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Genetic analyses of profit for Australian dairy cattle

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Abstract

Direct genetic evaluation of profit was investigated as an alternative to a selection index. $PROF_k$ was defined as (net income)/(food requirement) until the start of the k*th lactation, for* k = 2 *to 6. Genetic parameters such as heritabilities and genetic correlations were estimated for profit traits for Australian Holstein-Friesian and Jersey dairy cattle. Heritabilities for profit until the start of a given lactation were moderate, ranging from 0·12 (for profit until the start of the second lactation in Holsteins) to 0·31 (profit until the start of the third lactation in Jerseys). Genetic correlations between profit traits were very high, and approached unity for most pairs of traits, so that profit early and late in herd life were nearly the same trait. Genetic correlations between profit traits and stayabilities until a given lactation were high, ranging from 0·71 to 0·97. Genetic correlations between profit traits and first lactation milk yield traits were approximately 0·80 for Holsteins and 0·90 for Jerseys. A single analysis was carried out for lifetime profit using all data, including cows that were still in the herd at the time of data collection. Heritabilities were 0·13 for Holsteins and 0·19 for Jerseys. Genetic correlations between lifetime profit and first lactation yields were high. For the selection of dairy bulls, a multivariate analysis on a milk yield trait (e.g. protein yield) and profit until the last known lactation of bulls' progeny was suggested.*

Keywords: *dairy cattle, genetic parameters, profit analyses.*

Introduction

Traditionally, commercial dairy breeders have not used selection indices although scientific study of economic weights has occurred for some years. Only recently selection indices which combine milk, fat, and protein production have been implemented commercially (e.g. Dommerholt and Wilmink, 1986; Rozzi, 1991; Gibson, Graham and Burnside, 1992). A possible explanation why dairy breeders have not used selection indices as much as breeders in other industries is that individual yield traits are highly correlated and milk production in general is highly correlated with profit. However, milk production is not synonymous with profit, because phenotypic correlations between first lactation milk production and lifetime profit typically are in the range of 0·5 to 0·6 (e.g. Beaudry, Cassell, Norman and Pearson, 1988; De Haan, Cassell, Pearson and Smith, 1992; Cassell, Smith and Pearson, 1993). Paralleling this univariate approach to breeding objectives most predictions of breeding values for dairy sires is from univariate analyses.

Profit in a dairy enterprise is a function of milk production, herd life, food consumption, and costs such as those pertaining to health, reproduction and housing. To predict the genetic merit of dairy bulls for the profitability of their daughters, basically two approaches can be taken. Firstly, predicted breeding values for individual traits can be combined into a selection index, using economic weights for components of profit in the breeding goal, and correlations between the breeding goal and predicted breeding values. For this approach, economic weights usually are derived using a model of farm production and economics (see, for example, Visscher, Bowman and Goddard (1994) for an application for pasture-based dairy production systems). If estimated breeding values (EBVs) have been calculated using a multivariate analysis of all

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traits it is straightforward to combine these with economic weights in a selection index. However, combining univariate EBVs into a selection index is more difficult because the index weights vary according to the data used to calculate the EBVs. This approach, although very useful, assumes that genetic correlations and heritabilities for all the traits involved are known (when they are only estimated) and may not handle well non-linear relationships between traits. For example, in a seasonally calving herd there are complex relationships between fertility, milk yield, lactation length and culling which are difficult to model. A cow which conceives late in one season is likely to have a longer than average lactation with above average yield and is likely to calve late in the next season. This may result in her failing to conceive during the mating period, having a short lactation, and being culled at the end of it. To model this correctly during analysis of the data requires a multivariate analysis with milk yield, lactation length, fertility, inter-calving interval and culling in each season being treated as different traits. This requires estimates of numerous genetic parameters and a complex multitrait analysis. Even then there may be doubts that the analysis deals correctly with non-linear relationships between the traits.

These difficulties may be overcome by the second approach which is to calculate profit for individual cows (from production and herd life data) and estimate breeding values for profit directly. For such an analysis we only need to know few genetic parameters (heritabilities). In theory this approach leads to less accurate EBVs for profit than the selection index approach because it ignores differences in heritabilities between components of profit. However, this loss of efficiency may be compensated for by the advantages of direct analysis of profit.

It is also possible to use a combination of the two approaches. That is, several components of the breeding objective are combined into one 'trait', EBVs are calculated for this trait and for the other components of the objective, and the EBVs are used to make selection decisions possibly by combining them in an index. In this study we have combined age at first calving, milk production traits, lactation lengths, inter-calving interval, and length of herd life into one trait which we call 'profit', although we recognize that some components (e.g. milking speed) of a complete objective are not included.

There are two problems in estimating breeding values for profitability which apply to both the use of selection indices and a direct genetic evaluation for profit — information on herd life is only available after the cow has been culled and some important traits such as food intake are not usually measured. In this study food intake is predicted from the production and life history data. Both the selection index and direct evaluation of profit approaches require knowledge of the economic parameters but in the first approach the EBV are unaffected by their values.

