	28	34	31	34
	%	75.8	86.7	96.9	100	102.3	103.1	102.3	100	94.5
Milkfat kg	μ	127	145	160	164	167	167	165	161	151
	σ	34	38	41	43	41	44	45	44	44
	%	77.4	88.4	97.6	100	101.8	101.8	100.6	96.4	92.1
Protein %	μ	3.38	3.44	3.48	3.50	3.51	3.52	3.51	3.52	3.51
	σ	.26	.28	.29	.29	.31	.31	.29	.30	.30
	%	97	98	99	100	100	101	100	101	100
Milkfat %	μ	4.46	4.49	4.50	4.49	4.48	4.46	4.43	4.42	4.38
	σ	.52	.55	.57	.59	.68	.66	.60	.60	.60
	%	99.3	100.0	100.0	100.0	99.8	99.3	98.7	98.4	97.6
Jersey (n = 238,863)										
	n	36,757	34,119	32,113	31,924	28,909	25,233	19,378	12,520	17,910
Milk kg	μ	2,185	2,526	2,758	2,795	2,849	2,885	2,876	2,801	2,685
	σ	511	563	604	643	660	678	692	692	721
	%	78.2	90.4	98.7	100	101.9	103.2	102.9	100.2	96.1
Protein kg	μ	88	105	115	116	118	119	118	115	109
	σ	21	24	25	27	33	31	28	29	29
	%	75.9	90.5	99.1	100	101.7	102.6	101.7	99.1	94.0
Milkfat kg	μ	128	148	161	162	163	163	161	156	146
	σ	32	35	38	40	42	41	42	42	42
	%	79.0	91.4	99.4	100	100.6	100.6	99.4	96.3	90.1
Protein %	μ	4.02	4.14	4.16	4.16	4.16	4.14	4.13	4.12	4.08
	σ	.29	.30	.31	.30	.28	.29	.30	.31	.32
	%	96.6	99.5	100	100	100	99.5	99.3	.990	.981
Milkfat %	μ	5.87	5.87	5.84	5.79	5.73	5.65	5.61	5.57	5.46
	σ	.67	.63	.66	.69	.59	.53	.65	.65	.68
	%	101.4	101.4	100.9	100	99.0	97.6	96.9	96.2	94.3

strategies differing between Holstein-Friesian and Jersey farmers. For this reason age-production factors were calculated within breed. Survival rates shown in Table 3.5. appear consistent with on farm practice as a much larger percentage of 2 year old cows compared to older age groups is voluntarily culled (Shaw, pers. comm.). It was assumed that the herd was in equilibrium i.e. survival rates for each age group, overall replacement rate and herd size were constant over time and the herd was self-contained i.e. all replacements came from the herd and were not purchased. The age distribution was calculated using a discrete-time analogue of a special case of the McKendrick-von Foerster equation which can also be described by the Leslie matrix model (Constantino and Desharnais, 1991). In the context of systems analysis and modelling these have been termed Markov chains (Hillier and Lieberman, 1980; Cook and Russell, 1985) and have frequently been used to find optimal age distributions in animal production systems (Cartwright et

Table 3.5.: Proportion of cows in each age group for Holstein-Friesian and Jersey (1990/91 season).

	Holstein-Friesian			Jersey		
Age	n	%	Survival rate	n	%	Survival rate
2	85,307	17.2	0.880	36,757	15.4	0.928
3	75,086	15.1	0.955	34,119	14.3	0.941
4	71,727	14.5	0.899	32,113	13.4	0.994
5	64,459	13.0	0.877	31,924	13.4	0.906
6	56,520	11.4	0.944	28,909	12.1	0.873
7	53,348	10.8	0.944	25,233	10.6	0.768
8	36,382	7.3	0.603	19,378	8.1	0.646
9	21,955	4.4	0.713	12,520	5.2	0.715
10 +	31,306	6.3	0.356	17,910	7.5	0.358

al., 1975; Greer et al., 1980; Kristensen, 1987; Azzam et al., 1990a; Azzam and Azzam, 1991; Kristensen, 1992).

3.3.4.db) Estimation of age-production factor

The proportional milk production from each age group shown in Table 3.4. agreed well with reports for previous seasons (Ahlborn-Breier, 1989; Livestock Improvement, 1990a) and showed only small differences between breeds. The production level of 5-year old cows was used as a baseline since this age group was close to the average age resulting from the replacement rate of 22% used in the base model. Production averages at one point in time (1990/91 season) were estimated from a large dataset for each age group. As a consequence, the expression of differences in genetic merit between age groups was included in the averages. Thus, genetic gain expressed in younger cows, which on average were genetically superior, was reflected in the calculations.

Protein and milkfat percentages changed over and above the milk yield differences for different age groups but in opposite directions with increasing cow's age. Protein percentage generally increased with age while milkfat percentage decreased with age (Table 3.4.). An exception were two and three year old Holstein-Friesians which produced a lower milkfat percentage than their four year old counterparts. However, this difference in milk composition amounted to a difference of only $ 1/ha in returns from milk. This difference was well below the significance level for the calculations of the profit function. Consequently, only changes in milk yield were considered when calculating the proportional production.

The age-production factor F was calculated by combining the age distribution for each replacement rate as described in 3.3.4.d.a. and the proportional milk production for each age group as follows:

$$F_r = \frac{\sum_{2}^{i} ([(1 - r)(\sum_{2}^{i} \prod s_{2..n})^{-1}] \times \prod s_{2..n} \times P_a)}{\sum_{2}^{i} ([(1 - 0.22)(\sum_{2}^{i} \prod s_{2..n})^{-1}] \times \prod s_{2..n} \times P_a)}$$

where a = age group

i = number of groups of cows of same age (in this study ranging from 2 to 10+, thus i = 9)

r = replacement rate

s = survival rate for each age group

P = proportional production of milk yield for each age group

Thus, the age-production factor F was calculated by multiplying the age distribution vector with the proportional production vector for each age group and summing over all age groups. It was expressed as a proportion of the baseline, i.e. the replacement rate of 22% was set to 1. Age-production factors calculated are shown in Table 3.6. for Holstein-Friesian and Jersey for a range of replacement rates.

3.3.4.dc) Effect on energy requirements in milk

The calculation of energy requirements was also adjusted by multiplying with the age-production factor thus accounting for differences in the age distribution of herds. It might be expected that the changes in milk production would be balanced out by the changes in energy requirements, thus achieving the same net profit. However, the results showed that a change in energy requirements led to changes in stocking rate, as the area is the limiting production factor, and consequently culminated in changes in net profit per ha.

Table 3.6.: Age-production factors (F) for Holstein-Friesian and Jersey for different replacement rates.

Replacement rate (%)	Holstein-Friesian	Jersey
16	1.0768	1.0770
17	1.0639	1.0641
18	1.0510	1.0513
19	1.0388	1.0385
20	1.0259	1.0257
21	1.0130	1.0128
22	1.0000	1.0000
23	0.9872	0.9872
24	0.9743	0.9744
25	0.9615	0.9616
26	0.9486	0.9487
27	0.9357	0.9360
28	0.9228	0.9231

3.3.4.dd) Effect on revenue from cull cows

The age distribution of the herd also determines the age composition of the cows culled. Consequently, the average carcass weight of cull cows and thus revenue changes. The extent of the influence of differences in age distribution on the revenue from cull cow carcasses was evaluated assuming the same maturity curve for liveweight as for milk production. By including the effects of age distribution the 29% increase in cull cow revenue resulting from a 6% higher replacement rate was reduced to 26% for both Holstein-Friesian and Jersey breeds. With a 6% lower replacement rate the revenue from cull cows decreased by 30.5% when the age distribution was taken into account, which was slightly more than the 29% decrease without considering the age distribution. However, as the revenues from the meat of cull cows represent only 6% of the total revenues the effect of including the age-production factor on total revenues was relatively small and was therefore not included in the model.

In summary, accounting for the age distribution in the herd at different replacement rates increased net profit per ha at low replacement rates and decreased it at high replacement rates. Thus, the negative coefficient of replacement rate on net profit per ha (Figure 4.5.) became steeper. This was mainly caused by a lower revenue from milk per cow at higher replacement rates due to a larger number of younger cows producing below maturity level. While this was associated with lower energy requirements for lactation and maintenance leading to an increased stocking rate, the stocking rate increase did not offset the loss in revenue from milk, cull cows and increased variable costs. The change in net profit per ha for a unit increase in replacement rate doubled when the age distribution in the herd was included. Net profit per ha decreased by 6.7% for Friesian and 6.9% for Jersey for a change in replacement rate from 22% to 28%, whereas the decrease was only 3.3% for Friesian and 3.6% for Jersey if the age distribution was ignored. These results indicate that it was important to account for the age distribution when comparing the economic value of different replacement rates.

3.3.4.e) Survival rate of cows

Cow death at calving was reported as averaging 0.45% for Friesian cows ranging from 0 to 1.8% over four years (Everitt et al., 1978). Records from 384 herds with 66,663 lactating cows showed the percentage of death for cows ranging between 1.03% and 1.40% between age groups (Harris, 1989b) with a weighted mean of 1.21%. Since no published reports about a breed effect on survival rate of cows exists and only small breed differences would be expected the mean of 1.21% was used in the model for both breeds resulting in a survival rate of 98.7%.

3.3.4.f) Survival rates of calves (0 - 4 days)

Calf deaths within 48 hours of birth averaged 2.25% with a range from 1.3% to 3.1% for Friesian calves with small differences between years (Everitt et al., 1978). A study evaluating calf mortality between breeds found only small overall variation between breeds even though straightbred Friesians were compared with beef breeds. The overall calf mortality was 3.6% (Everitt et al., 1978). These mortality rates are lower than reports from overseas countries (Perez et al., 1990). Mortality rates dairy calves from birth to four days under New Zealand conditions were estimated by analysing records from 10,108 dairy herds representing 75.7% of all dairy herds in New Zealand during the 1989/90 season. These showed a mean mortality rate for dairy calves from birth to four days after birth of 3.6%. Consequently, a survival rate of 96.4% was used in the model for both breeds. A higher mortality rate is observed when calving is induced. This survival rate accounts for the effects of induction as the mortality rate was estimated from a large number of herds distributed throughout New Zealand.

3.3.4.g) Survival rates of replacements (4 days - 2 years)

Published estimates for survival rates of female replacement dairy cattle are lacking. Death rate for steers during this period was 3.8% (Everitt et al., 1980) and was used here as a baseline.

3.3.4.h) Dressing percentage

In New Zealand returns from slaughtered cows and calves (bobby calves) are based on carcass weight. The weight of carcass and thus the amount of saleable meat is determined by the dressing percentage and the liveweight. Dressing percentages and edible meat content are significantly affected by breed (Everitt et al., 1969; Kirton et al., 1972) and liveweight (McCall and Marshall, 1991). Dressing percentages differ significantly by about 4% between Friesian and Jersey (Everitt et al., 1969; Butler-Hogg and Wood, 1982). The lower dressing percentage of Jerseys compared to Friesians was shown to be more due to heavier internal organs rather than to gut fill in castrated male cattle at the age of 507 days (Butler-Hogg and Wood, 1982). Since the steers of both breeds were at the same stage of growth and had a similar body fat content the breed difference was not explained by the smaller size of the Jerseys. Everitt et al. (1969) also reported the dressing percentage of Jerseys to be 2% or more lower than for Friesians. Published estimates for the dressing percentage of New Zealand cows are lacking (Kirton, 1992; Hogg, 1992; Purchas, 1992; all pers. comm.). However, it may be assumed that the difference in dressing percentage is a physiological breed difference and would apply similarly in cows. For this reason the regression of liveweight on dressing percentage of Kirton (cited by McCall and Marshall, 1991) was modified to include this breed difference. The following equations were used in the model to estimate dressing percentages for each breed:

Friesian: $\hat{y}$ **(dressing %) = 0.41 + 0.000208 kg liveweight**
Jersey: $\hat{y}$ **(dressing %) = 0.39 + 0.000208 kg liveweight**

The expected dressing percentages for cows from the Friesian and Jersey population based on the first and second moments from the probability density function derived from liveweight data (Ahlborn-Breier and Dempfle, 1990; Ahlborn and Dempfle, 1992) are shown below (Table 3.7.). These dressing percentages are consistent with published results (Kirton et al., 1972; Everitt et al., 1980). However, industry statistics (New Zealand Meat and Wool Boards' Economic Survey, 1991a) show an average carcass weight of cull cows of 158 kg indicating that the dressing percentage might be lower than these published estimates. A determination of the statistical parameters for dressing percentage of cull cows is required to elucidate this difference.

Table 3.7.: Expected dressing percentages for Holstein-Friesian and Jersey cows.

	Liveweight (kg)		Dressing percentage (%)	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
Holstein-Friesian	440	74	50.15	1.54
Jersey	360	40	46.49	0.83

3.3.4.i) Ratio of calf weight at birth to mature cow liveweight

The weight of the calf at birth can be expressed in terms of the cow's liveweight. This enables differences in the weight of the calf resulting from differences in the size of the dam to be taken into account.

Data from experimental farms show an average weight of the calf at birth of 26 kg ± 3.0 kg for Jersey and 34 kg ± 5.8 kg for Friesian calves with respective cow weights of 350 kg ± 22 kg and 436 kg ± 46 kg (Bryant, 1992, pers. comm.). This gave ratios of 0.0743 for Jersey and 0.0780 for Friesian which were used in the model for the respective breeds. These data agree with published birth weights for Friesian calves ranging from 34.2 to 35.8 kg during four years of study (Everitt et al., 1978). While birth weight varies significantly between farms and between sires within breed (Everett et al., 1978) reliable estimates for this variation are scarce. However, the effects of this variation on changes in the bioeconomic model are small and are therefore not considered here.

3.3.5. Economic variables

The 1990/91 season was used as the base year for economic variables as this was the most recent season for which data for all the economic variables were available. However, during the 1990/91 season dairy farmers received unusually low prices for protein and milkfat (Figure 5.1. and Table 5.1.) which could have resulted in excessively conservative estimates of the importance of protein and milkfat. For this reason the milk price received during the 1991/92 season was used in the bioeconomic model as a baseline.

To gain an understanding of the possible variation encountered in the economic variables, prices and costs were compared over time, and time trends estimated.

3.3.5.a) Price for protein, milkfat, lactose and volume

The milk price received by dairy farmers in New Zealand was originally based on the quantity of milkfat only. At present returns depend on quality, quantity and composition of the milk. In New Zealand more than 90% of milk produced is used in manufacturing (New Zealand Dairy Board, 1991a). Thus, the most important factors in determining the milk price are the values of the major milk components, protein and milkfat, which are both used in manufacturing dairy products. A shift in emphasis from milkfat to protein by consumers is the cause of declining milkfat consumption in western countries (Rodenburg, 1990). This has resulted in lower returns for milkfat and relatively higher returns for protein and this trend is expected to continue. Accordingly, the New Zealand Dairy Board and dairy companies are structuring their pricing system with the objective to provide firstly equitable returns which reflect end product market returns to producers, and secondly economic signals to encourage appropriate change in raw milk composition.

Protein and milkfat are used in a broad range of dairy products and to a different extent in each product (Wiles, 1991). Product yield payout to dairy companies by the New

Zealand Dairy Board is now based on product mix and prices received for the end products. A standard cost model is used as a base (Larsen, 1985) and this payment system has resulted in less inequities for different dairy companies. With very few exceptions dairy companies pay for raw milk accounting for the two main milk components protein and milkfat, adjusting for differences in milk composition through a charge for the transport cost. A proportion of 1 to 0.5584 for protein to milkfat was used in this study resulting in the following payment system:

$$\textbf{Payout (\$/l milk)} = \textbf{5.2790 kg protein} + \textbf{2.9480 kg milkfat} - \textbf{0.0435 l milk}$$

The average of payouts from all dairy companies (Livestock Improvement, 1991; New Zealand Dairy Board, 1991b) received for the 1991/92 season was used as a New Zealand average in this study. Differences in payouts between dairy companies result from a number of factors such as current investment level, location and product mix. This means that differences in payouts between dairy companies (Lincoln University, 1991) are largely independent of the quantity or quality of the milk supplied by farmers.

3.3.5.b) Price for carcass of mature cow

Payment for cows sent for slaughter is according to the price schedule for manufacturing beef (Lincoln University, 1991). This schedule gives price differentials per kg carcass depending on the weight of the carcass (NZ Farmer, 1991). This was taken into account in the model by calculating the price per kg carcass weight, based on the weight of the carcass, using regression equations. The regression was calculated separately for Holstein-Friesians and Jerseys due to the different weight ranges applicable for carcasses from these breeds. The regression was based on the prices received for the weight range covering 95% of carcasses for each breed with the mean carcass weight of 220.66 kg (± 37 kg) for Holstein-Friesians and 167.36 kg (± 18.6 kg) for Jerseys:

Holstein-Friesian:

$$\$/\text{kg carcass} = 1.8760 + 0.000965 * \text{kg carcass}$$

Jersey:

$$\$/\text{kg carcass} = 1.8266 + 0.001246 * \text{kg carcass}$$

This results in a return of \$ 2.09 per kg carcass and \$ 461 per head for an average Holstein-Friesian cow and of \$ 2.04 per kg carcass and \$ 341 per head for an average Jersey cow culled. These values were used in the model as baseline.

3.3.5.c) Price for carcass of calf

It is common practise in New Zealand to cull surplus calves, which are not required as replacements, at the age of four days (bobby calves). Until 1989 these were paid on a per head basis irrespective of weight (NZ Meat and Wool Boards' Economic Service, 1991a). From the 1989/90 season onwards this was changed to a system of paying for bobby calves on a liveweight basis. Subsequently, a differential payment system was introduced with higher prices for heavier calves and no payment below the threshold value of 11 kg carcass weight (Dairy Meats Association, 1991). This results in different prices per kg carcass weight depending on the weight of the carcass. This price differential was taken into account in the model by estimating the price per kg carcass weight based on the weight of the calf using regression equations. The regression was calculated separately for Holstein-Friesians and Jerseys due to the different weight ranges achieved for calves from these breeds. The regression was based on the prices received for the weight range covering 95% of calves for each breed with the mean carcass weight of 17.16 kg (± 2.9 kg) for Holstein-Friesians and 13.37 kg (± 1.49 kg) for Jerseys:

Holstein-Friesian:
$$\$/\text{kg carcass} = 0.5486 + 0.1510 * \text{kg carcass}$$
Jersey:
$$\$/\text{kg carcass} = -1.5131 + 0.2975 * \text{kg carcass}$$

This results in a return of $ 3.14 per kg carcass and $ 54 per head for an average Holstein-Friesian and of $ 2.46 per kg carcass and $ 33 per head for an average Jersey bobby calf and these returns were used in the model to represent the baseline.

3.3.5.d) Price of calves sold for rearing

In recent years the number of calves slaughtered for export declined (NZ Meat and Wool Boards' Economic Service, 1991c). Throughout the same period the dairy cow population has been relatively stable (New Zealand Dairy Board, 1991a; Livestock Improvement, 1992) indicating that a larger number of male dairy calves are sold for rearing as replacements in the beef industry. This provides additional revenue for the dairy farmer and was accounted for in the bioeconomic model. Only male Holstein-Friesian calves are sold for rearing. In accordance with requirements for the beef industry it was assumed male calves sold for rearing were the heavier calves weighing on average 40 kg, thus representing a weight one standard deviation above average. During the 1990/91 season an average of $110 per head was received for these calves (Lincoln University, 1991). This resulted in a price of $2.75 per kg liveweight which was used in the model for male Holstein-Friesian calves which weighed more than 40 kg.

3.3.5.e) Variable costs

Variable costs for standard management techniques were included in the model. These consisted of annual costs per cow for health, electricity, shed expenses, artificial breeding, herdtesting and capital cost for cows as identified by Ahlborn and Bryant (1992) and are shown in Table 3.8. Estimates for these variable costs, except the capital cost for cows, were based on an analysis of the accounts from a random sample of 276 dairy farms (Livestock Improvement, 1991).

Cost of health care comprised the highest expenditure at $ 33 per cow. This included directly attributable costs for acute treatments as well as proportionately attributable costs for preventative measures like bloat and mineral drenches. This is in agreement with published data (MAF, 1991; Lincoln University, 1991) and also with averages calculated from accountants results derived from Waikato dairy farmer clients (Graham, 1992, unpublished).

Table 3.8.: Variable costs per cow (1990/91 season, r = replacement rate, interest rate = 12%, capital values for animals as given by Lincoln University, 1991).

Item		Cost/cow		
		Holstein-Friesian		Jersey
Health		$ 33		$ 33
Electricity		$ 16		$ 16
Shed expenses		$ 14		$ 14
Artificial breeding		$ 14		$ 14
Herd testing		$ 6		$ 6
		$ 83		$ 83
Cost of capital for stock (0.12%)				
		$/animal		$/animal
Mixed-age cows (r = 1)	$ 800	$ 96	$700	$ 84
In-calf heifers (r = 0.22)	$ 650	$ 17	$600	$ 16
Yearling heifers (r = 0.24)	$ 420	$ 12	$320	$ 9
Heifer calves (r = 0.26)	$ 150	$ 5	$110	$ 3
Total cost of capital for stock		$ 130		$ 112
Total variable cost/cow		$ 213		$ 195

Costs for electricity and shed expenses were proportionately accounted for and agreed with previous publications (MAF, 1991; Lincoln University, 1991). Ideally electricity costs should be accounted for per litre of milk harvested since milk volume determines the amount of electricity used for milking. This might be important since the Holstein-Friesian and Jersey breeds differ significantly in milk volume (Ahlborn-Breier, 1989; Ahlborn-Breier and Hohenboken, 1991; Ahlborn and Bryant, 1992) and in milking time (Arave et al., 1987). To assess the difference in electricity costs the total per annum milking time was estimated for Holstein-Friesians and Jerseys based on production at high and low stocking rates (Ahlborn and Bryant, 1992) and respective milking speeds (Arave et al., 1987). Milking speed did not differ between stocking rates for cows of the same breed (Bryant, pers. comm.). Table 3.9. shows the total milking time per annum per cow and per ha.

These estimates indicate that milking time per cow differs more between stocking rates (ranging from 24% to 38%) than between breeds with only an 8% difference between breeds in annual milking time per cow at a comparable stocking rate.

Table 3.9.: Total milking time estimates for Holstein-Friesian and Jersey cows.

	Stocking rate		Milk production	Milking speed	Annual milking time	
		cows/ha	kg/year	kg/min	h/cow	h/ha
Holstein-Friesian	Low	3.0	4,632	1.82	42.4	127
	High	4.0	3,350	1.82	30.7	123
Jersey	Low	3.6	3,306	1.32	41.7	150
	High	4.5	2,646	1.32	33.4	150

They also show that despite the lower milk volume Jerseys require a 18 to 20% longer annual milking time per ha due to the higher stocking rate. However, assuming a 3 kW vacuum-pump and an electricity cost of $ 0.12/kWh, this breed difference in milking time translates into only minor differences in electricity usage per cow for milk harvesting (< $1.00 per annum) and therefore these differences were ignored.
Artificial insemination is a routine management technique and was used in 91.4% of all herds (Livestock Improvement, 1990a) during the 1989/90 season. An analysis of cow census records from the 1989/90 season showed that in 9,970 herds 78.6% of cows were artificially inseminated. The costs for artificial insemination incurred per cow depend on the management ability of the farmer as well as the fertility of the herd. Increased fertility would be reflected in lower costs per cow in the form of a lower number of inseminations required as well as a lower replacement rate. Differences in fertility might exist between breeds. A higher calving rate of Holstein-Friesian and Holstein-Friesian x Jersey crossbred cows when compared to Jersey cows has been reported (Ahlborn-Breier, 1989). In contrast, a 3% higher non-return rate for Jerseys was indicated from data resulting from the results of 124,251 inseminations with Jersey semen and 364,523 inseminations with Holstein-Friesian semen (Livestock Improvement, 1992, unpublished data). Due to the poor evidence supporting a consistent breed difference in fertility no distinction between breeds was made for variable costs for artificial insemination. The annual cost of artificial insemination using a non-return rate of 75% was calculated as $14 per cow (Livestock Improvement, 1990, unpublished data) and varies only marginally between regions. This is consistent with published statistics (Graham, 1989; MAF, 1991; Lincoln University, 1991).

On average 69% of farmers are herd testing (Livestock Improvement, 1990a), therefore this management cost was

included in the model. Self sampling is used by 74% of all herdtesting farmers (Livestock Improvement, 1991, unpublished data) and 70% of these farmers test with an eight weekly interval. Thus, eight weekly self sampling is the most common frequency and was used as a basis for calculating the variable costs associated with herd testing of $ 6.00 per cow.
The sum of $ 20 for herd testing and artificial insemination calculated here agrees with results from an economic analysis of 276 dairy farms (Livestock Improvement, 1991).

Capital costs for cows and replacements were included as the cost of borrowing capital which represents an opportunity cost for capital. The cost of the capital for stock was larger than the sum of all other variable costs (Ahlborn and Bryant, 1992). Therefore the capital cost for cows per ha has a large effect on net farm income and needs to be taken into account for systems in which stocking rates and thus the number of cows per ha differ. The values (purchase price) of mixed age dairy cows for the 1990/91 season were reported as $ 800 for Holstein-Friesians and $ 700 for Jerseys (Lincoln University, 1991; MAF, 1992) and these were used as a baseline. An interest rate of 12% was used as a reasonable longterm estimate.
Capital costs for replacements were calculated taking the replacement rate into account. Replacements had a lower value and comprised only a small number of animals. Consequently, capital costs for replacements were a relatively small part of the variable cost.

3.3.5.f) **Fixed** costs

Fixed costs represent the costs relating to the farming enterprise and are incurred independently of the level of production or the number of cows per ha. They include costs for land, inputs required for growing the feed (fertilizer, purchased supplements, cultivation and harvesting of supplements, weed spraying etc.), vehicle expenses, repairs and maintenance of plant and machinery and administrative costs.

Profit was defined as the difference between returns and costs in this study. Consequently fixed costs represented a constant expenditure and these terms vanish when calculating the first derivative of the profit function (James, 1982; Ponzoni, 1986; Ahlborn and Bryant, 1992). Subsequently, fixed costs were ignored in the bioeconomic model. However, they need to be included when the ratio between returns and costs is considered, or enterprises or production systems with vastly differing expenditures for fixed cost items are compared.

Another reason for ignoring fixed costs was their property to in- or decrease in integer units only. In most cases fixed costs change following a stepwise function as generally only full units are employed like an additional labour unit or an additional cluster in the milking shed. The steps usually encountered with fixed costs were larger than the changes due to biological variables expected after 20 years of genetic progress. This means that the change due to genetic progress in the mean of the biological variables and the associated management actions such as a change in cow numbers were in most cases not substantial enough to trigger major changes in fixed costs. Therefore within the limits of this study fixed costs were considered constant and independent of the mean of the trait.

Another complication for the inclusion of fixed costs arises from the lack of direct opportunity cost for some fixed cost variables. Due to a lack of opportunity for use of parts of the land and the relatively high cost of relocating a dairy farming enterprise the opportunity cost for land and labour is very low and was therefore ignored. Since land is by far the highest fixed cost, and thus the highest input cost in a dairy farming enterprise, net income was expressed per ha for the calculations. This also takes the high cost of the land as the limiting factor into account.

Labour and the cost for the milking shed were considered as fixed costs, however, they do change in a stepwise fashion proportional to cow numbers. For example, the 14-aside herringbone type shed is most frequently encountered and is considered to be sufficient for the average herdsize of 164 cows with 10 cows per cluster being recommended. For a herdsize of 200 -250 cows a 20 to 24-aside milking shed is generally used, which requires the additional investment of on average $4,000 per additional cluster. An increased stocking rate will increase the total milking time if the same number of clusters is used. A 20% increase in the stocking rate will require two extra rows to be milked on the average farm, carrying 164 cows. This would increase milking time by about 10 minutes per milking. As larger farms usually also have larger milking sheds an increase in stocking rate results in a similar increase in milking time. For example, increasing the stocking rate of a 250 cow farm by 20% to 300 cows also results in an extra two rows and increases milking time by about 10 minutes per milking. Labour is paid per unit and not per hour and therefore the opportunity cost for these 10 minutes is difficult to assess economically and is likely to be small due to a lack of alternative employment in rural areas. Furthermore, an extension of the milking shed is seldomly carried out when increasing the herd size on a given farm. For this reason the cost of milking sheds was considered as a fixed cost. It should be noted that when considering measures of efficiency, i.e. when the profit function is defined as the ratio of returns over costs rather than the difference, that the extended milking time is offset by a lower per ha capital requirement for the milking shed since more cows are milked per cluster.

Labour was also considered as a fixed cost since wages are paid per labour unit and not as an hourly rate. Even when employing labour for the occasional milking wages are paid per milking and not per cow with relatively small differences between herd sizes. It is generally considered that one labour unit can handle up to 220 cows and larger herds require an additional labour unit. Once the decision to employ extra labour is made, the costs for labour remain constant with increasing stocking rate. When considering the utilisation or efficiency of the labour units employed, i.e. applying the profit equation as a ratio, a high number of cows per labour unit is advantageous.

3.3.5.g) Discount rate

Revenues and costs occuring at different times can be expressed and compared equitably by discounting future revenues to their present value. Discounting takes account of the time delay which occur in the accrual of some revenues and costs. This allows more realistic comparisons between various cashflow streams (Nicholas, 1987). In the dairyfarming system the carcass value is realised only at the end of the lifetime of the cow. Discounting the revenue from the cull cow carcass leads to a more equitable economic valuation of the traits which are influenced by the revenue from the carcass. The time of realisation of the revenue from the cull cow carcass depends on the average herdlife of the cow. Herdlife is thus included as the determinant for the time period after which revenue from the cull cow carcass is received. This is achieved by incorporating the reciprocal of herdlife which is also defined as replacement rate as the exponent in the denominator.

The discount rate chosen takes account of inflation and the actual interest rate then becomes the annual real interest rate as suggested by Smith (1978). Thus, revenue has been discounted in the following way:

$$\textbf{Discounted revenue} = \textbf{Revenue} * \frac{1}{\left(\frac{1 + c}{1 + i}\right)^{1/r}}$$

where c is the annual interest rate expressed as fraction,
i is the annual inflation rate expressed as fraction and
r is the average herdlife in years.

Annual interest rates have fluctuated considerably in New Zealand in conjunction with changes in the inflation rate. Interest rates of bonds issued by large firms with substantial assets and stable earning records give an indication of the expected marginal long-term real interest rates. The chosen discount rate was based on an annual interest rate of 8% and an annual inflation rate of 2%, which is consistent with longterm predictions from finance organisations (Jarvis and Perley, 1989). An average herdlife of 4.5 years resulting in a replacement rate of 22% (Ahlborn-Breier and Wickham, 1986; Harris, 1989b) was used in the model.

For the average dairy farm which is represented by the model, revenue from cull cow carcasses were reduced by 13% through discounting. This had the effect of increasing economic weights per ha for milkfat and protein by 1.5% and 0.2% for Holstein-Friesians and Jerseys, respectively, and decreasing economic weights per ha for milk volume by 2% and liveweight by 9% for Holstein-Friesians and by 3% and 7%, respectively, for Jerseys. The slighlty lower impact on the economic weights for Jersey is expected since the return from the cull cow carcass is considerably lower for Jersey cows. This difference existed even though only a relative small percentage of total revenue is derived from meat sales and the relatively short time frame of only 4.5 years after the birth of the animal.

In conclusion, discounting costs and revenues made an increase in liveweight less profitable than expected from current prices.

3.3.6. The objective variable

The objective examined was maximum net income per farm, which was defined as the difference between revenue and cost. The bioeconomic model was based on one of the major limiting factors, the area farmed and so on a given amount of dry matter available. This meant that an increased net farm income also implied a higher monetary efficiency per unit of area (ha) and dry matter (kg). For the same reason this also equated to the maximum production of milk solids per area (ha) and feed input (kg DM).

3.4. Validation of bioeconomic model

Mathematical models representing farm production systems are a valuable tool for animal breeders. The simulation of a wide range of scenarios over a short timeframe offers numerous advantages, especially in dairy cattle breeding with its notably long generation interval. Mathematical models, describing bioeconomic conditions, indicate which biological variables offer the greatest opportunity for genetic improvement of animal merit and thus increase of net farm income by genetic means (Dickerson, 1970).

However, for these simulation results to be valid and applicable in practice, it is essential that the mathematical model resembles the farm production system closely. A range of validation techniques and their application have been described by Sörensen (1990). Model validation of the present bioeconomic model was performed at three levels. First, the conceptual model was validated to ascertain whether it reflected the real situation, secondly, the computerized model was verified to ensure that it described the conceptual model, and thirdly the operational validity was tested to evaluate the behaviour of the computerized model in relation to the behaviour of the real system.

3.4.1. Validation of conceptual model

The objective validation of the conceptual model as a representation of the real situation requires observed data. Extensive literature exists about the mathematical expression of theoretical concepts of physiological systems which are used as subunits in this bioeconomic model (Blaxter, 1962; Moe et al., 1970; Agricultural Research Council, 1980; Baldwin et al., 1987; Holmes et al., 1987; Chwalibog, 1991a). These subunits such as utilisation and requirements of metabolisable energy provided trace validity (Sörensen, 1990). However, such data are scarce for the influence of management strategies and of relationships between biological input and output parameters in the production system. In this case trace validity was obtained by consulting farm production experts. Flow charts as suggested by Sargent (1982) were used to explain the system to farm production experts and consultants. The consensus was that the conceptual model developed in this study reflected reality closely.

3.4.2. Verification of computerized model

The computerized model was verified by tracing entities in the model to determine the correct logic (Sargent, 1982). The mathematical and logical consistency was extensively checked against manual calculations. In addition, the results were validated by dairy farm experts and practitioners, which enhanced the confidence in the bioeconomic model considerably.

Moreover, certain subunits of the model were validated by comparing simulated results with experimental data not used to construct the model or by utilising expert knowledge

(Pomar et al., 1991). For example, the efficiency coefficients for maintenance and milk production, k_{maint} and k_{lact}, were independently determined in an experiment carried out at Massey University (Holmes et al., 1992). The conclusion from this experiment (Holmes et al., 1992) was that the appropriate coefficient for maintenance requirement is at least 0.6 MJ ME/$kg^{0.75}$ confirming the values used in this model. Additionally, this experiment (Holmes et al., 1992) showed that a higher maintenance requirement, i.e. higher feed consumption, is significantly associated with higher liveweight, independently of variation in milk yield, validating one of the main assumptions in the model,

3.4.3. Operational validity

The behaviour of the computerized model was compared with the behaviour of the real system to test its operational validity (Pomar et al., 1991). However, a full validation of the model was not possible since the experimental data available were not sufficient to ensure an accurate representation of all system details. In this case, the predicted performance of the computerized model was compared with the performance achieved in a stocking rate experiment. This experiment (Ahlborn and Bryant, 1992) was initiated to test some of the assumptions about the biological variables in the model and in addition allowed the biological part of the bioeconomic model to be tested.

Real and simulated output data were compared through a subset of identical input data using the principle of a goodness of fit test (Naylor and Finger, 1967). In the bioeconomic model stocking rate and production per ha were calculated for a given level of production per cow. In contrast, in the experiment (Ahlborn and Bryant, 1992) production per cow and production per ha were measured at differing stocking rates. Thus, the validation was carried out in a 'reverse' fashion as the explanatory (x) variable in the experiment became the response (y) variable in the model and vice versa. In the validation procedure production per cow reported from the stocking rate experiment (Ahlborn and Bryant, 1992) was used as input datum in the bioeconomic model. All other variables and constants were kept at base level. This allowed comparison of the response from experimental data with estimates from the bioeconomic model. This is shown in Table 3.10. The validation was restricted to these two data sets measured at specific stocking rates, since the response curves spanning a range of stocking rates reported in Ahlborn and Bryant (1992) are predictions only and the design of the experiment did not allow the calculation of standard errors or confidence intervals (Ahlborn and Bryant, 1992).

The experimental results were based on a herd without replacements whereas the model included the DM requirements for young stock. To allow a more equitable comparison, the requirements for young stock were excluded from the model calculations through the addition of proportionate production and stocking rates. The proportion was calculated from the DM requirements for young stock estimated from the model.

The experiment was carried out at an above average production level due to the high DM production per ha at the experimental farm (Bryant, 1992, unpublished). Consequently, the DM available per ha was increased from the baseline to 13,500 kg/ha for the validation. Table 3.10. shows a close agreement between protein and milkfat yields per ha at the low stocking rate with an estimated reduction in protein and milkfat yields per ha at the low stocking rate of 1% for Holstein-Friesians and 2% for Jerseys. However, at the high stocking rate the difference between experimental data and results from the model was larger with 8% for Holstein-Friesians and 12% for Jerseys. The model predicted a lower production per ha at the high stocking rate than was actually achieved in the experiment. This difference is most likely

Table 3.10.: Production parameters from an experiment (Ahlborn and Bryant, 1992) and bioeconomic model for Holstein-Friesians and Jerseys (* = input data for experiment, # = input data for model).

		Low stocking rate		High stocking rate	
		Friesian	Jersey	Friesian	Jersey
Protein kg/cow		# 163	# 138	# 112	# 104
Milkfat kg/cow		# 214	# 200	# 150	# 157
Milk kg/cow		# 4511	# 3202	# 3256	# 2542
Stocking rate cows/ha	Expmt.*	*3.02	*3.57	*3.98	*4.53
	Model	3.00	3.54	3.64	4.07
Difference (%)		-1	-2	-8	-12
Protein kg/ha	Expmt.	486	487	448	473
	Model	483	487	410	417
Difference (%)		-1	0	-8	-12
Milkfat kg/ha	Expmt.	636	724	592	711
	Model	631	707	543	627
Difference (%)		-1	-2	-8	-12

due to an increase in DM production per ha and/or an increase in utilisation with higher grazing pressure resulting in a higher amount of DM and ME being harvested and available for milk production. While a 2,000 kg DM/ha higher DM production was observed in the experiment for the high stocking rate, a significant difference in DM production between stocking rates could not be ascertained due to the large coefficient of variation of this variable.

