
Chapter X. Economic value of culling information in the presence and absence of a milk quota (p 137-146)

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Economic Value of Culling Information in the Presence and Absence of a Milk Quota

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In order to determine the value of culling information, the net returns to housing, labour and management were calculated analytically using three different replacement policies in the presence and absence of a milk quota. The conclusions were that in the absence of a milk quota there are considerable benefits from using a decision support system, but under a quota the benefits are negligible if compared to the very simple policy of only replacing cows which fail to conceive within 238 days. If a system based on calculations assuming no quota is used under a quota the dairy farmer will be directly misinformed. Decision support systems for culling should be specifically designed for the quota situation, where reductions of costs are the most important means for improving herd net returns. Emphasis should therefore be put on information that support reductions on average costs of keeping a cow. Key words: Dairy cow, replacement, decision support.

INTRODUCTION

The dairy cow replacement problem has been the object of several studies in the literature. The preferred tool for optimization has been stochastic dynamic programming, and very detailed models have been developed by van Arendonk (1985, 1986), van Arendonk & Dijkstra (1985) and Kristensen (1987, 1989). The works mentioned have resulted in profound knowledge of the nature of the problem as well as the factors influencing the optimal replacement policy. Further Kristensen (1989) has discussed the problem of adjusting such models to fit a situation with a milk quota.

Thus from a theoretical point of view the replacement problem should be regarded as solved to a satisfactory degree. The detailed models, however, are at present not suitable for practical use in commercial dairy herds because of the extreme amount of computing time required to get an optimal policy. Therefore alternative approaches must be considered to provide the dairy farmer with culling information. In a paper of van Arendonk (1988) one method has been described, but the situation with a milk quota has not been considered, and the benefits from the method has not been compared to those of other alternatives.

In Denmark a decision support system for culling of dairy cows in commercial dairy herds is under consideration. In that connection the purpose of the present paper is to investigate the economic value of culling information for situations with and without quotas. This value is very important because it sets an upper limit on the costs of the very decision support system. In a later paper various methods for ranking of cows for replacement will be evaluated.

In order to determine the value of culling information the net returns to housing, labour and management were calculated using three different replacement policies in situations with a milk quota as well as situations without a milk quota.
Similar studies have been carried out under American and Dutch conditions by Marsh et al. (1987) and Dijkhuizen & Stelwagen (1988), respectively. However, neither of those have considered situations with a milk quota. Another difference from the present study is that the works mentioned are based on stochastic simulation. In the present study the net returns are calculated analytically from a stochastic replacement model based on dynamic programming.

Theoretical aspects of a milk quota

Kristensen (1989) found that the variation in future profitability due to variation in milk yield and calving interval among individual cows is considerably smaller under a milk quota than in situations without a quota. (The future profitability is defined as the gain—positive or negative—from keeping the cow for at least one additional period instead of replacing it immediately).

These results indicate that the economic value of information on milk yield and calving interval should be less under milk quotas. By relatively simple mathematical arguments it can be shown that the reason is the very nature of the production quota. The net returns \( R \) per cow per year as a function of milk yield \( Y \) per cow per year can be split up in a "constant" part \( c \), which is independent of milk yield, and a part which is fairly proportional to milk yield (except for a decreasing gross feed efficiency). Thus we have

\[
R = c + (p_m - 0.4p_f/e) Y
\]  

where \( p_m \) is the milk price, \( p_f \) is the price of a Scandinavian Feed Unit (SFU) and \( e \) is the gross feed efficiency. The constant 0.4 is the theoretical energy requirement in SFU to produce 1 kg fat corrected milk (4%). For convenience we shall assume \( e \) to be constant.