The aims of this study were to present a method for handling data from cows that are still in the herd for analysis of profit traits and to estimate heritabilities for profit traits and their correlations with stayabilities and first lactation milk production traits.

Table 1 *Summary statistics for production data for Holstein-Friesian (HF) and Jersey (J)*†

	Breed			
	HF		J	
No. of cows	382184		78391	
No. of lactations	1053523		228345	
Herd life (years)	4·6		4·3	
Replacement rate (%)‡	22		23	
Mean and standard deviation of traits	Mean	s.d.	Mean	s.d.
M (l)	4469	1469	3242	983
Ft (kg)	182	60	169	53
Pr (kg)	143	48	119	37
M_dev (l)	102	712	–352	619
F_dev (kg)	2	27	–4	26
Pr_dev (kg)	2	20	–7	19
Age at first calving (months)	26·7	3·9	25·5	3·2
Lactation length (days)	278	71	273	63

Distribution (%) of lactations over month of calving (January = 1)

	Month of calving											
	1	2	3	4	5	6	7	8	9	10	11	12
HF	2·7	3·0	4·3	5·2	6·5	9·2	15·5	26·2	15·5	6·2	3·2	2·5
J	0·5	0·8	2·3	4·1	5·7	10·8	22·3	31·3	15·6	4·6	1·4	0·6

Survivals (S, in %) and stayabilities (STAY, in %) for lactations 1 to 10

		1	2	3	4	5	6	7	8	9	10
HF	S	82	83	83	82	80	76	72	66	62	0
	STAY	100	82	68	57	47	37	28	21	14	9
J	S	82	80	80	79	76	71	67	62	57	0
	STAY	100	82	66	53	42	32	22	15	9	5

† M = milk yield, Ft = fat yield, Pr = protein yield, M_dev = test-day deviation for milk yield, Ft_dev = test-day deviation for fat yield, Pr_dev = test-day deviation for protein yield.
‡ Replacement rate = 100%/(herd life).

Material and methods

Data

Production data for Holstein-Friesian (HF) and Jersey (J) cows were provided by the Australian Dairy Herd Improvement Scheme (ADHIS). A more thorough description of the data is given elsewhere (Visscher and Goddard, 1995). All milk production records of cows calving for the first time between 1980 and 1992 were used in subsequent analyses. A maximum of 10 lactation records per cow was taken into account. For each lactation, date of calving, lactation length (LL), total lactation yield for milk (M), fat (Ft), and protein (Pr) was known, as was the average test-day deviation for milk (M_dev), fat (F_dev), and protein (Pr_dev) yield. (Abbreviations for milk production traits will always refer to first lactation production records, unless stated otherwise.) The average test-day deviation is calculated by ADHIS prior to the national animal model BLUP evaluation (Jones and Goddard, 1990), and is a linear combination of test-day yield deviations from contemporaries (cows that had a test on the same day) corrected for age at test day and stage of lactation (Jones, 1985). Summary statistics for the data are presented in Table 1.

Definition of profit traits

We define net income (P) as income minus all costs except food costs, and F as food requirements (or supply). Our profit trait of interest throughout this study was P/F (= PROF). The reasons for choosing this objective are given in Visscher *et al.* (1995) and are summarized below as follows.

(a) The total amount of food available is a variable controlled by management decisions. The usual method of calculating economic weights is to calculate the effect of a small change in each trait while holding management variables constant at their optimum value. In fact, Goddard (1983) and Visscher *et al.* (1994) show that the economic weights are the same regardless of whether the total food available is held at the optimum value for the existing genotype or re-optimized as the genotype changes by a small amount.

(b) In pasture-based systems total food cost is approximately proportional to total farm size. Therefore, calculating economic weights after rescaling for food supply is approximately the same as rescaling for total costs as recommended by Smith, James and Brascamp (1986).

(c) Using P/F as an objective avoids the need to decide on a cost for food which is difficult for pasture (what price of land is to be used?).

(d) Provided mean profit after accounting for all costs is close to zero, Brascamp, Smith and Guy (1985) show that relative economic weights are the same regardless of whether profit is expressed per cow or per unit of food.

Besides analysing lifetime profit, the interest of this study was also in analysing possible predictors for lifetime profit and in their correlations with first lactation yield traits and stayabilities. Therefore, profit traits were defined as profit until the start of a particular lactation. However, this definition meant that a method had to be chosen which dealt with cows that were still in the herd at the time of data collection.