The model assumes that the energy requirements for maintenance, milk yield, pregnancy and replacement completely determine the stocking rate and thus production per ha. This infers a simple multiplicative relationship between production per cow and production per ha. However, while comparisons of farms with stocking rates of up to 4 cows/ha would support this (Crabbe, 1983), stocking rate comparisons under controlled experimental conditions with constant management indicate a decrease in cow performance with increased stocking rate (King and Stockdale, 1980; Holmes and Macmillan, 1982; Senft and Thaurel, 1989; Ahlborn and Bryant, 1992) above a certain critical level (Jones and Sandland, 1974). This relationship then changes energy requirements and utilization and implies that at different stocking rates the achievable yield per ha differs. The larger difference between experimental results and estimates from the model support this hypothesis.

From this initial operational validation the model does compare favourably with reality and appears to represent the behaviour of real systems under experimental control. However, as more experimental results become available further validation of the model will be possible.
The model could be further refined by including annual variation in pasture growth (Azzam et al., 1990b). This would allow the study of effects of nutritional inadequacies during certain times of the year. This might be another one of the limiting factor in a pasture based dairying system.

4. RELATIVE ECONOMIC VALUES ESTIMATED WITH THE BIOECONOMIC MODEL

4.1. Introduction

The bioeconomic model was used to estimate economic values for the traits protein yield, milkfat yield and lactose yield, volume, liveweight and herdlife. Economic values link the contribution of any particular trait to profitability. Additionally, economic values provide a valuable means to rank traits which are measured in differing units, and compare their potential contribution to a particular selection objective such as optimising profit. Profit in this study was defined as a linear function of input and output variables. These variables included several biological traits as well as economic parameters and variable costs. The profit function has been shown as linear or near-linear in relation to changes in any single trait (Goddard, 1983). Economic values were estimated as the partial derivatives of the profit function with respect to a unit change in the trait concerned thus representing the slope of the profit function at a particular point. Since the rate of genetic progress in livestock is relatively slow, the point chosen for calculating partial derivatives was the level of the population mean (Goddard, 1983; Smith, 1984; Brascamp et al., 1985). The economic impact of a unit change in the trait concerned was evaluated by holding genetic levels of other traits constant, but including associated environmental or management effects (Bennett et al., 1980) such as changes in stocking rate.

The objective of this section of the study was to predict the effects on profitability of changes in the traits protein yield, milkfat yield and lactose yield, volume, liveweight and herdlife, brought about by genetic improvement, and to consequently rank these traits according to their long-term economic importance. In addition, results from this study ultimately make it possible to predict the profitability of a sire's progeny and the resulting increases in profit per ha.

4.2. Material and methods

The genetic standard deviation for each trait was estimated (Van Vleck, 1987) using the phenotypic standard deviation from the 1990/91 statistics (Table 3.3.) in combination with published estimates for the heritabilities (Ahlborn and Dempfle, 1992; Welper and Freeman, 1992). The phenotypic variance for most traits increases with age, resulting in larger phenotypic standard deviations (Table 3.4.), and consequently larger genetic standard deviations. Since estimates for genetic standard deviations comprised all age groups they were larger than those reported by Ahlborn and Dempfle (1992) which were based on primiparous two year old cows. Means, phenotypic and genetic standard deviations are shown in Table 4.1.

For each trait examined the revenues per animal from milk and meat were tabulated as well as the profit per ha, based on variable costs for different levels of each trait under consideration (Tables 4.2. - 4.10.). To allow a visualisation of the impact of changes in a particular trait on the profit function, these results were graphed (Figures 4.1. - 4.5.). The revenues were calculated for the range of the trait corresponding to two phenotypic standard deviations below and above the mean for each trait and within each breed. Thus, the graphs represent 95% of the phenotypic variation encountered in each of the populations of Holstein-Friesian and Jersey cows. Where possible, all graphs are shown over the same parameter space to facilitate comparisons between traits and breeds.

The economic values were estimated as partial derivatives of the profit function for each of the traits (Knap, 1985; Dempfle, 1986; De Vries, 1989; Ponzoni and Newman, 1989). This approach has the advantage that the partial derivatives directly reveal the influence of parameters on the economic values. The profit function and the derivation of the economic weights employed in this study was described by Dempfle (1986) and Munoz-Luna, Yadav and Dempfle (1988). The APL-program code developed by Dempfle (1986) was used in slightly modified form to calculate the economic values in this study. A copy of the code is included in Appendix 1.

The economic values are represented by the slope of the profit function at a particular point and take changes in other variables into consideration. Realised genetic progress changes the means of the biological variables and this is likely to affect other production system parameters. For example, a change in milk production, or in liveweight per cow, requires a change in stocking rate under the assumption that pasture is fully utilised at the baseline level. These changes in stocking rate were considered when estimating economic values.

Substantial shifts in the means of traits could also indicate the use of different production and/or management systems, or point to large changes in fixed costs (Brascamp et al., 1985; Smith et al., 1986; Amer and Fox, 1992). The reduction in stocking rate, associated with the increase in milk production per cow brought about by genetic progress over a 20 year period, was approximated by combining the results from this simulation study with regression equations from Ahlborn and Bryant (1992). The increase due to genetic progress over a 20 year period in milk production per cow was predicted to reduce stocking rate by between 25% and 29% for Holstein-Friesians and by between 27% and 38% for Jerseys. This estimation accounted for the distribution of costs over a smaller number of cows into account. Although these are significant reductions in the stocking rate, it is unlikely that this gain would require major changes in production or management systems or affect fixed costs (e.g. milking

Table 4.1.: Phenotypic and genetic parameters employed for Holstein-Friesians and Jerseys (μ = mean, σ_P = phenotypic standard deviation, h^2 = heritability, σ_G = genetic standard deviation).

	μ	σ_P	h^2	σ_G
Holstein-Friesian				
Protein (kg)	120	34	0.26	17
Milkfat (kg)	155	43	0.26	22
Lactose (kg)	159	44	0.26	22
Volume (kg)	3,466	961	0.28	508
Liveweight (kg)	440	74	0.24	36
Replacement rate (%)	22	6.3	0.09	1.9
Jersey				
Protein (kg)	110	28	0.24	14
Milkfat (kg)	154	41	0.26	21
Lactose (kg)	125	31	0.26	16
Volume (kg)	2,672	670	0.26	342
Liveweight (kg)	360	40	0.16	16
Replacement rate (%)	22	6.3	0.09	1.9

equipment), since it is a reduction rather than an increase in the stocking rate. Therefore, it was assumed that within the expected limits of change in the biological variables brought about by genetic progress, production and management system would remain unaltered.

The bioeconomic model did not include a possible interaction between stocking rate and per cow production nor did it include the management effect of a higher amount of DM being grown and/or utilized with higher stocking rates. However, the latter effect was simulated through higher amounts of DM available from the same area.

4.3. Milk production

The objective for this simulated dairy production system was to increase the profit per ha, however, improvement in milk production by genetic means can only be achieved through each individual cow. The economic value of one unit increase in one animals production of each of the milk components was calculated, and also the effect of this increase on all inputs and outputs of the dairy production system. The economic value of a unit increase in the yield of a particular milk component was defined as all revenue received minus all costs incurred during its production, assuming that the production system had reached equilibrium after the increase. In a pasture based production system these costs can only be measured indirectly, since feed intake figures for individual cows are not available generally. A change in milk production per cow requires a change in DM input which subsequently affects the stocking rate, as land is the limiting factor with the amount of DM available being a fixed quantity. This resulted in an adjustment of the allocation ratio of available DM between the revenue earning products milk and meat and the 'costs' of maintenance and rearing.

4.3.1. Protein

Changes in the protein yield per cow resulted in changes in a number of production system parameters e.g. a higher protein yield per cow required changes in stocking rate that affected revenue per ha from meat and also variable costs. Changes in biological and economic farm parameters per cow and per ha such as energy requirement, revenue and costs which result from changes in protein yield per cow are detailed in Table 4.2. Increasing the percentage of ME used for the production of milk with a higher protein content led to increased revenue per cow from milk. This more than offset the associated reduction in stocking rate and resulted in a higher revenue from milk per ha due to increased protein yield per cow for both, Holstein-Friesian and Jersey cows. A reduction in stocking rate led to a lower amount of liveweight carried per ha and reduced ME requirements per ha for maintenance and replacements, requiring a lower percentage of energy to be used for non-productive "costs" and so increasing the protein yield per cow. Consequently, the percentage of energy used for lactation increased considerably. The higher percentage of energy used for the revenue earning products with a high price paid for the increased protein yield improved profit and farm efficiency.

Economic parameters per ha for different levels of protein yield of Holstein-Friesians and Jerseys are shown in Figure 4.1. The functions shown in Figure 4.1. are the revenue from milk only, the sum of revenue from both milk and bobby calves, the sum of revenue from milk, bobby calves and cull cows and the profit function defined as the sum of revenues from milk and meat minus variable costs. The graph shows the range of revenue and profit for levels of protein yield per cow of two phenotypic standard deviations above and below the mean for each breed. This represents 95% of the phenotypic variation in protein yield observed in the Holstein-Friesian and Jersey cow populations.

Revenue per ha from milk increased in a slightly non-linear fashion with increasing protein yield per cow in both breeds. Revenue per ha from milk was 10% higher for Jerseys relative to Holstein-Friesians at the same level of protein yield per cow.

Table 4.2.: Changes in energy requirements, revenue and cost per cow and per ha for Holstein-Friesians and Jerseys for different levels of protein yield.

a) Holstein-Friesian

Protein (kg/cow)	50	86	103	120	137	154	188
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
Milk ($/cow)	580	760	849	941	1,029	1,118	1,298
Cull cow ($/cow)	74	74	74	74	74	74	74
Bobby calves ($/cow)	72	72	72	72	72	72	72
Maintenance (ME/cow)	21,046	21,046	21,046	21,046	21.046	21,046	21,046
Liveweight (ME/cow)	31,825	31,825	31,825	31,825	31,825	31,825	31,825
Lactation ME req. (%)	34.16	35.84	36.64	37.44	38.20	38.94	40.39
Stocking rate (cows/ha)	2.39	2.33	2.29	2.27	2.24	2.22	2.16
Milk ($/ha)	1,387	1,769	1,953	2,136	2,307	2,478	2,807
Cull cow ($/ha)	177	172	170	168	166	164	160
Bobby calves ($/ha)	173	169	167	165	161	157	143
Total revenue ($/ha)	1,737	2,110	2,290	2,468	2,636	2,802	3,124
Variable costs ($/ha)	504	492	485	479	474	468	457
Profit ($/ha)	1,232	1,618	1,804	1,989	2,162	2,335	2,667
Maintenance (ME/ha)	50,290	49,010	48,394	47,781	47,207	46,636	45,533
Replacements (ME/ha)	21,316	20,773	20,512	20,252	20,009	19,767	19,299
Lactation (ME/ha)	39,455	41,390	42,322	43,248	44,116	44,980	46,648
Liveweight (kg cows/ha)	1,051	1,025	1,012	999	987	975	952
Fat (kg/ha)	370	361	356	352	348	343	335
Protein (kg/ha)	124	200	237	273	307	341	406
Lactose (kg/ha)	386	371	367	362	358	353	345
Energy used for milk (ME/ha)	23,673	24,834	25,393	25,949	26,469	26,988	27,989
Energy " liveweight (ME/ha)	76,045	74,110	73,178	72,252	71,384	70,520	68,852
Energy milk/liveweight (%)	31.13	33.51	34.70	35.91	37.08	38.27	40.77

Table 4.2. continued: Changes in energy requirements, revenue and cost per cow and per ha for Holstein-Friesians and Jerseys for different levels of protein yield.

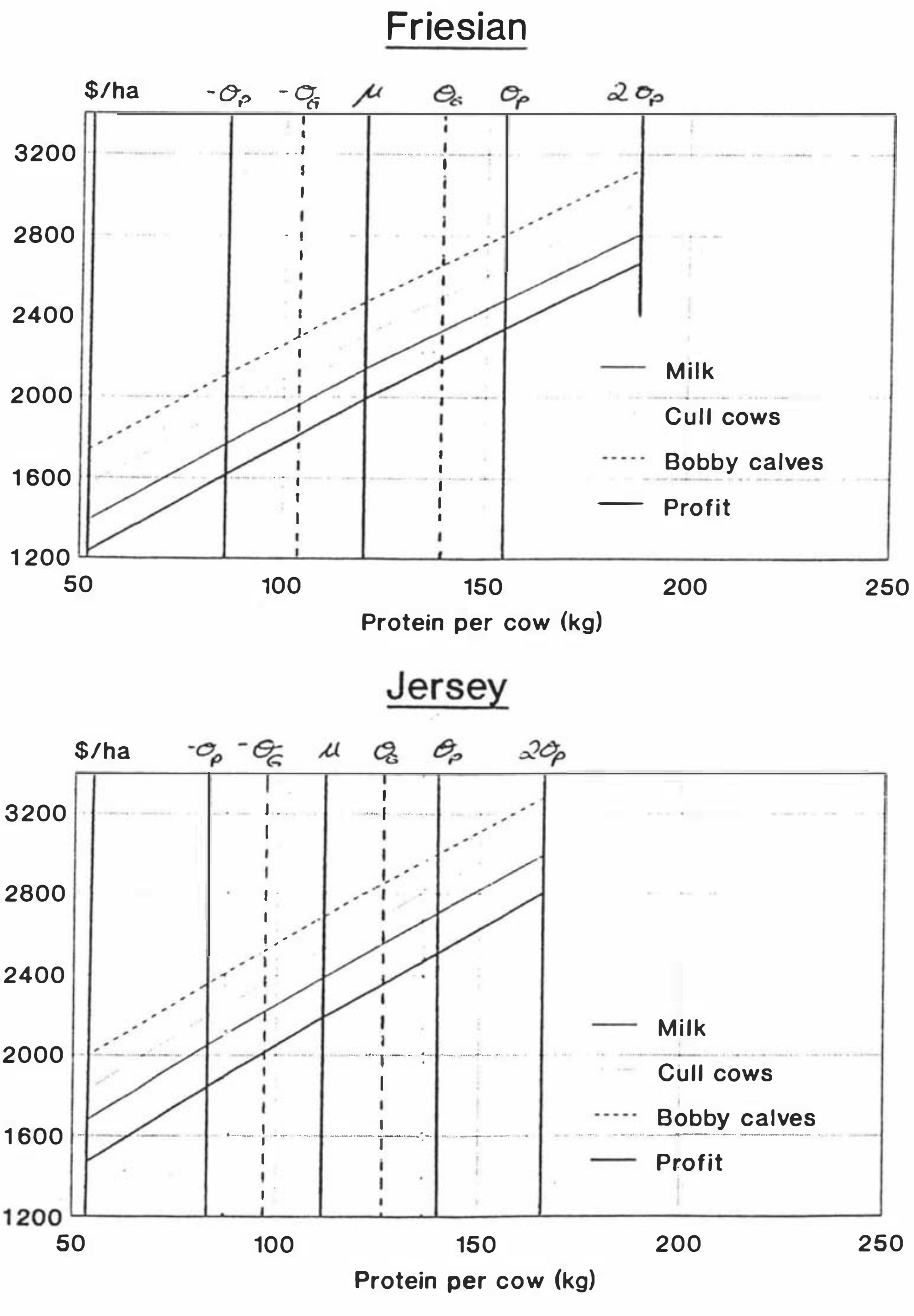
b) Jersey

Protein (kg/cow)	54	82	96	110	124	138	166
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
Milk ($/cow)	622	770	843	918	991	1,065	1,213
Cull cow ($/cow)	55	55	55	55	55	55	55
Bobby calves ($/cow)	62	62	62	62	62	62	62
Maintenance (ME/cow)	18,106	18,106	18,106	18,106	18,106	18,106	18,106
Liveweight (ME/cow)	27,104	27,104	27,104	27,104	27,104	27,104	27,104
Lactation ME req. (%)	36.40	37.92	38.65	39.37	40.06	40.74	42.06
Stocking rate (cows/ha)	2.71	2.65	2.61	2.58	2.55	2.53	2.47
Milk ($/ha)	1,685	2,036	2,204	2,371	2,532	2,688	2,994
Cull cow ($/ha)	148	144	143	141	139	138	135
Bobby calves ($/ha)	168	164	162	160	158	157	153
Total revenue ($/ha)	2,001	2,345	2,509	2,673	2,830	2,983	3,282
Variable costs ($/ha)	527	514	508	502	496	491	480
Profit ($/ha)	1,474	1,831	2,001	2,171	2,333	2,492	2,802
Maintenance (ME/ha)	49,068	47,896	47,336	46,779	46,245	45,723	44,703
Replacements (ME/ha)	20,462	19,973	19,740	19,507	19,285	19,067	18,642
Lactation (ME/ha)	42,045	43,800	44,638	45,472	46,272	47,053	48,579
Liveweight (kg cows/ha)	976	952	941	930	919	909	889
Fat (kg/ha)	416	406	402	397	392	388	379
Protein (kg/ha)	143	217	251	284	317	348	411
Lactose (kg/ha)	340	332	328	324	320	317	309
Energy used for milk (ME/ha)	25,227	26,280	26,783	27,283	27,763	28,232	29,147
Energy " liveweight (ME/ha)	73,455	71,700	70,862	70,028	69,228	68,447	66,921
Energy milk/liveweight (%)	34.34	36.65	37.80	39.67	40.10	41.25	43.55

Revenue per ha from bobby calves and cull cows decreased with higher protein yields per cow (see also Table 4.2.). As a consequence, the percentage of total revenue per ha derived from meat decreased with increasing protein yield per cow.
A steady increase in profit per ha was observed with increasing protein yield per cow in both, Holstein-Friesians and Jerseys (Figure 4.1.). Profit per ha was on average 8% higher for Jerseys resulting from the combination of 10% higher revenue per ha from milk, 10% lower revenue per ha from bobby calves and cull cows and 5% higher variable costs compared to Holstein-Friesians.

Variable costs per ha are represented by the difference between the line for the sum of revenues per ha from milk, bobby calves and cull cows and the line for profit per ha (Figure 4.1.). Variable costs per ha declined slightly with increasing protein yield per cow due to the associated lower stocking rate (see also Table 4.2.). This resulted in a slightly larger increase in profit per ha than in revenue from milk per ha with increasing protein yield per cow. Variable costs per ha were higher for Jerseys than for Holstein-Friesians (Table 4.2.).
Means, phenotypic and genetic standard deviations indicated in Figure 4.1. elucidate the smaller variation in protein yield of Jerseys compared to Holstein-Friesians which has been reported previously (Ahlborn and Dempfle, 1992). Despite the smaller variation and a lower mean in protein yield per cow Jerseys achieved a higher revenue from milk and profit per ha at low as well as at high levels of protein yield per cow. The smaller variation in protein yield per cow of Jerseys resulted in a greater increase in revenue and profit per ha per kg increase in protein yield per cow compared to Holstein-Friesians.
Stocking rate, milk solids yield per ha, profit per ha and economic values estimated as partial derivatives of the profit function were calculated for different levels of protein yield per cow and per ha and are shown in Table 4.3.

Figure 4.1.: Revenue per ha from milk ('milk'), sum of milk and bobby calves ('bobby calves'), sum of milk, bobby calves and cull cows ('cull cows') and profit per ha defined as sum of revenue from milk, bobby calves and cull cows minus variable costs ('profit') at different levels of protein yield per cow for Holstein-Friesians and Jerseys (prices for 1991/92 season).



The decrease in stocking rate with increasing protein yield per cow and the associated increase in milk solids per ha and profit per ha is obvious for both breeds.

The economic value of a kg increase in protein yield per cow at the level of the mean for protein yield was $ 4.64 per cow and $ 10.80 per ha for Holstein-Friesians and $ 4.58 per cow and $ 11.83 per ha for Jerseys (Table 4.3.). The economic values expressed as the increase in net returns per unit of phenotypic standard deviation were $ 157.72 per cow and $ 358.08 per ha for Holstein-Friesians and $ 126.24 per cow and $ 331.36 per ha for Jerseys.

Table 4.3.: Production parameters, profit per ha and economic values at different levels of protein yield per cow for Holstein-Friesian and Jersey cows.

Protein		Stocking	Fat+Prot.	Profit	Economic value	
(kg/cow)		rate			(/kg protein)	cows/ha
	kg/ha		$/ha	$/cow	$/ha	
Holstein-Friesian						
50	$-2\sigma_P$	2.390	494	1,232	4.88	11.67
86	$-\sigma_P$	2.329	561	1,618	4.76	11.08
103	$-\sigma_G$	2.299	593	1,804	4.70	10.80
120	μ	2.270	625	1,989	4.64	10.53
137	σ_G	2.243	655	2,162	4.58	10.28
154	σ_P	2.216	684	2,335	4.53	10.03
188	$2\sigma_P$	2.164	742	2,667	4.42	9.56
Jersey						
54	$-2\sigma_P$	2.710	563	1,474	4.80	13.02
82	$-\sigma_P$	2.645	623	1,831	4.69	12.41
96	$-\sigma_G$	2.614	652	2,001	4.64	12.12
110	μ	2.584	681	2,171	4.58	11.83
124	σ_G	2.554	709	2,333	4.53	11.57
138	σ_P	2.525	736	2,492	4.48	11.31
166	$2\sigma_P$	2.469	789	2,802	4.38	10.81

The profit function for different levels of protein yield per cow was non-linear with less economic gain per unit increase in protein yield at the high end of the scale, resulting in a decrease in marginal economic value. However, this digression from linearity was small and resulted in a reduction in the economic value for protein of 0.0008% per kg protein increase. This was equivalent to a 1% decrease of the economic value per cow and a 2% decrease of the economic value per ha for one genetic standard deviation increase in protein yield per cow. Consequently, the effect of non-linearity was ignored in the calculations.

4.3.2. Milkfat

The production of an additional kg of milkfat in the dairy production system described here was estimated to require about 35% more energy than the production of an additional kg of protein. Also, within the current pricing structure the price per kg milkfat was about 80% lower than that for protein. Consequently, a much smaller increase in revenue per ha resulted from increasing milkfat yield rather than from increasing protein yield.

The effects of increasing levels of milkfat yield per cow on energy requirements and other biological and economic farm production system parameters are shown in Table 4.4. Most changes were similar to those resulting from increases in protein yield per cow (Table 4.2.), however, a greater variation of the values for the parameters were found due to a larger variation in milkfat yield and the higher energy requirements per kg milkfat. Consequently, the reduction in stocking rate made possible by increasing milkfat yield per cow was slightly greater than the reduction resulting from an increase in protein yield. Stocking rate was reduced considerably more when an increase of one phenotypic standard deviation of milkfat yield was compared to an increase of one

phenotypic standard deviation of protein yield. Stocking rate was reduced by 5.3% for milkfat yield and 2.3% for protein yield.
As observed for protein, an increase in milkfat yield per cow caused a greater percentage of energy to be used for lactation and thus increased profit and farm efficiency. However, due to the lower price received for milkfat the economic impact of this change was less than that resulting from increased protein production.

Revenue per ha from the various saleable outputs and profits per ha are shown in Figure 4.2. for different levels of milkfat yield per cow for Holstein-Friesians and Jerseys. The functions shown in Figure 4.2. are the revenues from milk, the sum of revenues from milk and bobby calves, the sum of revenues from milk, bobby calves and cull cows and the profit function defined as the sum of revenues from milk and meat minus variable costs.

Revenue per ha from milk increased slightly non-linearly with increasing milkfat yield per cow in both breeds. Revenue per ha from milk were 11% higher for Jerseys than for Holstein-Friesians at the same level of milkfat yield per cow.
Revenue per ha from bobby calves and cull cows decreased with higher milkfat yields per cow. Consequently, the percentage of total revenue derived from meat decreased with increasing milkfat yield.

A steady slightly non-linear increase in profit per ha was observed with increasing milkfat yield per cow in both, Holstein-Friesians and Jerseys (Figure 4.2.). A higher milkfat yield per cow increased profit per ha despite a reduction in stocking rate. The same was observed with increases in protein yield per cow.
Profit per ha was on average 9% higher for Jerseys resulting from the combination of a 11% higher revenue per ha from milk and of a 10% lower revenue per ha from bobby calves and cull

Table 4.4.: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesians and Jerseys with different levels of milkfat yield.

a) Holstein-Friesian

milkfat (kg/cow)	69	112	133	155	177	198	241
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
milk ($/cow)	687	814	876	941	1,006	1,068	1,194
cull cow ($/cow)	74	74	74	74	74	74	74
bobby calves ($/cow)	72	72	72	72	72	72	72
maintenance (ME/cow)	21,046	21,046	21,046	21,046	21,046	21,046	21,046
liveweight (ME/cow)	31,825	31,825	31,825	31,825	31,825	31,825	31,825
Lactation ME requ. (%)	29.86	33.87	35.68	37.44	39.14	40.65	43.55
Stocking rate (cows/ha)	2.55	2.40	2.33	2.27	2.21	2.15	2.05
milk ($/ha)	1,750	1,954	2,046	2,136	2,222	2,299	2,447
cull cow ($/ha)	188	177	173	168	163	159	151
bobby calves ($/ha)	184	174	169	165	160	156	148
Total revenue ($/ha)	2,123	2,305	2,388	2,468	2,546	2,615	2,747
variable costs ($/ha)	537	507	493	479	466	455	433
Profit ($/ha)	1,585	1,799	1,895	1,989	2,080	2,160	2,314
Maintenance (ME/ha)	53,574	50,512	49,131	47,781	46,484	45,330	43,119
Replacements (ME/ha)	22,708	21,410	20,824	20,252	19,703	19,214	18,276
Lactation (ME/ha)	34,488	39,118	41,207	43,248	45,209	46,954	50,298
Liveweight (kg cows/ha)	1,120	1,056	1,027	999	972	948	901
Fat (kg/ha)	176	269	211	352	319	426	494
Protein (kg/ha)	306	289	281	273	266	259	246
Lactose (kg/ha)	406	383	372	362	352	343	327
Energy used for milk (ME/ha)	20,693	23,471	24,724	25,949	27,126	28,172	30,179
Energy " liveweight (ME/ha)	81,012	76,382	74,293	72,252	70,291	68,546	65,202
Energy milk/liveweight (%)	25.54	30.73	33.28	35.91	38.59	41.10	46.29

Table 4.4. continued: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesians and Jerseys with different levels of milkfat yield.

b) Jersey

milkfat (kg/cow)	72	113	133	154	175	195	236
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
milk ($/cow)	677	798	857	918	981	1,040	1,160
cull cow ($/cow)	55	55	55	55	55	55	55
bobby calves ($/cow)	62	62	62	62	62	62	62
maintenance (ME/cow)	18,106	18,106	18,106	18,106	18,106	18,106	18,106
liveweight (ME/cow)	27,104	27,104	27,104	27,104	27,104	27,104	27,104
Lactation ME req. (%)	31.33	35.63	37.53	39.37	41.17	42.76	45.76
stocking rate (cows/ha)	2.93	2.74	2.66	2.58	2.51	2.44	2.31
milk ($/ha)	1,980	2,189	2,282	2,371	2.458	2,536	2,682
cull cow ($/ha)	160	150	145	141	137	133	126
bobby calves ($/ha)	181	170	165	160	155	151	143
Total revenue ($/ha)	2,322	2,509	2,592	2,673	2,751	2,821	2,952
variable costs ($/ha)	568	533	517	502	487	474	449
Profit ($/ha)	1,753	1,976	2,075	2,171	2,264	2,347	2,503
maintenance (ME/ha)	52,981	49,667	48,199	46,779	45,390	44,161	41,848
Replacements (ME/ha)	22,094	20,712	20,099	19,507	18,928	18,416	17,451
Lactation (ME/ha)	36,188	41,149	43,347	45,472	47,551	49,392	52,853
Liveweight (kg cows/ha)	1,053	988	958	930	902	878	832
Fat (kg/ha)	210	310	354	397	439	476	545
Protein (kg/ha)	322	302	293	284	276	269	254
Lactose (kg/ha)	367	344	334	324	314	306	290
Energy used for milk (ME/ha)	21,713	24,689	26,008	27,283	28,531	29,635	31,712
Energy " liveweight (ME/ha)	79,312	74,351	72,153	70,028	67,949	66,108	62,647
Energy milk/liveweight (%)	27.38	33.21	36.05	38.96	41.99	44.83	50.62

cows compared to Holstein-Friesians. This difference in profit per ha between the breeds was larger at low levels of milkfat yield per cow and smaller at high levels.

Variable costs per ha are represented by the difference between the line for the sum of revenues per ha from milk, bobby calves and cull cows and the line for profit per ha (Figure 4.2.). Variable costs per ha declined with increasing milkfat yield per cow due to the lower stocking rate (see also Table 4.5.). This resulted in a slightly greater increase in profit per ha than in revenue from milk per ha with increasing milkfat yield per cow. Variable costs per ha were higher for Jerseys than for Holstein-Friesians at low as well as at high levels of milkfat yield per cow (Table 4.5.).

Both breeds exhibited a much larger phenotypic and genetic variation for milkfat yield per cow (Figure 4.2.) than for protein (Figure 4.1.) which is in agreement with other reports (Hill et al., 1983; Meyer, 1985; Schutz et al., 1990; Ahlborn and Dempfle, 1992; Welper and Freeman, 1992). Additionally, means and phenotypic and genetic variation encountered for milkfat yield per cow were very similar for both breeds, as observed previously for New Zealand dairy cattle (Ahlborn-Breier, 1989; Ahlborn and Dempfle, 1992).

Stocking rates, milk solids production, profit per ha and economic values for milkfat at different levels of milkfat yield per cow and per ha are shown in Table 4.5.
The reduction in stocking rate associated with an increased milkfat yield per cow was considerably higher than that for protein yield increases due to the higher energy requirement for the production of a kg milkfat. Due to the 80% lower price for milkfat a unit change in milkfat yield affected profit per ha less than a unit change in protein yield did.

Results from this study agreed with experimental results

(Ahlborn and Bryant, 1992) and showed that when stocked with equal liveweight per ha Jerseys produce 9% more milk solids per ha than Holstein-Friesians by giving an almost equal protein yield per ha but a higher milkfat yield per ha. This was due to the higher number of Jersey cows per ha resulting from their lower liveweight.

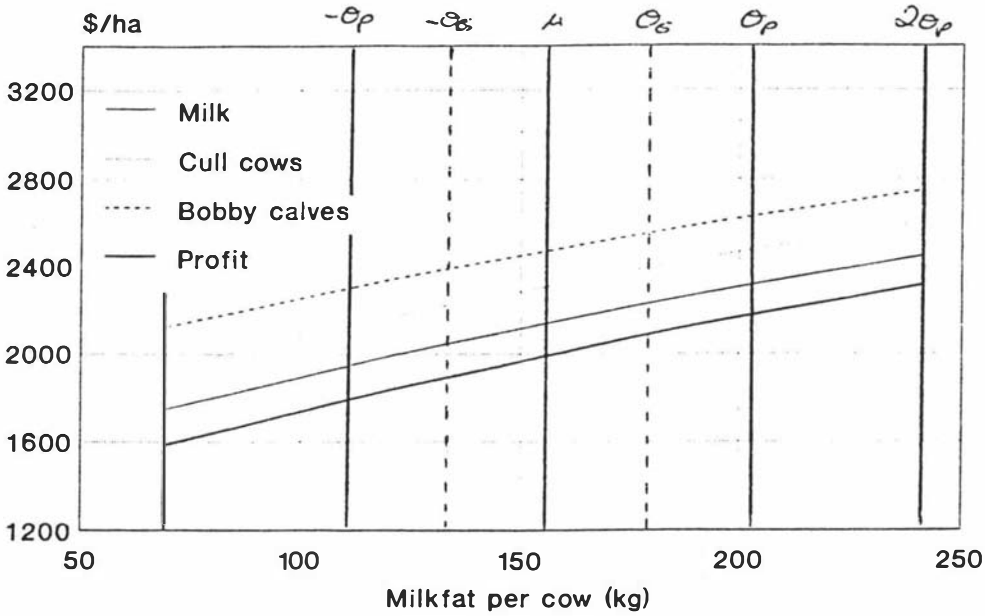
The economic value of a kg increase in milkfat yield per cow at the level of the mean for milkfat yield was $ 1.85 per cow and $ 4.19 per ha for Holstein-Friesians and $ 1.75 per cow and $ 4.51 per ha for Jerseys (Table 4.5.). The economic values, expressed as the increase in net return per unit of phenotypic standard deviation, were $ 79.37 per cow and $ 180.19 per ha for Holstein-Friesians and $ 71.55 per cow and $ 184.86 per ha for Jerseys. These economic values are considerably lower than those for protein (Table 4.3.). These results were in agreement with a similar study carried out for Australian Holstein-Friesians under similar feeding conditions (Beard, 1987).

These results show that the economic value of protein (Table 4.3.) is 2.5 times higher than that for milkfat (Table 4.5.), whereas the price paid by dairy companies per kg protein is only 1.8 times higher than that for milkfat. A similarly higher economic value for protein compared to the price ratio was reported by Beard (1987) and Groen (1989). The difference is due to the lower energy requirements per kg protein thus resulting in lower feed costs associated with increases in protein yield.

The decrease in stocking rate with increasing milkfat yield per cow and the associated increase in milk solids production per ha and so profit per ha in both breeds led to a decreased marginal economic value for milkfat yield per cow, as was also observed for protein yield per cow.
Jerseys returned a lower economic value for a kg increase in milkfat per cow than Holstein-Friesians but a higher economic

Figure 4.2.: Revenue per ha from milk ('milk'), sum of milk and bobby calves ('bobby calves'), sum of milk, bobby calves and cull cows ('cull cows') and profit per ha defined as sum of revenue from milk, bobby calves and cull cows minus variable costs ('profit') at different levels of milkfat yield per cow for Holstein-Friesians and Jerseys (prices for 1991/92 season).

Friesian



Jersey

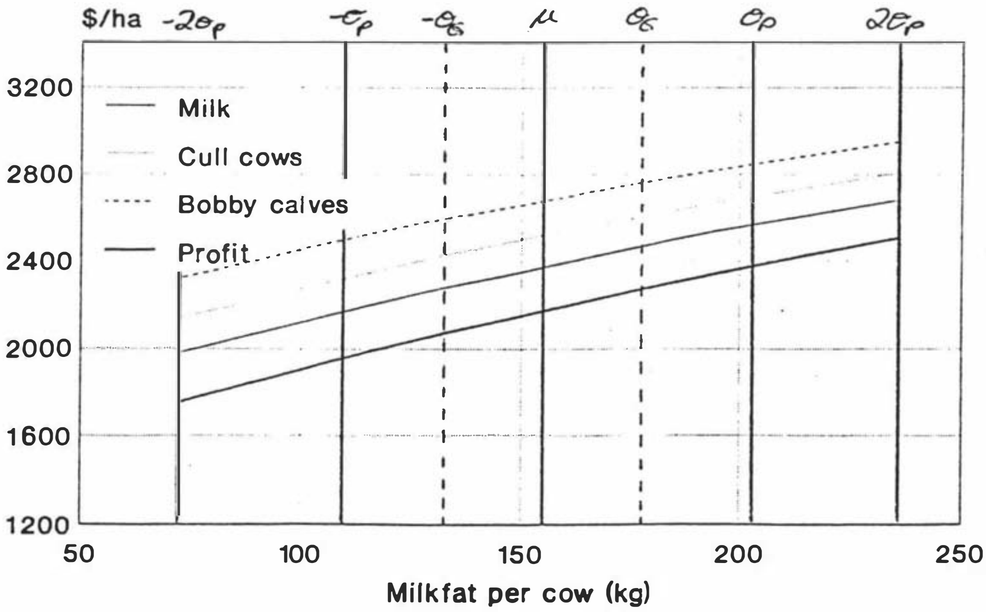


Table 4.5.: Production parameters, profit per ha and economic values at different levels of milkfat yield per cow for Holstein-Friesians and Jerseys.

Milkfat (kg/cow)	Stocking rate	Fat+Prot.	Profit	Economic value ($/kg milkfat)	
	cows/ha	kg/ha	$/ha	$/cow	$/ha
Holstein-Friesian					
69 $-2\sigma_P$	2.546	482	1,585	2.07	5.27
112 $-\sigma_P$	2.400	557	1,799	1.95	4.68
133 $-\sigma_G$	2.334	591	1,895	1.90	4.43
155 μ	2.270	625	1,989	1.85	4.19
177 σ_G	2.209	657	2,080	1.80	3.97
198 σ_P	2.154	685	2,160	1.75	3.77
241 $2\sigma_P$	2.049	740	2,314	1.67	3.41
Jersey					
72 $-2\sigma_P$	2.926	532	1,753	1.98	5.78
113 $-\sigma_P$	2.743	612	1,976	1.85	5.08
134 $-\sigma_G$	2.662	647	2,075	1.80	4.79
154 μ	2.584	681	2,171	1.75	4.51
175 σ_G	2.507	715	2,264	1.69	4.25
195 σ_P	2.439	744	2,347	1.65	4.02
236 $2\sigma_P$	2.311	800	2,503	1.56	3.61

value for a kg increase in milkfat per ha due to their higher stocking rate when compared to Holstein-Friesians. This was also found for protein yield increases.

The profit per ha with increasing milkfat yield per cow produced a slightly non-linear function. However, the departure from linearity was small but somewhat more than for protein yield. For an increase in milkfat yield per cow of one genetic standard deviation the economic values for milkfat deviated from the value at the mean (Table 4.5.) by 0.001% per kg increase in milkfat resulting in a reduction in the economic values of about 3% per cow and 6% per ha. With genetic progress in the order of 1-2% per annum the non-linearity of the profit function can be ignored except for extremely longterm predictions. Consequently, the non-linearity was ignored in the predictive calculations for this study.