In a situation without a milk quota, the total net returns \( H \) of the herd are set by the number of cows \( N \):

\[
H = RN = cN + (p_m - 0.4p_f/e) YN.
\]  

If a milk quota of \( M \) kg 4% milk is introduced the number of cows and the average milk yield must be adjusted to meet the quota. Thus the total net revenue \( H \) is set by the size of the milk quota:

\[
H = R(M/Y) = cM/Y + (p_m - 0.4p_f/e) M.
\]  

A higher value of a high yielding cow compared to a low yielding cow is due to a positive marginal net return from increased milk yield. Therefore it is relevant to investigate the marginal value of larger milk yield per cow. From Eq. 2 we get

\[
dH/dY = (p_m - 0.4p_f/e) N.
\]  

Under the assumptions made, the marginal value is seen to be constantly equal to the gross margin per kg of milk, which under usual conditions is positive. In the quota situation we get from Eq. 3:

\[
dH/dY = -cM/Y^2.
\]  

The constant \( c \) contains the costs, that are directly related to the number of cows (the costs of keeping a cow). It can be calculated as the value of calf and weight gain less feed costs for maintenance, gain and embryo, and other costs that do not depend on yield. Thus
under usual conditions \( c \) will be negative, which means that the marginal value also in this case is positive, but unlike Eq. 4 it is decreasing by the square of milk yield.

Realistic values of \( p_m, p_j, e \) and \( c \) could be 2.70 Dkr, 1.60 Dkr, 0.9 and \(-4000\) Dkr, respectively. If these values are used in Eqs. (4) and (5) we find from (4) that the marginal value is 1.99 N without a quota and 4000 \( M/Y^2 \) under a quota. If we assume the housing capacity to be \( N=100 \) cows (no quota) and the milk quota to be \( M=600000 \) kg milk (no restriction on herd size) the marginal value of 1 kg additional average milk yield of the herd is as shown in Fig. 1.

It should be emphasized that the two curves of the figure do not apply to the same herd. Like Eqs. (4) and (5) they reflect the pure effects of limits in either herd size or milk production. The situation of a herd not using a quota entirely is not covered by this very simple model. However, the parameter values used in the figure have been chosen in order to make the two curves comparable at a realistic level of milk yield (from 6000 kg milk and up).

As it appears from Fig. 1, the marginal value of increased milk yield for any realistic level of milk yield is much smaller under milk quota than without a quota. At an average milk yield of 7000 kg the marginal value is more than 4 times larger without a quota. In other words the economic advantage of increasing the average milk yield of the herd through replacement is much smaller in a situation with a quota than without a quota where the housing capacity is the major limitation.

Also the costs of keeping a cow (expressed by \( c \)) should be considered. Under a quota, the marginal value in Eq. (5) is proportional to \( c \). Large costs of keeping a cow (i.e. \( c \) numerically large) mean larger marginal value and consequently larger propensity to replace because of low milk yield. Without a quota the situation is different, since \( c \) does not influence the marginal value at all, as it is seen from Eq. (4).

The benefits of decreasing the average costs of keeping a cow by means of replacement is not larger under a quota than without a quota, as the number of cows is smaller rather than larger. Relatively, however, decreasing costs becomes more interesting under milk quota, because the possibilities to increase herd returns by higher milk yield are vanishing.

The difference in the marginal value of increased milk yield per cow may also be
explained by intuitive arguments. The optimization of replacement has as its basic purpose to ensure that at any time the most effective cows are used for production. Without a quota, where housing capacity is the major limitation, individual efficiency is equivalent to herd efficiency, because the number of cows is fixed. Under a (sufficiently low) quota the housing capacity is not limiting, which means that the efficiency of the individual animal is not necessarily equal to herd efficiency. If the quota is not met at the current efficiency there will always be the possibility to increase the number of cows by one or more animals. This is particularly relevant when the costs of keeping a cow (c in Eq. (5)) are low and/or the average milk yield is high (cf. Fig. 1).