Using a simple herd model, net income and food requirements are calculated for an average cow at any time during her life in the herd. Let P_k and F_k be the net income and food requirement until the start of lactation k,

$$P_k = (k-1) \times (\text{Value calf}) - (k-1) \times \text{Cost} - (\text{Rcost} + \text{Value calf}) + \sum_{1}^{k-1} M \times \text{Pay} + CV_k \quad (1)$$

and

$$F_k = k \times \text{PREG} + \text{CMAIN}(k) + \text{CGROW}(k) + \sum_{1}^{k-1} M \times E_m \quad (2)$$

and

$$\text{PROF}_k = P_k / F_k$$

with, Value calf = sale value of calves sold in the first few weeks after birth; Cost = non-food production costs per cow per lactation, such as costs for milk recording, artificial breeding, and veterinary treatment; Rcost = non-food costs of rearing a replacement heifer; ΣM = cumulative production (milk yield, or a function of milk, fat, and protein yield); Pay = returns from M; PREG = food requirement per pregnancy; CMAIN(k) = cumulative food requirement for maintenance; CGROW(k) = cumulative food requirement for growth; E_m = metabolizable energy requirement for M.

CV_k is the current value of a cow at the start of the kth lactation: CV_k = cull value if the cow is culled before the start of the kth lactation = sale value if the cow is still in the herd at the start of the kth lactation.

The sale value is defined by comparing, at any time, the future net income (FP) and future food requirements (FF) for a cow with the average net income and food consumption for the whole herd. At value CV it would be as profitable to sell her now as to leave her in the herd, hence it is the value that a farmer can afford to pay for an average cow of that age. Sale value was calculated from

$$(FP - CV)/FF = \bar{P}/\bar{F}, \text{ so } CV = FP - FF \times \bar{P}/\bar{F}.$$

To determine values of CV, assumptions were made with respect to future income and food consumption for average cows in the herd. For an average cow, her past net income (PP), past food consumption (PF), expected future net income (FP), and expected future food consumption (FF) at any time during her life in the herd can be determined using averages for yield per lactation, lactation length, mature body weight, costs and returns, survival, and inter-calving interval.

For a cow in her nth lactation, expected future net income and future food consumption are calculated as,

$$FP = (1-p)\,[(\text{Value calf}) - \text{Cost} + M_n \times Pay_n] + \sum_{i=n+1}^{max} [M_i \times Pay_i + (\text{Value calf}) - \text{Cost}]\prod_{j=n}^{i-1} S_j + (\text{Cull value}) \quad (3)$$

and,

$$FF = (1-p)\,[M_n \times E_m + MAIN(n) + GROW(n) + PREG] + \sum_{i=n+1}^{max} [M_i \times E_m + MAIN(i) + GROW(i) + PREG]\prod_{j=n}^{i-1} S_j \quad (4)$$

with, max = maximum lactation number; Cull value = sale value for culled cow; S_j = probability of survival from lactation j to $j+1$; p = proportion of current lactation which has been completed; MAIN(i) and GROW(i) are the energy requirement for the ith lactation (in contrast to CMAIN(i) and CGROW(i), which were defined as cumulative energy requirements); past profit (PP) and past food (PF) for a cow in her nth lactation follow from equations (1) and (2), with an additional term which is the proportion (p) of the profit and food requirement pertaining to the current (nth) lactation.

Herd parameters and assumptions for formulas. Parameters and equations from Visscher *et al.* (1995) were used to calculate average food requirements for growth and maintenance. Food requirements were calculated for each day of life. To calculate the yield for each day of herd life, a Wood curve was used, $y(t) = at^b e^{(-ct)}$, with, $y(t)$ = yield per day at day of lactation t, b = 0·18 and c = 0·004 (e.g. Strandberg and Lundberg, 1991). The scaling parameter a is calculated from the given total lactation yield and the lactation length. Values for E_m, the energy requirement for milk, fat and protein yield, were taken from Dommerholt and Wilmink (1986).

Table 2 *Assumed herd parameters for Holstein-Friesian (HF) and Jersey (J) cattle*

	Breed	
	HF	J
Returns milk ($/l)	–0·02	
Returns fat ($/kg)	2·20	
Returns protein ($/kg)	4·40	
Calf value ($)	50	40
Cull value ($)	500	400
Cost ($ per cow per year)	100	90
Rcost ($ per replacement heifer)	70	60
Mature body weight (kg)	500	400
Lactation length (days)	280	
Inter-calving interval (days)	365	
Herd life	4·6	4·3
Replacement rate (%)	22	23
Production of mature cows		
Milk (l per lactation)	5200	3600
Fat (kg per lactation)	216	193
Protein (kg per lactation)	170	139

A set of parameters for a Holstein-Friesian (HF) and Jersey (J) farm is presented in Table 2. Costs and returns follow assumptions made by Visscher *et al.* (1994). Throughout this study, costs, returns, and net income are in Australian dollars ($). Average survival scores were taken from Visscher and Goddard (1995), and age correction factors relative to production of mature cows from Beard (1992). The mature weights of HF and J cattle in Australia were calculated from K. T. Beard (unpublished data). The difference in mature weight between HF and J is smaller than in other countries, but consistent with values from Ahlborn and Dempfle (1992) for New Zealand data.

Using the parameters from Visscher *et al.* (1995) and from Table 2, corresponding net income and food requirement values at different days of herd life are shown in Table 3.