4.3.3. Lactose

Lactose is a major milk component and represents about 38% of the solids in milk. For both, Holstein-Friesian and Jersey, lactose is on average 4.6% by volume of the milk produced, and so Holstein-Friesians produce more lactose than milkfat and Jerseys produce less.

Currently, dairy farmers receive no direct monetary return for the lactose shipped with milk supplied to dairy companies. However, between 60% and 70% of the lactose harvested is processed (Olsen, 1992) into products used as pharmaceuticals, infant milk formula, dairy, bakery, confectionary and processed food products. Of the returns from the sale of these products approximately $ 10 million annually were distributed to dairy farmers via a higher payout for milkfat and protein resulting in an average of $ 714 additional payout for the 1991/92 season to each dairy farmer irrespective of the amount of lactose supplied.

Lactose secreted by the cow requires energy for its production and thus competes with milkfat, protein, liveweight and maintenance for the limited amount of DM available in the dairy production system. Under the current pricing system returns from lactose are distributed in equal shares and so production of lactose represents a cost due to its energy requirements without giving any direct revenue. This is evident from Table 4.6. which shows the effect of increases in lactose yield per cow on biological and economic increases in lactose yield per cow on biological and economic production parameters. Higher lactose yields per cow increased the energy requirements per cow for lactation necessitating lower stocking rates. The reduction in stocking rates was less than that for increased protein or milkfat yield, due to the lower energy requirements for each additional kg of lactose when compared to protein and milkfat. As observed with increased protein and milkfat yield per cow the percentage of energy used for lactation increased. However, in contrast to protein and milkfat no direct additional revenue was received for lactose and this resulted in a lower revenue from milk per ha and a reducing profit per ha with increasing lactose yield per cow. These results agree with economic comparisons of Holstein-Friesians and Jerseys at a comparable stocking rate for liveweight (Ahlborn and Bryant, 1992) where the economic superiority of Jerseys was to a large extent due to their lower production of lactose per ha and their channelling of the extra available metabolisable energy into revenue earning milkfat production. Protein production per ha was similar for both breeds.

The declining revenue from milk per ha and profits per ha associated with increasing lactose yield per cow are shown in Figure 4.3. for Holstein-Friesians and Jerseys.
Revenue per ha from milk decreased in a slightly non-linear fashion with increasing lactose yield per cow in both breeds. Revenue per ha from bobby calves and cull cows decreased slightly with higher lactose yield per cow. Due to a much smaller reduction in stocking rate when compared to protein and milkfat this decrease was small by comparison.
In contrast to protein and milkfat, profit per ha decreased with increasing lactose yield for both Holstein-Friesians and Jerseys. While variable costs per ha declined with increasing lactose yield per cow this reduction did not counteract the loss in revenue from the reduction in stocking rate.

Table 4.6.: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesian with different levels of lactose yield.

a) Holstein-Friesian

Lactose (kg/cow)	72	116	137	159	181	203	247
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
milk ($/cow)	941	941	941	941	941	941	941
Cull cow ($/cow)	74	74	74	74	74	74	74
Bobby calves ($/cow)	72	72	72	72	72	72	72
Maintenance (ME/cow)	21,046	21,046	21,046	21,046	21,046	21,046	21,046
Liveweight (ME/cow)	31,825	31,825	31,825	31,825	31,825	31,825	31,285
Lactation ME req. (%)	33.62	35.58	36.47	37.44	38.31	39.18	40.83
Stocking rate (cows/ha)	2.409	2.340	2.306	2.270	2.239	2.207	2.148
milk ($/ha)	2,267	2,200	2,169	2,136	2,107	2,077	2,021
Cull cow ($/ha)	178	173	170	168	165	163	159
Bobby calves ($/ha)	175	169	167	165	162	160	156
Total revenue ($/ha)	2,619	2,542	2,507	2,468	2,434	2,400	2,335
Variable costs ($/ha)	509	494	487	479	473	466	453
Profit ($/ha)	2,111	2,048	2,020	1,989	1,962	1,934	1,882
Maintenance (ME/ha)	50,703	49,204	48,527	47,781	47,121	46,459	45,197
Replacements (ME/ha)	21,491	20,856	20,568	20,252	19,973	19,692	19,157
Lactation (ME/ha)	38,830	41,096	42,121	43,248	44,246	45,248	47,155
Liveweight (kg cows/ha)	1,060	1,029	1,015	999	985	971	945
Fat (kg/ha)	373.2	362.2	357.2	351.7	346.9	342.0	332.7
Protein (kg/ha)	289.7	281.2	277.3	273.0	269.3	265.5	258.3
Lactose (kg/ha)	171.2	269.0	313.3	362.0	405.1	448.3	530.7
Energy used for milk (ME/ha)	23,298	24,658	25,272	25,949	26,548	27,149	28,293
Energy " liveweight (ME/ha)	76,670	74,404	73,379	72,252	71,254	70,252	68,345
Energy milk/liveweight (%)	30.39	33.14	34.44	35.91	37.26	38.65	41.40

Table 4.6. continued: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesian with different levels of lactose yield.

b) Jersey

Lactose (kg/cow)	63	94	109	125	141	156	187
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
Milk ($/cow)	918	918	918	918	918	918	918
Cull cow ($/cow)	55	55	55	55	55	55	55
Bobby calves ($/cow)	62	62	62	62	62	62	62
Maintenance (ME/cow)	18,106	18,106	18,106	18,106	18,106	18,106	18,106
Liveweight (ME/cow)	27,104	27,104	27,104	27,104	27,104	27,104	27,104
Lactation ME req. (%)	36.43	37.93	38.63	39.63	40.07	40.72	42.02
Stocking rate (cows/ha)	2.710	2.645	2.615	2.584	2.554	2.526	2.471
Milk ($/ha)	2,486	2,428	2,400	2,371	2,344	2.319	2,268
Cull cow ($/ha)	148	144	143	141	139	138	135
Bobby calves ($/ha)	168	164	162	160	158	157	153
Total revenue ($/ha)	2,802	2,736	2,705	2,673	2,642	2,613	2,556
Variable costs ($/ha)	526	514	508	502	496	491	480
Profit ($/ha)	2,276	2,222	2,197	2,171	2,146	2,122	2,076
Maintenance (ME/ha)	49,044	47,890	47,352	46,779	46,238	45,736	44,731
Replacements (ME/ha)	20,452	19,971	19,746	19,507	19,282	19,073	18,653
Lactation (ME/ha)	42,081	43,809	44,615	45,472	46,282	47,033	48,538
Liveweight (kg cows/ha)	975	952	942	930	919	909	889
Fat (kg/ha)	416.2	406.4	401.8	397.0	392.4	388.1	379.6
Protein (kg/ha)	298.2	291.2	287.9	284.4	281.1	278.1	272.0
Lactose (kg/ha)	170.8	248.8	285.1	323.8	360.3	394.2	462.1
Energy used for milk (ME/ha)	25,249	26,286	26,769	27,283	27,769	28,220	29,123
Energy " liveweight (ME/ha)	73,419	71,691	70,885	70,028	69,218	68,467	66,962
Energy milk/liveweight (%)	34.39	36.67	37.76	39.67	40.12	41.22	43.49

The graphs show that the mean as well as phenotypic and genetic variation of lactose yield per cow (Figure 4.3.) closely resemble the parameters for milkfat yield of Holstein-Friesians (Figure 4.2.). Similar results have been reported for US Holsteins (Schutz et al., 1990; Welper and Freeman, 1992). However, for Jerseys the mean and phenotypic and genetic variation of lactose yield per cow were similar to protein yield. This represents a much smaller variation in lactose yield per cow for Jerseys when compared to Holstein-Friesians.

Stocking rates, milk solids production, profit per ha and economic values for lactose at different levels of lactose yield per cow are shown in Table 4.7.
Results from this study agreed with experimental results (Ahlborn and Bryant, 1992) which showed that with a stocking rate based on liveweight, Jerseys produce 9% more milk solids per ha than Holstein-Friesians from an almost equal protein yield per ha and a higher milkfat yield per ha due to a higher stocking rate for Jerseys.

The decreasing profit per ha associated with an increase in lactose yield per cow resulted in a negative economic value for lactose.
The economic value of a kg increase in lactose yield per cow at the level of the mean for lactose yield was - \$ 0.57 per cow and - \$ 1.30 per ha for Holstein-Friesians and - \$ 0.62 per cow and - \$ 1.61 per ha for Jerseys (Table 4.7.). The economic values expressed as the increase in net returns per unit of phenotypic standard deviation were - \$ 19.33 per cow and - \$ 57.05 per ha for Holstein-Friesians and - \$ 19.33 per cow and - \$ 49.95 per ha for Jerseys. This represents 12% and 14% of the economic value of a kg protein for Holstein-Friesians and Jerseys, respectively. The economic value of an additional unit of lactose was negative indicating that profit would be increased with a lower lactose yield.

Figure 4.3.: Revenue per ha from milk ('milk'), sum of milk and bobby calves ('bobby calves'), sum of milk, bobby calves and cull cows ('cull cows') and profit per ha defined as sum of revenue from milk, bobby calves and cull cows minus variable costs ('profit') at different levels of lactose yield per cow for Holstein-Friesians and Jerseys (prices for 1991/92 season).

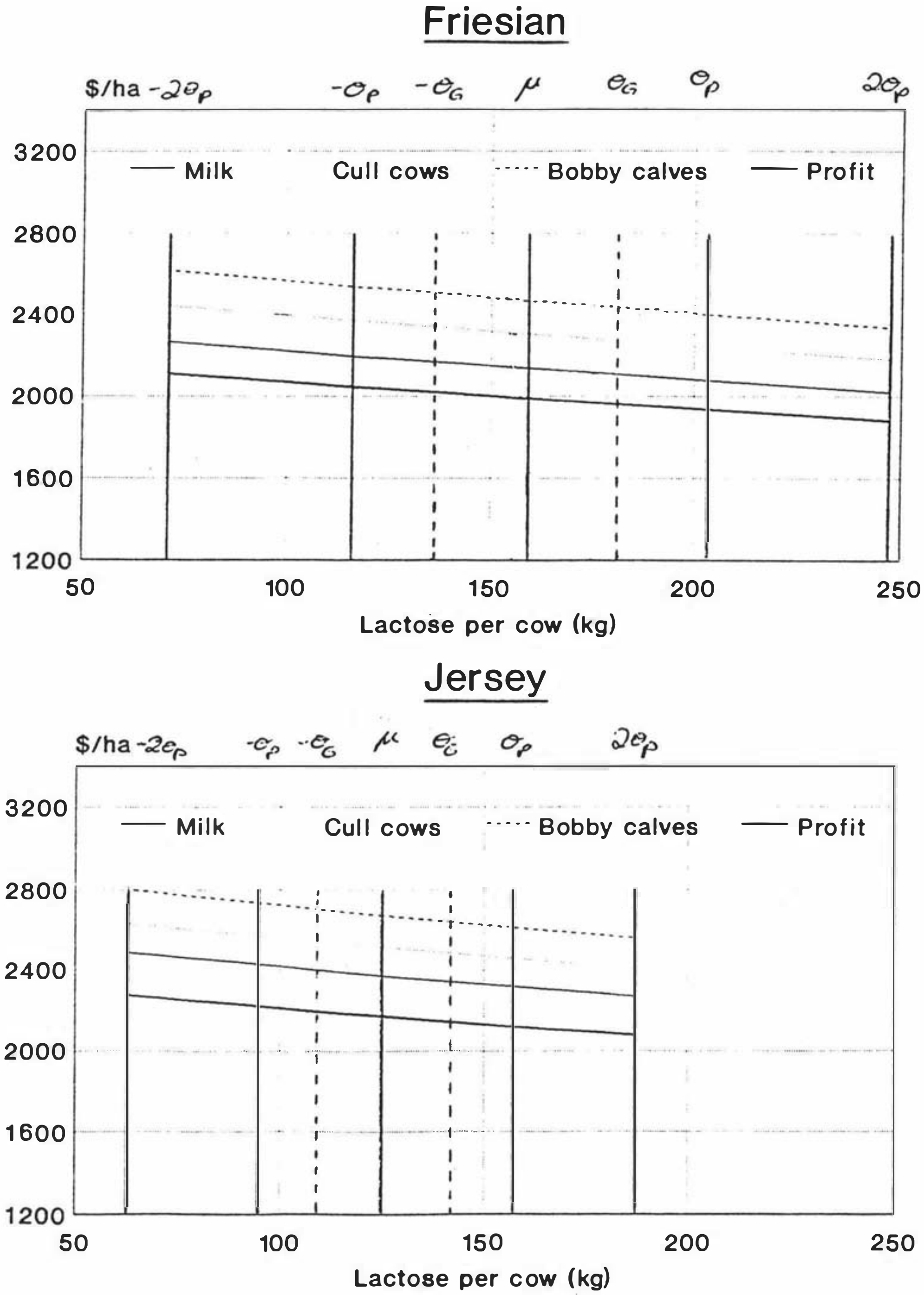


Table 4.7.: Production parameters, profit per ha and economic values at different levels of lactose yield per cow for Holstein-Friesians and Jerseys.

Lactose (kg/cow)		Stocking rate cows/ha	Fat+Prot. kg/ha	Profit $/ha	Economic value ($/kg lactose)	
					$/cow	$/ha
Holstein-Friesian						
72	$-2\sigma_P$	2.409	663	2,111	-0.61	-1.46
116	$-\sigma_P$	2.338	643	2,049	-0.59	-1.38
137	$-\sigma_G$	2.306	635	2,020	-0.58	-1.35
159	μ	2.270	625	1,989	-0.57	-1.30
181	σ_G	2.239	616	1,962	-0.56	-1.26
203	σ_P	2.207	607	1,934	-0.56	-1.23
247	$2\sigma_P$	2.148	591	1,882	-0.54	-1.16
Jersey						
63	$-2\sigma_P$	2.709	714	2,276	-0.65	-1.77
94	$-\sigma_P$	2.645	698	2,222	-0.64	-1.69
109	$-\sigma_G$	2.615	690	2,197	-0.63	-1.65
125	μ	2.584	682	2,171	-0.62	-1.61
141	σ_G	2.554	674	2,146	-0.62	-1.57
156	σ_P	2.526	666	2,122	-0.61	-1.54
187	$2\sigma_P$	2.471	652	2,076	-0.60	-1.47

4.3.4. Milk volume

The economic value was determined from the economic impact of a unit change in milk volume holding genetic levels of all other traits constant. Since milk volume did not affect any other traits or variables the negative economic value per unit of milk volume was equivalent to the charge for transport costs per kg of volume of - \$ 0.0435 per kg for the

1991/92 season (Bodeker, pers. comm., 1993) for both Holstein-Friesians and Jerseys. Consequently, the economic value per ha for a kg milk volume was - $ 0.09 for Holstein-Friesians and - $ 0.11 for Jerseys. The economic values for a phenotypic standard deviation were - $ 41.80 per cow and - $ 94.85 per ha for Holstein-Friesians and - $ 29.15 per cow and - $ 75.31 per ha for Jerseys. In summary, the economic value of milk volume was found to be negative and very small.

4.4. Liveweight

4.4.1. Effects of liveweight changes

Liveweight of cows plays an intricate double-sided role in any dairy production system. On one hand liveweight contributes to revenue in the form of meat sales while on the other hand liveweight adds to costs in the form of maintenance requirements. The importance of liveweight in any specific dairy production system depends on the monetary value of those inputs and outputs that are affected by a change in liveweight.

Revenue from the sale of meat from cull cows and bobby calves comprise about 15% of the gross farm income of a New Zealand dairy farming enterprise (Livestock Improvement, 1991; MAF, 1991; Ahlborn and Bryant, 1992). Liveweight is dependent on body condition and skeletal size (Ahlborn and Dempfle, 1992; Stewart and Taylor, 1992), and an increase in liveweight will increase revenue from meat.

Liveweight is a biological variable which interacts with a large number of variables in the dairy production system and influences production efficiency and so farm income in a number of ways. The bioeconomic model determined the numerous influences of liveweight in a pasture based dairy production system and their impact on net farm income. The area of pasture or the amount of DM available is the limiting factor of the dairy production system modelled here, and the economic value for liveweight gives an indication of the value of a kg of DM whether used for milk or meat production, and their opportunity cost in this competitive situation.

A higher liveweight increases maintenance requirements (Holmes et al., 1992) and thus reduces the efficiency of milk production (Bonczek et al., 1992). Approximately 60% of the variable costs in a dairy production system are directly related to producing or purchasing feed. Therefore the efficiency of the conversion of feed into milk is of prime economic importance. Production efficiency of dairy cattle is usually expressed as gross energy efficiency, which is defined as the ratio of energy contained in milk over the total energy intake from feed (Blake et al., 1986; Buttazoni and Mao, 1989). More than 90% of the cow's total annual energy intake is determined by its energy requirements for lactation and for maintenance of liveweight (Agricultural Research Council, 1980; Holmes et al., 1987). More than 50% of this input is required for liveweight maintenance.

Within breed, small cows are more feed efficient than large cows (Sieber et al., 1988; Yerex et al., 1988). As heavier cows have a higher maintenance requirement than lighter cows (Agricultural Research Council, 1980; Holmes et al., 1987), their higher liveweight results in a lower gross energy efficiency of converting feed into milk or milk solids (Buttazoni and Mao, 1989; Sieber et al., 1988). Variation between cows in net energy required for the production of one unit of milk or the maintenance of one unit of metabolic liveweight is relatively small, and the net energy efficiency for maintenance has a low heritability (Buttazoni and Mao, 1989). The efficiency of physiological processes (digestion, nitrogen and energy uptake or utilization of energy) which convert feed into milk or milk solids is relatively constant within breeds (Trigg and Parr, 1981; Davey et al., 1983), as well as between breeds (Bauman et al.; 1985; Blake et al., 1986). Therefore, differences in gross efficiency are mainly the result of variations in energy requirements for liveweight maintenance.

Pastoral grazing systems present a competitive ad lib feeding situation for cows. In theory every cow is allocated an equal quantity of grass. However, in practice higher producing cows achieve a higher feed intake under this management system (Bryant and Trigg, 1981; Holmes et al., 1981; Davey et al., 1983). Direct measurement of feed intake is difficult for pasture grazing and so an indirect measurement had to be used. In this study the energy requirements for lactation and maintenance of liveweight needed to estimate feed intake were calculated from data obtained by empirical means.

Since all nutrients are derived from pasture, the farm area is the main production limiting factor. The number of cows per unit of area i.e. the stocking rate, is therefore a variable influencing net farm income. Net farm income in a pasture based production system is affected by changes in gross energy efficiency through variations in liveweight.

4.4.2. Economic value of liveweight

Liveweight affected almost all composite variables in the pasture based dairy production system. A higher liveweight required a higher maintenance requirement per cow and this resulted in a lower stocking rate, given that the amount of feed available was a constant. Higher liveweight resulted in higher revenue per cow and per ha from cull cows and bobby calves and the lower stocking rate resulted in lower variable costs per ha. Furthermore, the lower stocking rate reduced per ha production of milkfat, protein and lactose. The benefit of the additional revenue from meat per ha and the reduced variable costs did not compensate for the loss in revenue from milk due to the decreased milk production per ha at the lower stocking rate, and this led to a negative economic value for liveweight. Table 4.8. shows the effects on some production parameters of changes in liveweight of one phenotypic (74 kg for Holstein-Friesians, 40 kg for Jerseys) and one genetic (36 kg for Holstein-Friesians, 16 kg for Jerseys) standard deviation (Table 4.1.). The genetic standard deviation was calculated using the heritability estimates for liveweight from Ahlborn and Dempfle (1992).

The increase in energy requirements per ha for the maintenance of cows and growth and maintenance of heifers with higher liveweights is obvious in Table 4.8. While the energy requirements for lactation did not change per cow with increased liveweight less energy was required for lactation per ha due to the lower stocking rate. Therefore, with a higher liveweight, a lower percentage of the available metabolisable energy was used for milk production.

Changes in production parameters due to a higher liveweight were slightly non-linear and these changes were larger at lower liveweights. This was due to the metabolism requiring relatively less maintenance energy at higher levels of liveweight. For example, for Holstein-Friesians an increase of one phenotypic standard deviation in liveweight from 366 kg to 440 kg decreased stocking rate by 9%, while the same increase in liveweight from 440 kg to 514 kg decreased stocking rate by only 8%.

Table 4.8.: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesians and Jerseys for different levels of liveweight.

a) Holstein-Friesian

Liveweight (kg/cow)	292	366	404	440	476	514	588
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
Milk ($/cow)	941	941	941	941	941	941	941
Cull cow ($/cow)	44	58	66	74	82	91	109
Bobby calves ($/cow)	37	54	63	72	83	94	119
Maintenance (ME/cow)	15,475	18,332	19,741	21,046	22,325	23,649	26,159
Liveweight (ME/cow)	23,068	27,538	29,760	31,825	33,856	35,967	39,989
Lactation ME req. (%)	45.23	40.89	39.03	37.44	36.01	34.62	32.27
Stocking rate (cows/ha)	2.74	2.48	2.37	2.27	2.18	2.10	1.96
Milk ($/ha)	2,580	2,333	2,226	2,136	2,054	1,975	1,841
Cull cow ($/ha)	121	145	157	168	179	191	214
Bobby calves ($/ha)	103	133	149	165	181	198	233
Total revenue ($/ha)	2,804	2,610	2,532	2,468	2,414	2,364	2,288
Variable costs ($/ha)	579	523	500	479	461	443	413
Profit ($/ha)	2,225	2,087	2,032	1,989	1,953	1,921	1,874
Maintenance (ME/ha)	42,437	45,447	46,715	47,781	48,738	49,648	51,176
Replacements (ME/ha)	17,442	18,993	19,670	20,252	20,786	21,303	22,199
Lactation (ME/ha)	52,240	47,228	45,078	43,248	41,588	39,992	37,268
Liveweight (kg cows/ha)	801	907	956	999	1,039	1,079	1,150
Fat (kg/ha)	425	384	367	352	338	325	303
Protein (kg/ha)	330	298	285	273	263	252	235
Lactose (kg/ha)	437	395	377	362	348	335	312
Energy used for milk (ME/ha)	31,344	28,337	27,047	25,949	24,953	23,995	22,361
Energy " liveweight (ME/ha)	63,260	68,272	70,422	72,252	73,912	75,508	78,232
Energy milk/liveweight (%)	49.55	41.51	38.41	35.91	33.76	31.78	28.58

Table 4.8. continued: Changes in energy requirements, revenue and costs per cow and per ha for Holstein-Friesians and Jerseys for different levels of liveweight.

b) Jersey

Liveweight (kg/cow)	280	320	344	360	376	400	440
	$-2\sigma_P$	$-\sigma_P$	$-\sigma_G$	μ	σ_G	σ_P	$2\sigma_P$
Milk ($/cow)	918	918	918	918	918	918	918
Cull cow ($/cow)	40	47	52	55	58	63	71
Bobby calves ($/cow)	35	48	56	62	68	78	97
Maintenance (ME/cow)	14,995	16,575	17,499	18,106	18,706	19,594	21,046
Liveweight (ME/cow)	22,260	24,714	26,155	27,104	28,045	29,441	31,729
Lactation ME req. (%)	44.16	41.59	40.22	39.37	38.56	37.41	35.68
Stocking rate (cows/ha)	2.90	2.73	2.64	2.58	2.53	2.46	2.34
Milk ($/ha)	2,660	2,505	2,423	2,371	2,323	2,254	2,149
Cull cow ($/ha)	116	128	136	141	146	154	166
Bobby calves ($/ha)	101	130	148	160	173	192	226
Total revenue ($/ha)	2,877	2,764	2,707	2,673	2,642	2,600	2,542
Variable costs ($/ha)	563	530	513	502	492	477	455
Profit ($/ha)	2,314	2,233	2,194	2,171	2,150	2,123	2,087
Maintenance (ME/ha)	43,451	45,243	46,192	46,779	47,334	48,110	49,278
Replacements (ME/ha)	17,786	18,702	19,197	19,507	19,804	20,224	20,869
Lactation (ME/ha)	50,998	48,401	46,459	45,472	44,535	43,214	41,209
Liveweight (kg cows/ha)	811	873	908	930	951	982	1,030
Fat (kg/ha)	445	419	406	397	389	377	360
Protein (kg/ha)	319	300	291	284	279	270	258
Lactose (kg/ha)	363	342	331	324	317	308	293
Energy used for milk (ME/ha)	30,599	28,825	27,875	27,283	26,721	25,928	24,725
Energy " liveweight (ME/ha)	64,502	67,459	69,041	70,028	70,965	72,286	74,291
Energy milk/liveweight (%)	47.44	42.73	40.37	38.96	37.65	35.87	33.28

Figure 4.4. shows the slight non-linear trend for the revenue from milk, cull cows, bobby calves and profit per ha. Profit per ha decreased non-linearly.

Higher liveweight clearly decreased profit per ha over a wide range of liveweight (Figure 4.4.). While this decrease was non-linear, Figure 4.4. shows that within the range for liveweight from 280 kg to 580 kg which included 95% of all cows no local minimum was observed. Additionally, as the non-linearity of the profit line is only slight, a linear decrease may be used without much loss in accuracy.

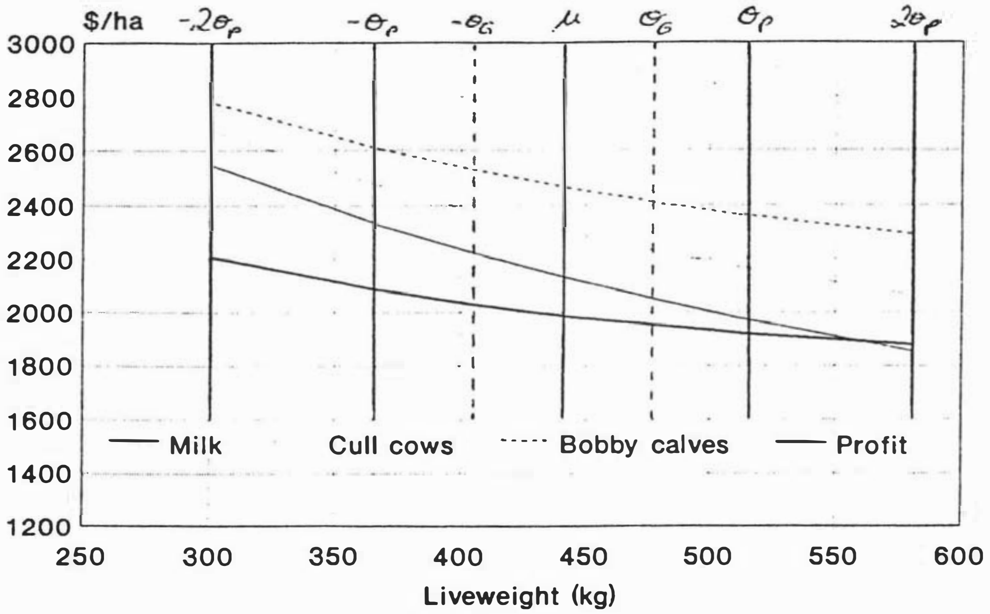
The difference in mean liveweight and the associated genetic and phenotypic variation between Holstein-Friesians and Jerseys was considerable. The lower liveweight of Jerseys resulted in less revenue from meat due to the lower price paid for lighter carcasses.

The resulting economic values for various levels of liveweight are shown in Table 4.9. together with stocking rate, milk solids production per ha and profit per ha.
For the mean of the population the economic value per kg of liveweight was - $ 0.49 per cow for Holstein-Friesians and - $ 0.53 for Jerseys. On a per hectare basis the economic value was - $ 1.10 for Holstein-Friesian and - $ 1.37 for Jerseys at the mean values of 440 kg and 360 kg liveweight respectively.

Other recent simulation studies using profit functions also reported a negative economic value for liveweight (Dempfle, 1986; Van Raden, 1988). Combining body size and production with their respective economic values in the selection objective would therefore result in more accurate estimates of daughter profitability for dairy sires and would increase net farm income in the long term (Ahlborn and Dempfle, 1992).

Figure 4.4.: Revenue per ha from milk ('milk'), sum of milk and bobby calves ('bobby calves'), sum of milk, bobby calves and cull cows ('cull cows') and profit per ha defined as the sum of revenue from milk, bobby calves and cull cows minus variable costs ('profit') at different levels of liveweight for Holstein-Friesians and Jerseys (prices for 1991/92 season).

Friesian



Jersey

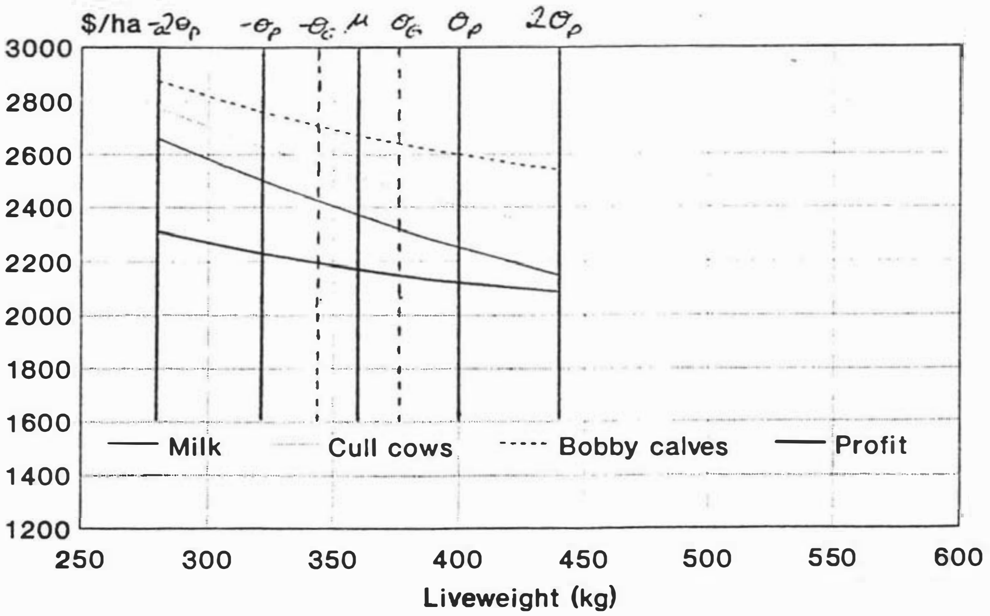


Table 4.9.: Production parameters, profit per ha and economic values at different levels of liveweight for Holstein-Friesians and Jerseys.

Live weight	Stocking rate	Fat+Prot.	Profit	Economic value /kg liveweight	
kg	cows/ha	kg/ha	$/ha	$/cow	$/ha
Holstein-Friesian					
292 $-2\sigma_P$	2.742	755	2,225	-0.81	-2.23
366 $-\sigma_P$	2.479	682	2,087	-0.63	-1.56
404 $-\sigma_G$	2.366	651	2,032	-0.55	-1.31
440 μ	2.270	625	1,989	-0.49	-1.10
476 σ_G	2.183	601	1,953	-0.42	-0.92
514 σ_P	2.099	578	1,921	-0.36	-0.76
588 $2\sigma_P$	1.956	538	1,874	-0.26	-0.50
Jersey					
280 $-2\sigma_P$	2.898	764	2,314	-0.78	-2.27
320 $-\sigma_P$	2.730	719	2,233	-0.65	-1.77
344 $-\sigma_G$	2.640	696	2,194	-0.58	-1.52
360 μ	2.584	681	2,171	-0.53	-1.37
376 σ_G	2.530	667	2,150	-0.49	-1.23
400 σ_P	2.455	647	2,123	-0.43	-1.04
440 $2\sigma_P$	2.341	618	2,087	-0.33	-0.77

4.5. Replacement rate

The cow's herdlife or stayability directly affects the replacement rate. This assumes that available DM, the limiting factor, is to be fully utilised. An increased herdlife or survival rate means fewer annual replacements and the effect of a change in the replacement rate on net farm profit was examined resulting in an estimation of the economic value of the factor herdlife. A change in herdlife affects the replacement rate and so the age distribution of the herd (Cartwright et al., 1975; Azzam et al., 1990) and this was taken into account in the bioeconomic model as described previously (Chapter 3.3.4.). In the following herdlife is expressed as its reciprocal, the replacement rate. Changes in the replacement rate had a number of effects on various production parameters.

When herdlife is reduced and replacement rates are higher more young animals and a lower number of mature cows were carried on the farm. As a result less milk was produced per cow. The associated reduction in energy requirements for milk was found to be slightly greater than the increase in energy requirements for the higher number of young stock and this led to a slightly higher stocking rate of 0.002% (0.005 cows/ha for Holstein-Friesians and 0.006 cows/ha for Jerseys) for each unit increase in replacement rate (Table 4.10.). However, this small increase in stocking rate did not offset the loss in milkfat and protein production per cow, and for each unit increase in replacement rate milkfat and protein yields per ha were reduced by on average 7 kg (Table 4.10.) for both Holstein-Friesians and Jerseys. As the increase in stocking rate was very small the lower milk production per cow resulted in a decrease in revenue from milk per ha.

The sum of the revenue from milk, cull cows and bobby calves and profit per ha for replacement rates between 16% and 28% for Holstein-Friesians and Jerseys are shown in Figure 4.5. Increasing the replacement rate decreased revenue per ha from milk and bobby calves. On the other hand, increasing the replacement rate resulted in more cows being culled. However, the increase in revenue per ha from cull cows per ha was considerably smaller than the loss in revenue from milk and bobby calves (Figure 4.5.). Additionally, variable costs increased per cow and per ha with a higher replacement rate.

These effects were combined in the calculation of profit per ha. The change in net profit per ha per unit increase in

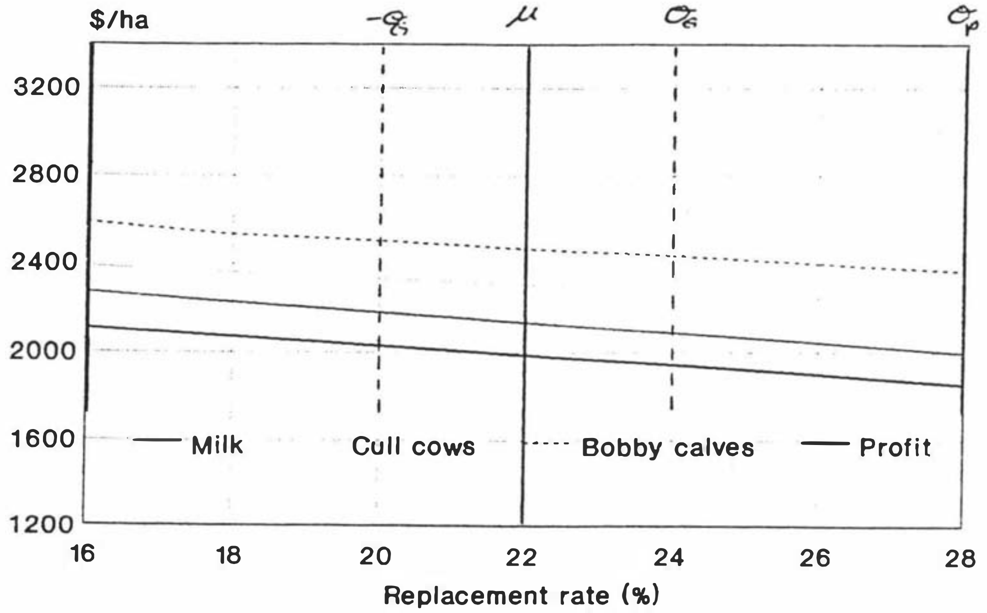
Table 4.10.: Production parameters, profit per ha and economic values at different levels of replacement rates for Holstein-Friesians and Jerseys.

Replmnt. rate	Stocking rate	Fat+Prot.	Profit	Economic value $/% replmnt. rate	
%/a	cows/ha	kg/ha	$/ha	$/cow	$/ha
Holstein-Friesian					
16 $-\sigma_P$	2.242	664	2,110	- 8.47	-18.99
20 $-\sigma_G$	2.260	638	2,031	- 9.29	-20.09
22 μ	2.270	625	1,989	- 9.47	-21.00
24 σ_G	2.280	611	1,946	- 9.65	-22.01
28 σ_P	2.300	584	1,856	-10.02	-23.05
Jersey					
16 $-\sigma_P$	2.544	723	2,309	- 9.04	-22.99
20 $-\sigma_G$	2.570	695	2,218	- 9.34	-24.00
22 μ	2.584	681	2,171	- 9.29	-24.01
24 σ_G	2.597	667	2,122	- 9.24	-24.00
28 σ_P	2.624	639	2,022	- 9.55	-25.06

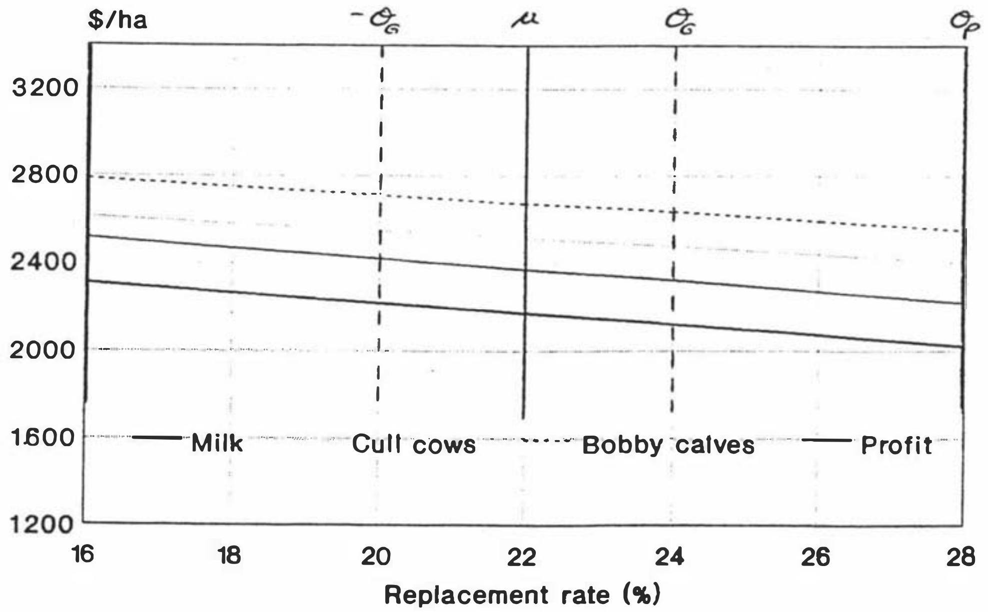
replacement rate and decrease in herdlife was defined as the economic value for replacement rate and herdlife and is shown in Table 4.10. Profit per ha decreased nearly linearly by on average 1% with a relatively stronger decline at high replacement rates (Figure 4.5.). The economic value per ha for a unit (1%) increase in replacement rate ranged between $ -19 and $ -23 per ha for Friesian and between $ -23 and $ -25 per ha for Jersey. The lower value corresponds with low replacement rates and the higher value with high replacement rates (Table 4.10.). The lower economic value for replacement rate for Jerseys was due to a higher loss in milk revenue per ha and a smaller increase in revenue from cull cows when compared to Holstein-Friesians. The economic value per cow varied with increasing replacement rates (Table 4.10.).

