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Optimal cow replacement on New Zealand seasonal supply dairy farms

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ABSTRACT

Dairy farmers make management decisions each season about which cow to replace. At present dairy famrers can use the production index. The production index is an historical measurement of a cow's milkfat production ranking, free from the influences of herd environment, age, stage of lactation and herd genetic level.

A dynamic programming method is outlined which incorporates genetic, reproductive and economic information. This method ranks cow on their annualised present value. A sensitivity analysis was undertaken and the effects of the changes in the different economic parameters are discussed. The optimal cow rankings produced by the dynamic programming method were shown to be robust to changes in milkfat, manufacturing beef and heifer replacement prices and interest rate.

Keywords Replacement; optimal; dynamic programming; dairy cattle.

INTRODUCTION

Decisions to replace dairy cows are either voluntary or involuntary. Involuntary decisions are, predominately, not in the farmer's control and include death, barrenness and mastitis. Voluntary replacement is within the farmer's control and commonly based on a combination of subjective and objective information about the cow. To aid the farmer in voluntary replacement decisions, the Livestock Improvement Division of the New Zealand Dairy Board produces production indices for each cow, for which information is available. The production index is a measure of a cow's milkfat production free of the influence of age, herd environment, stage of lactation and herd genetic level (Wickham and Stichbury, 1980). Using this index the likely criterion for culling is short term maximisation of milkfat production. However, on commercial farms where income is derived from the sale of milk and meat, voluntary replacement decisions should be based on a comparison of the anticipated income from the present cow and that of her replacement heifer. In a number of studies techniques involving essentially this comparison have been used to provide general replacement guidelines and policies although, little attention has so far been paid to the development of culling guides for individual cows.

This paper outlines a dynamic programming method which incorporates genetic, reproductive and economic information.

BASIS OF MODEL

Inputs

To enable the utilisation of dynamic programming techniques in cow replacement decision making, information about the costs and revenues over the duration of the present and replacement cow had to be obtained. Furthermore, information was required about the probability of and financial loss associated with involuntary removal and death.

The usefulness of the dynamic programming model to predict the future net revenues from dairy cows is dependent on the prediction of future milkfat production. In this study the future milkfat production was computed using best linear unbiased prediction (BLUP) techniques. An intraherd BLUP model was used (Henderson, 1975), to compute the estimate of a cow's future production as the sum of the additive genetic and permanent environment effects for that cow. A major advantage of the BLUP technique was to enable the prediction of the future milkfat production of freshening heifers, since the numerator relationship matrix was included in the model.

The prediction of future milkfat production was used along with age and calving date in the calculation of the value of each cow's milkfat production. Incorporation of calving date into the model allowed the variation in individual cow lactation length and the likelihood of induced calving to be accounted for in the coming and future seasons. When including calving date in the model, the optimum time to calve was not the planned start of calving. Although late calvers should be penalised, it must be recognised that some optimal calving spread exists for each herd. In this model it was assumed therefore, that the optimal date to calve for any given cow was in the first 6 weeks after the planned start of calving. The net return from each cow was calculated for the value of the milkfat production, the value of the new born calf (both taking into account the effect of calving date), the interest on the capital value of the cow, the salvage value of the cow and the appreciation on the cow. The net return was weighted by the probability of death and involuntary replacement. The general equation for calculation of the net return is given in Appendix 1.

Model Outline

To rank cows based on future profitability projections a dynamic programming procedure was utilised. The basic concepts of dynamic programming are those of the *state* (age, calving status, milkfat production, ...) of the *system* (a cow) and the *transition* from 1 state to another over as number of stages (seasons). Dynamic programming is used to formulate a recursive relation between each of the stages of the sequence. Optimization starts at the final stage and moves toward the present stage. The dynamic programming procedure computes an annualised present value (APV) for each state in the present stage.

For the dynamic programming model, a stage was defined as 12 months. Cows were described by 3 state variables namely lactation number, milkfat production and calving date. The model assumed cows who have completed their 10th lactation were replaced by 2-year-old heifers. There were 5 calving date categories, 52 states describing milkfat production and 10 states describing lactation number resulting in a total of 2600 states. For the dynamic programming model, the transition probabilities were computed from the probabilities for each state variable. because of the definition of milkfat production, which has the same expectation in all future lactations for a given cow, the probaility of transition from the present milkfat state to another is 0.0. Conversely, the probability of transition to the same state is 1.0. The dynamic programming equations are given in Appendix 2.

RESULTS

Output

The costs, prices and production characteristics used in th model are given in Table 1. the prices are related to the 1985 - 86 season.

Fig. 1 illustrates the results for the dynamic programming model for 3 age groups. *This figure* shows the change in APV for cows in the 5 calving date categories as the milkfat production increased from 100 to 300 kg per lactation. Also shown is the impact of calving date category on the APV within an age and milkfat production level. There were 3 main interactions, production level within calving date category and age, age within calving date category and production level and calving date category within production level and age.