Statistical analyses

All analyses were performed using residual maximum likelihood (REML; Patterson and Thompson, 1971) with a sire model. Sire models were used throughout because multiple trait animal models for large data sets are still prohibitively expensive in terms of computer requirements. In all analyses, relationships between bulls through their sires were taken into account by fitting the relationship matrix, i.e. one generation of pedigree on the paternal side was included. The multivariate

Table 3 *Past and future net income ($) and food requirements (GJ of metabolizable energy) at different days of herd life for Holstein-Friesian (HF) and Jersey (J)*†

	Breed											
	HF						J					
Day	PP	FP	PF	FF	CV	P/F	PP	FP	PF	FF	CV	P/F
0	− 70	4839	38	236	730	11·3	−60	3796	32	182	617	10·7
365	652	4118	85	189	829	13·5	558	3178	71	142	688	13·4
730	1550	4014	135	180	874	15·2	1325	3021	113	132	717	15·2
1095	2534	3750	187	165	873	16·2	2166	2835	157	121	716	16·4
1460	3568	3381	240	146	840	16·9	3050	2559	201	107	689	17·1
1825	4628	2954	294	124	790	17·4	3957	2227	246	90	645	17·7
2190	5697	2498	348	101	733	17·8	4871	1889	291	74	597	18·1
2555	6765	2062	402	80	677	18·1	5783	1585	337	59	553	18·4
2920	7823	1611	455	57	622	18·3	6688	1265	381	43	508	18·6
3285	8867	1139	509	33	568	18·4	7580	902	426	25	461	18·7
3650	9897	500	562	0	500	18·5	8461	400	470	0	400	18·8

For average cow:

	HF	J
P	4769	3735
F	274	214
P/F	17·4	17·5

† Day = day of herd life, PP = past net income, FP = expected future net income, PF = past food requirements, FF = expected future food requirements, CV = cull or sale value, P/F = net income/food if cow is culled, P = profit, F = food requirement.

equal designs REML algorithm described by Meyer (1985a) was used for all analyses.

Two different data sets were analysed for each of the two breeds:

(1) *Analyses of stayabilities, profit, and first lactation records.* Profit, production, and stayability records were analysed using,

$$Y = \text{HYS\_B} + \text{MONTH\_B} + \text{MONTH\_C} + \text{BCODE} + \text{COUNTRY} + \text{GROUP} + \text{SIRE} + b_i \times \text{NZ} + b_2 \times \text{NA} + b_3 \times \text{AGE} + \text{residual} \quad (5)$$

with, Y = stayability, profit, and first lactation production records; HYS_B = herd-year-season of birth, with four seasons per year (December-March, April-June, July-August, September-November); MONTH_B = month of birth (1 to 12); MONTH_C = month of calving (1 to 12); BCODE = breedcode of the dam (five levels; unknown, HF, J, HF × J, J × HF); GROUP = sire group based on year of birth (five groups; ≤ '75, '76-'80, '81-'82, '83-'84, '85-'86); COUNTRY = country of origin of sire (Australia or rest of the world); SIRE = fixed or random sire (sires were considered fixed if the number of years between the birth of the sire and the first calving of his progeny was 8 years or more. Fixed sires were included in the analysis to improve the data structure (Meyer, 1985b; Van Vleck, 1985). Only records of those fixed sires with more than 5000 and 1000 progeny (for HF and J respectively were included); b_i = regression coefficient; NZ = percent New Zealand genes in the sire, NA = percent North American genes in the sire; AGE = age at first calving (months).

NZ and NA of each bull were calculated from the country of origin code (ADHIS, 1993) of the bull, its sire, and its maternal grandsire. Heterosis effects were removed by fitting breed of dam since all sires were purebred and separate analyses were carried out for HF and Jersey sires.

The model aims to remove as much systematic variation between groups of bulls as practical, so that this variation is not included in estimates of variance components. For example, NA and NZ were fitted to remove a HF and NZ breed effect, and COUNTRY was fitted because farmers may treat daughters of Australian bred bulls differently from bulls bred elsewhere, for example because they paid more for the overseas bulls' semen.

Length of herd life was measured by a series of stayability scores where stayability until the start of the *ith* lactation ($STAY_i$) was defined as follows:

$STAY_i$ = 100% if the cow commenced her *i*th lactation; $STAY_i$ = 0% if the cow did not commence her *i*th lactation; $STAY_i$ is unknown if the cow did not have an opportunity to commence her *i*th lactation.