Figure 4.5.: Revenue per ha from milk ('milk'), sum of milk and bobby calves ('bobby calves'), sum of milk, bobby calves and cull cows ('cull cows') and profit per ha defined as the sum of revenue from milk, bobby calves and cull cows minus variable costs ('profit') at different levels of replacement rate defined as the reciprocal of herdlife for Holstein-Friesians and Jerseys (prices for 1991/92 season).

Friesian



Jersey



A negative economic value for a unit increase in the replacement rate in the order of - $ 9.25 per cow or - $ 22 per ha showed that an increase in replacement rate had a considerable effect on net farm income. The magnitude of the economic value for replacement rate was twice that of the economic value for a unit (1 kg) increase in protein yield, and about five times the magnitude of the economic value of milkfat (Table 4.5.). This was due to the decrease in stocking rate per unit increase (%/a) in replacement rates of 0.005 for Holstein-Friesians and 0.006 for Jerseys being similar to the decrease in stocking rate resulting from an unit increase (kg) in milkfat yield per cow and about twice as high as the decrease in stocking rate due to a unit increase (kg) in liveweight.

The main factors contributing to this result were the lower milkfat and protein production of the cows due to their lower average age and the increased energy requirements for the higher number of young stock. The results showed a strong negative effect of an increase in replacement rate on net farm income. This indicated that all traits influencing the replacement rate, either through involuntary or voluntary culling, have a significant impact on net farm income.

4.6. **Comparison of economic values for different traits**

Selection objectives must be closely related to the requirements of the production-marketing system and this relationship is expressed in the economic values of various traits. Ranking traits according to their economic importance is a necessary step when assessing the feasibility of including traits in a selection objective. A comparison between traits for breeding aspects needs to take the observed genetic and environmental variation into account.

The magnitude of the effect of an increase of one phenotypic standard deviation in each trait on stocking rate is shown in Table 4.11. As estimates for the environmental variation of replacement rate for the New Zealand dairy production system are not available, the phenotypic variation for replacement rate was estimated by assuming a coefficient of variation of 15%. Clearly, liveweight and milkfat are the variables with the highest impact on stocking rates.

Economic values per cow for all the traits examined are shown in Table 4.12. for Holstein-Friesians and Jerseys. Replacement rate had the highest absolute economic value, followed by protein yield and milkfat yield.
The strong negative economic value of replacement rate in the order of - $ 9.25 per cow and - $ 21.00 per ha reflected the markedly decreased economic efficiency of the New Zealand dairy production system when cows had a shorter herdlife. This result is indirectly supported by the considerably longer average herdlife of 7 years for cows in New Zealand (Ahlborn and Wickham, 1986; Ahlborn-Breier, 1989; Harris, 1989b) when compared to the average herdlife recorded in

Table 4.11.: Comparison of decrease in stocking rates per phenotypic standard deviation increase in various traits for Holstein-Friesians and Jerseys.

	Change in stocking rate (cows/ha)	
	Holstein-Friesian	Jersey
Protein	- 0.054	- 0.059
Milkfat	- 0.116	- 0.145
Lactose	- 0.063	- 0.058
Milk volume	0.000	0.000
Liveweight	- 0.171	- 0.129
Replacement rate	- 0.028	- 0.040

dairy production systems in North America and Europe (Van Arendonk, 1984; Van Arendonk, 1985; Dentine et al., 1987; Kristensen, 1987; Ducrocq et al., 1988; Kristensen, 1989; Dekkers, 1991; Harris and Freeman, 1992). This indicates that New Zealand dairy farmers recognise long herdlife and thus low replacement rates as economically important and substantiates the need for its inclusion in the selection objective.

The result of a lower economic value for lactose (Table 4.12.) when compared to liveweight was unexpected. A unit (kg) increase in lactose yield per cow required 34 MJ ME while a unit increase (kg) of liveweight required 57 MJ ME for Holstein-Friesian and 59 MJ ME for Jersey. The resulting reduction in the stocking rate was more severe for a unit increase in liveweight than for a unit increase in lactose yield. However, for liveweight increases, the loss in revenue from the reduced milk yield per ha associated with a lower stocking rate, was partly counterbalanced by higher revenues from cull cows and bobby calves and also by a

Table 4.12.: Economic values per cow for Holstein-Friesians and Jerseys.

	Holstein-Friesian $/cow	Jersey $/cow
Protein (kg)	4.6389	4.5805
Milkfat (kg)	1.8458	1.7451
Lactose (kg)	- 0.5712	- 0.6235
Volume (l)	- 0.0435	- 0.0435
Lactose and Volume combined (kg)	- 0.0697	- 0.0725
Liveweight (kg)	- 0.4850	- 0.5310
Replacement rate (%)	- 9.2500	- 9.2900

slightly lower variable cost per ha. In comparison, for increases in lactose yield, the loss in revenue from milk yield per ha was offset only by slightly lower variable costs per ha. This resulted in a lower economic value of lactose yield when compared to liveweight.

Lactose and volume have been evaluated here separately to clearly identify the different ways in which these two traits impact on the economics of dairy production. However, lactose and volume are genetically highly correlated and it is currently impossible to change one trait without changing the other. Consequently, the economic values for lactose and volume were combined. This was achieved by expressing the economic value for lactose on a per kg volume basis (Table 3.3.: Holstein-Friesian 4.60% lactose, Jersey 4.69% lactose) and adding this economic value to the economic value for volume. This resulted in an economic value of $ -0.07 for volume and lactose combined for both, Holstein-Friesian and Jersey (Table 4.12.)

Lactose yields are currently not recorded for New Zealand dairy cattle and thus it is not possible to estimate genetic parameters for this trait. Therefore volume was used as a characteristic in the selection index to predict the breeding value of lactose and volume combined in this selection objective (Table 4.12.).

5. SENSITIVITY ANALYSIS

Economic values were obtained in this study by differentiating the profit function with respect to each trait and evaluating the partial derivative at the mean value for all other traits. Accordingly, economic values reflect the increase in profit for specific management and economic circumstances. Changes in parameters and input and output prices can alter the economic values as has been pointed out (Fowler et al., 1976; Vandepitte and Hazel, 1977; Smith, 1983) and evaluated previously in other production systems (De Vries, 1989; Groen and Korver, 1989; Ponzoni and Newman, 1989; Boichard, 1990). The influence of changes in parameters and prices on the economic values can be assessed with a sensitivity analysis (De Vries, 1989; Groen and Korver, 1989). In a sensitivity analysis a range of possible situations, parameter values or changes in inputs and outputs are simulated and evaluated for their effect on the economic values.

Changes in economic and biological variables and parameters were evaluated in this study to test the sensitivity of economic values to changes in price and production circumstances. The changes were simulated with the bioeconomic model. The resulting changes in outputs and efficiencies were analysed with respect to their effect on economic values.
The simulation of changes in the economic variables included the returns for milk components and for meat from cows and calves and the costs of inputs. The range of price changes evaluated for each trait was determined after analysis of past trends and predictions of most likely future trends.
For milk components this included a regression analysis of prices paid to dairy farmers during the last 20 years and estimates of the future price ratio between protein and milkfat and potential future prices for lactose and volume.

The range of potential price changes for meat prices were derived from a regression analysis of meat prices during the last 20 years.
Changes in variable costs experienced during the last six years were derived from an analysis of dairy farmer's accounts and used in this sensitivity analysis as the best estimate of future changes.
Changes in the biological parameters were assumed to occur within the potential biological variation. As statistical parameters are not known for a large number of biological parameters like efficiency constants a change of 10% was tested in the sensitivity analysis for these parameters.

The sensitivity analysis identified parameters and variables with a strong influence on economic values. A variable was considered to have a strong influence on the economic value if the expected range of changes increased or decreased an economic value by more than 25%. These parameters and variables need to be frequently re-evaluated to ensure a close alignment between the breeding objective and dairy farm profitability.

5.1. Economic variables

5.1.1. Returns for milk components

Longterm price movements were predicted and their effects evaluated in a sensitivity analysis. The analysis was based on changes in the production system which could be achieved according to the phenotypic and genetic parameters estimated for the population under study.

In this sensitivity analysis the effects of price changes of single milk components on their economic worth was evaluated. Estimates for expected future returns for the major milk components were derived from an analysis of prices received by New Zealand dairy farmers during the last 20 years.

Until recently, the returns for milk to the New Zealand dairy farmer were directly proportional to the milkfat content of the milk. These returns were therefore used in historical comparisons. Table 5.1. shows nominal (Livestock Improvement, 1990) and inflation-adjusted prices paid per kg milkfat during the last 20 years. The inflation-adjustment was based on December 1990. It is evident that the real price per kg milkfat paid to farmers showed a steady downwards trend and has been more volatile since 1985 (Figure 5.1.). The regression for this inflation-adjusted decline over the period 1970 - 1992 was estimated as:

1970-1992: NZ(1990) \$/kg milkfat = \$ 273.32 - \$ 0.1345 year

The standard error for the regression coefficient was \$ 0.0267/kg milkfat*year. This regression coefficient was used to estimate the expected future returns for milk.

Figure 5.1.: Real (inflation-adjusted to Dec. 1990) prices for milkfat and meat from cull cows and bobby calves during the last 20 years.

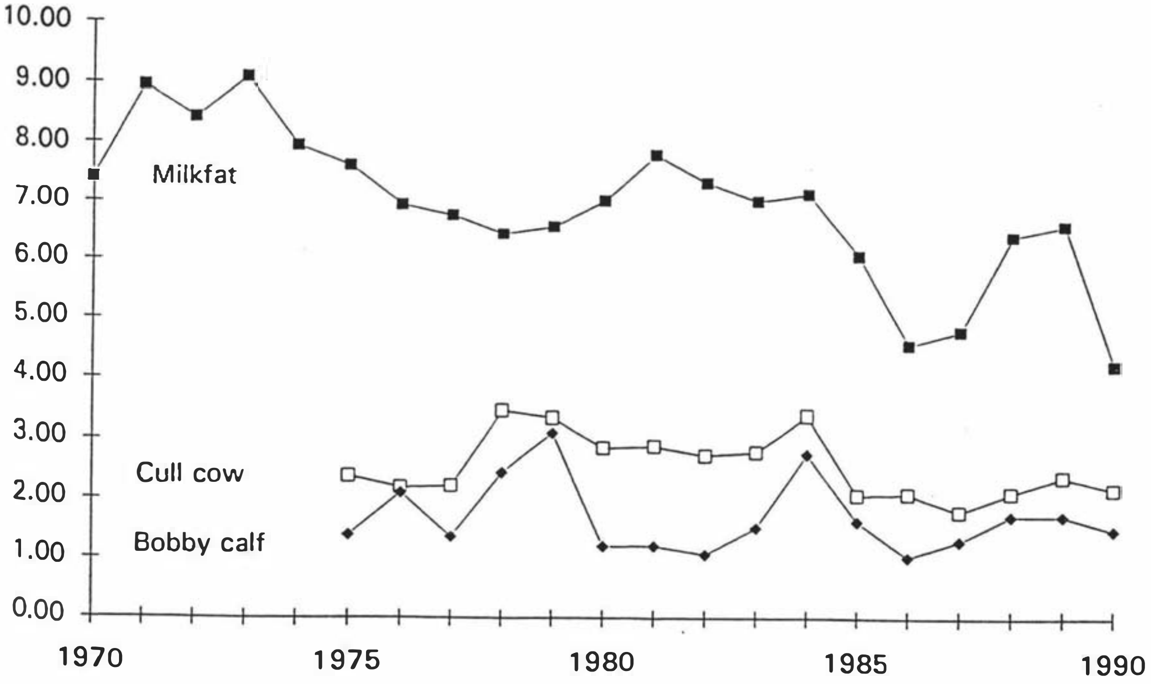


Table 5.1.: **Prices for milkfat, cull cow carcass and bobby calves (nominal and inflation-adjusted [December 1990]).**

	Inflation-adjusted price			Nominal price			
Year	Milkfat $/kg	Cull cow $/kg	Bobby calf $/kg	Milkfat $/kg	Cull cow $/kg	Bobby calf $/kg	Bobby calf $/hd.
1970	7.41			0.85			
1971	8.95			1.12			
1972	8.41			1.11			
1973	9.08			1.32			
1974	7.95			1.30			
1975	7.61	2.38	1.39	1.44	0.45	0.26	8.43
1976	6.94	2.19	2.11	1.52	0.48	0.46	14.76
1977	6.78	2.22	1.37	1.71	0.56	0.35	11.05
1978	6.44	3.45	2.44	1.79	0.96	0.68	21.68
1979	6.58	3.34	3.09	2.13	1.08	1.00	32.05
1980	7.02	2.85	1.21	2.64	1.07	0.46	14.57
1981	7.79	2.87	1.22	3.39	1.25	0.53	17.03
1982	7.32	2.71	1.06	3.67	1.36	0.53	17.04
1983	7.00	2.77	1.52	3.64	1.44	0.79	25.25
1984	7.14	3.38	2.75	4.06	1.92	1.56	50.00
1985	6.07	2.08	1.64	3.98	1.36	1.07	34.30
1986	4.57	2.09	1.04	3.54	1.62	0.81	25.79
1987	4.79	1.80	1.31	4.07	1.53	1.11	35.66
1988	6.41	2.11	1.73	5.70	1.88	1.54	49.20
1989	6.61	2.38	1.73	6.30	2.27	1.65	52.90
1990	4.23	2.17	1.48	4.23	2.17	1.48	47.50
1991	6.00	2.14	1.52	6.05	2.16	1.53	47.70
1992	6.50						

a) Protein

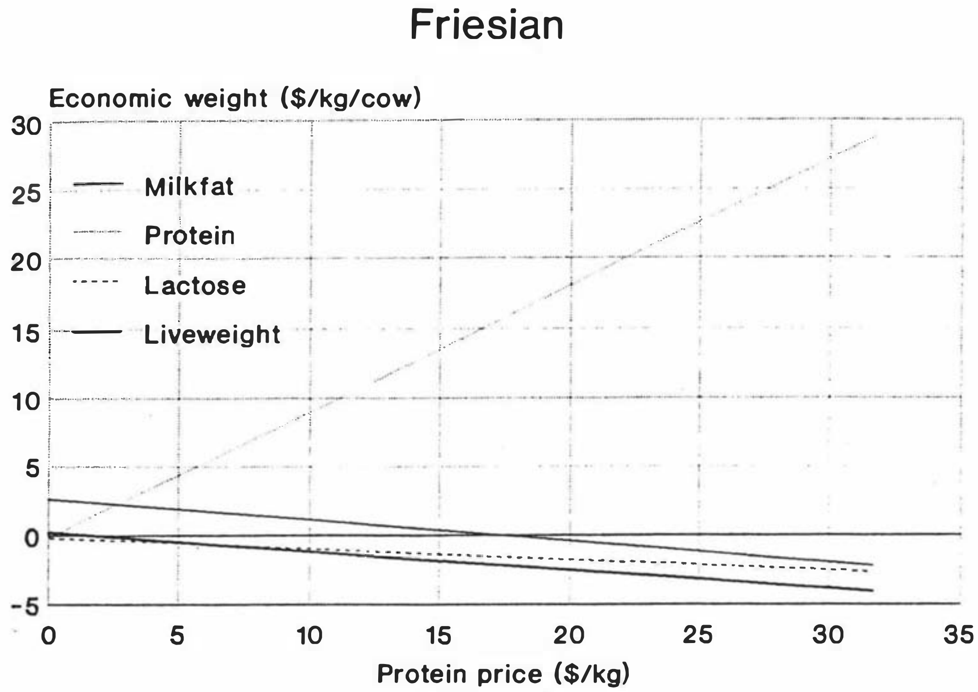
A worldwide trend of higher prices for protein than for milkfat has been reported (Rodenburg, 1990). Improved returns are due to the recognition of the nutritional value and wide-ranging functionality of protein. Additionally, most dairy products containing protein have experienced price increases (Sheppard and Urquhart, 1991) in recent years. In particular, the demand for dairy products or milk components used as ingredients in commercially produced foods for the retail market grew faster than the demand for dairy products in consumer catering markets (Sliter, 1990). The versatility of the physical properties of proteins has made possible a wide range of these products. This diversification is likely to continue in the future, so increasing the demand for protein.

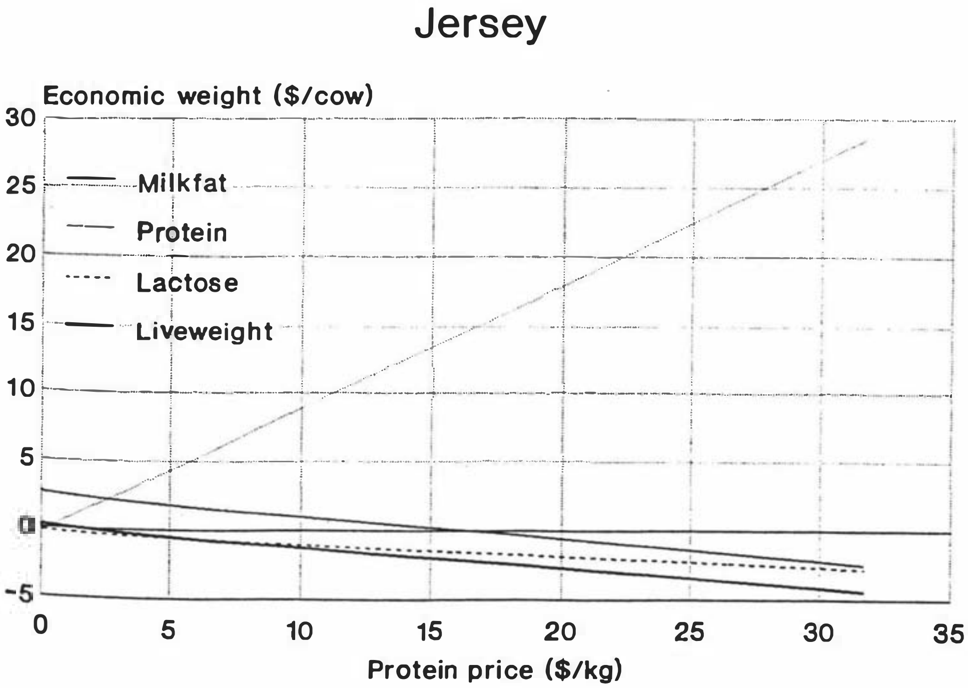
The higher returns for protein are now reflected in the change from a payment based on milkfat content only to a payment based on milk solids (Sliter, 1990). Changes in product ratios encountered due to a reduced butter production (Sheppard and Urquhart, 1991) resulted in changes in the ratio of the values of milkfat and protein. Consequently, milk component pricing systems which took the value of protein into account were introduced for the New Zealand dairy production system reflecting the increasing value of protein.

In New Zealand, the relative returns for protein and milkfat are estimated from returns from overseas markets for the six major dairy products: butter or anhydrous milkfat, cheese, casein, wholemilk powder, skimmilk powder and buttermilk powder. These products comprise 95% of all New Zealand dairy exports. For the sensitivity analysis, manufacturing and other direct costs are subtracted from the returns and apportioning of the components used in the manufacture of each specific product gives the ratio of returns for milkfat and protein (Nichol, pers. comm., 1991). The ratio of returns from milkfat and protein declined considerably during the last years dropping from 1.83:1.00 (milkfat : protein) in 1986/87 to 0.56:1.00 in 1989/90 and is expected to fall to a ratio of 0.1:1.0 during the next 10 to 15 years (New Zealand Dairy Board, 1991b). Accordingly, the returns received by dairy farmers for milkfat decreased relative to the returns received for protein since the milk component pricing system has been introduced in 1987 from an initial returns ratio of 1.03:1.00 (milkfat : protein) (Beckett, pers. comm.: Nicholl, pers. comm., 1990) to 0.6:1.00 in 1991/92 (Anonymous, 1992). It is expected that this trend will continue resulting in increasing returns for protein in the near future due to its greater versatility and higher monetary value.

This scenario was simulated by assuming protein returns between the limits zero and three times the current price (1991/92 season) paid per kg protein. For all other variables the prices for the 1991/92 season were used. The economic values per cow resulting from this simulation are shown in Figure 5.2. for Holstein-Friesians and Jerseys. Results showed that with increasing returns for protein the economic value per cow for protein increased and the economic values for all other milk components and liveweight decreased. Figure 5.2. also shows the lesser decline in the economic value for lactose compared to those for milkfat and liveweight.
The effects of changes in the price paid for protein on the economic values were similar in Holstein-Friesians and Jerseys.

Figure 5.2.: Changes in economic values for protein, milkfat, lactose and liveweight for Holstein-Friesians and Jerseys with an increasing price for protein.





Returns for protein were indirectly decreased if under constant prices the ratio of returns of milkfat : protein changes in favour of milkfat. The effect of different price ratios of milkfat : protein on profit per ha and profit per cow and on other economic values per ha is shown in Table 5.2. The table is based on a milkfat price equivalent of $ 6.00/kg, which represents the 1991/92 season payout.

Results showed that with decreasing protein value profit per ha increased. Accordingly, economic values for protein declined and economic values for milkfat increased. The reason for this result was that milk contains more milkfat than protein. Economic values for lactose and volume were only marginally affected by changes in the milkfat : protein price ratio. These results were similar to those reported in a study of the Australian dairy farming industry (Beard, 1987).

The effect on the economic values for liveweight, due to variations in the returns for protein differed between Holstein-Friesians and Jerseys. In Jerseys increases in liveweight became less economic with decreasing protein returns. In Holstein-Friesians liveweight increases were less economic with decreasing protein price but at very low protein values e.g. a milkfat : protein price ratio of 1.83 : 1 slightly more economic. With a very low but positive price for milkfat, e.g. a milkfat : protein price ratio of 0.1 : 1, the economic value for milkfat became negative for both, Holstein-Friesians and Jerseys.

Predicted returns for milk in ten (year 2001) and twenty (year 2011) years time based on the inflation-adjusted regression equation for milkfat (5.1.1.) in combination with a milkfat : protein price ratio of 0.1 : 1 are also shown in Table 5.2. These results indicated that the economic value for protein will increase considerably to the detriment of milkfat. Furthermore, the economic value for lactose will become less negative and the economic value for liveweight could become positive for both Holstein-Friesians and Jerseys.

Table 5.2.: Changes in profit per ha and per cow with increasing protein prices for Holstein-Friesians and Jerseys (* = base model).

Protein price ($/kg)	Milkfat price ($/kg)	Price ratio F/P	Profit		Economic value/ha				
			/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Liveweight (kg)
Holstein-Friesian									
Milkfat equivalent $(NZ 1990) 6.00 / kg milkfat									
$ 8.13	$ 0.09	0.10	1,762	776	17.17	-2.01	-1.15	-0.09	-0.85
$ 5.71	$ 2.63	0.46	1,995	879	11.51	3.46	-1.30	-0.09	-1.11
$ 5.27 *	$ 2.95	0.56	1,987	875	10.51	4.20	-1.30	-0.09	-1.10
$ 4.90	$ 3.23	0.66	1,985	874	9.67	4.84	-1.29	-0.09	-1.10
$ 2.68	$ 4.90	1.83	1,966	866	4.65	8.65	-1.28	-0.09	-1.07
Year 2001	**Predicted milkfat equivalent of $(NZ 1990) 4.19/kg**								
$ 6.00	$ 0.07	0.10	1,340	590	7.85	3.26	-0.87	-0.09	-0.37
Year 2011	**Predicted milkfat equivalent of $(NZ 1990) 2.84/kg**								
$ 4.41	$ 0.05	0.10	732	326	9.48	-0.81	-0.48	-0.10	0.30
Jersey									
Milkfat equivalent $(NZ 1990) 6.00 / kg milkfat									
$ 8.13	$ 0.09	0.10	1,848	715	19.47	-2.41	-1.37	-0.11	-0.94
$ 5.71	$ 2.63	0.46	2,168	839	12.95	3.69	-1.61	-0.10	-1.37
$ 5.27 *	$ 2.95	0.56	2,169	840	11.81	4.52	-1.61	-0.10	-1.37
$ 4.90	$ 3.23	0.66	2,175	842	10.85	5.23	-1.61	-0.10	-1.38
$ 2.68	$ 4.90	1.83	2,207	854	5.09	9.50	-1.64	-0.10	-1.42
Year 2001	**Predicted milkfat equivalent $(NZ 1990) 4.19/kg**								
$ 6.00	$ 0.07	0.10	1,233	477	14.48	-1.59	-0.92	-0.11	-0.13
Year 2011	**Predicted milkfat equivalent $(NZ 1990) 2.84/kg**								
$ 4.41	$ 0.05	0.10	773	299	10.75	-0.98	-0.57	-0.11	0.47

Table 5.3.: Changes in profit per ha and per cow and economic values for milk prices predicted for the year 2001 and 2011 (predicted prices based on regression from 1970 - 1992, milkfat : protein price ratio of 0.56 : 1) for Holstein-Friesians and Jerseys (1991/92 season prices for other variables).

Protein	Milkfat	Year	Profit		Economic value/ha				
($/kg)	($/kg)		/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Liveweigt (kg)
Holstein-Friesian									
$ 4.91	$ 2.75	1991	1,818	801	9.81	3.96	-1.19	-0.09	-0.91
$ 3.89	$ 2.18	2001	1,340	590	7.85	3.26	-0.87	-0.09	-0.37
$ 2.86	$ 1.60	2011	854	376	5.87	2.56	-0.56	-0.10	0.17
Jersey									
$ 4.91	$ 2.75	1991	1,988	769	11.04	4.26	-1.47	-0.10	-1.13
$ 3.89	$ 2.18	2001	1,471	569	8.83	3.53	-1.09	-0.11	-0.45
$ 2.86	$ 1.60	2011	948	367	6.60	2.78	-0.70	-0.11	0.24

Changes in economic values due to decreasing returns for milk are shown in Table 5.3. for Holstein-Friesians and Jerseys. Milk prices were estimated from the regression equation and the milkfat : protein price ratio was assumed constant at 0.56 : 1. Results showed that declining returns for milk decreased economic values for all milk components except lactose which became less negative. As the relative return for meat increases with decreasing milk prices economic values for liveweight increased and became positive.

b) Milkfat

The future of milkfat has been debated in most dairy producing countries and also in most sectors of the New

Zealand dairy industry. Very small and even negative future values have been suggested. Prices received for butter are normally used as indicators for the value of milkfat. World production of butter is expected to increase by 2% annually over the next few years (Brown, 1991) against a worldwide decline in consumption estimated at 3% per year. The major causes for this development are the high price of butter relative to other fats, the development of competing products, health and nutritional considerations and a reduction in government subsidies. Since none of these causes for the decline in butter consumption is likely to be reversed in the near future, prices for butter are expected to continue to decline (Brown, 1991). The manufacture of butter allows the production of skim milk powder as a joint process, which indirectly increases the value of milkfat. Additionally, it needs to be considered that the other main export products, cheese and whole milk powder, also contain considerable amounts of milkfat and could not be made without it. Thus, milkfat will always have some value.

In New Zealand, a large part of dairy export returns are still derived from butter even though its importance is declining. In 1989/90 28% of the total dairy export values (FOB) came from butter. In 1990/91 the percentage was 21%. The figures for cheese were 14% and 15% respectively (Sheppard and Urquhart, 1991). The lower amount of butter produced in New Zealand during 1990/91 was a reflection of the reduction in the EEC butter quota. Until recently the quota agreement guaranteed EEC butter prices at considerably higher than world market prices for a predetermined tonnage of New Zealand butter exported to the United Kingdom. This resulted in a relatively high price for milkfat in New Zealand when compared to the prevailing world market price and resulted in a sharp drop in milkfat returns since the reduction in the quota.

New Zealand milk contains on average 4.8% milkfat (New

Zealand Dairy Board, 1991a) and butter has an average milkfat content of 81% (Australian Dairy Corporation, 1991). From these figures it can be estimated that 49% of all milk processed (for manufacturing) was used to produce butter, which comprised only 28% of the total dairy export values. Worldwide, this percentage was even higher. Using data from Sliter (1990) it was estimated that in 1989 approximately 59% of the world's (processing) milk supply was utilized for the manufacture of butter. Based on the above information, it was considered unlikely that the price for milkfat would increase substantially in the near future.

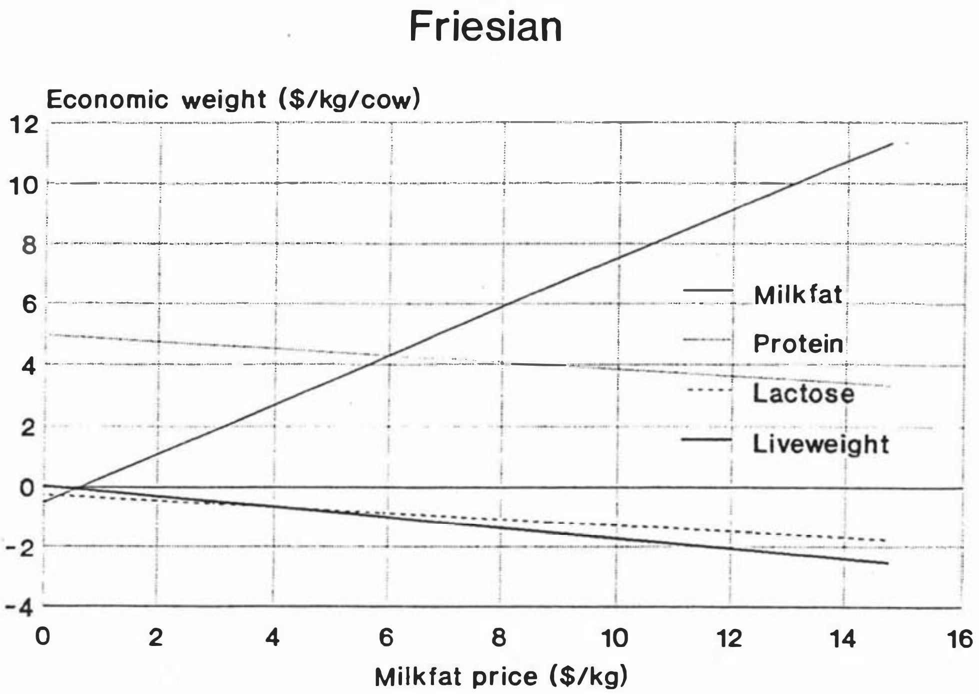
Accordingly, changes in the milkfat price were evaluated over the range from a slight penalty to twice times the current milkfat price of $ 2.95/kg milkfat. For other input or output variables prices for the 1991/92 season were used. Economic values per cow for protein, milkfat, lactose and liveweight corresponding to these increases in milkfat price are shown in Figure 5.3. for both, Holstein-Friesians and Jerseys. The economic values of protein and lactose decreased at a similar rate while the decline for the economic value of liveweight was higher.

Economic values per ha and profit per cow and per ha for different milkfat prices are shown in Table 5.4. With an increase in the milkfat price of 100% the economic values per ha for protein, milkfat, lactose, milk volume and liveweight changed from $ 10.53, $ 4.19, $ -1.30, $ -0.09, $ -1.10, respectively, for the base model to $ 9.77, $ 9.58, $ -1.97, $ -0.09 and $ -2.26 for Holstein-Friesians. A similar reduction in economic values for protein, lactose, volume and liveweight was observed for Jerseys.

A higher milkfat price decreased the economic values for protein, lactose, volume and particularly liveweight linearly.

Differences between breeds in the variation of economic

Figure 5.3.: Changes in economic values for protein, milkfat, lactose and liveweight for Holstein-Friesians and Jerseys with an increasing price for milkfat.



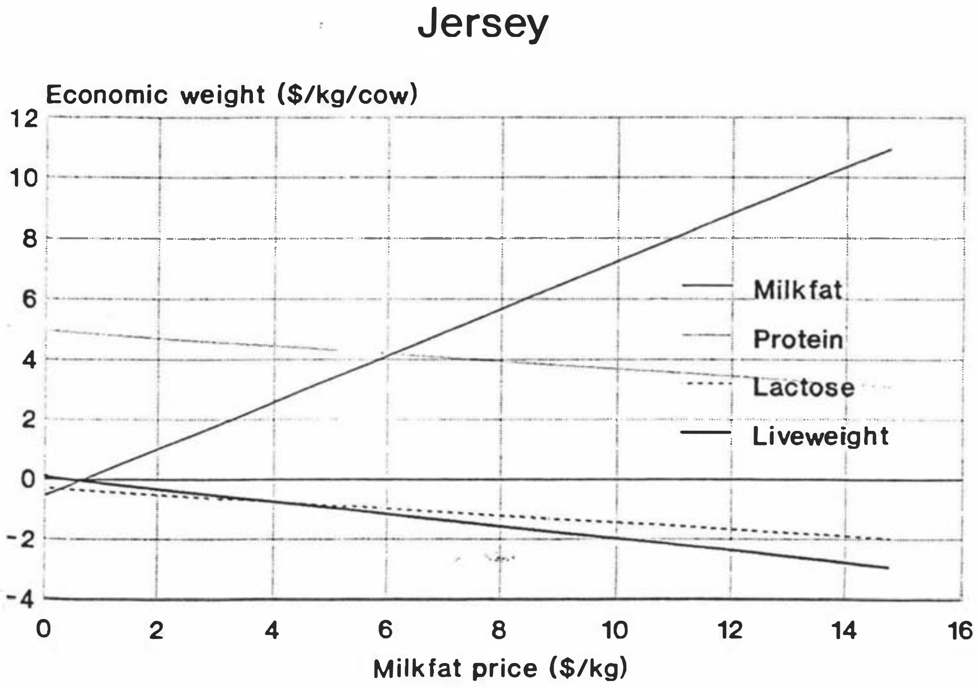


Table 5.4.: Changes in profit per ha and per cow resulting from increasing milkfat prices for Holstein-Friesians and Jerseys (* = base model).

Milkfat price ($/kg)	Change %	Price ratio F/P	Profit		Economic value/ha				
			/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Liveweight (kg)
Holstein-Friesian									
$ 1.474	-50	0.28	1,471	647	10.91	1.50	-0.96	-0.09	-0.52
$ * 2.948	0	0.56	1,989	876	10.53	4.19	-1.30	-0.09	-1.10
$ 4.422	+50	0.84	2,508	1,105	10.15	6.88	-1.63	-0.09	-1.68
$ 5.896	+100	1.12	3,026	1,333	9.77	9.58	-1.97	-0.09	-2.26
$ 8.844	+200	1.68	4,063	1,790	9.02	14.97	-2.65	-0.08	-3.42
Jersey									
$ 1.474	-50	0.28	1,586	614	12.32	1.54	-1.18	-0.11	-0.60
$ * 2.948	0	0.56	2,171	840	11.84	4.51	-1.61	-0.10	-1.37
$ 4.422	+50	0.84	2,756	1,067	11.35	7.48	-2.05	-0.10	-2.15
$ 5.896	+100	1.12	3,342	1,293	10.86	10.45	-2.48	-0.10	-2.92
$ 8.844	+200	1.68	4,512	1,746	9.89	16.39	-3.35	-0.09	-4.47

values resulting from increasing milkfat prices were small. Reductions in the economic values for protein, lactose and volume were very similar for both Holstein-Friesians and Jerseys but a much stronger decline in the economic value for liveweight was observed for Jerseys than for Holstein-Friesians. This was due to the lower returns from meat for Jerseys and the resulting higher loss in revenues when using energy for increasing liveweight compared to milk production.

c) Lactose

Lactose has as yet not been included in the payment system. The New Zealand dairy industry processes between 60% and 70% of the lactose extracted from raw milk (Olson, 1992). Returns from the resulting products are distributed among all suppliers without any accounting for the actual amount of lactose supplied. Steady advances in manufacturing technology and improvements in efficiency of the processes combined with a higher demand and developments of new food ingredients might lead to a higher return for lactose products and subsequently a payment system accounting for the lactose supplied.

The effect of a positive price for lactose, e.g. a payment system including prices paid for protein, milkfat and lactose and a penalty for volume, are shown in Table 5.5. for Holstein-Friesians and Jerseys. Any increase in the return for lactose in the future has to outweigh the increased energy requirements for its production to result in a positive economic value for lactose.