The increase in APV within age and calving date category was curvilinear with respect to milkfat production, except for the 10th lactation where the increase in the APV was directly proportional to increase in milkfat production and the 5th calving date category where there was no increase in the APV with increasing milkfat production. In both these cases replacement occured in the next season. The curvilinear effect decreased as age increased since the time difference between the time of planned and optimal replacement decreased.

Increasing the age within a given calving date category reduced the extremes of the APV as the APV diminished in the high milkfat production states and increased in the low milkfat production states. These effects may be explained by first, the increase in the probability of death or involuntary removal with age and secondly, that planned replacement due to old age occured at an earlier date. The decrease in the APV for high producing older cows was related to a reduction in the number of years their superiority for milkfat production was expressed before planned replacement. Conversely, the increase in the APV for older low producing cows was related to a reduction in years the inferiority for milkfat production was expressed before either planned or optimal replacement.

A decrease in the APV with movement from calving date categories 1 to 5 within an age and milkfat production group was due to a reduction in lactation length and probability of calf survival.

Case Study

The dynamic programming model was applied to a herd of 168 Jersey dairy cows. Their estimates for

TABLE 1 Costs, prices and production characteristics used in the study.

Parameter	Value
Price of milkfat in wholemilk for manufacture	364.2 c/kg
Price of bobby calves	25.3 $/hd
Price of manufacturing beef	144.3 c/kg
Cost of veterinary induction	$5.0
Rate of genetic improvement	0.7 %
Price of replacement heifer	$550
Future production of replacement heifer	200 kg milkfat/yr
Interest rate (real)	5.8 %

future milkfat production ranged from 136.2 to 337.9 kg of milkfat with a herd average of 214.5 kg. These cows were all candidates for the herd in the 1985-86 season. Eighty two percent of the cows were expected to calve in the first 6 weeks and all cows were expected to calve within the first 15 weeks. It was assumed that the herd was to remain constant at 147 cows, hence 21 cows were be culled voluntarily. The results from the dynamic programming model produced a range from $485 to $874 in cow values with a standard deviation of $48.00. The average APV per cow for the unculled cows was $656.40 when all cows were available as candidates for culling and $666.78 for the culled cows.

Sensitivity Analysis

As well as construction of a method to rank cows on future profitability, it is also important to examine the effect of changing the parameters (costs and prices) on which farmers base their decisions. A Spearman's rank correlation was calculated when each of the following parameters were varied.

1. Milkfat price
2. Manufacturing beef price.
3. Replacement heifer price.
4. Interest rate.
5. Rate of genetic gain.

The results are summarised in Table 2. Two parameters which caused change to the optimal rankings were those associated with the cost of replacement (price of manufacturing beef and the price of the heifer replacement), whereas, changes in the price of milkfat had no effect. This was found to be in agreement with the findings of Stewart *et al.* (1977), Allaire and Cunningham (1980) and van Arendonk (1986a; 1986b). Interest rate was also found to affect the optimal rankings. However, if the inflation adjusted interest rate (Smith, 1978) was used the variation in the choice of the interest rate was likely to be small and, hence the effect on the optimal rankings would be minimal.

Milkfat, manufacturing beef and replacement heifer prices were varied simultaneously to mimic the market place situation. It was found that the rank correlation for an individual cow's APV for all combinations of prices was 0.99. This indicated that the changes to the optimal rankings produced by the dynamic programming model caused by changes to