Lack of opportunity to commence her *i*th lactation occurs when a cow was still in the herd at the end of the data period but had calved less than *i* times. Because we could not always tell from the data whether or not a cow was still in the herd, we defined $STAY_i$ to be unknown if [date of last {*k*th} calving + $(i - k - 1) \times 365$ days + 500 days] was before the date of the last known test for the herd. Thus if a cow had calved for the 3rd time less than 500 days before the end of the data from her herd, $STAY_4$ was defined to be unknown for that cow. Using this definition of stayability, $STAY_1$ = 100%. Net income over food requirement ($PROF_i$) was defined analogously, i.e. P/F until lactation *i* was calculated for cows that had the opportunity to express $PROF_i$ (and $STAY_i$). For cows that were culled before the start of lactation *i*, the cull value was added to her net income, while for cows still in the herd at the start of lactation *i* her sale value (from Table 3) was added. Note that the food component of $PROF_i$ depends on the life history parameters, in particular the age of the cow when she calved for the *i*th time, as this determines lifetime maintenance requirement. PROF for a cow's lifetime depends on the number of lactations for which she survived and whether or not she is still in the herd.

In a previous analysis (Visscher and Goddard, 1995) it was found that there was evidence of some confounding between sires and the time of year their progeny were born (and the time they were mated and subsequently calved). Following Moore, Kennedy, Schaeffer and Moxley (1991), it was therefore decided to fit herd-year-season (HYS) of birth as the main contemporary group (CG) effect and age at first calving as a covariate.

(2) *Analysis of lifetime profit.* First lactation records and lifetime profit were analysed using (5). For culled cows, the lifetime profit trait (LTP) was defined as PROF at the time of culling. For a cow still in the herd at the end of the data period and in her *k*th lactation $PROF_k$ was calculated. For such cows, estimating lifetime profit is a problem akin to estimating whole lactation yield from part lactation yield. In this case 'extending' part-lifetime PROF was done using,

$$LTP = CG + b_{6,k}[\{PROF\}_k - CG] \quad (6)$$

where, CG = unregressed mean PROF of contemporaries, $b_{6,k}$ = genetic regression of $PROF_6$ on $PROF_k$ calculated in the previous analysis. Ideally, the regression coefficient used should be $b_{\infty,k}$, but $b_{6,k}$ was assumed to be similar and was the latest lactation for which there was sufficient data to estimate genetic parameters (i.e. LTP and $PROF_6$ were assumed to be the same trait). A separate analysis was carried out in which the genetic regression coefficients were set to unity, in which case (6) reduces to LTP = $\{PROF\}_k$.

Summary statistics for both analyses are presented in Table 4.

Results

Model calculations

Using the parameters from Table 2, resulting model calculations for HF and J are shown in Table 3. Although the average net income for a HF cow was proportionately 0·28 higher than for a J cow ($4769 *v.* $3735), total food requirements were also 0·28 higher, resulting in a very similar P/F value for HF and Jerseys (Table 3). This arises because of the lower body weight and lower milk production assumed for J. Past net income (PP) at the beginning of a cow's herd life reflected the non-food costs per replacement heifer. Expected future net income (FP) at the beginning of year 11 of herd life (3650 days) were the cull values of the cows, because it was (arbitrarily) assumed that no cows survived after the 10th lactation. P/F values at each year of herd life were

Table 4 *Summary statistics for analyses (1) and (2)*†

	Breed			
	HF		J	
Analysis (1)				
No. of records	19269		8768	
No. of random sires	442		170	
% of data by fixed sires	46		71	
Mean and standard deviation of traits	Mean	s.d.	Mean	s.d.
$PROF_2$	17·5	2·3	18·0	2·4
$PROF_3$	17·2	2·6	17·7	2·8
$PROF_4$	17·1	2·6	17·5	2·9
$PROF_5$	17·0	2·6	17·4	2·8
$PROF_6$	16·9	2·6	17·3	2·8
Analysis (2)				
No. of records	187101		37099	
No. of random sires	1483		329	
% of data by fixed sires	14		43	
Mean and standard deviation of traits	Mean	s.d.	Mean	s.d.
LTP	17·4	2·9	17·4	3·1

† HF = Holstein-Friesian, J = Jersey, $PROF_i$ = profit until start lactation *i*, LTP = lifetime profit.

Table 5 *Estimates of heritabilities (on diagonals), genetic correlations (below diagonals), and phenotypic correlations (above diagonals), and their standard errors (in brackets), for profit traits and their correlation with stayabilities and first lactation production records for Holstein-Friesians (first rows) and Jerseys (second rows, in italics)*†‡