A payment for lactose of 10% of the value of protein with a payout of $ 6.00 (as used in the base model) is shown in Table 5.5. Due to the high processing costs it was considered unlikely that a payment for lactose would be higher than 10% of the price value of protein. The results showed that including payment for lactose increased profit per ha and per cow only marginally. Economic values for protein and milkfat decreased to a similar extent in both breeds. However, a payment of lactose in the order of 10% of the price of protein was not sufficient to counteract the energy requirements for the production of lactose. This resulted in a still negative, yet much smaller, economic value for lactose when compared with a nil payment for lactose. The change in the economic value for lactose was slightly more pronounced for Jerseys than for Holstein-Friesians. Economic values for liveweight were only marginally affected.

Table 5.5.: Changes in profit per ha and per cow due to an increased value for lactose for Holstein-Friesians and Jerseys (* = base model).

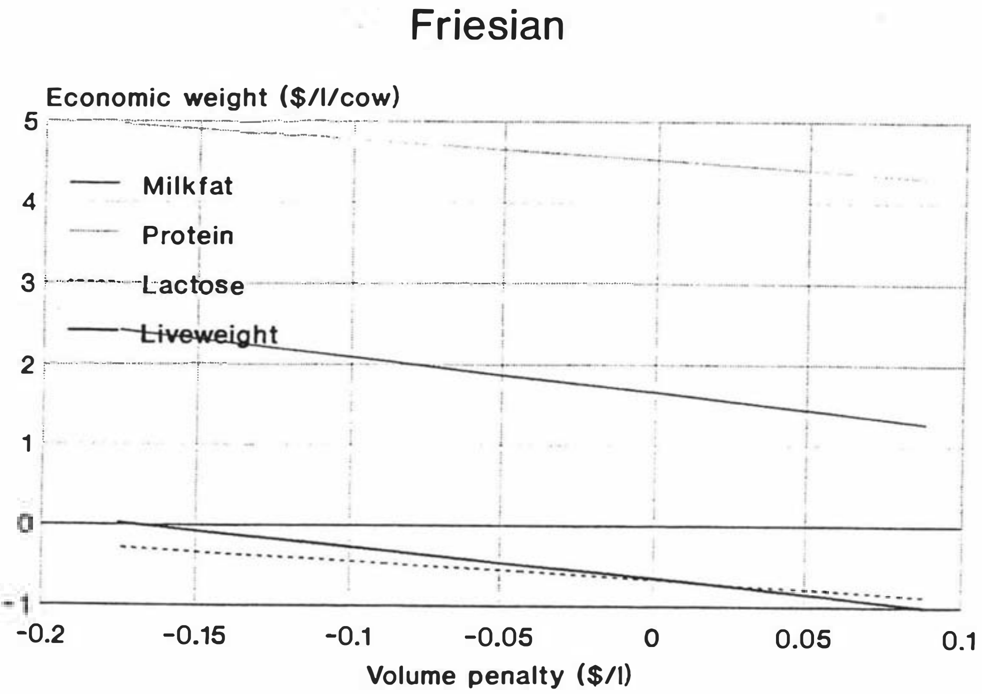
Protein	Milkfat	Lactose	Profit		Economic value/ha				
($/kg)	($/kg)	($/kg)	/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Liveweight (kg)
Holstein-Friesian									
$ * 5.279	2.948	0.00	1,989	876	10.53	4.19	-1.30	-0.09	-1.10
$ 4.913	2.751	0.49	1,998	880	9.69	3.73	-0.19	-0.09	-1.11
Jersey									
$ * 5.279	2.948	0.00	2,171	840	11.84	4.51	-1.61	-0.10	-1.37
$ 4.913	2.751	0.49	2,148	831	10.91	4.03	-0.32	-0.10	-1.34

d) Volume

Volume charges take the cost of processing high volumes of milk into account. This is of particular importance in a dairy industry like New Zealand's where 95% of the milk is used for manufacturing (New Zealand Dairy Board, 1991a). Large differences in milk component levels exist in the New Zealand dairy industry due to the use of two main breeds with vastly different milk component percentages. Volume charges have a direct influence on net farm income. In contrast to lactose, volume does not require any extra energy to be produced and thus does not affect any of the other biological variables.

A higher volume charge increased economic values per cow for all other traits as is shown graphically in Figure 5.4. The range of volume penalties evaluated ranged from plus to minus 300% of the volume charge used in the base model of $ 0.0435 per litre. Increases in economic values were of similar extent for protein, milkfat and liveweight, while the increase for lactose was slightly lower. This was observed for both Holstein-Friesians and Jerseys.

Figure 5.4.: Changes in economic values for protein, milkfat, lactose and liveweight for Holstein-Friesians and Jerseys due to changes in volume penalty.



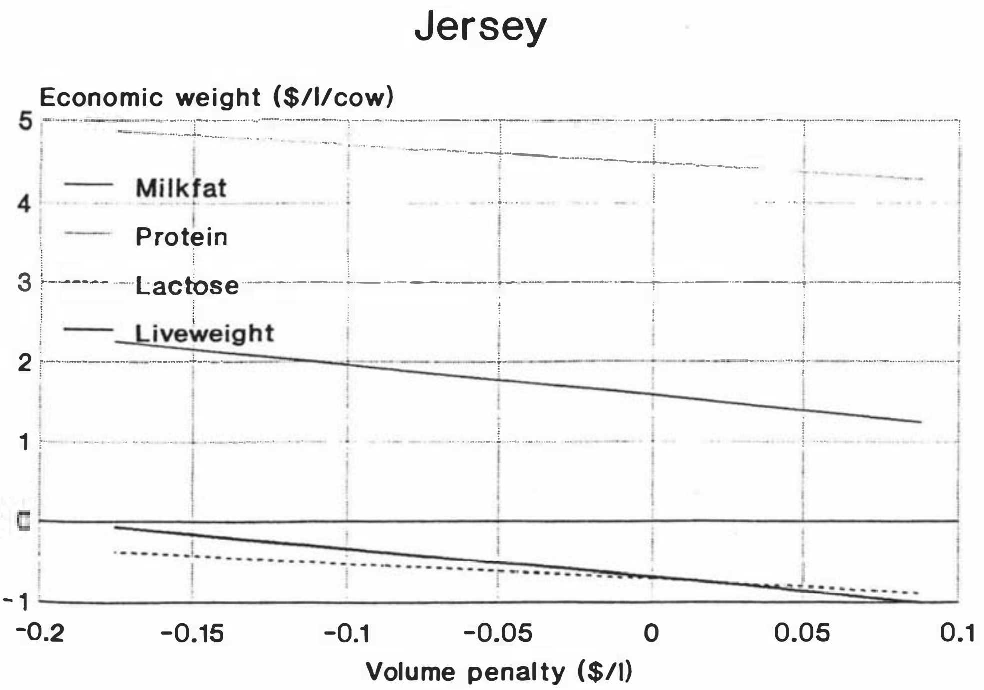


Table 5.6.: Changes in profit per ha and per cow with increasing costs for volume for Holstein-Friesians and Jerseys (* = base model).

Protein ($/kg)	Milk-fat ($/kg)	Volume ($/kg)	Profit /ha ($)	Profit /cow ($)	Economic value/ha Prot-ein (kg)	Milk-fat (kg)	Lac-tose (kg)	Vol-ume (kg)	Live-weight (kg)
Holstein-Friesian									
$ * 5.279	2.948	-0.044	1,989	876	10.53	4.19	-1.30	-0.09	-1.10
$ 4.913	2.751	-0.088	1,643	724	10.78	4.63	-1.07	-0.09	-0.71
Jersey									
$ * 5.279	2.948	-0.044	2,171	840	11.84	4.51	-1.61	-0.10	-1.37
$ 4.913	2.751	-0.088	1,867	723	12.09	4.94	-1.39	-0.10	-0.97

The effect of a doubling of the volume charge on profit per cow and per ha and on economic values per ha are shown in Table 5.6. for Holstein-Friesians and Jerseys. Profit per cow and per ha was reduced considerably. However, with the reduced profit a unit of the valuable milk component increases in value resulting in higher economic values per ha. This shows the advantages of the profit function where the volume charge does not have a direct influence on the other biological traits yet its indirect effects are reflected in changes of the economic values.

5.1.2. Returns for carcass of mature cow

Inflation-adjusted prices for beef have declined in the past two decades due to lower demand on the world market. Consumption per head of beef in Western countries has been static recently and is not expected to increase for a number of reasons such as dietary considerations and static or declining populations of some countries. A slight improvement in returns might occur through increasing affluence in some countries in the Middle East and higher consumption levels of beef meat in Japan and Korea. Consequently, beef meat prices are expected to remain relatively stable during the next 5 to 10 years and a price of \$ 2.04 /kg carcass weight is considered a good long-term forecast (McCall, 1991, pers. comm.).

Table 5.1. shows nominal (NZ Meat and Wool Boards' Economic Service, 1991d) and inflation-adjusted prices received per kg of carcass for manufacturing beef. The inflation-adjustment (NZ Department of Statistics, 1991) was based on 1990 being 100. Prices have been relatively stable during the last 20 years (Figure 5.1.) and real prices for manufacturing beef declined only slightly. The regression of the inflation-adjusted price per kg carcass of manufacturing beef over time was estimated as:

$$\text{NZ(1990) \$ / kg carcass} = \$\ 83.28 - \$\ 0.04075 * \text{year}$$

and indicates a consistent trend of falling returns with a reduction of about \$ 0.04 per kg carcass for manufacturing beef per year.

This regression coefficient was used to estimate future expected prices for mature cows. The expected price for meat in the year 2000 represented a decrease of 20% in the price. This resulted in a slightly lower profit per ha of 1.6% for Holstein-Friesians and 1.3% for Jerseys as shown in Table 5.7. Thus, a relatively large change in meat price had a small effect on profit per ha. As only a small percentage of the herd is culled at the end of the season the revenues from cull cows represent only about 5% of the total revenue of a dairy farm, resulting in the small effect on dairy farm income and profit per ha. Lower meat prices increase economic values for protein, milkfat and lactose as these components contribute a relatively larger percentage to net farm income.

Table 5.7.: Changes in profit per ha and per cow resulting from changes in returns for cow meat for Holstein-Friesians and Jerseys (* = base model).

Carcass price ($/kg)	Change (%)	Profit		Economic value/ha				
		/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Live-weight (kg)
Holstein-Friesian								
$ 2.09 *	0	1,989	876	10.53	4.19	-1.30	-0.09	-1.10
$ 1.68	-20	1,956	862	10.56	4.23	-1.28	-0.09	-1.15
$ 1.04	-50	1,905	839	10.59	4.30	-1.24	-0.09	-1.23
$ 2.50	+20	2,022	891	10.51	4.15	-1.32	-0.09	-1.05
Jersey								
$ 2.09	0	2,171	840	11.84	4.51	-1.61	-0.10	-1.37
$ 1.68	-20	2,143	829	11.86	4.55	-1.59	-0.10	-1.43
$ 1.04	-50	2,101	813	11.90	4.61	-1.56	-0.10	-1.51
$ 2.50	+20	2,199	851	11.81	4.47	-1.63	-0.10	-1.32

5.1.3. Returns for carcass of calf

Returns received for bobby calf meat during the last 20 years are shown in Table 5.1. in nominal and real terms. Figure 5.1. shows returns received for bobby calf meat in relation to returns received for milkfat and cull cow meat. Returns for bobby calf meat are shown as $/kg liveweight and were transformed from the reported per head prices using the average weight of calves as declared by meat companies (Dairy Meats Association, 1991; Lincoln University, 1991; NZ Meat & Wool Boards' Economic Service, 1991b) and adjusted for inflation (NZ Department of Statistics, 1991) to allow comparisons with previous years. These inflation-adjusted returns were used to estimate a regression of returns for bobby calf meat over time which resulted in the following equation:

$$\text{NZ(1990) \$ / kg carcass} = \$\ 50.81 - \$\ 0.02477 * \text{year.}$$

This indicated that, when compared with milkfat returns, calf meat returns did not show a decline in real terms although fluctuations in returns for calf meat did occur during the last 20 years. Accordingly, downward as well as upward changes can be expected for returns for calf meat in future years.

The future was simulated by estimating economic values on the basis of an average inflation-adjusted return of $ 1.69 per kg liveweight. This figure was derived from returns during the last 16 years and covered the most likely upward and/or downward changes. The extent of likely changes was determined from the variation in returns per kg liveweight with a standard deviation of $ 0.606 experienced during the last 16 years. Table 5.8. shows the economic values for Holstein-Friesians and Jerseys for the average return and one standard deviation above and below this average return.

Table 5.8.: Changes in profit per ha and per cow resulting from changes in returns for calf meat for Holstein-Friesians and Jerseys (1991/92 season prices for other variables).

Price carcass ($/kg)	Change	Profit		Economic value/ha				
		/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Live-weight (kg)
Holstein-Friesian								
$ 3.38	mean	1,936	853	10.57	4.26	-1.26	-0.09	-1.29
$ 4.59	+1 sd	1,964	865	10.55	4.22	-1.28	-0.09	-1.26
$ 2.17	-1 sd	1,909	841	10.59	4.29	-1.24	-0.09	-1.33
Jersey								
$ 3.38	mean	2,095	811	11.90	4.62	-1.55	-0.10	-1.89
$ 4.59	+1 sd	2,125	822	11.87	4.58	-1.58	-0.10	-1.85
$ 2.17	-1 sd	2,065	799	11.92	4.66	-1.53	-0.10	-1.94

The results showed that a 36% change in the price for calf meat changed the profit per ha by only one percent. Accordingly the economic values did not change significantly. The exception was liveweight which became less negative in the order of 3% for both, Holstein-Friesians and Jerseys. This can be explained by the relatively small amount of revenue that bobby calves contribute to the total revenue per cow and per ha.

5.1.4. Costs of inputs

Changes in costs for inputs were assessed by varying variable costs, interest rate and stock prices. The effect of a 10% increase in variable costs, a 10% increase in stock prices or an increase in interest rate of 2% on profit per ha and per cow, economic values for milk components and liveweight are shown in Table 5.9. for Holstein-Friesians and Jerseys.

Variable costs were relatively stable during the last decade. This was shown by an analysis of accounts from 276 dairy farms. While milk price varied as much as 37% during the last six years, variable costs per cow (excluding the capital cost for cows) varied only between 8% and 10% of the gross milk income per ha (Ahlborn and Bryant, 1992). This is in agreement with a cost/price structure study by Wright and Pringle (1983).

The cost of capital required to buy cows and replacements increases with higher interest rates. A change in the interest rate of 2% is considered a longterm estimate. The capital cost for cows and replacements was taken into account as the cost of borrowing and was the largest single variable cost per cow (Ahlborn and Bryant, 1992). This was reflected in the decreased profit but resulted only in marginal changes in economic values.

Table 5.9.: Changes in profit per cow and per ha with a 10% increase in variable costs, a 10% increase in stock prices and a 2% increase in interest rate for Holstein-Friesians and Jerseys.

Variable	Change	Profit		Economic value/ha				
	(%)	/ha ($)	/cow ($)	Protein (kg)	Milkfat (kg)	Lactose (kg)	Volume (kg)	Live-weight (kg)
Holstein-Friesian								
Base model	0	1,989	876	10.53	4.19	-1.30	-0.09	-1.10
Variable costs	+10	1,970	868	10.55	4.21	-1.29	-0.09	-1.08
Interest rate	+ 2	1,969	867	10.55	4.22	-1.28	-0.09	-1.08
Stock prices	+10	1,977	871	10.54	4.21	-1.29	-0.09	-1.09
Jersey								
Base model	0	2,171	840	11.84	4.51	-1.61	-0.10	-1.37
Variable costs	+10	2,150	832	11.85	4.54	-1.60	-0.10	-1.34
Interest rate	+ 2	2,152	833	11.85	4.54	-1.60	-0.10	-1.35
Stock prices	+10	2,159	836	11.85	4.53	-1.60	-0.10	-1.36

Variation in stock prices had the least effect on profit per cow, profit per ha and on economic values. Historically, prices for mature cows and rising 2 year old in-calf heifers changed in accordance with variations in the price for milk or milkfat. The returns per kg milkfat can be multiplied by 110 to arrive at a reasonable estimate for the cost price for dairy cows (Rayne, 1989; Lincoln University, 1991). However, using actual prices for the last three years and allowing for a price differential between Jerseys and Holstein-Friesians the factor was closer to 150 for Holstein-Friesians and 130 for Jerseys. This close relationship between the returns for milkfat and the cost price of dairy cows has a stabilising effect on net farm income.

An increase in input costs had only a relatively small effect on economic values. An increase in costs per cow increased the economic values for milk components and decreased the economic value for liveweight slightly.

Generally, the effect of increased costs was small for both Holstein-Friesians and Jerseys. Interest rates and variable costs had a slightly greater effect on profit per cow and profit per ha than on stock prices.

5.2. Biological variables

One of the general characteristics of biological variables is their inherent underlying variation. Thus, the mean of each variable is the most likely value, but a range of possible values is encountered for all variables. The variation is traditionally described by the second moment of the frequency distribution for the variable. However, the standard deviation is not known for a number of biological variables partly due to the difficulty and relatively high cost of measurement. Consequently, the effect of likely changes in the values of the biological variables was evaluated by assuming a coefficient of variation of 10% for these variables. This was calculated using the baseline value as a mean resulting in an approximate standard deviation for these variables:

$$\text{Range for variable } (\pm) = (\mu * 10) / 100$$

In addition, some biological variables such as energy efficiency are estimates only with an associated large standard error requiring the evaluation of a wide range of values to arrive at a reasonable approximation of their effects on net farm income.

The results from this sensitivity analysis indicated considerable fluctuations of economic values due to changes in the biological variables. the reasons for this were either inherent to biological variation or poor estimation accuracy.

5.2.1. Metabolisable energy available

The amount of energy available from pasture for feeding dairy cattle per annum is one of the most variable factors in this dairy production system and is largely determined by the management of the farm. Besides the application of fertilizer to increase the amount of DM grown, utilization and energy content of the DM influence the amount of metabolisable energy available for cows.

The effect of changes in these variables, and thus the amount of available metabolisable energy, on economic values was evaluated. Results are shown in Table 5.10. for the base situation and changes of one (energy content of DM) and two (kg DM/ha grown) standard deviations above and below the mean. As first and second moments were not available for the proportion of feed utilised this variable was decremented from 87.8% in 10% steps.

The amount of metabolisable energy available affected both stocking rate and total farm profit, resulting in differing economic values per ha. However, the relativity between economic values for the various traits and economic values per cow remained the same as profit was defined as the difference between revenues and costs. The minimal effect of management policies on economic values per cow was reported by Dekkers (1991) after an analysis of the effect of less than optimal management policies on economic values for dairy cattle. Groen (1989) also concluded that production levels and feed quality have no noteworthy influence on the economic values for milk and beef production traits. However, both studies were restricted to estimating only economic values

Table 5.10.: Changes in economic values per ha due to changes in DM grown, utilisation and energy content of DM [* = base model, P = protein (kg), F = milkfat (kg), L = lactose (kg), V = volume (kg), LW = liveweight (kg)].

a) Holstein-Friesian

kg DM/ha grown	Utilisation %	MJ ME/kg DM	MJ ME/ha available	Economic value/ha				
				P	F	L	V	LW
Changes in DM grown								
17,660	77.8	11.0	151,134	13.78	5.48	-1.70	-0.12	-1.44
15,880	77.8	11.0	135,901	12.16	4.84	-1.50	-0.11	-1.27
*13,500	77.8	11.0	115,533	10.53	4.19	-1.30	-0.09	-1.10
11,420	77.8	11.0	97,732	8.91	3.55	-1.10	-0.08	-0.93
9,340	77.8	11.0	79,932	7.29	2.90	-0.90	-0.06	-0.76
Changes in utilisation of DM								
13,500	87.8	11.0	130,383	11.89	4.73	-1.46	-0.10	-1.24
*13,500	77.8	11.0	115,533	10.53	4.19	-1.30	-0.09	-1.10
13,500	67.8	11.0	100,683	9.18	3.65	-1.13	-0.08	-0.96
13,500	57.8	11.0	85,833	7.83	3.11	-0.96	-0.07	-0.82
Changes in energy content of DM								
13,500	77.8	11.8	123,935	11.30	4.50	-1.39	-0.10	-1.18
*13,500	77.8	11.0	115,533	10.53	4.19	-1.30	-0.09	-1.10
13,500	77.8	10.2	107,131	9.77	3.87	-1.20	-0.09	-1.02

b) Jersey

kg DM/ha grown	Utilisation %	MJ ME/kg DM	MJ ME/ha available	Economic value/ha				
				P	F	L	V	LW
Changes in DM grown								
17,660	77.8	11.0	151,134	15.49	5.90	-2.11	-0.14	-1.80
15,880	77.8	11.0	135,901	13.66	5.21	-1.86	-0.12	-1.58
*13,500	77.8	11.0	115,533	11.88	4.51	-1.51	-0.10	-1.37
11,420	77.8	11.0	97,732	10.02	3.82	-1.36	-0.09	-1.16
9,340	77.8	11.0	79,932	8.19	3.12	-1.12	-0.07	-0.95
Changes in utilisation of DM								
13,500	87.8	11.0	130,383	13.36	5.09	-1.82	-0.12	-1.55
*13,500	77.8	11.0	115,533	11.83	4.51	-1.61	-0.10	-1.37
13,500	67.8	11.0	100,683	10.32	3.93	-1.40	-0.09	-1.20
13,500	57.8	11.0	85,833	8.19	3.35	-1.20	-0.08	-1.02
Changes in energy content of DM								
13,500	77.8	11.8	123,935	12.70	4.84	-1.73	-0.11	-1.47
*13,500	77.8	11.0	115,533	11.83	4.51	-1.61	-0.10	-1.37
13,500	77.8	10.2	107,131	10.98	4.18	-1.49	-0.09	-1.27

per cow and calculations of economic values per ha were not reported.

The comparison of the extent of a decrease or increase in a variable by one standard deviation (Table 5.10.) showed that the amount of DM grown per area had a larger effect on metabolisable energy available and economic values per ha than the energy content of DM. Increasing the amount of DM grown by one standard deviation increased economic values per ha slightly more than a 10% increase in utilisation would.

Generally, economic values per ha increased with a higher amount of metabolisable energy available. This indicated that economic values per ha were higher with more effective management whereas economic values per cow remained constant. This suggests the need for including the quality of management and its effect on the amount of metabolisable energy available when citing economic values per ha. This requirement did not arise when expressing relative economic values or economic values per cow.

5.2.2. Biological animal parameters

All biological parameters used in the bioeconomic model were evaluated to identify the effect of likely changes in their magnitude on profit per cow and profit per ha and also on the economic values. The robustness of the bioeconomic model with respect to changes in biological parameters was assessed for:

a) changes in efficiency constants for maintenance, growth and pregnancy and energy in body gain, for both cows and heifers
b) changes in the energy efficiency of lactation, the constant for milk energy and partial energy coefficients for fat, protein and lactose,

c) changes in survival rates of cows, calves (0 to 4 days) and replacements (4 days to 2 years) and

d) changes to dressing out percentage, ratio of calf to cow weight at birth and the percentage of calves sold for rearing (the latter applies to Holstein-Friesians only).

Changes in stocking rate, profit per ha and economic values for protein, milkfat, lactose, milk volume and liveweight resulting from a 10% change in these biological parameters are shown in Table 5.11. for Holstein-Friesians and Jerseys.

Changes in the efficiency constants for maintenance of cows and heifers, growth, pregnancy and energy in body gain did affect the stocking rate and consequently a number of other farm production system parameters, resulting in slightly different economic values. Changes in the constant for the efficiency of a cow's maintenance (k_{maint}) had the greatest effect on profit per ha and economic values, followed by the constant for the efficiency of lactation (k_{lact}), and the energy coefficient for milkfat. A 10% increase in the efficiency constant for maintenance increased the economic values of milkfat by 1.6% for Holstein-Friesians and 1.2% for Jerseys and the economic values of protein by 3.6% for both, Holstein-Friesians and Jerseys. The effect on economic values for liveweight was minimal.

Increasing the efficiency constants for growth (k_{gain}) and pregnancy (k_{pren}) and decreasing the energy in body gain by 10% had a small positive effect on the economic values for all milk components and liveweight in both, Holstein-Friesians and Jerseys.

Changes in energy efficiency of lactation, the constant for milk energy and partial energy coefficients for milkfat, protein and lactose affected economic values to a similar extent (Table 5.11.) than efficiency constants for maintenance. Increasing the energy coefficients for milk components by 10% resulted in higher economic values for the milk components and even more negative economic values for liveweight in both breeds.

Changes in survival rates of cows, calves or replacements affected farm production parameters and economic variables only marginally. This was also the case if the ratio of calf to cow weight increased.

In summary, changes in the economic values observed in association with changes in the biological animal parameters were relatively small. The largest change was a 3.6% increase in the economic value for protein observed with a 10% increase in the energy efficiency for cow's maintenance. The mean value used in this model for the energy efficiency for cow's maintenance in the New Zealand environment was one of the parameters for which a published estimate exists (Holmes et al., 1992). Consequently, the values resulting from this bioeconomic model are expected to be valid for the New Zealand dairyfarming system. The result of the sensitivity analysis also agreed with the conclusion of Holmes et al. (1992), that estimates for maintenance requirements are relatively independent of the magnitude of the energy efficiency constant for maintenance.
All biological parameters had only a minimal effect on the economic value for milk volume.

Table 5.11.: Changes in stocking rate, profit per ha and economic values per ha resulting from a 10% increase in biological variables for Holstein-Friesians and Jerseys (e.g. a 10% increase in the cow's efficiency constant for maintenance increases profit/ha from $ 1,989 to $ 2,075).

a) Holstein-Friesian

Variable	Stocking rate	Profit	Economic value/ha				
			Protein kg	Milkfat kg	Lactose kg	Volume kg	Livewgt kg
	cows/ha	$/ha					
Base	2.270	1,989	10.53	4.19	-1.30	-0.09	-1.10
Efficiency constants							
Maintenance (cow)	2.368	2,075	10.92	4.26	-1.41	-0.10	-1.10
Maintenance (heifer)	2.298	2,013	10.64	4.21	-1.33	-0.09	-1.10
Growth	2.283	1,999	10.58	4.20	-1.31	-0.09	-1.10
Pregnancy	2.279	1,996	10.57	4.20	-1.31	-0.09	-1.10
Energy in body gain	2.283	2,000	10.58	4.20	-1.31	-0.09	-1.10
Lactation							
Constant for milk energy	2.273	1,992	10.54	4.19	-1.30	-0.09	-1.11
Coefficient for milkfat	2.315	2,029	10.71	4.48	-1.35	-0.09	-1.17
Coefficient for protein	2.290	2,007	10.76	4.21	-1.32	-0.09	-1.13
Coefficient for lactose	2.294	2,010	10.63	4.21	-1.19	-0.09	-1.14
Efficiency of lactaction	2.350	2,059	10.99	4.49	-1.26	-0.10	-1.22
Survival rates							
Cows	2.270	1,995	10.53	4.18	-1.30	-0.09	-1.09
Calves (0 to 4 days)	2.270	1,993	10.53	4.19	-1.30	-0.09	-1.09
Calves (4 days to 2 years)	2.270	1,994	10.53	4.18	-1.30	-0.09	-1.09
Other biological variables							
Dressing out %	2.270	2,008	10.52	4.17	-1.31	-0.09	-1.07
Ratio of calf to cow weight	2.261	2,010	10.48	4.15	-1.31	-0.09	-1.02
% calves sold as bobbies	2.270	2,001	10.52	4.17	-1.31	-0.09	-1.06

Table 5.11. continued: Changes in stocking rate, profit per ha and economic values per ha resulting from a 10% increase in biological variables for Holstein-Friesians and Jerseys (e.g. a 10% increase in the cow's efficiency constant for maintenance increases profit/ha from $ 2,171 to $ 2,247).

b) Jersey

Variable	Stocking rate	Profit	Economic value/ha				
	cows/ha	$/ha	Protein kg	Milkfat kg	Lactose kg	Volume kg	Livewght kg
Base	2.584	2,171	11.84	4.51	-1.61	-0.10	-1.37
Efficiency constants							
Maintenance (cow)	2.693	2,247	12.27	4.59	-1.74	-0.11	-1.39
Maintenance (heifer)	2.615	2,182	11.97	4.55	-1.64	-0.11	-1.40
Growth	2.596	2,166	11.90	4.54	-1.62	-0.10	-1.40
Pregnancy	2.593	2,163	11.88	4.54	-1.61	-0.10	-1.40
Energy in body gain	2.597	2,167	11.90	4.54	-1.61	-0.10	-1.39
Lactaction							
Constant for milk energy	2.587	2,174	11.85	4.51	-1.62	-0.10	-1.38
Coefficient for milkfat	2.642	2,220	12.06	4.86	-1.69	-0.11	-1.47
Coefficient for protein	2.608	2,191	12.11	4.52	-1.64	-0.11	-1.41
Coefficient for lactose	2.608	2,192	11.93	4,52	-1.48	-0.11	-1.41
Efficiency of lactaction	2.680	2.252	12.38	4.86	-1.58	-0.11	-1.53
Survival rates							
Cows	2.584	2,176	11.83	4.50	-1.62	-0.10	-1.36
Calves (0-4 days)	2.584	2,160	11.85	4.53	-1.60	-0.10	-1.39
Calves (4 days - 2 years)	2.584	2,160	11.85	4.52	-1.60	-0.10	-1.38
Other biological variables							
Dressing out %	2.584	2,187	11.82	4.49	-1.62	-0.10	-1.34
Ratio of calf to cow weight	2.575	2,186	11.78	4.47	-1.62	-0.10	-1.24
Calves sold as bobbies (%)	2.584	2,180	11.83	4.49	-1.62	-0.10	-1.30

5.3. Comparison of variables for sensitivity impact

Economic values per cow were sensitive to changes in the price for protein. With an increase in the returns for protein economic values per cow for protein increased while they decreased for other milk components and liveweight. Changes in the price for protein had by far the largest effect on economic values of all the variables tested.
With the predicted declining real returns for milk and a future payment for milk components strongly in favour of protein the economic value per cow for protein will increase considerably to the detriment of milkfat. This situation will result in relatively higher returns from meat and the economic value per cow for liveweight could become positive.

A higher milkfat price decreased economic value per cow for all other traits and particularly liveweight. However, the effect was not as strong as for an increase in the price for protein due to the higher energy required per kg of milkfat.

Economic values were relatively robust to changes in prices for lactose and volume. Including lactose as a component in the milk payment increased profit per cow and per ha only marginally. A payment of 10% of the value of protein was not sufficient to offset the energy requirements for the production of lactose. A higher volume charge increased economic values per cow only marginally for all traits.

Relatively large changes in returns for meat from cows or calves had only a small effect on the economic values per cow. This was explained by the relatively small contribution of returns from meat in the order of 13% to the total revenue. As expected lower meat prices increased the economic values for milk components slightly.
An increase in input costs such as variable costs, interest rates and stock prices had only a relatively small effect on economic values per cow with changes in the variable costs having the greatest effect.

Results from the sensitivity analysis showed that the bioeconomic model was relatively robust to changes in the biological parameters. Changes in the biological variables generally had only a small effect on economic values per cow. The observed independence of economic values to changes in the biological parameters could be attributed to the relatively flat shape of the response curve of profit near base values. Similar observations have been reported for a bioeconomic feedlot model comparing beef cattle genotypes (Amer, 1992). From the above results it can be conluded that changes in the biological animal parameters or inaccuracies in their estimates did not have a large impact on profit per cow, profit per ha per year and economic values.

In summary, economic values estimated with the bioeconomic model were sensitive to price changes in protein and, to a lesser extent, milkfat. All other variables and parameters evaluated had only a small effect on economic values. Consequently, it is suggested that the economic values be re-estimated with changes in the price for protein and milkfat to allow a close agreement between the breeding objective and the maximisation of profit in this dairy production system.

6. EFFECTS OF TRAITS OTHER THAN PRODUCTION ON SURVIVAL RATES

6.1. Introduction

A number of traits other than production are not directly related to costs or revenues in a dairy farming enterprise. However, it is frequently reported that traits other than production influence herd life (Honnette et al., 1980; DeLorenzo and Everett, 1982; Ahlborn-Breier and Wickham, 1986; Rogers et al., 1988; Harris and Freeman, 1992). Cows contribute to net farm income only during their productive years and represent a cost during the rearing period. Thus, an increase in herd life increases a cow's profitability (De Haan et al., 1992). Consequently, a trait which influences survival rate also affects the cow's profitability and net farm income.

The objective of this study was to quantify the effects of traits other than production on survival rate and to identify which of the traits other than production should be considered for inclusion in the breeding objective as selection criteria for the trait survival rate. Survival rate is defined as (1 - replacement rate) with the reversal of the sign for the economic values estimated (Table 5.11.).

6.2. Material and methods

Records containing information on production, management and conformation traits from 1,713 Ayrshire, 22,970 Holstein-Friesian and 17,165 Jersey cows were analysed. Management and conformation traits were recorded during the first lactation. Production information was recorded as long as the cow was a member of the milking herd between the 1987/88 and 1990/91 season. The analysis was restricted to herds which were herd testing during the respective seasons. Table 6.1. shows the number of observations for each breed by each lactation.

Table 6.1.: Number of cows with production, management and survival information at different lactations.

Lactation	Ayrshire	Holstein-Friesian	Jersey
1	2,181	29,466	21,129
2	1,713	22,972	17,165
3	1,041	13,611	10,724
4	378	4,598	4,615

Survival of a cow to the following season was determined by examining whether production records existed for that cow's second, third and fourth lactation. Survival was defined as a binomial trait. A cow was given a '1' if she had recorded a minimum lactation length of 100 days during a consecutive season, otherwise the value given was '0'.

Milk production was required to be measured at least eight weekly through the national milk recording scheme. Aliquot samples were analysed for protein and milkfat percentage. Records were edited for yield and records with abnormally low or high ($\mu \pm 3\ \sigma$) production were deleted.

The management traits adaptability to milking, shed temperament, milking speed and also the farmer's overall opinion (Table 6.2.) of the primiparous cows used in the study were scored by the farmer on a linear scale using scores from 1 to 9. The cows were assessed once during the two month period following calving.

Conformation traits (Table 6.2.) were assessed by trained evaluators using a 1 to 9 linear scale (Ahlborn-Breier et al., 1990). For body weight and stature one point on the linear scale equated to 50 kg body weight and 5 cm height at withers where '1' equated to < 250 kg and < 105 cm, '2' equated to 250 - 299 kg and 105 - 109 cm etc., respectively. Conformation traits were assessed between 2 and 28 weeks after calving, resulting in a mean of 12 weeks with a standard deviation of 3 weeks after calving. All heifers in a herd were assessed at the same day and usually by the same evaluator. All evaluators had been trained to evaluate all breeds using the standard scoring system.

The following mixed model was used in the analysis:

$$\begin{aligned}\textbf{Survival} = \ & \mu + \textbf{Herd} + \textbf{Herd Year} + \textbf{Calving week} \\ & + \textbf{Age at first calving} + \textbf{Protein yield} \\ & + \textbf{Trait}_1 + \textbf{Trait}_2 + \ldots + \textbf{Trait}_{17} + \textbf{Error}\end{aligned}$$

where herd, herd year, calving week and age at first calving were treated as fixed effects. The general linear model procedure from the Statistical Analysis System (1985) was used. A transformation of the binomial response variable was tested but did not improve the fit of the model and results from this model are therefore not detailed here.

The inclusion of the traits in the model was based on the results from a stepwise regression.

A mixed model analysis with milkfat yield instead of protein yield was also carried out and resulted in a similar ranking of traits with respect to their effect on survival rate. As protein is the main milk component only results for the analysis including protein yield are reported.

6.3. Results

Means and standard deviations for all variables included in the analysis are shown in Table 6.2. for Ayrshires, Holstein-Friesians and Jerseys. Means and standard deviations for production traits for this age group agreed with other

Table 6.2.: Means and standard deviations of production and non-production traits of primiparous cows included in the analysis.

	Ayrshire		Holstein-Friesian		Jersey	
	μ	σ	μ	σ	μ	σ
Protein kg	102.40	28.54	101.07	26.33	93.04	22.04
Milkfat kg	128.52	36.53	131.34	34.26	131.60	32.25
Milk kg	2907.43	789.33	3006.97	789.55	2321.64	524.71
Lactose kg	135.20	36.70	139.83	36.71	107.96	24.40
Protein %	3.52	0.27	3.37	0.28	4.01	0.31
Milkfat %	4.43	0.50	4.40	0.51	5.67	0.57
Days in milk days	251.84	35.27	246.06	35.37	248.26	34.67
Adaptability to milking	5.86	1.70	5.73	1.63	6.13	1.54
Temperament	6.16	1.54	5.93	1.58	6.31	1.48
Milking speed	6.36	1.40	6.05	1.41	6.37	1.32
Overall opinion	6.50	1.37	6.26	1.48	6.55	1.39
Weight	3.75	0.89	4.52	1.04	2.98	0.75
Stature	4.34	0.90	5.43	1.07	3.65	0.81
Capacity	6.02	1.05	5.47	1.02	6.17	1.16
Rump angle	5.56	0.71	5.36	0.83	5.27	0.70
Rump width	5.22	0.90	5.17	0.95	5.53	1.05
Legs	5.43	0.62	5.72	0.80	5.51	0.63
Udder support	5.72	0.90	5.21	0.99	5.73	1.14
Fore udder	5.52	0.99	5.01	1.06	5.59	1.20
Rear udder	5.44	0.98	4.87	0.99	5.41	1.22
Front teat placement	4.50	0.67	4.29	0.72	4.31	0.71
Rear teat placement	5.34	0.81	5.32	0.82	5.06	0.69
Udder overall	5.41	0.96	4.92	1.08	5.36	1.23
Dairy conformation	5.76	0.99	5.55	1.03	6.13	1.14

published reports (Ahlborn-Breier, 1989; Ahlborn-Breier and Hohenboken, 1991; Livestock Improvement, 1991; Ahlborn and Dempfle, 1992; Ahlborn and Bryant, 1992; Livestock Improvement, 1992).