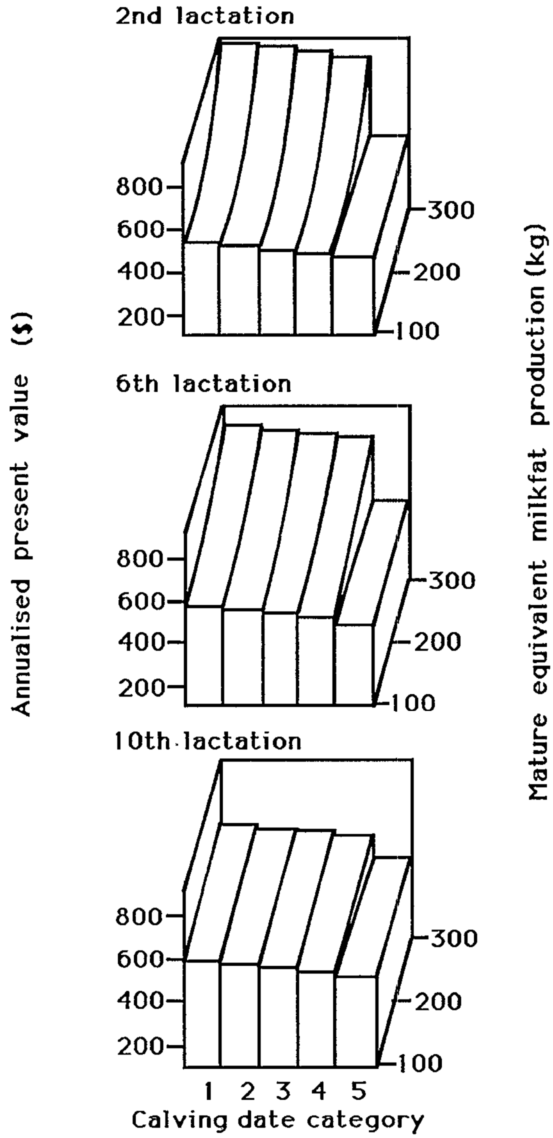

FIG. 1 Examples of the results for the dynamic programming model for 3 age groups, namely, 2nd, 6th and 10th lactations.

TABLE 2 Rank correlations for different parameter combinations

Parameter combination	Rank correlation
Milkfat price from $2.60 to $4.60/kg	1.00
Manufacturing beef price from $0.50 to $2.00/kg	0.98
Replacement heifer price from $450 to $750/hd	0.99
Interest rate from 0.0% to 15.0%	0.99
Rate of genetic gain from 0.0% to 1.5%	1.00

either the price of manufacturing beef or the replacement heifer price were lessened by their interaction.

CONCLUSIONS

The shortcomings of the present culling guide system based on a production index are that the likely criterion for culling is short term maximisation of milk production but it does not incorporate any economic variables nor look far enough into the future. The culling guide developed in this study overcomes the above limitations. The future net returns for individual cows are estimated and these returns are weighted by the probability of events occurring in the future (death or involuntary removal). Inclusion of the cow's expected calving dates in the model allows the economic effects of calving date to be considered. These allow the farmer to cull individual cows on expected monetary return rather than just production.

REFERENCES

Allaire F.R.; Cunningham E.P. 1980. Culling on low milk yield and its consequences for a dairy herd. *Livestock production science* **7**: 349-359.

van Arendonk J.A.M. 1986a. Studies on replacement policies in dairy cattle II. Optimum policies and the influence of changes in production and prices. *Livestock production science* **13**: 101-121.

van Arendonk J.A.M. 1986b. Studies on replacement policies in dairy cattle III. Optimum policies and the influence of variation in reproduction and production. *Livestock production science* **13**: 339-349.

Henderson C.R. 1975. Use of all relatives in intraherd prediction of breeding values and producing abilities. *Journal of dairy science* **58**: 1910-1916.

Smith C. 1978. The effect of inflation and the form of investment on the estimated value of genetic improvement in farm livestock. *Animal production* **26**: 101-110.

Stewart H.M.; Burnside E.B.; Wilton J.W.; Pfeiffer W.C. 1977. Dynamic programming of dairy cow replacement problem. *Journal of dairy science* **60**: 602-617.

Wickham B.W.; Stichbury J.W. 1980. Cow and sire evaluation in New Zealand. In *Symposium in dairy cattle sire evaluation*, Warsaw, Poland.

APPENDIX 1

The general equation for calculating net returns;

$$NR_{jkl} = MFR_{jkl} - ID_{jl} + CV_l + A_k - IC_k \ldots A1.1$$

where: NR_{jkl} is the net return for a cow of age k in the 10th milkfat production state and the lth calving date category.

MFR_{jkl} is the net return for a cow of age k in the 10th milkfat production state and the lth calving date category.

ID_{jl} is the inducing cost for a cow for in the jth milkfat production state and the lth calving date category.

CV_l is the calf value for a cow in the lth calving date category.

A_k is the appreciation for a cow of age k.

IC_k is the interest on capital value of a cow of age k.

APPENDIX 2

The equations for the dynamic programming algorithm.

$$F_i(j, k, l) = \max[(\text{keep}(j, k, l), \text{replace}(j, k, l)] \quad i \neq l$$
$$= \delta[(\text{keep}(j, k, l)] \quad i = l \ldots A2.1$$

where:

$$\text{keep}(j, k, l) = \beta\{[NR_{jkl} + [1-\pi_{kir}].T_{jkl}.F_{i-l}(j, k, l) + \pi_{kir}.[SV_k + NR_i^{hfr} - CHfr]].[1-\pi k_d] + \pi_{kd}.[NR_i^{hfr} - CHfr]\}$$

$$\text{replace}(j, k, l) = \beta\{[SV_k + NR_i^{hfr} - CHfr].[1-\pi_{ld}] + \pi_{ld}.[NR_{i-l}^{hfr} - CHfr]\}$$

$\delta = r/[1-(1+r)^{-n}]$

$\beta = 1/(1+r)$

r is the interest rate.

n is planning horizon.

SV_k is salvage value for a cow of age k.

CHfr is the cost of a replacement heifer.

NR_i^{hfr} is the net returns for a heifer at stage i.

π_{kir} is probability of involuntary removal for a cow of age k.

π_{kd} is probability of death for a cow of age k.