	$PROF_2$	$PROF_3$	$PROF_4$	$PROF_5$	$PROF_6$
$PROF_2$	0·12 (0·03)	0·83	0·78	0·76	0·75
	0·31 (0·07)	*0·85*	*0·79*	*0·78*	*0·77*
$PROF_3$	0·97 (0·03)	0·15 (0·03)	0·94	0·92	0·90
	0·93 (0·03)	*0·31 (0·07)*	*0·94*	*0·92*	*0·91*
$PROF_4$	0·95 (0·02)	0·99 (0·0)	0·16 (0·03)	0·97	0·96
	0·91 (0·04)	*0·99 (0·0)*	*0·27 (0·06)*	*0·97*	*0·96*
$PROF_5$	0·94 (0·03)	0·99 (0·01)	1·00 (0·0)	0·17 (0·03)	0·99
	0·94 (0·03)	*0·99 (0·01)*	*0·99 (0·0)*	*0·24 (0·06)*	*0·99*
$PROF_6$	0·93 (0·03)	0·99 (0·01)	0·99 (0·0)	1·00 (0·0)	0·17 (0·03)
	0·93 (0·04)	*0·99 (0·01)*	*0·99 (0·0)*	*1·00 (0·0)*	*0·25 (0·06)*
σ_P	0·019	0·021	0·022	0·022	0·022
	0·021	*0·024*	*0·025*	*0·025*	*0·024*
Genetic correlation with:					
$STAY_2$	0·89 (0·04)	0·80 (0·07)	0·81 (0·06)	0·79 (0·07)	0·76 (0·08)
	0·95 (0·02)	*0·82 (0·07)*	*0·78 (0·08)*	*0·82 (0·07)*	*0·81 (0·07)*
$STAY_3$	0·90 (0·04)	0·95 (0·02)	0·96 (0·02)	0·96 (0·01)	0·95 (0·02)
	0·88 (0·06)	*0·98 (0·01)*	*0·99 (0·01)*	*0·97 (0·02)*	*0·96 (0·02)*
$STAY_4$	0·85 (0·06)	0·88 (0·05)	0·92 (0·03)	0·92 (0·03)	0·92 (0·03)
	0·87 (0·08)	*0·97 (0·02)*	*0·98 (0·02)*	*0·96 (0·03)*	*0·95 (0·03)*
$STAY_5$	0·80 (0·08)	0·86 (0·06)	0·90 (0·04)	0·91 (0·03)	0·91 (0·04)
	0·90 (0·10)	*0·89 (0·08)*	*0·87 (0·08)*	*0·91 (0·06)*	*0·89 (0·07)*
$STAY_6$	0·71 (0·10)	0·81 (0·08)	0·83 (0·06)	0·84 (0·06)	0·86 (0·05)
	0·93 (0·10)	*0·95 (0·07)*	*0·94 (0·06)*	*0·97 (0·05)*	*0·97 (0·05)*
Average genetic correlation and s.e. with: M, Ft, and Pr	0·79 (0·06)	0·84 (0·04)	0·81 (0·05)	0·80 (0·05)	0·81 (0·05)
	0·93 (0·03)	*0·93 (0·04)*	*0·92 (0·04)*	*0·91 (0·05)*	*0·91 (0·04)*
M_dev, F_dev, Pr_dev	0·80 (0·06)	0·82 (0·04)	0·80 (0·04)	0·79 (0·04)	0·80 (0·04)
	0·90 (0·04)	*0·94 (0·03)*	*0·92 (0·04)*	*0·92 (0·05)*	*0·91 (0·05)*

† A s.e. of 0% means <0·005. All s.e. for phenotypic correlations were ≤0·02.
‡ $PROF_i$ = profit until start lactation i, $STAY_i$ = stayability until lactation i, M = milk yield, Ft = fat yield, Pr = protein yield, M_dev = test day deviation for milk yield, Ft_dev = test day deviation for fat yield, Pr_dev = test day deviation for protein yield.

net income over food requirements if a cow was culled at that time (rather than keeping her for another year).

The current value (CV) of a cow at the beginning of each year of herd life reflects her implicit market value. CV is highest at the start of lactation 2 and 3 for HF, and at lactation 3 and 4 for J. The CV at the start of lactation 11 is the same as her FP, i.e. the cull value. CV at the start of the first lactation is the value at which the farm could purchase heifers without affecting P/F. Visscher *et al.* (1995) refer to this value as the implicit value of a replacement heifer.

Analyses of profit, stayability, and first lactation records
Average values for profit traits (Table 4) were close to averages from model calculations (Table 3). Results from the joint analyses of stayabilities, first lactation production records, and profit traits, are shown in Table 5. Heritabilities for P/F values until lactations 2 to 6 ($PROF_2$ to $PROF_6$) were moderate to low, with substantially higher heritabilities for the Jersey data. Genetic correlations among the profit traits were very large, both for HF and J data. Genetic correlations of profit traits with stayabilities ranged from 0·71 (between $PROF_2$ and $STAY_6$ for HF) to 0·97 (between $PROF_6$ and $STAY_6$ for J). Genetic correlations between profit traits and first lactation production traits were approximately 0·8 and 0·9 for HF and J respectively (Table 5). Correlations between test day deviations and profit traits were similar to those between lactation yields and profit.

Genetic regressions of $PROF_6$ on P/F values until the start of lactations 2 to 5 were calculated from the results in Table 5, and are shown in Table 6. For both the HF and J breeds, all regressions were very close to unity.