Management traits all had similar means and standard deviations and did not differ greatly between any of the breeds. Standard deviations for management traits were relatively large with around 1.4 scores when compared to conformation traits. This was partially due to the large number of recorders as cows were scored by their farmers for these traits.

Conformation traits had lower means than management traits. Additionally, conformation traits showed considerably less variation between cows than management traits. This was especially noticable with the conformation traits legs, rump angle and front teat placement. For example, the traits legs and rump angle had the smallest standard deviation with 0.62 scores and 0.70 scores for Ayrshires and Jerseys, respectively.
Conformation traits were similar for all breeds except for weight and stature for which mean scores in the order of Jersey < Ayrshire < Holstein-Friesian were recorded. Capacity was lowest for Holstein-Friesians and highest for Jerseys. These differences, however, could be partly due to the relative subjectivity of the observations as different inspectors were used for the various breeds with potentially different scales being applied within each breed despite training of evaluators using a standard scale.

Survival rates were very similar for all breeds and are shown in Table 6.3. for three subsequent lactations. While the survival rate from the first to the second lactation was on average 78%, survival rates dropped to about 60% between first and third lactation and around 50% between first and fourth lactations. It should be noted that only about a

Table 6.3.: **Means and standard deviations for survival rates between subsequent lactations.**

Survival Lactation	Breed	n	Survival rate (%) μ	σ
1st - 2nd	Ayrshire	1,713	78	42
	Holstein-Friesian	22,972	77	42
	Jersey	17,165	79	40
1st - 3rd	Ayrshire	1,041	64	49
	Holstein-Friesian	13,611	61	49
	Jersey	10,274	67	47
1st - 4th	Ayrshire	378	48	50
	Holstein-Friesian	4,598	49	50
	Jersey	4,615	54	50

fifth of all primiparous cows under survey had been in herds which were consistently herd testing for four years and could therefore be included in the analysis from their first to their fourth lactation. Cows withdrawn from herd testing can be assumed to be a random sample as only whole herds were withdrawn from herd testing.

Regression coefficients for protein yield and traits other than production related to survival from first to second lactation are shown in Table 6.4. Protein yield significantly ($p \leq 0.0001$) affected survival rates in all breeds. Increases in protein yield were strongly associated with a higher survival rate. An increase in 10 kg protein increased survival rate from first to second lactation by

Table 6.4.: Partial regression coefficients for traits affecting survival rate (%) from 1^{rst} to 2nd lactation (significant regression coefficients [$\hat{b} > 0$ with $p \leq 0.005$] are highlighted; + = $p \leq 0.10$, * = $p \leq 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.01$).

	Ayrshire	Holstein-Friesian	Jersey
n	1,713	22,972	17,165
Protein	0.51 ***	0.42 ***	0.39 ***
Adaptability to milking	0.88	0.94 ***	0.86 *
Temperament	1.99 *	0.82 *	1.19**
Milking speed	-0.31	1.54 ***	0.95 *
Overall opinion	1.99 +	2.84 ***	2.24 ***
Liveweight	-0.23	0.99 +	-0.17
Stature	-0.43	0.67	0.43
Capacity	3.50 +	1.37 *	-0.02
Rump angle	-2.11	0.06	0.68
Rump width	0.06	0.70	0.70
Legs	-3.34	-0.70	0.06
Udder support	-0.87	2.63 ***	1.31 **
Fore udder	0.0	1.73 ***	1.04 **
Rear udder	1.04	1.61 ***	1.62 ***
Front teat placement	1.57	0.66	-0.58
Rear teat placement	-3.19	-0.08	-0.09
Udder overall	-0.44	2.26 ***	1.49 ***
Dairy conformation	4.51 *	2.19 ***	0.49

4.2% in Holstein-Friesians and 3.9% in Jerseys.

All management traits significantly affected survival rates. Higher and more favourable scores for any of the management traits increased survival rates. These relationships were all significant in Holstein-Friesians and Jerseys but only for temperament in Ayrshires. It should be noted that the numbers of animals tested for this particular analysis were relatively small for Ayrshires.
In contrast, only a few conformation traits affected survival rate: udder support, fore udder, rear udder and udder overall. This was observed for Holstein-Friesians and Jerseys. In Ayrshires only dairy conformation had a significant effect on survival rate. Dairy conformation was also significant in Holstein-Friesians.

Quadratic relationships between survival rates and yield, management and type traits were tested but did not improve the fit of the model and did not result in significant coefficients ($p \leq 0.05$). The lack of a quadratic relationship between survival rate and conformation traits was also reported by Rogers et al. (1989).

Standardised regression coefficients allow a comparison of the impact of the regression coefficients for different traits on survival rate. Standardised regression coefficients were calculated for traits with a significant effect on survival rate from first to second lactation and are shown in Table 6.5. for Holstein-Friesians, Jerseys and Ayrshires. When compared on a standardised basis, it is apparent that protein production has by far the highest influence on survival rate, followed by the farmer's overall opinion of the heifer and udder support, udder overall and dairy conformation. Other conformation traits, although significantly influencing survival rate, have only a minor influence on culling decisions made by the farmer.

Table 6.5.: Standardised partial regression coefficients for traits affecting survival rate (%) from 1^{rst} to 2^{nd} lactation (only significant regression coefficients are shown).

	Ayrshire	Holstein-Friesian	Jersey
n	1,713	22,972	17,165
Protein	14.56	11.06	8.60
Adaptability to milking		1.53	1.32
Temperament	3.06	1.30	1.76
Milking speed		2.17	1.25
Overall opinion		4.20	3.11
Capacity		1.40	
Udder support		2.60	1.49
Fore udder		1.83	1.25
Rear udder		1.59	1.98
Udder overall		2.44	1.83
Dairy conformation	4.46	2.26	

Regression coefficients for protein yield and traits other than production for survival from first to third lactation are shown in Table 6.6. Results were very similar to the regression coefficients found for the first to second lactation but generally significant regression coefficients were slightly larger. Traits which significantly affected survival rate from first to second lactation were generally the ones which significantly affected survival rate from first to third lactation despite a smaller number of observations. These results confirmed the effects of protein yield, adaptability to milking, temperament, milking speed, overall opinion and the conformation traits udder support,

Table 6.6.: Partial regression coefficients for traits affecting survival rate (%) from 1^{rst} to 3^{rd} lactation (significant regression coefficients [$\hat{b} > 0$ with $p \leq 0.005$] are highlighted; + = $p \leq 0.10$, * = $p \leq 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.01$).

	Ayrshire	Holstein-Friesian	Jersey
n	1,041	13,611	10,724
Protein	0.66 ***	0.56 ***	0.69 ***
Adaptability to milking	2.04 +	1.23 **	0.84 +
Temperament	0.04 +	1.62 ***	1.00 *
Milking speed	-0.01	1.63 ***	0.18
Overall opinion	0.05 **	3.65 ***	1.92 ***
Liveweight	-1.36	1.24	-1.86
Stature	-2.23	1.21	1.03
Capacity	4.88 +	1.09 +	0.20
Rump angle	-1.17	0.17	0.78
Rump width	3.83	0.50	0.34
Legs	-4.01	-1.21	0.06
Udder support	-1.26	2.43 ***	1.80 **
Fore udder	-0.43	2.01 ***	1.80 **
Rear udder	0.03	2.21 ***	1.60 **
Front teat placement	0.02	1.09	-0.07
Rear teat placement	-0.00	-1.60 *	-0.01
Udder overall	-0.23	2.36 ***	1.75 ***
Dairy conformation	3.16	2.80 ***	0.63

fore udder, rear udder, udder overall and dairy conformation on the survival rate.

Table 6.7. shows the regression coefficients for protein yield and traits other than production for survival from first to fourth lactation. Again, significant regression coefficients had increased in magnitude compared to the survival from first to third lactation. The number of traits which significantly affected survival rate to the fourth lactation were considerably reduced.

Protein yield and management traits were still significant while conformation traits generally were not. The cow's behaviour during the first lactation with respect to management traits still had a significant effect on her survival from first to fourth lactation. Even over a six year observation period the management traits assessed during the first lactation had a significant effect on her survival between third and fourth lactation. This might indicate that either certain behaviour patterns are repeated during subsequent lactations or that the farmer forms an opinion about a cow during the first lactation and does not change this opinion subsequently, even if there might be a reason to do so.

The only significant conformation traits were for fore udder for Jerseys and rump angle for Holstein-Friesians. The significant effect for rump angle was somewhat surprising since it had not been significant in the previous survival rates.

Table 6.7.: Partial regression coefficients for traits affecting survival rate (%) from 1rst to 4th lactation (significant regression coefficients [$\hat{b} > 0$ with $p \le 0.005$] are highlighted; + = $p \le 0.10$, * = $p \le 0.05$, ** = $p \le 0.01$, *** = $p \le 0.01$).

	Ayrshire	Holstein-Friesian	Jersey
n	378	4,598	4,615
Protein	0.69 ***	0.65 ***	0.74 ***
Adaptability to milking	1.27	1.63 *	3.13 ***
Temperament	1.74	2.20 **	2.88 ***
Milking speed	0.27	2.89 ***	0.99
Overall opinion	6.67 *	4.03 ***	3.51 ***
Liveweight	0.65	0.43	-0.36
Stature	2.33	1.91	1.40
Capacity	4.70	0.26	0.10
Rump angle	-4.49	3.68 *	2.30
Rump width	5.32	-1.34	-0.52
Legs	-1.75	3.27 +	-1.77
Udder support	1.55	1.45	2.85
Fore udder	2.94	1.54	2.84 **
Rear udder	5.64 +	0.03	2.44 +
Front teat placement	-6.94	-0.56	-1.58
Rear teat placement	-4.31	-0.78	-0.27
Udder overall	2.68	0.77	0.63
Dairy conformation	6.24 *	-1.08	-0.17

6.4. Conclusion

Results of this study showed the overwhelming effect of production traits on survival rate and thus replacement rate and longevity. The management traits adaptability to milking, shed temperament, milking speed and overall opinion and the conformation traits udder support, fore udder, rear udder, udder overall and dairy conformation also affected survival rates significantly.

Of the traits other than production, management traits had the greatest effect on survival rates per unit of measurement and on a standardised basis. This confirms results previously reported for New Zealand dairy cattle (Wickham, 1979; Ahlborn-Breier and Wickham, 1986).

The importance of the udder traits for survival rate has also been reported for overseas populations (Honnette et al., 1980; Dentine et al., 1987; Rogers et al., 1988; De Haan et al., 1992) and New Zealand dairy cattle (Ahlborn-Breier and Wickham, 1986).

Other linear type traits caused only relatively small increments in the R^2 of the model. This was also reported by De Haan et al. (1992) but is in contrast to results from a study analysing sire evaluations (Cassell et al., 1990).

In summary, the management traits adaptability to milking, shed temperament, milking speed and overall opinion and the conformation traits udder support, fore udder, rear udder, udder overall and dairy conformation should be evaluated for inclusion in the breeding objective as selection criteria for the trait survival rate.

7. AN AGGREGATE GENOTYPE AND SELECTION INDEXES FOR NEW ZEALAND DAIRY CATTLE

ESTIMATION OF GENETIC PARAMETERS FOR THEIR IMPLEMENTATION

The purpose of most breeding programs is to improve the average performance of more than one trait for a population. Traits to be improved are defined in the aggregate genotype or breeding value T. The objective of this study was firstly to establish an aggregate genotype and a selection index for the New Zealand dairy cattle populations which was based on net economic values and genetic parameters and secondly to estimate genetic parameters for the traits included in the breeding objective and the selection criteria.

7.1. An aggregate genotype for New Zealand dairy cattle

A breeding objective or aggregate genotype was specified for the New Zealand dairy cattle populations. This breeding objective was based on the goal of achieving the highest net farm profit by breeding cows of high economic merit. This goal can be accomplished with a breeding objective which includes traits with high economic values as selection objectives.

In the New Zealand dairy production system the highest net farm profit is achieved with cows with high protein and milkfat production, low volume and lactose yield, low liveweight and high survival rate as shown in previous chapters.

Protein yield made the largest monetary contribution. Milkfat yield accounted for less than half the monetary contribution of protein, based on current prices. While protein and milkfat yield increases contribute positively to farm net income increases in lactose yield, volume, liveweight reduce the net income.

Economic values used for determining the selection objectives are listed in Table 4.12. Traits which showed an economic value of zero were not included as selection objectives in the aggregate genotype.

Beside being of economic value it is important that traits can be improved genetically. This requires either a moderate to high heritability of the trait or a large phenotypic variance. Heritabilities and phenotypic variances for the selection objectives are listed in Table 7.2. and in more detail in Table 10.1.

The aggregate genotype or breeding value T for New Zealand dairy cattle was defined as:

$$T = \mathbf{a'Y} = a_1Y_1 + a_2Y_2 + \ . \ . \ . \ . \ + a_mY_m = \Sigma\ aY$$

where $\mathbf{Y}$ is a vector of additive genetic values for m traits included in the aggregate genotype T,

a is a vector of breed-specific constants which represent the relative economic values of the m traits in Y (Table 4.12.).

Incorporating the breed-specific economic values derived earlier and consolidating the economic values for lactose ($0.03/kg) and volume the aggregate genotype for Holstein-Friesians (T_H) and Jerseys (T_J) becomes:

$$T_H = \mathbf{a_H'Y} = \$4.64\text{ Protein} + \$1.85\text{ Milkfat} - \$0.07\text{ Volume} - \$0.49\text{ Liveweight} + \$9.25\text{ Survival rate}$$

$$T_J = \mathbf{a_J'Y} = \$4.58\text{ Protein} + \$1.75\text{ Milkfat} - \$0.07\text{ Volume} - \$0.53\text{ Liveweight} + \$9.29\text{ Survival rate}$$

The aggregate genotype T_H for Holstein-Friesians and T_J for Jerseys reflect the total economic value of genes an individual is carrying for this group of traits.

7.2. Selection indexes for New Zealand dairy cattle

The aggregate genotypes T_H and T_J are not measurable and therefore cannot be selected for directly. Improvement in T_H and T_J is achieved by selection based on selection indexes I_H and I_J respectively, which were defined as:

$$I_H = \mathbf{b'}_H\mathbf{X}_H = b_{H1}X_{H1} + b_{H2}X_{H2} + \ldots + b_{Hn}X_{Hn} = \Sigma\ b_HX_H$$

$$I_J = \mathbf{b'}_J\mathbf{X}_J = b_{J1}X_{J1} + b_{J2}X_{J2} + \ldots + b_{Jn}X_{Jn} = \Sigma\ b_JX_J$$

where **b** was a vector of breed-specific weighting factors

X is a vector of breed-specific phenotypic measures for the n selection criteria included in the selection index.

Selection criteria were chosen to predict the selection objectives. A trait was only included in the selection index as selection criterion if it had low to moderate phenotypic correlations with other selection criteria (Table 10.2.), a moderate to high genetic correlation between selection objective and selection criterion (Table 10.2.) and a moderate to high heritability (Table 10.1.).

This excluded the traits stature, rump angle, rump width, legs, front teat placement and rear teat placement in both Holstein-Friesians and Jerseys.

7.2.1. The selection index for Holstein-Friesians

The selection index for Holstein-Friesians included the nine selection criteria protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and udder support.

The latter five traits are included as predictors for the selection objective survival. These traits were selected according to their influence on survival rate from first to second lactation (Table 6.4.). Using these traits as selection criteria makes selection for survival possible without having to wait an additional year for the survival records to be compiled.

While dairy conformation, fore udder and rear udder also significantly influenced survival rate these traits had a low genetic correlation with survival rate (< 0.15) and were therefore not used as selection criteria. Genetic progress in these three traits will still be achieved as all three traits had a high phenotypic (0.41, 0.68 and 0.70) and genetic (0.64, 0.86 and 0.89) correlations with udder overall which is included as a selection criteria.

Adaptability to milking was not included as a selection criterion due to its high phenotypic correlation (0.61) with temperament which had also a slightly higher heritability.

Capacity had a moderately high phenotypic correlation (0.41) with liveweight and therefore its inclusion as an additional selection criterion was not necessary.

A high genetic correlation of the traits front teat placement (0.86) and rear teat placement (0.89) with the selection criterion udder overall is expected to improve these traits genetically with the implementation of this selection index.

7.2.2. The selection index for Jerseys

The selection index for Jerseys used the nine selection criteria protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and fore udder.

Thus, the selection criteria for Jerseys were identical with the ones for Holstein-Friesians except for the addition of fore udder and the deletion of udder support.

The traits udder overall, overall opinion, temperament, milking speed, udder support and fore udder are used as predictiors for survival rate from first to second lactation.

Adaptability to milking was not included as it showed a high phenotypic correlation with overall opinion (0.62) and temperament (0.68) in addition to a high genetic correlation with both overall opinion (0.82) and temperament (0.99). This will ensure genetic progress in this trait as a correlated response.

The traits udder overall and rear udder, while showing a significant influence on survival rate, had a low genetic correlation with survival rate (< 0.10). Additionally, both traits had high phenotypic (> 0.53) and genetic (> 0.70) correlations with udder overall and fore udder thus eliminating the need for inclusion as a selection criteria in the selection index.

7.3. Genetic parameters for selection objectives and selection criteria

7.3.1. Introduction

Selection for a breeding objective or aggregate genotype requires the construction of a selection index containing observable traits, the selection criteria. In the selection index the values for the selection criteria for each animal are combined into a single score using weighting factors. The weighting factors are based on the relative economic value of each trait in the breeding objective, genetic covariances between selection objectives and selection criteria, phenotypic covariances between selection criteria and genetic variances for the selection objectives in the breeding objective and the selection criteria in the selection index.

Accordingly, estimates of the variance and covariance components for the traits included in the breeding objective and in the selection indexes are required.

A number of overseas studies have reported genetic parameter estimates for production and conformation traits for a range of dairy cattle populations (White, 1973; Cassell et al., 1974; Bowden, 1982; Hay et al., 1983; Dadati et al., 1985; Meyer, 1985; Meyer et al., 1985; De Jager and Kennedy, 1987; Meyer et al., 1987; Foster et al., 1988; Klei et al., 1988; Norman and Powell, 1988; Colleau et al., 1989; Schwark and Fahr, 1989; Schutz et al., 1990; Tempelman and Burnside, 1990). However, covariance component estimates for management traits are lacking at present. For New Zealand dairy cattle populations genetic parameters for management and conformation traits have not been estimated. Available estimates of genetic parameters for production traits are based on test-day yields (Wickham, 1985) and require updating with lactation yields for each of the major breeds.

Currently the weighting factors for the selection index used for the genetic improvement of New Zealand dairy cattle are based on genetic parameter estimates from overseas studies.
A national recording scheme for management and conformation traits was introduced for New Zealand dairy cattle in 1987 based on a linear scoring system (Ahlborn-Breier, 1988). Preliminary variance and covariance estimates for these conformation and management traits based on 1987/88 season records from 2,320 New Zealand Holstein-Friesian cows from 245 sires were reported by Sosa-Ferreyra et al. (1990) and Sosa-Ferreyra (1992).
A large number of records for Holstein-Friesian, Jersey and Ayrshire cows has accrued since the introduction of the Traits Other than Production (T.O.P.) system. This database provided the opportunity to calculate reliable genetic parameters for production, management and conformation traits for the New Zealand major dairy cattle breeds Holstein-Friesian, Jersey and Ayrshire.
The objective of this study was to estimate variance and covariance components for production and non-production traits based on data collected from New Zealand Holstein-Friesian, Jersey and Ayrshire primiparous cows. These parameters can be used to determine effective selection criteria and to derive new weighting factors for the

selection indexes of New Zealand dairy cattle.

7.3.2. Material and methods

The analysis was based on data from 26,689 Holstein-Friesian, 22,529 Jersey and 3,209 Ayrshire primiparous cows. Records containing information on production, management and conformation traits were assembled from the 1987/88 to 1990/91 season.

Records were edited for parentage and yield. Those with abnormally low or high ($\hat{\mu} \pm 3\ \hat{\sigma}$) production were deleted. So were records from sires with less than 12 daughters and from herds with less than 5 heifers. Only cows first calving between the ages of 22 and 30 months were included in the analysis. The dataset was restricted to herds which were herd tested in at least two consecutive seasons to allow an accurate assessment of a cow's survival to the next lactation. This resulted in a total number of 1,406 herds spread over three years of recording. Table 7.1. lists the number of records for the various breeds for each of the years included in the analysis.

Cows providing the data comprised half-sib groups from sires most of whom were contributing to the systematic progeny test as part of the Sire Proving Scheme (Livestock Improvement, 1990a and 1990b). The final dataset included 491 Holstein-Friesian sires with 21,870 daughters distributed over 711 herds, 359 Jersey sires with 15,885 daughters spread over 515 herds and 52 Ayrshire sires with 1,390 daughters distributed over 180 herds.

On average a sire had 44.6 daughters (minimum 6, maximum 212) spread over 19.4 herds (minimum 1, maximum 86 herds). On average a herd had 29.8 primiparous cows which typically came from 13 different sires. The percentages of crossbred cows was 28% for Holstein-Friesians, 9% for Jerseys and 27% for Ayrshires.

Table 7.1.: **Number** of records for estimating variance and covariance components for production and non-production traits.

Year of 1st lactation	Holstein-Friesian	Jersey	Ayrshire
1987/1988	4,865	6,624	689
1988/1989	10,656	7,652	1,201
1989/1990	11,168	8,253	1,319
TOTAL	**26,689**	**22,529**	**3,209**

Production traits (protein, milkfat and milk yield, protein and milkfat percentage), weight, stature, survival from first to second lactation, farmer's overall opinion of heifer, management traits (adaptability to milking, shed temperament, milking speed) and conformation traits (dairy conformation, udder overall, capacity, rump angle, rump width, legs, udder support, fore udder, rear udder, front teat placement and rear teat placement) were analysed. A detailed definition of the traits analysed and their method of measurement was given in the previous chapter (6) and unadjusted means and standard deviations for these traits are given in Table 6.2.

Survival was defined as a binomial trait. Cows with a minimum lactation length of 100 days in the second lactation were rated survivors and given a value of one, others were considered culled and given a value of zero.

The following mixed linear model was used in the analysis:

$$Y = \mu + \text{Herd} + \text{Sire} + \text{Herd}\times\text{Year} + \text{Calving week} + \text{Age at first calving} + \text{Breed of dam} + \text{Genetic group} + \text{Error}$$

where herd, herd×year, calving week, age at first calving, breed of dam and genetic group were treated as fixed effects and sire as the random effect. These variables had been identified in a separate analysis as significant influences on the traits analysed. In the analysis calving week was treated as a factor variable with one level being equivalent to two weeks.

The analysis was carried out within breed of sire. The inclusion of breed of dam in the Holstein-Friesian and Jersey analysis allowed to take account of the significant additive genetic differences and non-additive genetic effects reported for these populations (Ahlborn-Breier and Hohenboken, 1991). This was necessary as 30% of the Holstein-Friesian-sired cows and 22% of the Jersey-sired cows were Holstein-Friesian × Jersey crossbreds.

The genetic group identified older sires and was included to account for differences in genetic merit due to genetic progress. Genetic progress in these populations has been reported for production traits (Ahlborn-Breier et al., 1987) but was considered unlikely for traits other than production.

Stage of lactation at assessment did not significantly influence conformation or management traits as the majority of the cows calved during August and September resulting in small differences in stage of lactation at a given time. The mean stage of lactation at time of inspection was 12 weeks with a standard deviation of 3 weeks. Consequently stage of lactation was not included in the model for the analysis of these traits.

There was no significant interaction between calving week and herd×year or age at calving and so interactions were not included in the model.

Records from daughters of all sires were used to estimate the fixed effects but only daughters of sires under progeny test were used for estimating the additive sire variance and covariance components (Meyer, 1986).

A number of methods are available for the estimation of large sample variance parameters in mixed models with unbalanced data. The model falls into this category due to unequal numbers of observations in the sub-classes, including missing sub-classes. One of these methods, the Maximum Likelihood Estimation (ML) has the advantage that it locates the maximum of the likelihood function which lies within the parameter space for a given set of data, model of analysis and parameters. ML estimators of variance components are translation invariant, functions of every sufficient statistic, consistent and asymptotically normal, efficient and non-negative but therefore biased (Kennedy, 1981). However, unbiasedness is not of concern in this analysis as heritabilities are estimated by taking a ratio of estimates of variance parameters. This will usually be a biased estimate even if the parameter estimates are unbiased (Anderson, 1984).

While ML equations maximise the likelihood over the entire sample space of the observation vector, Restricted Maximum Likelihood (REML) takes the estimation of fixed effects in a mixed model into account (Patterson and Thompson, 1974). REML has been described as intrinsically a ML procedure and can be regarded as being ML over a restricted sample space (Anderson, 1984). REML operates on the likelihood of linear functions of the data vector with expectations zero, also called linearly independent error contrasts, which are independent of the fixed effects, while Maximum Likelihood Estimation derives the estimates from the likelihood of the complete observation vector. Consequently, REML takes the loss in degrees of freedom due to fitting fixed effects into account.

For the partition of the phenotypic variation into genetic and other components REML has become the method of choice in animal breeding situations due to the availability of computational resources (Meyer, 1989) and REML was used in this analysis.

Variance and covariance components were estimated using

Meyer's univariate and multitrait REML procedure (Meyer, 1985, 1986 and 1987). These programs use an Expectation-Maximisation-type algorithm based on first derivatives.
A canonical decomposition is utilised to reduce the multivariate analysis to a corresponding series of univariate analyses. This avoids the need to calculate the inverse and forces the genetic variance/covariance matrix to be semi-positive definite. A series of Householder (orthogonal) transformations changes the coefficient matrix for random effects to tridiagonal form (Meyer, 1986 and 1987).
Univariate variance components within and between the random effects for each trait were estimated first and these estimates were used as starting values for the multivariate analysis.
The phenotypic variance was estimated as:

$$\sigma^2_P = \sigma^2_e + (\sigma^2_{sire} * 4)$$

The precision of the estimators of the variance components was indicated by their large sample standard errors. These were approximated at convergence using numerical differentiation to second derivatives of the likelihood function (Meyer, 1985 and 1987).

Cows in the majority of herds included in the dataset could be considered a random sample of the national population as in these herds 80% of the cows were mated to young sires. Thus, selective mating of dams was avoided and dams represented a random sample of the national population.

The variance and covariance components were estimated with a sire model without accounting for relationships and therefore could be biased due to selection. When a high selection intensity is achieved in the sire population, resulting in a reduction in genetic variation, it is necessary to account for bias due to selection when estimating variance components from paternal half sib groups in dairy cattle (Ahlborn and

Dempfle, 1992).
However, with the exception of production traits sires can be considered a random sample of the national population as information about the genetic merit of these sires for traits other than production was not available at the time when the mating decisions were made. Additionally, the progeny derived from a large number of paternal grandsires (98 Holstein-Friesian, 107 Jersey and 27 Ayrshire paternal grandsires) and an even larger number of maternal grandsires. Due to the lack of selection in the majority of the traits analysed relationships were not included in the model.
Selection of the dams of sires is usually even less precise than the selection of paternal grandsires, therefore this selection bias would be of even lesser significance and was not included in the model.

7.3.3. Results and discussion

Genetic parameters were estimated for all traits included in the current selection index for the New Zealand dairy cattle populations Holstein-Friesian, Jersey and Ayrshire. Detailed results from these analyses including adjusted means, phenotypic amd genetic variances, heritabilities, phenotypic and genetic correlations and their standard errors are presented in the appendix (Tables 10.1. -10.3.). Parameters for Ayrshires had large standard errors due to the small sample size and should be treated with caution. Therefore, results in this section will concentrate on the genetic parameters for the breeding objective and selection indexes for Holstein-Friesians and Jerseys defined in the previous section.

Adjusted means and their standard errors for all traits analysed are presented in the appendix in Table 10.1. for Holstein-Friesians (10.1.a), Jerseys (10.1.b) and Ayrshires (10.1.c).

Fixed effects considered in the model were significant for most traits analysed and values were very similar for all three breeds. For survival from first to second lactation only herd and year effects were significant.
Calving week was a large fixed effect. Production losses of 1.9 kg protein and 2.6 kg milkfat per week were associated with later calving dates, due to the practice of ending the milking season for the majority of cows simultaneously, resulting in a forced shorter lactation for later calving cows. The mean age at first calving of 24.4 months (± 21 days) reflected the extremely seasonal dairy production system in New Zealand and has been reported previously (Ahlborn and Dempfle, 1992). Production increased with a higher age at first calving.
Means and variation for the fixed effects were similar to an earlier study of 2,165 New Zealand Holstein-Friesians (Sosa-Ferreyra, 1992).

Protein, milkfat and milk yield levels were representative of primiparous cows with a mean lactation length of only 247 days (standard deviation 36 days) and have been reported previously (Ahlborn and Dempfle, 1992). These production levels reflected New Zealand pasture-based feeding conditions. The mean protein yields were 101 kg for Holstein-Friesians and 93 kg for Jerseys.
Phenotypic and additive genetic variances for all traits are presented in the appendix in Table 10.1. for Holstein-Friesians (10.1.a), Jerseys (10.1.b) and Ayrshires (10.1.c). Phenotypic variances for milk production of Holstein-Friesians and Jerseys are comparable with previously published estimates for a subset of these New Zealand primiparous cows (Ahlborn and Dempfle, 1992). Additive genetic variances were lower for milkfat yield and protein for Holstein-Friesians and for all production traits for Jerseys. This resulted in slightly lower heritability estimates than previously reported (Ahlborn and Dempfle, 1992).

Survival rates from first to second lactation were very similar for all breeds with 0.77 for Holstein-Friesians and 0.80 for Jerseys.

The mean score for management and conformation traits was close to five, coinciding with the median of the linear scale. These results for management and conformation traits confirmed results from previous studies based on subsets of the datasets for 16,966 Holstein-Friesians and 11,287 Jerseys (Ahlborn-Breier et al., 1990) and 2,165 Holstein-Friesians (Sosa-Ferreyra, 1992) from the 1987/88 season.
Management traits showed higher phenotypic variances than conformation traits.

7.3.3.a) Heritabilities

Heritabilities for **protein, milkfat and volume** ranged between 0.17 and 0.29. Heritability estimates for production traits largely confirmed results from an earlier study based on a subset of the data used (Ahlborn and Dempfle, 1992). Generally, heritability estimates for protein, milkfat and milk yield were within the range of estimates reported for paternal half sib groups of other populations (Maijala and Hanna, 1974; Hill et al., 1983; De Jager and Kennedy, 1987; Schutz et al., 1990; Ahlborn and Dempfle, 1992). However, heritabilities for production traits of Jerseys were relatively low when compared to other published estimates. For example, Ahlborn and Dempfle (1992) using a subset of the current data reported heritabilities of 0.24 for protein and 0.26 for milkfat for New Zealand Jerseys. A possible explanation for this difference in heritability estimates could be that results based on a larger sample of the population gave a relatively smaller genetic variance for these traits.

Liveweight and stature had moderate to high heritabilities, ranging between 0.12 and 0.39, Jerseys returning slightly

Table 7.2.: Heritabilities of traits used as selection objectives in the aggregate genotype and as selection criteria in the selection indexes.

Trait	Holstein-Friesian	Jersey
Protein (kg)	0.25	0.17
Milkfat (kg)	0.21	0.17
Volume (kg)	0.28	0.22
Liveweight (kg)	0.39	0.12
Survival 1→2 (%)	0.04	0.02
Udder overall (score)	0.27	0.24
Overall opinion (score)	0.09	0.12
Temperament (score)	0.10	0.14
Milking speed (score)	0.15	0.21
Udder support (score)	0.25	-
Fore udder (score)	-	0.24

lower values. Stature had a markedly higher heritability than liveweight as had been shown previously (Ahlborn and Dempfle, 1992). For Holstein-Friesians, estimates for liveweight and stature were higher than in a previous study based on a subset of the records used (Ahlborn and Dempfle, 1992). This can be explained with a larger estimated genetic variance in the complete dataset which might be due to a larger number of sires analysed. Another possible reason for the higher genetic variances of Holstein-Friesians for stature when compared to estimates from Ahlborn and Dempfle (1992) may be the recent inclusion of North American sires in the progeny testing scheme. North American Holstein-

Friesians have partly been selected for large stature and this may have increased the genetic variance estimated from the complete dataset.

In contrast, the genetic variance for Jerseys for stature in this analysis was slightly lower than that found in the above-mentioned study. Jersey sires comprising this dataset originated in New Zealand and so the dataset did not include imported Jersey sires resulting in a more homogeneous population.

Heritabilities for the body size traits liveweight and stature generally agreed with estimates published overseas for a range of different breeds and countries (Thompson et al., 1981; Thompson et al., 1981; Smith et al., 1985; Foster et al., 1988; Smith et al., 1986; Klei et al., 1988; Meyer et al., 1987; Lawstuen et al., 1987; Colleau et al., 1989; Boldman et al., 1992). The heritability for liveweight was substantially higher than the estimate given by Sosa-Ferreyra (1992) which was based on a small dataset of 2,165 Holstein-Friesians.

Stature is a measure of skeletal size and thus is less influenced by variations in the environment. This is reflected in the higher heritability estimates for stature when compared to liveweight.

Heritabilities for **survival from first to second lactation** were very low with 0.04 for Holstein-Friesians and 0.02 for Jerseys. These heritabilities were as low as reported elsewhere (Robertson and Barker, 1966; Schaeffer and Burnside, 1974; Hudson and Van Vleck, 1981; Burnside et al., 1984; Van Doormaal et al., 1985; Ducrocq, 1987; Harris, 1989; Rogers et al., 1991a; Boldman et al., 1992) indicating that survival rate is largely influenced by environmental factors.

However, survival rate had a high coefficient of variation in the order of 50% and its large phenotypic variation to some extent offsets the low heritability. Accordingly, genetic progress in this trait could be achieved.

Heritabilites for the management traits overall **opinion, temperament and milking speed** were low for Holstein-Friesians and Jerseys, ranging between 0.09 and 0.21. This could indicate that either the environment, which includes the farmer's attitude and the scorer being confounded within herd has a much larger influence on management traits. It could also be possibly that large environmental influences were omitted with the recording system used. Genetic improvement of these traits based on data gathered with this recording system would consequently be slow as the phenotypic variance is not large and so does not counteract the low heritability. Heritabilities for management traits were slightly higher than those reported based on 2,165 of the Holstein-Friesian records used here (Sosa-Ferreyra, 1992). Heritabilities for temperament and milking speed were slightly higher than those reported in the literature (Thompson et al., 1981; Smith et al., 1985; Zarnecki et al., 1985; Foster et al., 1988; Lawstuen et al., 1987; Boldman et al., 1992).

Heritabilities for the conformation traits **udder overall, udder support and fore udder** were similar in magnitude to those for production traits. Heritabilities for these conformation traits largely agreed with estimates published overseas (Thompson et al., 1981; Thompson et al., 1981; Smith et al., 1985; Foster et al., 1988; Smith et al., 1986; Klei et al., 1988; Meyer et al., 1987; Lawstuen et al., 1987; Boldman et al., 1992).

7.3.3.b) Phenotypic correlations

Phenotypic correlations for the selection criteria are shown in Table 7.3. for Holstein-Friesians and Jerseys. Phenotypic correlations for all traits analysed are presented in the appendix in Table 10.2. for Holstein-Friesians (10.2.a), Jerseys (10.2.b) and Ayrshires (10.2.c) and their standard errors in Table 10.3.
Phenotypic correlations within production traits were high and positive (> 0.82) in both breeds as has frequently been observed previously (Meyer, 1985; De Jager and Kennedy, 1987; Schutz et al., 1990; Ahlborn-Breier and Hohenboken, 1991).

Phenotypic correlations between **liveweight** and **production** traits of around 0.20 for both breeds were consistent with recently published results for North American Holstein-Friesians (Sieber et al., 1988; Foster et al., 1988) as well as those for New Zealand Holstein-Friesians and Jerseys (Ahlborn-Breier and Hohenboken, 1991).

Phenotypic correlations between the management traits **overall opinion, temperament** and **milking** speed were moderately high and positive (0.18 - 0.65). This might indicate that dairy farmers were not able to clearly distinguish between these traits. Similar estimates were reported by Sosa-Ferreyra (1992) for Holstein-Friesians.
Phenotypic correlations of **temperament** and **milking** speed **with** production traits were low but positive. This would suggest dairy farmers scored the management traits temperament and milking speed without bias from production traits. These results are in agreement with low but positive estimates for phenotypic correlations between milkout, milking speed, temperament, excitability and yield traits in other studies

Table 7.3.: Phenotypic correlations (* 100) between selection criteria included in the selection indexes (* estimate not calculated).

a) Holstein-Friesian

	F	V	LW	UO	OO	TM	MS	US
Protein	88	91	20	5	25	13	3	0
Milkfat		82	16	6	26	13	5	2
Volume			19	4	26	14	2	*0
Liveweight				*0	*0	*0	*0	*0
Udder Overall					12	7	8	72
Overall opinion						65	38	9
Temperament							18	5
Milking speed								9

b) Jersey

	F	V	LW	UO	OO	TM	MS	FU
Protein	91	92	93	9	23	13	3	7
Milkfat		86	20	9	24	14	4	7
Volume			20	10	24	14	3	6
Liveweight				*0	*0	*0	*0	*0
Udder Overall					13	8	6	70
Overall opinion						68	35	10
Temperament							19	7
Milking speed								6

(Norman and Van Vleck, 1972; Foster et al., 1988). Phenotypic correlations between **overall opinion and production traits** of around 0.25 indicated that yield was a main factor in the value of the cows even at an early stage of lactation at which the assessment was carried out.