Lifetime profit analyses
The mean lifetime profit (Table 4) was nearly identical to the mean calculated from the herd model in Table 3. In Table 7, the estimated genetic covariance matrix for lifetime profitability (LTP) and

Table 6 *Genetic regressions of* $PROF_6$ *on* $PROF_k$ $(b_{6,k})$ *for Holstein-Friesian (HF) and Jerseys (J)*

	k				
	2	3	4	5	6
HF	1·3	1·1	1·0	1·0	1·0
J	1·0	0·9	0·9	1·0	1·0

first lactation records is shown for the scenario where all genetic regression coefficients in equation (6) were set to unity. When the regression coefficients given in Table 6 were used the results were very similar and therefore they are not presented. Heritabilities for LTP were 0·13 and 0·19 for HF and J respectively. Genetic correlations between LTP and first lactation yields were approximately 0·80 for HF and 0·90 for Jerseys. LTP was most highly correlated with protein yield, reflecting the payment system assumed (see Table 1). In contrast to the results with $PROF_2$ to $PROF_6$, genetic correlations between LTP and test-day deviations were lower than the corresponding correlations for lactation yields for HF. For Jerseys, correlations between LTP and test-day deviations were similar to those between LTP and lactation yields (Table 7). The genetic correlation between LTP and first lactation lactation length (LL) was 0·75 and 0·8 for HF and J, respectively .

Heritabilities for production yield traits were on average 0·19 for HF and 0·24 for Jerseys. Heritabilities for the corresponding test-day deviations were significantly larger, on average 0·28 and 0·37 for HF and J respectively (Table 7). The estimate of the heritability for LL was low (0·07 and 0·11 for HF and J).

Discussion

Herd model

The average P/F for a Jersey cow was almost identical to that for a HF cow, despite the assumption that mature equivalent milk production of HF cows was proportionately 0·44 higher than the production of Jerseys (Table 1). However, the payment system we assumed was based on yields of protein and fat with a penalty for volume. Consequently, the returns from the production of mature cows were $1119 and $964 for HF and J respectively, a proportional difference of only 0·16. Furthermore, cumulative food requirements for growth and maintenance until 5 years of age were proportionately about 0·17 less for Jerseys (calculated using relationships described by Visscher *et al*., 1995), assuming mature weights of 500 and 400 kg for HF and J respectively. The model calculations (Table 3) also showed a very similar average P/F value for Jerseys and HF (17·5 and 17·4, respectively). In other countries, the difference in body weight between Holsteins and Jerseys is likely to be larger, but the larger difference in food requirements for growth and maintenance may be offset by a larger difference

Table 7 *Estimates of heritabilities (on diagonals), genetic correlations (below diagonals), and phenotypic correlations (above diagonals), and their standard errors (in brackets), for LTP and first lactation records for Holstein-Friesians (first rows) and Jerseys (second rows, in italics)*†‡

	LTP	M	Ft	Pr	M_dev	F_dev	Pr_dev	LL
LTP	0·13 (0·01)	0·57	0·60	0·60	0·45	0·48	0·51	0·54
	0·19 (0·03)	*0·62*	*0·64*	*0·64*	*0·53*	*0·56*	*0·57*	*0·56*
M	0·77 (0·02)	0·21 (0·01)	0·90	0·97	0·78	0·62	0·74	0·79
	0·89 (0·03)	*0·27 (0·04)*	*0·93*	*0·97*	*0·82*	*0·71*	*0·79*	*0·78*
Ft	0·87 (0·02)	0·76 (0·02)	0·17 (0·01)	0·94	0·63	0·74	0·69	0·81
	0·93 (0·03)	*0·89 (0·02)*	*0·23 (0·03)*	*0·96*	*0·70*	*0·78*	*0·74*	*0·82*
Pr	0·89 (0·02)	0·93 (0·01)	0·84 (0·01)	0·18 (0·01)	0·69	0·63	0·75	0·83
	0·92 (0·03)	*0·96 (0·01)*	*0·94 (0·01)*	*0·23 (0·03)*	*0·74*	*0·71*	*0·79*	*0·82*
M_dev	0·64 (0·03)	0·93 (0·01)	0·64 (0·03)	0·81 (0·02)	0·31 (0·02)	0·77	0·91	0·34
	0·88 (0·03)	*0·99 (0·00)*	*0·86 (0·03)*	*0·93 (0·02)*	*0·39 (0·05)*	*0·84*	*0·92*	*0·40*
F_dev	0·74 (0·03)	0·60 (0·03)	0·91 (0·01)	0·67 (0·03)	0·62 (0·03)	0·27 (0·02)	0·84	0·31
	0·92 (0·03)	*0·86 (0·03)*	*0·99 (0·01)*	*0·91 (0·02)*	*0·84 (0·03)*	*0·36 (0·05)*	*0·89*	*0·39*
Pr_dev	0·79 (0·02)	0·83 (0·02)	0·73 (0·02)	0·89 (0·01)	0·88 (0·01)	0·74 (0·02)	0·27 (0·02)	0·37
	0·93 (0·03)	*0·96 (0·01)*	*0·93 (0·02)*	*0·99 (0·01)*	*0·94 (0·01)*	*0·91 (0·02)*	*0·35 (0·05)*	*0·42*
LL	0·75 (0·03)	0·78 (0·02)	0·76 (0·03)	0·84 (0·02)	0·53 (0·04)	0·46 (0·05)	0·53 (0·04)	0·07 (0·01)
	0·80 (0·06)	*0·86 (0·04)*	*0·86 (0·04)*	*0·90 (0·03)*	*0·80 (0·06)*	*0·79 (0·06)*	*0·85 (0·05)*	*0·11 (0·02)*

† All s.e. for phenotypic correlations were ≤0·01.
‡ LTP = lifetime profit, M = milk yield, Ft = fat yield, Pr = protein yield, M_dev = test-day deviation for milk yield, Ft_dev = test-day deviation for fat yield, Pr_dev = test-day deviation for protein yield, LL = lactation length.

in yield between the two breeds. Stott and DeLorenzo (1988) reported higher profits per parity (except for parity 5) for US Holsteins compared to US Jerseys, although their assumed payment system favoured Holsteins through a positive value of milk volume.

Profit and stayability traits
Heritabilities for cumulative P/F values were slightly higher than those reported by Klassen, Monardes, Jairath, Cue and Hayes (1992) for Canadian Holsteins. They estimated heritabilities of approximately 0·1 for lifetime yields and 'milk value/cost of food', although it was not clear how the amount of food was measured or determined. Bertrand, Berger, Freeman and Kelley (1985) estimated repeatabilities of 0·13 and 0·04 for profit per lactation and profit per day respectively.

High genetic correlations among the PROF traits are partly explained by the part-whole relationships between the profit traits. They are consistent with high genetic correlations between production in different lactations (e.g. Meyer, 1985b) and stayabilities to different lactations (Visscher and Goddard, 1995). Large genetic correlations (>0·91) among lifetime yields were reported by Klassen *et al.* (1992). Cassell *et al.* (1993) estimated within herd-year phenotypic correlations between relative net income (RNI) until 48, 60, and 72 months of age. Correlations ranged from 0·80 to 0·94 (Cassell *et al.*, 1993). Phenotypic correlations between lifetime profit traits and lifetime yield ranged from 0·60 to 1·0, depending on the assumed costs and returns (Beaudry *et al.*, 1988). Genetic regressions of profitability later in life ($PROF_6$) on earlier P/F traits were essentially unity (Table 6).

Genetic correlation between profit traits and first lactation production records were slightly higher than those reported by Beaudry *et al.* (1988), De Haan *et al.* (1992) and Cassell *et al.* (1993). Beaudry *et al.* (1988) found phenotypic correlations between lifetime profit traits and first lactation milk yield of approximately 0·50 and estimated a correlation between profit per day and milk yield of 0·65. De Haan *et al.* (1992) estimated phenotypic correlations of approximately 0·50 between RNI and first lactation milk value, and Cassell *et al.* (1993) found phenotypic correlations of 0·52 to 0·63 between first lactation milk yield and RNI until 48, 60, and 72 months of age. Phenotypic correlations between PROF traits and first lactation yield traits were approximately 0·62 and 0·70 for HF and J respectively (results not shown in tables). Other genetic parameters for stayabilities and first lactation production records were reported previously (Visscher and Goddard, 1995).

Lifetime profitability
The results from Tables 5 and 6 indicated that P/F early and late in (herd) life were very similar traits. This implies that cumulative profit early in life is a very good indicator of lifetime profit. Therefore, just as repeatability models are a reasonable approximation of milk yields and survival scores in different lactations, the analysis of lifetime profit is a reasonable approximation. This allows the P/F values for all cows to be included in one analysis regardless of their age. Hence, bulls could be ranked according to the P/F value of their daughters once it is known if the daughters survived to a second lactation or not. With a heritability of LTP between 0·10 and 0·20 (Table 7), reasonable accuracies of bull selection can be achieved, e.g. accuracies between 0·82 and 0·90 based on 80 effective daughters per bull.

Implications for genetic evaluation schemes
In the **Introduction** two methods of predicting breeding values for profit were contrasted: a selection index approach and direct genetic evaluation of the trait profit. The advantage of direct evaluation of profit is that a single trait takes account of milk production in different lactations, lactation lengths, inter-calving interval and length of herd life without the need to model the (possibly non-linear) relationships between them. One disadvantage is that no account is taken of differences in heritability between the components of profit. By using a multi-trait analysis it may be possible to utilize the advantage without suffering this disadvantage. A multiple trait analysis involving the most highly heritable production traits (e.g. Pr_dev) and lifetime profit (i.e. LTP) could be carried out. When there was limited data on a bull's daughters, his EBV for profit would depend mainly on the more highly heritable Pr_dev data, but as information accumulated his EBV for profit would depend mainly on the more 'valid' LTP data. In this way a number of lowly heritable traits (lactation length, inter-calving interval and length of herd life) would be taken into account without the need to explicitly carry out genetic evaluations for them and include them in a selection index. However, there are some traits (e.g. milking speed) which are not included in the current definition of lifetime profit and so EBV for them would still need to be combined with the EBV for LTP when making selection decisions.

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