Phenotypic correlations between the conformation traits **udder overall, udder support and fore udder** were high (> 0.70). This indicates that the score for udder overall contains part of the information from udder support (Holstein-Friesians) or fore udder (Jerseys).
Phenotypic correlations between **conformation and production traits** were close to zero and not significant for both breeds. These results are in agreement with previous reports (Norman and Van Vleck, 1972; Bar-Anan and Ron, 1983; Zarnecki et al., 1985; Meyer et al., 1987; Foster et al., 1988; Misztal et al., 1992).
Phenotypic correlation estimates between **conformation and management traits** were close to zero. Similar estimates were also reported by Sosa-Ferreyra (1992) for New Zealand Holstein-Friesians.

7.3.3.c) Genetic correlations between selection objectives and selection criteria

Genetic correlations between traits included in the aggregate genotype and the selection index are shown in Table 7.4. Genetic correlations for all traits analysed are presented in the appendix in Table 10.2. for Holstein-Friesians (10.2.a), Jerseys (10.2.b) and Ayrshires (10.2.c) and their standard errors in Table 10.3. As expected standard errors for genetic correlations were considerably higher than for heritabilities or phenotypic correlations.

Genetic correlations between the production traits **protein** yield, milkfat yield and volume were high and positive (0.67 - 0.86) and estimates of similar magnitude have been regularly reported in other studies (Meyer, 1985; de Jager and Kennedy, 1987; Schutz et al., 1990; Wade and Van Vleck, 1989; Ahlborn-Breier and Hohenboken, 1991). Estimates of the genetic correlation between milkfat and protein yield were higher than in the studies cited above, which might be attributed to the single trait selection for milkfat yield in the New Zealand dairy cattle populations.

Genetic correlations between liveweight and milkfat yield, protein yield and volume were similar in magnitude as observed previously (Foster et al., 1988; Ahlborn-Breier and Hohenboken, 1991; Ahlborn and Dempfle, 1992; Misztal et al., 1992). The highest genetic correlations were encountered between liveweight and volume in Holstein-Friesians (0.33) and between liveweight and protein yield in Jerseys (0.54). The substantial difference between breeds is in agreement with Ahlborn and Dempfle (1992) who also observed higher genetic correlations for Jerseys than Holstein-Friesians for these traits.

Size and production traits in New Zealand dairy cattle populations exhibited slightly higher genetic correlations than were expected in comparison with reports from overseas studies which have reported genetic correlations of zero between stature and volume (Brum and Ludwick, 1969; Grantham et al., 1974). More recent publications which are based on comparable methodology and large datasets give estimates for the genetic correlation between stature and volume of around 0.15 for Holstein-Friesians (Bar-Anan and Ron, 1983; Foster et al., 1988; Norman and Powell, 1988; Misztal et al., 1992). This magnitude is still considerably less than the results from this study and as found by Ahlborn and Dempfle (1992). This might signify population-specific pleiotropism with some genes affecting variation in production as well as in size traits. The magnitude of the genetic correlation between

Table 7.4.: Genetic correlations between traits in aggregate genotype and criteria in selection index (* 100).

a) Holstein-Friesian

	P	F	V	LW	SRV	UO	OO	TM	MS
Milkfat	75								
Volume	85	70							
Liveweight	27	15	33						
Survival 1→2	15	31	1	-12					
Udder Overall	-17	-11	-17	0	-17				
Overall opin.	44	51	41	0	33	6			
Temperament	33	35	31	0	19	4	85		
Milking speed	- 1	13	-10	0	33	-4	46	13	
Udder support	-24	-19	-22	0	-16	95	11	9	-2

b) Jersey

	P	F	V	LW	SRV	UO	OO	TM	MS
Milkfat	80								
Volume	86	67							
Liveweight	54	51	43						
Survival 1→2	76	89	76	37					
Udder Overall	- 3	- 5	-10	0	10				
Overall opin.	39	29	26	0	57	15			
Temperament	22	20	15	0	41	19	82		
Milking speed	6	3	- 7	0	6	-14	34	9	
Fore udder	6	8	- 7	0	19	87	17	10	27

size and production traits indicates a noticeable correlated genetic response of liveweight and wither height in these populations when selecting for increased protein yield. This positive association between size and production traits means that selection for any of the production traits will result in larger cows with increased growth and maintenance costs unless liveweight is correctly specified in the aggregate genotype. This correlated response will be larger for Jerseys due to their higher genetic correlations.
In New Zealand body weight has a negative economic value as was described in chapter 4 and also as reported by Dempfle (1986). The same was found by Van Raden (1988) for the North American dairy production environment. Consequently, it is beneficial to include selection against size in the breeding objective to ensure the breeding of cows with a higher overall economic merit and so to increase net farm income.
For Holstein-Friesians selection can be carried out against liveweight without sacrificing much genetic progress in production traits. However, for Jerseys the inclusion of liveweight could slow genetic progress in production traits as a correlated response.

Genetic correlations between **survival rate from first to second lactation and production traits** differed between breeds. Survival rate was genetically much stronger correlated with production traits in Jerseys, with values of 0.76 for protein and 0.89 for milkfat, than in Holstein-Friesians, with values of 0.15 for protein and 0.31 for milkfat. The values for Holstein-Friesians agree with those given for 48 months "stayability" in North American Holstein-Friesians (De Lorenzo and Everett, 1982).

Genetic correlations between **survival rate and size traits** were moderately positive for Jerseys and slightly negative for Holstein-Friesians. Accordingly, with selection for production traits only, Jersey cows would increase in size while Holstein-Friesian cows would slightly decrease in liveweight and stature. The difference in magnitude of the genetic correlations might signify breed-specific pleiotropism, especially since breed estimates of similar magnitude have been reported for the Holstein-Friesian (Rogers et al., 1989a; Boldman et al. 1991) and Jersey (Rogers et al., 1991a) populations in North America. A clear reason for this, however, is not apparent.

Moderately positive genetic correlations between survival rate from first to second lactation and management traits indicated that temperament, milking speed and the overall opinion as measured by the owner are traits which can be used to genetically improve survival rate. It needs to be considered that overall opinion is also partially genetically correlated with production traits. A similar result was reported by Foster et al. (1988b).

Genetic correlations between survival rate and conformation traits were moderate and negative for udder overall and udder support in Holstein-Friesians and moderate and positive for udder overall and fore udder in Jerseys. This suggests that these conformation traits are of some value in selection programmes aimed at increasing survival rates. Other published reports state that genetic correlations between survival rate and conformation traits are low or antagonistic (De Lorenzo and Everett, 1982; Smith and Quaas, 1984; Dentine et al., 1987; Rogers et al., 1988; Rogers et al., 1989a, 1989b; Boldman et al., 1992). Two studies (Dentine et al., 1987; Rogers et al., 1991b) reported that registered daughters from sires with an above average conformation evaluation were less likely to be culled than non-registered daughters resulting in selective matings. The reason for this difference was not determined. It could be the result of a favourable bias for daughters from higher priced sires and the owners greater reluctance to cull these cows. This may be due to a greater financial and time investment rather than to genetic differences.

Genetic correlations between conformation and production traits were moderately negative for udder overall and udder support (Holstein-Friesians) and close to zero for fore udder (Jerseys). These results are in agreement with previous reports (Norman and Van Vleck, 1972; Bar-Anan and Ron, 1983; Zarnecki et al., 1985; Meyer et al., 1987; Foster et al., 1988; Misztal et al., 1992) and indicate that conformation traits would be ineffective in improving production traits.

7.4. Conclusion

The aggregate genotype for New Zealand dairy cattle including the selection objectives protein yield, milkfat yield, volume, liveweight and survival rate is expected to increase the economic merit of New Zealand dairy cows genetically. Estimating the genetic parameters for these traits and their selection criteria in the selection indexes showed the genetic and phenotypic basis for these traits. Results from the analysis also suggest that parameter estimates did not differ substantially from other populations for the traits examined despite the use of a different primary trait of selection and the data used for this study coming from a pasture based milk production system.

The heritability of the subjectively assessed trait liveweight had a magnitude similar to those found for production traits. This demonstrates that current breeding and progeny testing schemes could be used to genetically influence cow size. The higher heritability and the higher accuracy and repeatability and lower cost of measurement in conjunction with a very high positive genetic correlation might make stature a more effective selection criterion than liveweight.

The use of management and conformation traits as selection criteria to predict survival will allow the selection of sires and cows at an earlier stage than through the use of survival rate records. This will avoid an increase in the generation interval with the inclusion of survival rate in the breeding objective.

8. SELECTION INDEXES

8.1. Introduction

Knowledge of the economic values and genetic parameters allows to specify population-specific selection indexes for a given aggregate genotype or breeding objective. Since the aggregate genotype T is not measurable and cannot be selected for directly, improvement in T is achieved through the use of the optimum (Smith-Hazel) selection index. The properties of this selection index were described in section 2.1.4.1. The objective of this study was establish the weighting factors for the selection indexes for New Zealand Holstein-Friesian and Jersey using up-to-date economic values and genetic parameters for the traits included which maximise the correlation between the aggregate genotype and the selection indexes.

8.2. Selection index equations

An optimum selection index was specified for the New Zealand Holstein-Friesian and Jersey dairy cattle populations. Standard errors for the genetic parameter estimates for the Ayrshire population were high due to a small sample size and did not allow the construction of a reliable selection index for this breed.

The aggregate genotype T for Holstein-Friesians (T_H) and Jerseys (T_J) was defined in section 7.1. as

$$\begin{aligned} T_H = a_H'Y = &\ \$4.64 \text{ Protein} + \$1.85 \text{ Milkfat} - \$0.07 \text{ Volume} \\ &- \$0.49 \text{ Liveweight} + \$9.25 \text{ Survival rate} \end{aligned}$$

$$\begin{aligned} T_J = a_J'Y = &\ \$4.58 \text{ Protein} + \$1.75 \text{ Milkfat} - \$0.07 \text{ Volume} \\ &- \$0.53 \text{ Liveweight} + \$9.29 \text{ Survival rate} \end{aligned}$$

where Y is a vector of additive genetic values for 5 traits included in the aggregate genotype T, a is a vector of breed-specific constants which represent the relative economic values of the five traits in Y.

Since T_H and T_J are not measurable they cannot be selected for directly. Improvement in T_H and T_J is achieved by selection based on selection indexes I_H and I_J respectively, which were defined as:

$$I_H = \mathbf{b'}_H X_H = b_{H1}X_{H1} + b_{H2}X_{H2} + \ldots + b_{H9}X_{H9} = \Sigma\ b_H X_H$$

$$I_J = \mathbf{b'}_J X_J = b_{J1}X_{J1} + b_{J2}X_{J2} + \ldots + b_{J9}X_{J9} = \Sigma\ b_J X_J$$

where b was a vector of breed-specific weighting factors chosen to

a) maximise the correlation and

b) minimise the variance between index I and aggregate genotype T,

c) maximise the probability of selecting the largest sample values of the aggregate genotype T by selecting the largest value of the index criteria,

d) maximise the probability of selecting the higher of a combination of aggregate genotypes and

e) maximise genetic progress in any one-round selection by the index,

X is a vector of breed-specific phenotypic measures for the n selection criteria included in the selection index.

The weighting factors b_H and b_J in the selection index I_H and I_J represent partial regression coefficients and were obtained by solving the following index equations :

$$\mathbf{P}_H\,\mathbf{b}_H = \mathbf{G}_H\,\mathbf{a}_H \Rightarrow \mathbf{b}_H = \mathbf{P}_H^{-1}\,\mathbf{G}_H\,\mathbf{a}_H$$

$$\mathbf{P}_J\,\mathbf{b}_J = \mathbf{G}_J\,\mathbf{a}_J \Rightarrow \mathbf{b}_J = \mathbf{P}_J^{-1}\,\mathbf{G}_J\,\mathbf{a}_J$$

where P is a n*n matrix of phenotypic covariances between the n selection criteria in X,
G is a n*m matrix of genetic covariances between the n selection criteria in X and the m traits in Y,
P^{-1} is the inverse of matrix P.

The equations for the weighting factors b_H and b_J leading to the selection indexes I_H and I_J were set up in matrix form. Two programs were written using the APL system to solve the simultaneous linear equations. The first program calculates weighting factors for the case where traits in the aggregate genotype T are the same as the selection criteria in the selection index I. The second program does so for the case where traits in the aggregate genotype T differ from the selection criteria in the selection index I (indirect selection). A copy of the programs is included in the Appendix.

The aggregate genotype T included the traits protein yield, milkfat yield, volume, liveweight and survival rate from first to second lactation. The selection index I_H for Holstein-Friesians included the traits protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and udder support while the selection index I_J for Jerseys included the traits protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and fore udder.

The economic values (Tables 4.12.) and phenotypic and genetic parameters (Tables 7.2.-7.4.) derived in previous chapters were used to determine the weighting factors for the

selection indexes I_H and I_J.
Variance and covariance estimates used in the calculation of weighting factors for the selection indexes are shown in Table 8.1. (phenotypic parameters) and in Table 8.2. (genetic parameters). These variance and covariance estimates were based on parameters derived from univariate analyses. Variance and covariance estimates based on the multitrait analyses with different combinations of traits and differed only slightly from estimates calculated from univariate analyses. Covariance estimates calculated from results based on univariate analysis were somewhat higher than the estimates from multitrait analyses. For traits with low standard errors the difference was about 1% and for traits with a higher sampling variation the difference was in the order of 10%.
Calculating covariance estimates from univariate estimates can lead to rounding errors. However, standard errors of the parameters were higher than the estimated difference introduced by rounding errors, therefore covariances calculated from univariate estimates could be used.

The selection indexes I^1_H for Holstein-Friesians and I^1_J for Jerseys were constructed. Weighting factors for these selection indexes resulting from the simultaneous linear equations for this selection index are listed in Table 8.4. They are shown in the form to be used in the selection index as well as standardised by the respective mean for the trait.

Selection indexes I_H and I_J were constructed to allow selection for survival rate to be simultaneous with selection for all other traits. Selection indexes I_H and I_J included survival rate from first to second lactation as a selection objective in the aggregate genotype but not as a selection criterion in the selection index. This meant that the survival rate was indirectly estimated from all other selection criteria in the selection index. This decreases the generation interval by one year compared to direct

Table 8.1.: Phenotypic variances and covariances used for determining weighting factors for selection indexes.

a) Holstein-Friesians

	P	F	V	LW	SRV	UO	OO	TM	MS	US
Protein	280.22	333.91	7954.411	2.410	1.268	0.839	5.270	2.927	0.588	0.000
Milkfat		513.80	9705.725	2.610	1.808	1.364	7.422	3.963	0.000	0.399
Volume			272668.0	71.406	37.479	20.950	170.979	98.325	12.219	0.000
Liveweight				0.518	0.017	0.000	0.000	0.000	0.000	0.000
Survival (1->2)					0.159	0.020	0.065	0.032	0.023	0.014
Udder overall						1.006	0.152	0.094	0.094	0.635
Overall opinion							1.586	1.101	0.560	0.100
Temperament								1.809	0.283	0.059
Milking speed									1.369	0.093
Udder support										0.773

Table 8.1.continued: Phenotypic variances and covariances used for determining weighting factors in selection indexes.

b) Jerseys

	P	F	V	LW	SRV	OO
Protein	234.440	313.536	5524.22	1.813	1.212	3.277
Milkfat		506.360	7589.18	2.317	1.950	5.026
Volume			153792.0	40.376	31.033	87.586
Liveweight				0.265	0.006	0.000
Survival (1->2)					0.142	0.039
Overall opinion						0.866
Temperament						
Milking speed						
Fore udder						

	TM	MS	FU
Protein	2.411	0.469	1.087
Milkfat	3.816	0.920	1.598
Volume	66.498	12.021	23.869
Liveweight	0.000	0.000	0.000
Survival (1->2)	0.032	0.012	0.011
Overall opinion	0.766	0.333	0.094
Temperament	1.467	0.235	0.086
Milking speed		1.044	0.062
Fore udder			1.029

Table 8.2.: Genetic variances and covariances used in determining weighting factors for selection indexes.

a) Holstein-Friesians).

	P	F	V	LW	SRV	UO	OO	TM	MS	US
Protein	70.300	65.815	2001.435	1.020	0.091	-0.741	1.414	1.206	-0.044	-0.879
Milkfat		109.540	2057.45	0.707	0.234	-0.598	2.047	1.597	0.721	-0.869
Volume			78866.0	41.755	0.203	-24.807	44.146	37.948	-14.887	27.001
Liveweight				0.203	-0.004	0.000	0.000	0.000	0.000	0.000
Survival (1->2)					0.005	-0.006	0.009	0.006	0.013	-0.005
Udder overall						0.270	0.012	0.009	-0.011	0.216
Overall opinion							0.147	0.142	0.093	0.018
Temperament								0.190	0.030	0.017
Milking speed									0.281	-0.005
Udder support										0.191

Table 8.2.continued: Genetic variances and covariances used in determining weighting factors for selection indexes.

b) Jerseys

	P	F	V	LW	SRV	OO
Protein	40.132	47.170	1080.645	0.602	0.152	0.870
Milkfat		86.628	1236.925	0.836	0.262	0.950
Volume			39344.0	15.017	4.767	18.160
Liveweight				0.031	0.002	0.000
Survival (1->2)					0.001	0.006
Overall opinion						0.124
Temperament						
Milking speed						
Udder support						
Fore udder						

	TM	MS	US	FU
Protein	0.625	0.177	-0.059	0.187
Milkfat	0.835	0.130	-0.043	0.367
Volume	13.339	-6.468	-9.219	-6.844
Liveweight	0.000	0.000	0.000	0.000
Survival (1->2)	0.006	0.001	-0.001	0.003
Overall opinion	0.129	0.056	0.041	0.030
Temperament	0.201	0.019	0.035	0.022
Milking speed		0.217	0.063	0.062
Udder support			0.216	0.204
Fore udder				0.243

selection as the survival rate from first to second lactation is not known until the second lactation has started.

Genetic correlations indicated that survival rate was better predicted by the farmers overall opinion, the animal's temperament, milking speed and protein and milkfat production than through conformation traits, especially in Jerseys.

Table 8.3.: **Weighting factors ($/cow/annum) for selection criteria included in the selection indexes I_H (Holstein-Friesians) and I_J (Jerseys).**

Trait	**Holstein-Fries.**		**Jersey**	
(sc = score)	**$/unit**	**stand.**	**$/unit**	**stand.**
Protein (kg)	0.579	15.047	0.950	20.686
Milkfat (kg)	0.206	7.002	0.095	3.038
Volume (kg)	0.008	6.160	-0.011	-5.564
Liveweight (kg)	-5.919	-6.097	4.875	3.608
Udder overall (sc)	6.759	7.299	5.267	6.139
Overall opin. (sc)	0.638	0.938	5.971	6.867
Temperament (sc)	3.255	5.110	1.246	1.843
Milking speed (sc)	3.725	5.252	2.869	3.759
Udder support (sc)	-3.824	-3.786	-	-
Fore udder (sc)	-	-	6.843	8.144

8.3. Results and discussion

The weighting factors b_H and b_J calculated for the selection indexes I_H and I_J are presented in Table 8.3. The weighting factors (b's) for these selection criteria ranged between -5.92 and 14.28.

The weighting factors represent the solution to 9 linear equations and vary with different values for genetic and phenotypic parameters and are therefore population specific. For this reason, weighting factors are usually not published making comparisons with other dairy cattle populations impossible. An example of this specificity is seen by comparing differences between Holstein-Friesian and Jersey index weights in the current study. Volume and liveweight have negative economic values for both, Holstein-Friesians and Jerseys, but the index weights are positive for volume in Holstein-Friesians and for liveweight in Jerseys (Table 8.3.). The difference between breeds in genetic and phenotypic correlations between liveweight and volume and the remaining traits in the selection index resulted in these different index weights.

To allow a comparison of the importance of each trait the standardised weighting factors which take the standard deviations for each trait into account are also shown in Table 8.3. The standard deviations for the various traits differ considerably.

Protein yield was the most important trait with $ 15 per standard deviation in Holstein-Friesians and $ 21 in Jerseys. In Jerseys, overall opinion and fore udder returned high economic weighting factors.
Liveweight had a negative weighting factor for Holstein-Friesians but a positive one for Jerseys despite both breeds having negative economic values for liveweight.

The weighting factors shown in Table 8.3. are in line with those reported in previous studies for the same dairy cattle population and the same production system (Wickham, 1979; Ahlborn-Breier and Wickham, 1986; Ahlborn-Breier and Wickham, 1990).

8.4. Conclusion

The high economic value of protein yield in the New Zealand dairy production system is reflected in the highest weighting factors for the selection indexes constructed.

It would be useful to estimate the genetic gain possible with different combinations of traits as selection criteria in comparison to the selection indexes proposed here. This might identify selection indexes which might allow lower recording costs without a loss in genetic progress in the goal of breeding dairy cows with high economic merit.

9. CONCLUSION

Genetic and economic aspects of changes in the mean of a trait were combined in this study to quantitatively derive an aggregate genotype with the aim to improve the economic merit of New Zealand dairy cattle. A selection index was developed for ranking individuals in the Holstein-Friesian and Jersey dairy cattle populations of New Zealand.

Relative economic values for production traits and traits other than production were estimated. A net farm income function was defined for a pasture based milk production system with unlimited output in a competitive marketing system. The effects of changes in genetic, biological and economic parameters on the animal's life cycle and various components of farm income was simulated with a bioeconomic computer model.
The economic variables included prices for milkfat, protein, lactose, volume, carcass of mature cow, carcass of calf, calf sold for rearing as well as variable costs, fixed costs and discount rate. The biological variables included dry matter production per ha, utilisation of energy and requirements for maintenance, lactation, prenatal growth, postnatal growth, weight gain, milk production, liveweight, replacement rate, age distribution of the herd, survival rate of cows, calves and replacements, dressing percentage and ratio of calf weight at birth to cow liveweight. The model was validated and verified. The results showed the trade-off between milk production and stocking rate i.e. on herdsize and thus net farm income. The reduction in stocking rate required to achieve a phenotypic standard deviation increase in protein yield was twice the reduction in stocking rate needed to obtain a phenotypic standard deviation increase in milkfat yield.

The economic value for protein yield was $ 4.64/kg/cow for Holstein-Friesians and $ 4.58/kg/cow for Jerseys, followed by $ 1.84/kg/cow and $ 1.75/kg/cow, respectively for milkfat yield. Liveweight (kg) had a negative economic value of $ 0.49/kg/cow for Holstein-Friesians and $ 0.53/kg/cow for Jerseys. An increase in survival rate by 1% had a positive economic value of $ 9.25/cow for Holstein-Friesians and $ 9.29/cow for Jerseys. Surprisingly, lactose had a lower economic value than liveweight. The explanation for this is that an increase in liveweight gives a loss in revenue due to a reduced milk yield per ha but a higher return from cull cows and bobby calves.

The effects of changes in parameters and input and output variables in the bioeconomic model were evaluated in a sensitivity analysis.

Results showed that declining returns for milk reduced economic values for all milk components and simultaneously increased economic values for liveweight. Changes in the price paid for protein had the highest impact on all other economic values.

Considerable variations in prices for cull cows and bobby calves and also in input variables and biological animal parameters had only a minor impact on economic values. It was found that the bioeconomic model was relatively robust to changes in the input variables and gave stable economic values.

An increase in survival rate increases a cow's profitability as cows contribute to net farm income only during their lactation years and constitute a cost during the rearing period. Thus, a trait which influences survival rate also affect the cow's profitability and net farm income. The effects of traits other than production on survival rate were quantified. Results showed that after production traits the farmer's overall opinion and the traits udder support and udder overall had the greatest impact on survival rate.

These traits were used as selection criteria for survival rate in the selection indexes. The conformation traits rump angle, rump width, legs, front teat placement and rear teat placement did not affect survival rate.

Variance and covariance components were estimated for all 23 traits used in the current selection index. Genetic parameters for production, management and conformation traits were estimated using multitrait REML procedures.
Results showed that parameter estimates did not differ substantially from other populations. Heritabilities were 0.25 for protein yield and 0.21 for milkfat yield for Holstein-Friesians and 0.17 for both traits in Jerseys. High positive genetic correlations were observed between shed temperament and adaptability to milking and also between liveweight, stature and capacity in both Holstein-Friesians and Jerseys. This suggests that the traits adaptability to milking, capacity and either liveweight or stature may be deleted from the current recording system.

An aggregate genotype and selection indexes for Holstein-Friesians and Jerseys were constructed from the economic values and genetic parameters estimates. Only traits with non-zero economic values were included in the aggregate genotype. Some traits with high genetic correlations with other traits were excluded.
The aggregate genotype T included the traits protein yield, milkfat yield, volume, liveweight and survival rate.
The selection index I_H for Holstein-Friesians included the traits protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and udder support.
The selection index I_J for Jerseys included the traits protein yield, milkfat yield, volume, liveweight, udder overall, overall opinion, temperament, milking speed and fore udder.
The weighting factors calculated for these selection indexes

ranged between -$ 5.92/unit/cow and $ 6.84/unit/cow.

These selection indexes include the economically important trait survival rate in the aggregate genotype without extending the current generation.

This study is the first comprehensive analysis of available data and has

1) identified economic values for traits influencing the profit function in the New Zealand dairy cattle production system

2) derived multitrait estimates of genetic and phenotypic parameters for production, management and conformation traits of the New Zealand Ayrshire, Holstein-Friesian and Jersey populations,

3) combined genetic and phenotypic population parameters and economic values in an aggregate genotype for New Zealand dairy cattle with the objective to increase net farm income

4) developed selection indexes for Holstein-Friesians and Jerseys which maximise the correlation with the aggregate genotype using the estimates for phenotypic and genetic parameters.

Further investigations assessing the impact of changes in genetic and phenotypic parameters and economic values on the weighting factors used would evaluate the robustness of these selection indexes. A detailed evaluation of the potential genetic improvement achievable with different combinations of the various traits with the estimated parameters could lead to further improvements of genetic progress in economic merit of New Zealand dairy cattle.

10. Appendix

10.1. APL-CODE OF BIOECONOMIC MODEL

```
[0]    PRINT
[1]    ' Print definitions and values '
[2]    ' '
[3]    'A[ 1] Volume penalty / l milk                                 ',⍕A[1]
[4]    'A[ 2] Price increase / kg milk per percent increase of fat    ',⍕A[2]
[5]    'A[ 3] Price increase / kg milk per percent increase of protein',⍕A[3]
[6]    'A[23] Price increase / kg milk per percent increase of lactose',⍕A[23]
[7]    'A[ 4] Replacement rate                                        ',⍕A[4]
[8]    'A[ 5] Annual survival rate (cow)                              ',⍕A[5]
[9]    'A[ 6] Dressing out percentage (regression intercept)          ',⍕A[6]
[10]   'A[ 7] Base price / kg carcass (cow)                           ',⍕A[7]
[11]   'A[ 8] Increase in price / increase in kg carcass (cow)        ',⍕A[8]
[12]   'A[ 9] Survival rate of calf (birth - 4 days)                  ',⍕A[9]
[13]   'A[10] Survival rate of calf (4 days - 2 years)                ',⍕A[10]
[14]   'A[11] Ratio of calf weight (birth) to mature cow weight       ',⍕A[11]
[15]   'A[12] Base price / kg of bobby calf (liveweight)              ',⍕A[12]
[16]   'A[13] Increase in price of bobby calf / kg of liveweight      ',⍕A[13]
[17]   'A[14] Cost / cow for herd testing                             ',⍕A[14]
[18]   'A[15] Cost / cow for artificial insemination                  ',⍕A[15]
[19]   'A[16] Cost / cow for health                                   ',⍕A[16]
[20]   'A[17] Cost / cow for electricity and shed expenses (16 and 14)',⍕A[17]
[21]   'A[18] Cost / cow for interest at 12 percent for price of 800  ',⍕A[18]
[22]   'A[19] Cost of heifer             12                      550  ',⍕A[19]
[23]   'A[20] Cost of yearling and calf  12                420 and 150',⍕A[20]
[24]   'A[21] Price / kg bobby calf sold for rearing                  ',⍕A[21]
[25]   'A[22] Percentage of calves sold as bobbies                    ',⍕A[22]
[26]   'B[ 1] Eff. maintenance of cow / day and BW*0.75               ',⍕B[1]
[27]   'B[ 2] Eff. maintenance of heifer / day and BW*0.75            ',⍕B[2]
[28]   'B[ 3] Energy contained in 1 kg of body gain (growing heifer)  ',⍕B[3]
[29]   'B[ 4] Efficiency of growth                                    ',⍕B[4]
[30]   'B[ 5] Coefficient for pregnancy                               ',⍕B[5]
[31]   'B[ 6] Constant for milk energy                                ',⍕B[6]
[32]   'B[ 7] Coefficient for energy / percent fat                    ',⍕B[7]
[33]   'B[ 8] Coefficient for energy / percent protein                ',⍕B[8]
[34]   'B[ 9] Efficiency of lactation                                 ',⍕B[9]
[35]   'B[10] Efficiency of lactation                                 ',⍕B[10]
[36]   'B[11] Farm area (ha)                                          ',⍕B[11]
[37]   'B[12] DM available from pasture (kg DM / ha)                  ',⍕B[12]
[38]   'B[13] Energy content of DM (MJ ME / kg DM)                    ',⍕B[13]
[39]   'B[14] Age-production factor                                   ',⍕B[14]
[40]   'C[ 1] Milk yield                                              ',⍕C[1]
[41]   'C[ 2] Fat percentage                                          ',⍕C[2]
[42]   'C[ 3] Protein percentage                                      ',⍕C[3]
[43]   'C[ 4] Lactose percentage                                      ',⍕C[4]
[44]   'C[ 5] Bodyweight of mature cow                                ',⍕C[5]
[45]   C2←C[1]×C[2]÷100
[46]   C3←C[1]×C[3]÷100
[47]   C4←C[1]×C[4]÷100
[48]   'C2    Fat kg                                                  ',⍕C2
[49]   'C3    Protein kg                                              ',⍕C3
[50]   'C4    Lactose kg                                              ',⍕C4
```

```
[0]     DEFINITIONS X
[1]     A←23⍴0
[2]     B←14⍴0
[3]     C←5⍴0
[4]     A[1]←¯0.0435 ⍝ Volume penalty / l milk
[5]     A[2]←0.03948 ⍝ Price increase / kg milk per percent increase of fat
[6]     A[3]←0.05279⍝⍝ Price increase / kg milk per percent increase of protein
[7]     A[23]←0 ⍝ Price increase / kg milk per percent increase of lactose
[8]     A[4]←0.22 ⍝    Replacement rate
[9]     A[5]←0.9679 ⍝  Annual survival rate (cow)
[10]    A[6]←0.41 ⍝    Dressing out percentage (regression intercept)
[11]    A[7]←1.875976 ⍝Base price / kg carcass (cow)
[12]    A[8]←9.65E¯4 ⍝ Increase in price / increase in kg carcass (cow)
[13]    A[9]←0.964 ⍝   Survival rate of calves (birth - 4 days)
[14]    A[10]←0.9 ⍝    Survival rate of calves (4 days - 2 years)
[15]    A[11]←0.076 ⍝  Ratio of calf weight (birth) to cow weight
[16]    A[12]←0.5486 ⍝ Price / kg carcass (bobby calf)
[17]    A[13]←0.151 ⍝  Price increase / kg carcass (bobby calf)
[18]    A[14]←6 ⍝      Cost / cow for herd testing
[19]    A[15]←14 ⍝     Cost / cow for artificial insemination
[20]    A[16]←33 ⍝     Cost / cow for health
[21]    A[17]←30 ⍝     Cost / cow for electricity and shed expenses (16 and 14)
[22]    A[18]←96 ⍝     Cost / cow for interest at 12 percent for price of 800
[23]    A[19]←78 ⍝     Cost / heifer       '       12     '           '      650
Editing:  DEFINITIONS X [F] 0                                   APL       Num Ins
[24]    A[20]←68 ⍝     Cost / yearling and calf   12     '           420 and 150
[25]    A[21]←2.75 ⍝   Price / kg of bobby calf sold for rearing
[26]    A[22]←0.8 ⍝    Percentage of calves sold as bobbies
[27]    B[1]←0.5002 ⍝  Eff. maintenance of a cow / day and BW*0.75
[28]    B[2]←0.55 ⍝    Eff. maintenance of a growing heifer / day and BW*0.75
[29]    B[3]←14 ⍝      Energy contained in 1 kg of body gain (growing heifer)
[30]    B[4]←0.45 ⍝    Efficiency of growth
[31]    B[5]←54.14 ⍝   Coefficient for pregnancy
[32]    B[6]←¯0.108 ⍝  Constant for milk energy
[33]    B[7]←0.384 ⍝   Coefficient for energy / percent fat
[34]    B[8]←0.223 ⍝   Coefficient for energy / percent protein
[35]    B[9]←0.199 ⍝   Coefficient for energy / percent lactose
[36]    B[10]←0.6 ⍝    Efficiency of lactation
[37]    B[11]←69 ⍝     Farm area (ha)
[38]    B[12]←10500 ⍝  Energy available from pasture (kg DM / ha)
[39]    B[13]←11 ⍝     Energy content of DM  (MJ ME / kg DM)
[40]    B[14]←1 ⍝  Age-production factor
[41]    C[1]←3466 ⍝    Milk yield (kg)
[42]    C[2]←4.47 ⍝    Fat percentage
[43]    C[3]←3.47 ⍝    Protein percentage
[44]    C[4]←4.6 ⍝    Lactose percentage
[45]    C[5]←440 ⍝     Bodyweight of mature cow (kg)
[46]    C2←C[1]×B[14]×C[2]÷100 ⍝ Fat (kg)
[47]    C3←C[1]×B[14]×C[3]÷100 ⍝ Protein (kg)
```

```
[48]    C4←C[1]×B[14]×C[4]÷100 ⍝ Lactose (kg)
[49]    →(X≠'F')/0
[50]    A[5]←0.59 ⍝    Dressing out percentage (regression intercept)    Jersey
[51]    A[7]←1.826579 ⍝Base price / kg carcass (cow)                        ''
[52]    A[8]←1.246573 ⍝Increase in price / increase in kg carcass (cow)    ''
[53]    A[11]←0.0743 ⍝ Ratio of calf weight (birth) to cow weight           ''
[54]    A[12]←1.5131 ⍝Price / kg carcass (bobby calf)                       ''
[55]    A[13]←0.3375 ⍝ Price increase / kg carcass (bobby calf)             ''
[56]    A[18]←34 ⍝     Cost / cow interest at 12 percent for price of 700   ''
[57]    A[19]←72 ⍝     Cost / heifer  '    '  12    '    '    '    '  600   ''
[58]    A[20]←52 ⍝     Cost / calf    '    '  12    '    '    '  330 + 110  ''
[59]    A[21]←0 ⍝      Price/kg bobby calf sold for rearing                 ''
[60]    A[22]←1 ⍝      Percentage of calves sold as bobbies                 ''
[61]    B[14]←1 ⍝  Age-production factor                                 ''
[62]    C[1]←3372 ⍝    Milk yield (kg)                                      ''
[63]    C[2]←5.75 ⍝    Fat percentage
[64]    C[3]←4.12 ⍝    Protein percentage
[65]    C[4]←4.68 ⍝    Lactose percentage                                   ''
[66]    C[5]←360 ⍝     Bodyweight of mature cow (kg)                        ''
[67]    C2←C[1]×B[14]×C[2]÷100 ⍝ Fat (kg)
[68]    C3←C[1]×B[14]×C[3]÷100 ⍝ Protein (kg)
[69]    C4←C[1]×B[14]×C[4]÷100 ⍝ Lactose (kg)
```

```
[0]     X COMMAND Y;ANC;NC;EW;A;B;C;PROFIT0;PROFIT1;PROFIT2;PROFIT3;PROFIT4;C2;C3
       ;C4
[1]     ' Date and time ',⍕⎕TS
[2]     DEFINITIONS X
[3]     →(Y≠'P')/E1
[4]     PRINT
[5]    E1:EW←5⍴0
[6]     PROFIT0←HERDPROFIT Y
[7]     ANC←NC
[8]     C[1]←C[1]+1E¯4
[9]     PROFIT1←HERDPROFIT 'K'
[10]    C[1]←C[1]-1E¯4
[11]    C[2]←C[2]+1E¯6
[12]    PROFIT2←HERDPROFIT 'K'
[13]    C[2]←C[2]-1E¯6
[14]    C[3]←C[3]+1E¯6
[15]    PROFIT3←HERDPROFIT 'K'
[16]    C[3]←C[3]-1E¯6
[17]    C[4]←C[4]-1E¯6
[18]    PROFIT4←HERDPROFIT 'K'
[19]    C[4]← C[4]+1E¯6
[20]    C[5]← C[5]+1E¯4
[21]    PROFIT5←HERDPROFIT 'K'
[22]    C[5]←C[5]-1E¯4
[illegible]
[23]    [illegible]
[24]    [illegible]
[25]    EW[3]← [illegible]
              [illegible] ¯4-PROFIT0)÷1E¯6
[27]    EW[5]←(PROFI[illegible]
[28]    '                                                   '
[29]    '          Milk(kg)        Fat(o/o)       Protein(o/o)      Lactose(o/o)    L[illegible]
       ght(kg)'
[30]    'Economic weights / ha'                             '
[31]    15 4 ⍕EW÷B[11]
[32]    'Economic weights standardized'
[33]    15 4 ⍕EW÷EW[2]
[34]    'Economic weight / cow'
[35]    15 4 ⍕EW÷ANC
[36]    'Revenue of one unit'
[37]    15 4 ⍕(A[1]+(A[2]×C[2])+(A[3]×C[3])),(A[2]×C[1]),(A[3]×C[1])
[38]    '                   '
[39]   ⍝ Calculations based on fat and protein yield (kg)
[40]    PROFIT0←HERDPROFIT1 Y
[41]    ANC←NC
[42]    C[1]←C[1]+1E¯4
[43]    PROFIT1←HERDPROFIT1 'Y'
[44]    C[1]←C[1]-1E¯4
[45]    C2←C2+1E¯4
```

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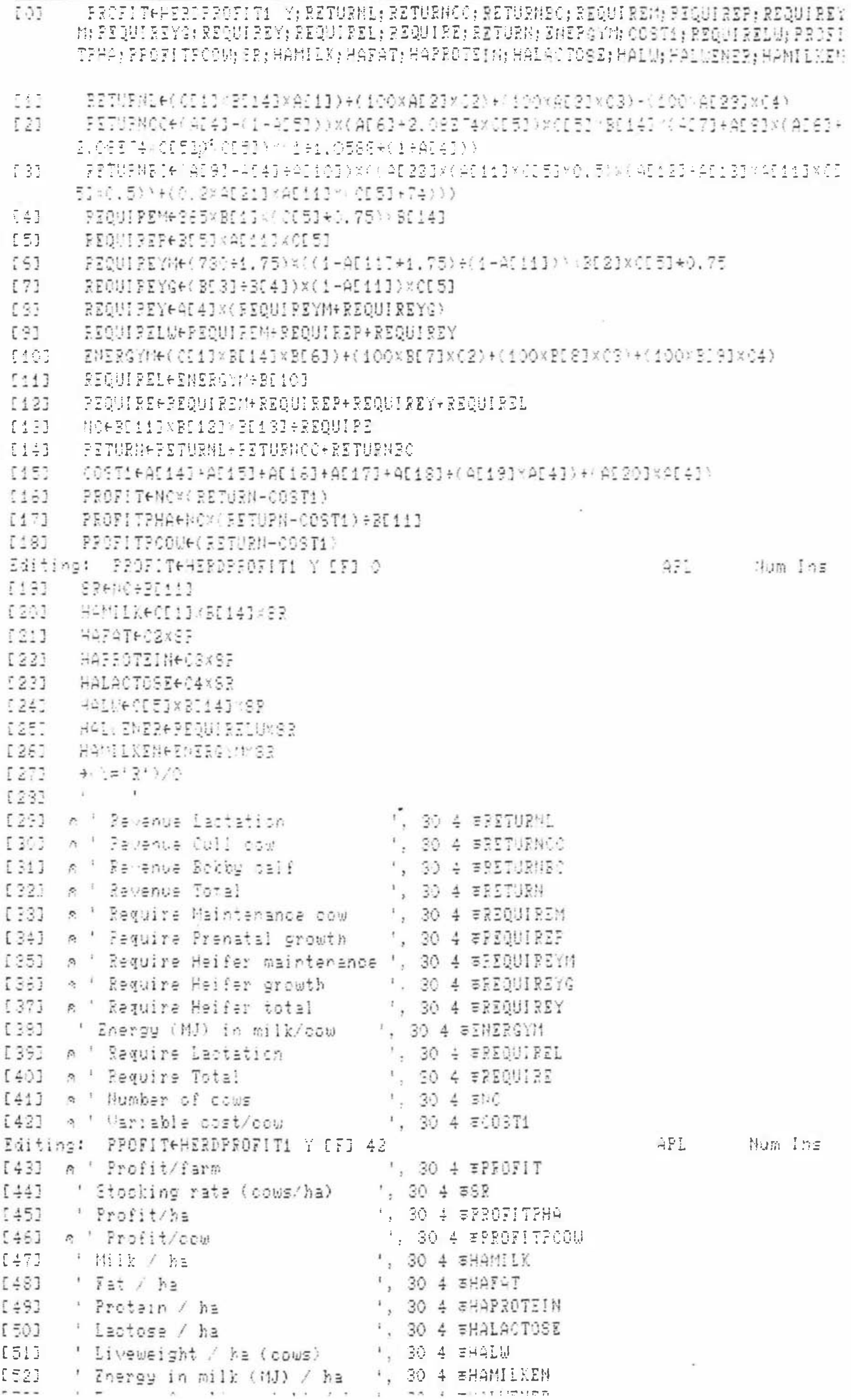
[46]   PROFIT2←HERDPROFIT1 'Y'
[47]   C2←C2-1E¯4
[48]   C3←C3+1E¯4
[49]   PROFIT3←HERDPROFIT1 'Y'
[50]   C3←C3-1E¯4
[51]   C4←C4+1E¯4
[52]   PROFIT4←HERDPROFIT1 'Y'
[53]   C4←C4-1E¯4
[54]   C[5]←C[5]+1E¯4
[55]   PROFIT5←HERDPROFIT1 'Y'
[56]   C[5]←C[5]-1E¯4
[57]   EW[1]←(PROFIT1-PROFIT0)÷1E¯4
[58]   EW[2]←(PROFIT2-PROFIT0)÷1E¯4
[59]   EW[3]←(PROFIT3-PROFIT0)÷1E¯4
[60]   EW[4]←(PROFIT4-PROFIT0)÷1E¯4
[61]   EW[5]←(PROFIT5-PROFIT0)÷1E¯4
[62]   '                                '
[63]   '            Milk(kg)        Fat(kg)     Protein(kg)     Lactose(kg)    Liveweig
      ht(kg)'
[64]   'Economic weights / ha'
[65]   15 4 ⍕EW÷B[11]
[66]   'Economic weights standardized'
[67]   15 4 ⍕EW÷EW[2]
Editing:  X COMMAND Y [F] 67                                     APL      Num Ins
[68]   'Economic weights / cow'
[69]   15 4 ⍕EW÷ANC
[70]   'Revenue of one unit'
[71]   15 4 ⍕A[1],(100×A[2]),(100×A[3])
```



```
[0]    PROFIT←HERDPROFIT1 Y;RETURNL;RETURNCC;RETURNBC;REQUIREM;REQUIREP;REQUIREY
      M;REQUIREYG;REQUIREY;REQUIREL;REQUIRE;RETURN;ENERGYM;COST1;REQUIRELW;PROFI
      TPHA;PROFITPCOW;SR;HAMILK;HAFAT;HAPROTEIN;HALACTOSE;HALW;HALWENER;HAMILKEN

[1]    RETURNL←(C[1]×B[14]×A[1])+(100×A[2]×C2)+(100×A[3]×C3)-(100×A[23]×C4)
[2]    RETURNCC←(A[4]-(1-A[5]))×(A[6]+2.08E¯4×C[5])×C[5]×B[14]×(A[7]+A[8]×(A[6]+
      2.08E¯4×C[5])*C[5])×÷1.0588÷(1÷A[4]))
[3]    RETURNBC←(A[9]-A[4]÷A[10])×((A[22]×(A[11]×C[5]*0.5)×(A[12]+A[13]×A[11]×C[
      5]*0.5))+(0.2×A[21]×A[11]×C[5]+74)))
[4]    REQUIREM←365×B[1]×(C[5]*0.75)×B[14]
[5]    REQUIREP←B[5]×A[11]×C[5]
[6]    REQUIREYM←(730÷1.75)×((1-A[11]*1.75)÷(1-A[11]))×B[2]×C[5]*0.75
[7]    REQUIREYG←(B[3]÷B[4])×(1-A[11])×C[5]
[8]    REQUIREY←A[4]×(REQUIREYM+REQUIREYG)
[9]    REQUIRELW←REQUIREM+REQUIREP+REQUIREY
[10]   ENERGYM←(C[1]×B[14]×B[6])+(100×B[7]×C2)+(100×B[8]×C3)+(100×B[9]×C4)
[11]   REQUIREL←ENERGYM÷B[10]
[12]   REQUIRE←REQUIREM+REQUIREP+REQUIREY+REQUIREL
[13]   NC←B[11]×B[12]×B[13]÷REQUIRE
[14]   RETURN←RETURNL+RETURNCC+RETURNBC
[15]   COST1←A[14]+A[15]+A[16]+A[17]+A[18]+(A[19]×A[4])+(A[20]×A[4])
[16]   PROFIT←NC×(RETURN-COST1)
[17]   PROFITPHA←NC×(RETURN-COST1)÷B[11]
[18]   PROFITPCOW←(RETURN-COST1)
Editing:  PROFIT←HERDPROFIT1 Y [F] 0                                   APL      Num Ins
[19]   SR←NC÷B[11]
[20]   HAMILK←C[1]×B[14]×SR
[21]   HAFAT←C2×SR
[22]   HAPROTEIN←C3×SR
[23]   HALACTOSE←C4×SR
[24]   HALW←C[5]×B[14]×SR
[25]   HALWENER←REQUIRELW×SR
[26]   HAMILKEN←ENERGYM×SR
[27]   →(Y='R')/0
[28]   '     '
[29]  ⍝ ' Revenue Lactation          ', 30 4 ⍕RETURNL
[30]  ⍝ ' Revenue Cull cow           ', 30 4 ⍕RETURNCC
[31]  ⍝ ' Revenue Bobby calf         ', 30 4 ⍕RETURNBC
[32]  ⍝ ' Revenue Total              ', 30 4 ⍕RETURN
[33]  ⍝ ' Require Maintenance cow    ', 30 4 ⍕REQUIREM
[34]  ⍝ ' Require Prenatal growth    ', 30 4 ⍕REQUIREP
[35]  ⍝ ' Require Heifer maintenance ', 30 4 ⍕REQUIREYM
[36]  ⍝ ' Require Heifer growth      ', 30 4 ⍕REQUIREYG
[37]  ⍝ ' Require Heifer total       ', 30 4 ⍕REQUIREY
[38]    ' Energy (MJ) in milk/cow   ', 30 4 ⍕ENERGYM
[39]  ⍝ ' Require Lactation          ', 30 4 ⍕REQUIREL
[40]  ⍝ ' Require Total              ', 30 4 ⍕REQUIRE
[41]  ⍝ ' Number of cows             ', 30 4 ⍕NC
[42]  ⍝ ' Variable cost/cow          ', 30 4 ⍕COST1
Editing:  PROFIT←HERDPROFIT1 Y [F] 42                                  APL      Num Ins
[43]  ⍝ ' Profit/farm                ', 30 4 ⍕PROFIT
[44]    ' Stocking rate (cows/ha)   ', 30 4 ⍕SR
[45]    ' Profit/ha                 ', 30 4 ⍕PROFITPHA
[46]  ⍝ ' Profit/cow                 ', 30 4 ⍕PROFITPCOW
[47]    ' Milk / ha                 ', 30 4 ⍕HAMILK
[48]    ' Fat / ha                  ', 30 4 ⍕HAFAT
[49]    ' Protein / ha              ', 30 4 ⍕HAPROTEIN
[50]    ' Lactose / ha              ', 30 4 ⍕HALACTOSE
[51]    ' Liveweight / ha (cows)    ', 30 4 ⍕HALW
[52]    ' Energy in milk (MJ) / ha  ', 30 4 ⍕HAMILKEN
```

10.2.a APL-CODE FOR CALCULATING SELECTION INDEX COEFFICIENTS

For the case G = C and m = n

```
[0]     MAIN;X;XP;XG;XA
[1]     ⍝'*****  Calculation of selection index coefficients (b-values)  *****'
[2]    ⍝ ⍞←⎕TCNL
[3]     ⍎(0≠1↑⍴XN←X↓⍞,0⍴X←¯1↑⍴⍞←⎕TCNL,'No. of traits N: ')/'N←⍎XN'
[4]     ⍎(0≠1↑⍴XT←X↓⍞,0⍴X←⍴⍞←⎕TCNL,'Traits: ')/'T←(N,8)⍴XT'
[5]     ⍎(0≠1↑⍴XP←MATINPTS 0⍴⍞←⎕TCNL,'Phenotypic covariance matrix P: ')/'P←XP'
[6]     ⍎(0≠1↑⍴XG←MATINPTS 0⍴⍞←⎕TCNL,'Genetic covariance matrix G: ')/'G←XG'
[7]     ⍎(0≠1↑,⍴XA←X↓⍞,0⍴X←¯1↑⍴⍞←⎕TCNL,'Economic values A: ')/'A←(⍴G)⍴⍎XA'
[8]     ⍞←⎕TCNL
[9]     B←((N,1)⍴⍉+/G×A)⌹P
[10]    'The selection index coefficients are: '
[11]    '    '
[12]    ⎕←T,⍕B
```

```
[0]      Z←MATINPTS Y;I;M;V;X;⎕IO
[1]    ⍝ '*****  Input routine for creating symmetric matrices  *****'
[2]     'Enter upper diagonal of matrix row by row'
[3]     ⎕IO←I←M←0
[4]    L1:V←1↓⍎'0 ',X↓⍞,0⍴X←⍴⍞←'Row ',(⍕I+1),': '
[5]     ⍎(M=0)/'→(M=0)/0,,Z←(2⍴M←⍴V)⍴0'
[6]     Z[I+⍳(M-I);I]←Z[I;I+⍳(M-I)]←V
[7]     →(M>I←I+1)/L1
```

10.2.b APL-CODE FOR CALCULATING SELECTION INDEX COEFFICIENTS

For the case G ≠ C and m ≠ n

```
[0]    MAINA;X;XP;XG;XA
[1]    ⍕'+++++  Calculation of selection index coefficients (b-values)  +++++'
[2]    '+++++  Traits in objective and criteria differ, m ≠ n and G ≠ C +++++'
[3]    ⎕←⎕TCNL
[4]   ⍝ Y←((⌽∨\⌽M)∧(∨\M)∧M∨1⌽1⌽1,M←' '≠X)/X
[5]   ⍝ MC←⌈/C←+/∧\(⌽,¯1↓1-MB/⍳⍴MB/)⌽((+/MB),⍴MB)⍴ML←~MB←' '=Y,' '
[6]   ⍝ ML(MB/⍳⍴MB)MC-C
[7]   ⍝ Z←((+/MB),MC)⍴ML/Y,' '
[8]    ⍎(0≠1↑⍴XN←X↓⍞,0⍴X←¯1+⍴⍞←⎕TCNL,'No. of traits (selection criteria) N: ')/'
      N←⍎XN'
[9]    ⍎(0≠1↑⍴XT←X↓⍞,0⍴X←⍴⍞←⎕TCNL,'Traits as selection criteria: ')/'T←(N,8)⍴XT'

[10]   ⍎(0≠1↑⍴XP←MATINPTS 0⍴⍞←⎕TCNL,'Phenotypic covariance matrix P: ')/'P←XP'
[11]   ⍎(0≠1↑⍴XG←M_INPUT 0⍴⍞←⎕TCNL,'Genetic covariance matrix G: ')/'G←XG'
[12]   ⍎(0≠1↑⍴XA←X↓⍞,0⍴X←¯1+⍴⍞←⎕TCNL,'Economic values A: ')/'A←(⍴G)⍴⍎XA'
[13]   ⎕←⎕TCNL
[14]   B←((N,1)⍴⍉+/G×A)⌹P
[15]   'The selection index coefficients are: '
[16]   '    '
[17]   ⎕←T,⍕B
```

```
[0]     Z←M_INPUT I;N;M;V
[1]     N←1↑⎕,⍞←'No. of rows ?'
[2]     Z←(N,M←1↑⎕,⍞←'No. of columns ?')⍴⍳I←1
[3]     →8×⍳N=M
[4]     'Row ',⍕I,V←⍳0
[5]     →5×⍳M>⍴V←V,⎕
[6]     Z[I;]←M⍴V
[7]     →((N≥I←I+1),1)/ 4 0
[8]     →4×⍳'N'=1↑⍞,⍞←'Is the matrix symmetric (Y/N) ?'
[9]     'Row ',(⍕I),'Column 1 to ',⍕I,V←⍳0
[10]    →10×⍳I>⍴V←V,⎕
[11]    Z[⍳I;I]←Z[I;⍳I]←I⍴V
[12]    →9×⍳N≥I←I+1
```

Table 10.1.: Adjusted means (μ), phenotypic (σ_P^2) and additive genetic (σ_A^2) variances and heritability estimates ($\hat{h}^2$) with their standard deviations (s.d.) and standard errors (s.e.) for production and non-production traits for primiparous cows.

a) Holstein-Friesian

Trait	μ	s.d.	σ_P^2	s.e.	σ_A^2	s.e.	$\hat{h}^2$	s.e.
Protein	100.56	25.97	280.22	30.851	70.30	7.26	0.25	0.025
Milkfat	130.83	33.94	513.80	55.209	109.54	12.08	0.21	0.022
Milk	2991.68	777.96	272668	3091	78866	7815	0.29	0.027
Protein %	3.38	0.28	0.060	0.0008	0.027	0.002	0.47	0.034
Milkfat %	4.40	0.51	0.203	0.0026	0.090	0.0076	0.44	0.034
Weight	4.51	1.03	0.518	0.0063	0.203	0.0189	0.39	0.031
Stature	5.41	1.07	0.624	0.0082	0.306	0.0250	0.49	0.036
Capacity	5.46	1.02	0.812	0.0093	0.257	0.0062	0.32	0.027
Survival 1st→2nd Lact.	0.767	0.423	0.159	0.0161	0.005	0.0015	0.03	0.010
Udder Overall	4.91	1.08	1.006	0.0111	0.270	0.0065	0.27	0.024
Dairy Conformation	5.53	1.03	0.851	0.0956	0.259	0.0234	0.30	0.026
Overall Opinion	6.24	1.47	1.586	0.0159	0.147	0.0221	0.09	0.014
Adaptability to Milking	5.72	1.63	1.908	0.0191	0.164	0.2736	0.09	0.014
Shed Temperament	5.91	1.57	1.809	0.0183	0.190	0.0271	0.11	0.015
Milking Speed	6.04	1.41	1.369	0.0141	0.281	0.0254	0.15	0.018
Rump Angle	5.37	0.83	0.589	0.0064	0.152	0.0146	0.26	0.023
Rump Width	5.16	0.95	0.630	0.0701	0.178	0.0168	0.28	0.025
Legs	5.73	0.80	0.417	0.0041	0.026	0.0048	0.06	0.011
Udder Support	5.19	0.99	0.773	0.0084	0.191	0.0189	0.25	0.023
Fore Udder	5.00	1.06	0.909	0.0096	0.187	0.0049	0.21	0.021
Rear Udder	4.86	0.99	0.905	0.0089	0.185	0.0044	0.21	0.021
Front Teat Placement	4.29	0.72	0.817	0.0089	0.197	0.0197	0.24	0.023
Rear Teat Placement	5.32	0.82	0.456	0.0051	0.133	0.0127	0.29	0.026

Table 10.1.cont'd: Adjusted means (μ), phenotypic (σ_P^2) and additive genetic (σ_A^2) variances and heritability estimates ($\hat{h}^2$) with their standard deviations (s.d.) and standard errors (s.e.). for production and non-production traits for primiparous cows.

b) Jersey

Trait	μ	s.d.	σ_P^2	s.e.	σ_A^2	s.e.	$\hat{h}^2$	s.e.
Protein	92.85	21.77	234.44	2.9549	40.132	6.2666	0.17	0.025
Milkfat	131.42	31.98	506.36	6.3622	86.628	12.8790	0.17	0.025
Milk	2317.65	520.02	153792	2002	39344	4598	0.22	0.028
Protein %	4.01	0.32	0.699	0.1046	0.028	0.0031	0.40	0.040
Milkfat %	5.67	0.57	0.251	0.4032	0.122	0.0128	0.49	0.045
Weight	2.97	0.74	0.265	0.3210	0.031	0.0054	0.12	0.020
Stature	3.64	0.80	0.364	0.4760	0.082	0.0109	0.23	0.029
Capacity	6.16	1.15	0.866	0.1063	0.124	0.0199	0.14	0.022
Survival 1st→2nd Lact.	0.796	0.403	0.142	0.1644	0.001	0.0010	0.01	0.007
Udder Overall	5.35	1.23	1.110	0.1456	0.263	0.0344	0.24	0.029
Dairy Conformation	6.12	1.14	0.892	0.1120	0.612	0.0235	0.18	0.025
Overall Opinion	6.54	1.15	0.866	0.1063	0.124	0.0199	0.14	0.022
Adaptability to Milking	6.12	1.54	1.507	0.1846	0.208	0.0248	0.14	0.022
Shed Temperament	6.30	1.48	1.467	0.1786	0.201	0.0328	0.14	0.022
Milking Speed	6.37	1.31	1.044	0.1345	0.217	0.0299	0.21	0.027
Rump Angle	5.28	0.70	0.401	0.5299	0.104	0.0131	0.26	0.031
Rump Width	5.53	1.04	0.603	0.7429	0.096	0.0147	0.16	0.024
Legs	5.52	0.63	0.232	0.2724	0.013	0.0033	0.06	0.015
Udder Support	5.72	1.14	0.943	0.1238	0.216	0.0286	0.23	0.029
Fore Udder	5.58	1.19	1.029	0.1347	0.243	0.0319	0.24	0.029
Rear Udder	5.39	1.22	0.960	0.1254	0.223	0.0294	0.23	0.029
Front Teat Placement	4.31	0.72	0.459	0.6176	0.123	0.0143	0.27	0.032
Rear Teat Placement	5.06	0.69	0.437	0.5582	0.085	0.0119	0.19	0.026

Table 10.1.cont'd: Adjusted means (μ), phenotypic (σ_P^2) and additive genetic (σ_A^2) variances and heritability estimates ($\hat{h}^2$) with their standard deviations (s.d.) and standard errors (s.e.). for production and non-production traits of primiparous cows.

c) Ayrshire

Trait	μ	s.d.	σ_P^2	s.e.	σ_A^2	s.e.	$\hat{h}^2$	s.e.
Protein	102.02	27.63	258.10	11.394	62.66	27.592	0.24	0.092
Milkfat	128.77	35.59	468.51	19.956	91.24	41.583	0.20	0.083
Milk	2899.38	762.24	235822	10197	48382	23116	0.21	0.085
Protein %	3.53	0.28	0.51	0.237	0.02	0.006	0.38	0.117
Milkfat %	4.54	0.50	0.17	0.875	0.09	0.026	0.51	0.136
Weight	3.69	0.88	0.40	0.173	0.10	0.040	0.24	0.092
Stature	4.29	0.90	0.50	0.247	0.23	0.072	0.45	0.127
Capacity	5.97	1.04	0.73	0.323	0.19	0.076	0.26	0.096
Survival 1st→2nd Lact.	0.790	0.407	0.15	0.622	0.01	0.008	0.08	0.059
Udder Overall	5.39	0.95	1.49	0.661	0.39	0.160	0.26	0.096
Dairy Conformation	5.71	0.97	0.66	0.285	0.16	0.006	0.24	0.091
Overall Opinion	6.48	1.35	1.49	0.661	0.39	0.136	0.26	0.096
Adaptability to Milking	5.80	1.68	2.05	0.923	0.63	0.229	0.31	0.104
Shed Temperament	6.11	1.51	1.73	0.779	0.52	0.195	0.30	0.102
Milking Speed	6.35	1.38	1.39	0.653	0.48	0.180	0.35	0.110
Rump Angle	5.57	0.71	0.05	0.002	0.002	0.006	0.38	0.117
Rump Width	5.20	0.88	0.17	0.009	0.09	0.026	0.51	0.136
Legs	5.43	0.63	2.05	0.092	0.63	0.229	0.31	0.104
Udder Support	5.70	0.91	1.73	0.779	0.52	0.195	0.30	0.102
Fore Udder	5.53	0.97	1.39	0.065	0.48	0.180	0.35	0.110
Rear Udder	5.42	0.98	1.49	0.066	0.39	0.160	0.26	0.959
Front Teat Placement	4.49	0.67	0.66	0.027	0.06	0.038	0.10	0.626
Rear Teat Placement	5.33	0.80	0.66	0.029	0.16	0.061	0.24	0.907

Table 10.2.: Heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

a) Holstein-Friesian

	P	F	M	WG	ST	CA	SRV	UO	DC	OO	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	25	88	91	20	19	19	19	5	21	25	12	13	3	2	10	-2	0	1	7	-2	1
F	75	21	82	16	14	18	20	6	21	26	13	13	5	0	8	-2	2	3	7	1	1
M	85	70	28	19	19	17	18	4	21	26	13	14	2	1	11	0	0	1	6	-2	3
WG	27	15	33	39	83	41	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	24	11	29	96	49	26	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	26	28	30	60	38	32	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	15	31	1	-12	-19	27	4	5	9	13	5	6	5	1	4	-2	4	3	4	0	0
UO	-17	-11	-17	-	-	-	-17	27	41	12	8	7	8	-	-	-	72	68	70	44	16
DC	15	18	22	-	-	-	-6	64	30	15	7	7	0	-	-	-	33	30	33	16	10
OO	44	51	41	-	-	-	33	6	26	9	61	65	38	-	-	-	9	9	10	-	-
AM	27	32	26	-	-	-	20	12	14	91	8	69	21	-	-	-	-	5	7	-	-
TM	33	35	31	-	-	-	19	4	12	85	98	10	18	-	-	-	5	6	6	-	-
MS	-1	13	-10	-	-	-	33	-4	-11	46	23	13	15	-	-	-	9	7	4	-	-
RA	13	3	4	-	-	-	16	-	-	-	-	-	-	26	-7	11	-14	-13	-15	-10	-4
RW	12	9	24	-	-	-	0	-	-	-	-	-	-	-22	28	-11	11	7	12	3	2
LE	-6	1	-1	-	-	-	-4	-	-	-	-	-	-	22	-12	6	-11	-9	-12	-4	0
US	-24	-19	-22	-	-	-	-16	95	56	11	-	9	-2	-37	34	-33	25	56	60	25	14
FU	-15	-8	-15	-	-	-	-9	86	50	0	2	0	-1	-36	30	-36	86	21	45	21	6
RU	-3	-5	-3	-	-	-	-14	89	57	13	9	-15	10	-32	39	-32	86	69	24	20	10
FT	-24	-16	-21	-	-	-	-27	66	41	-	-	-	-	-29	10	3	51	46	39	29	33
RT	-5	5	0	-	-	-	-2	28	33	-	-	-	-	-10	8	9	24	6	15	58	28

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to Milking, TM = Temperament, MS = Milking Speed, RA = Rump Angle, RW= Rump Width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

Table 10.2. continued: Heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

b) Jersey

	P	F	M	WG	ST	CA	SRV	UO	DC	OO	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	17	91	92	23	23	24	21	9	27	23	14	13	3	1	13	-4	3	7	8	-4	-1
F	80	17	86	20	21	22	23	9	26	24	14	14	4	1	13	-3	3	7	7	-3	0
M	86	67	22	20	22	21	21	10	25	24	15	14	3	1	12	-4	3	6	9	-3	1
WG	54	51	43	12	59	34	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	55	54	48	90	23	18	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	25	16	8	50	12	15	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	76	89	76	37	40	18	2	4	5	11	6	7	3	1	3	0	3	3	4	-1	0
UO	-3	-5	-10	-	-	-	10	24	40	13	8	8	6	-	-	-	96	70	73	42	22
DC	23	17	8	-	-	-	22	53	18	18	11	11	2	-	-	-	31	33	33	10	7
OO	39	29	26	-	-	-	57	15	32	12	62	68	35	-	-	-	10	10	11	-	-
AM	26	23	20	-	-	-	47	1	12	82	13	69	21	-	-	-	-	6	8	-	-
TM	22	20	15	-	-	-	41	19	11	82	99	14	19	-	-	-	7	7	8	-	-
MS	6	3	-7	-	-	-	6	14	9	34	19	9	21	-	-	-	6	6	3	-	-
RA	5	13	11	-	-	-	18	-	-	-	-	-	-	26	-9	11	-13	-13	-11	-6	-2
RW	6	15	8	-	-	-	-6	-	-	-	-	-	-	-14	16	-9	9	7	8	3	-1
LE	-5	2	0	-	-	-	8	-	-	-	-	-	-	39	-21	6	-11	-9	-9	-3	-2
US	-2	-1	-10	-	-	-	-8	70	44	25	-	17	29	-26	16	-13	23	63	58	28	22
FU	6	8	-7	-	-	-	19	87	52	17	10	10	27	-23	8	-11	89	24	53	22	13
RU	2	-3	-3	-	-	-	-3	86	49	17	12	12	9	-31	9	-8	40	71	23	20	18
FT	-24	-23	-17	-	-	-	-17	57	4	-	-	-	-	-17	19	3	50	27	26	27	43
RT	-32	-34	-23	-	-	-	-23	48	-4	-	-	-	-	-19	-4	0	42	22	32	78	19

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to milking, TM = Temperament, MS = Milking speed, RA = Rump Angle, RW= Rump width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

Table 10.2.continued: Heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

c) Ayrshire

	P	F	M	WG	ST	CA	SRV	UO	DC	OO	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	27	88	92	19	23	19	21	14	21	39	25	23	21	3	11	-1	6	7	13	7	8
F	63	19	84	15	18	19	21	14	20	39	24	22	22	1	7	-2	5	9	12	4	4
M	87	54	22	16	21	17	17	14	16	38	25	22	21	5	8	1	3	5	15	6	6
WG	53	13	47	26	78	27	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	67	28	68	95	47	12	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	17	7	0	59	35	27	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	15	53	-19	-54	-50	-19	7	2	9	13	6	9	4	-1	4	-3	0	0	4	2	-1
UO	41	47	23	-	-	-	53	9	43	14	8	9	48	-	-	-	59	56	60	36	18
DC	59	48	28	-	-	-	67	59	26	21	14	19	8	-	-	-	29	26	30	17	11
OO	74	63	58	-	-	-	53	60	76	25	63	68	48	-	-	-	11	9	16	-	-
AM	52	33	50	-	-	-	37	43	62	88	32	67	36	-	-	-	-	2	9	-	-
TM	63	46	59	-	-	-	33	51	64	94	96	31	31	-	-	-	8	2	9	-	-
MS	53	51	37	-	-	-	56	47	68	90	75	82	35	-	-	-	8	9	6	-	-
RA	-24	-35	-4	-	-	-	-54	-	-	-	-	-	-	31	-21	18	-10	-6	-9	-9	-1
RW	48	12	18	-	-	-	28	-	-	-	-	-	-	-65	34	-7	11	5	9	1	-1
LE	29	-21	47	-	-	-	-34	-	-	-	-	-	-	58	-30	4	-9	-2	-7	-4	0
US	33	44	8	-	-	-	81	96	52	40	-	28	27	-36	18	22	10	48	44	19	14
FU	15	14	-18	-	-	-	33	66	54	25	-7	4	52	-33	34	-23	67	11	31	20	11
RU	-7	2	-28	-	-	-	30	87	26	29	17	25	47	-35	-5	16	86	61	11	11	12
FT	42	11	47	-	-	-	-34	47	50	-	-	-	-	-50	-10	-61	15	9	12	17	32
RT	8	-1	-2	-	-	-	-12	64	39	-	-	-	-	-30	4	-33	55	53	49	80	35

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to Milking, TM = Temperament, MS = Milking Speed, RA = Rump Angle, RW= Rump Width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

Table 10.3.: Standard errors for heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

a) Holstein-Friesian

	P	F	M	WG	ST	CA	SRV	UO	DC	OO	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	2	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	3	2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M	2	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WG	6	7	6	3	0	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	6	6	6	1	4	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	6	6	6	4	5	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	12	11	12	11	11	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
UO	7	7	7	-	-	-	11	2	1	1	1	1	1	-	-	-	0	0	0	1	1
DC	7	7	6	-	-	-	12	4	3	1	1	1	1	-	-	-	1	1	1	1	1
OO	7	7	7	-	-	-	13	8	8	1	0	0	1	-	-	-	1	1	1	-	-
AM	8	8	8	-	-	-	14	9	8	3	1	0	1	-	-	-	-	1	1	-	-
TM	8	8	8	-	-	-	14	8	8	7	1	1	1	-	-	-	1	1	1	-	-
MS	8	8	7	-	-	-	12	8	7	7	9	9	2	-	-	-	1	1	1	-	-
RA	17	7	7	-	-	-	12	-	-	-	-	-	-	2	1	1	1	1	1	1	1
RW	7	7	6	-	-	-	11	-	-	-	-	-	-	7	3	1	1	1	1	1	1
LE	10	10	9	-	-	-	16	-	-	-	-	-	-	9	9	1	1	1	1	1	1
US	7	7	7	-	-	-	12	1	5	8	-	8	8	6	6	9	2	0	0	1	1
FU	7	7	7	-	-	-	12	2	5	9	9	9	8	6	7	9	3	2	1	1	1
RU	7	7	7	-	-	-	12	2	5	9	8	8	8	6	6	9	2	4	2	1	1
FT	6	7	6	-	-	-	11	4	6	-	-	-	-	6	7	9	5	6	6	3	1
RT	7	7	7	-	-	-	11	6	6	-	-	-	-	7	7	9	6	7	7	5	3

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to milking, TM = Temperament, MS = Milking Speed, RA = Rump Angle, RW= Rump Width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

Table 10.3.continued: Standard errors for heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

b) Jersey

	P	F	M	WG	ST	CA	SRV	UO	DC	OO	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	2	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	3	2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M	2	5	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WG	9	9	9	2	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	8	8	8	3	3	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	10	10	10	9	10	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	9	6	9	19	18	19	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
UO	10	10	9	-	-	-	11	3	1	1	1	1	1	-	-	-	1	0	0	1	1
DC	10	10	10	-	-	-	11	7	3	1	1	1	1	-	-	-	1	1	1	1	1
OO	10	10	10	-	-	-	12	10	10	2	1	0	1	-	-	-	1	1	1	-	-
AM	10	10	10	-	-	-	13	10	9	4	2	0	1	-	-	-	-	1	1	-	-
TM	10	10	10	-	-	-	14	10	10	4	1	2	1	-	-	-	1	1	1	-	-
MS	10	10	10	-	-	-	15	9	10	10	10	10	3	-	-	-	1	1	1	-	-
RA	10	10	9	-	-	-	18	-	-	-	-	-	-	3	1	1	1	1	1	1	1
RW	11	10	10	-	-	-	19	-	-	-	-	-	-	10	2	1	1	1	1	1	1
LE	14	14	13	-	-	-	23	-	-	-	-	-	-	12	13	1	1	1	1	1	1
US	10	10	9	-	-	-	18	0	8	10	-	10	9	9	10	13	3	1	1	1	1
FU	10	10	9	-	-	-	11	3	7	10	10	10	9	9	10	13	3	3	1	1	1
RU	10	10	9	-	-	-	11	3	8	10	10	9	8	10	13	10	5	3	1	1	1
FT	9	9	9	-	-	-	11	6	9	-	-	-	-	9	9	13	7	8	8	3	1
RT	10	10	9	-	-	-	11	8	10	-	-	-	-	9	10	13	8	9	9	5	3

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to Milking, TM = Temperament, MS = Milking Speed, RA = Rump Angle, RW= Rump Width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

Table 10.3.continued: Standard errors for heritability and phenotypic and genetic correlation estimates (* 100) for primiparous cows (h^2 = diagonal, r_p = upper, r_g = lower triangle).

c) Ayrshire

	P	F	M	WG	ST	CA	SRV	UO	DC	00	AM	TM	MS	RA	RW	LE	US	FU	RU	FT	RT
P	9	1	0	3	3	3	3	2	3	2	3	3	3	3	3	2	2	2	3	3	3
F	16	8	1	3	3	3	3	2	3	2	3	3	3	3	3	2	2	2	3	3	3
M	6	19	3	3	3	3	2	3	2	3	3	3	3	3	2	2	2	3	3	3	3
WG	22	28	24	9	1	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST	17	25	18	4	13	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CA	27	29	28	19	22	10	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRV	27	23	30	26	25	31	3	3	3	3	3	3	3	1	1	2	2	2	2	3	3
UO	26	27	30	-	-	-	34	4	2	2	3	2	2	-	-	-	2	2	1	2	2
DC	20	24	26	-	-	-	21	23	9	2	3	3	3	-	-	-	2	2	3	3	3
OO	12	16	17	-	-	-	20	20	15	7	1	1	2	-	-	-	2	2	2	-	-
AM	20	25	21	-	-	-	23	31	19	6	10	2	3	-	-	-	-	2	3	-	-
TM	18	23	20	-	-	-	26	23	19	4	4	10	3	-	-	-	3	2	3	-	-
MS	20	22	23	-	-	-	21	25	18	7	14	12	11	-	-	-	3	2	3	-	-
RA	25	26	26	-	-	-	19	-	-	-	-	-	-	10	3	1	2	3	3	3	3
RW	22	27	25	-	-	-	22	-	-	-	-	-	-	17	10	1	2	3	3	3	3
LE	26	30	24	-	-	-	27	-	-	-	-	-	-	18	25	2	2	3	2	2	1
US	27	28	31	-	-	-	12	3	24	25	-	28	28	28	28	30	5	2	2	2	2
FU	28	31	28	-	-	-	29	20	24	25	26	27	19	37	36	41	28	4	2	2	2
RU	32	35	33	-	-	-	33	8	29	28	30	30	26	25	27	29	9	28	6	3	3
FT	27	32	28	-	-	-	38	27	26	-	-	-	-	24	28	24	31	32	33	7	3
RT	25	28	27	-	-	-	33	22	24	-	-	-	-	23	24	24	23	23	24	16	11

P = Protein (kg), F = Milkfat (kg), M = Milk (kg), WG = Weight, ST = Stature, C = Capacity, SRV = Survival Rate, UO = Udder Overall, DC= Dairy Conformation, OO = Overall Opinion, AM = Adaptability to Milking, TM = Temperament, MS = Milking Speed, RA = Rump Angle, RW= Rump Width, LE = Legs, US = Udder Support, FU = Fore Udder, RU= Rear Udder, FU = Fore Udder, RU = Rear Udder, FT = Front Teat Placement, RT = Rear Teat Placement

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