MATERIAL AND METHODS

As a consequence of the arguments of the previous section, we should expect the value of culling information, that primarily includes milk yield (directly and indirectly) to be considerably lower under a milk quota than without a quota. In order to test this hypothesis the net returns to housing, labour and management were calculated using 3 different replacement policies in situations with a milk quota as well as situations without a milk quota. The net returns are expressed relative to the most limiting factor, i.e. per kg milk under quota and per cow per year without a quota.

The three policies were formulated as follows: 1) Replace cows that fail to conceive within 154 days; 2) replace cows that fail to conceive within 238 days; and 3) replace cows according to an optimal policy from the stochastic replacement model used by Kristensen (1989).

Policy 1 and 2 were chosen because they match two of the policies tested in a similar study by Dijkstra & Stelwagen (1988) who compared the returns from 4 policies in situations without a milk quota. In this study Policies 1 and 2 are the same no matter if a milk quota is present or not. Policy 3, on the other hand, is different depending on the presence or absence of a milk quota. In each situation a policy is used that maximizes net return relative to the most limiting factor (i.e., per kg milk or per cow respectively). In the following an optimal policy in the absence of a quota is denoted as Policy 3a, and an optimal policy under a quota is denoted as Policy 3b.

Under Policy 1 and 2 cows were voluntarily replaced at 32 and 40 weeks after calving respectively. Under policy 3 cows were voluntarily replaced at the optimal stage of lactation depending on the individual properties of the cow.

In similar studies Marsh et al. (1987) as well as Dijkstra & Stelwagen (1988) have used stochastic simulation models for evaluation of policies. In this study a direct calculation of net returns is carried out. The calculations are based on the stochastic dynamic programming model used by Kristensen (1989), which may be regarded as a Markov decision process. The biological parameters of the model are published by Kristensen (1986). To describe the method used for calculation we shall introduce the notation of such process.

The system (a cow) is defined by its state $i$ ($i=1, \ldots, I$) defined by the present properties (genetic class, lactation number and stage, milk yield in previous and present lactation and expected length of the calving interval). As soon as the state is observed we will have to choose an action $d$ (in this case $d=1, 2$ for "keep" or "replace"). A set of actions (one for each possible state) makes up a policy $s$. We shall denote as $s(i)$ the action that the policy $s$ defines for state $i$. Depending on the state and action, a reward $r^d_i$ is gained (in this case the reward is the net return). Further we assume that some physical quantity denoted as $m^d_i$ is involved. In this case the physical quantity may either be the amount of milk produced by a cow in state $i$ when the action $d$ is taken or it may be the duration of the present stage depending on whether we are producing under a quota or not. The transition probability
from state \( i \) at the present stage to state \( j \) at the next stage also depends on the action taken, and it is denoted \( p_{ij}^d \). If \( d = s(i) \) the symbols \( r_i^d \), \( m_i^d \) and \( p_{ij}^d \) are also written as \( r_i \), \( m_i \) and \( p_{ij} \) respectively. It is possible to show that for any policy \( s \), we have:

\[
g' m_i + f_i = r_i + \sum_{j=1}^{I} p_{ij} f_j, \quad i = 1, \ldots, I, \tag{7}
\]

where \( g' \) is the average net return per unit of the physical quantity represented by \( m_i \) under the policy \( s \). In the equations (7), \( f_1^i, \ldots, f_I^i \) together with \( g' \) must be regarded as unknowns. The variable \( f_i^i \) is called the relative value of state \( i \) under the policy \( s \), but it is of no interest in this connection. Depending on whether \( m_i \) is the milk yield or the duration of the stage, \( g' \) gives the average net return per kg milk produced or per unit of time (i.e. per cow per year). The \( I \) equations of (7) may be solved for the unknowns \( g' \) and \( f_1^i, \ldots, f_I^i \) if we add the restriction \( f_I^i = 0 \). Thus for any policy we can calculate the net revenue per cow per year and per kg of milk produced by solving a set of \( I+1 \) simultaneous linear equations.

The model used contains approximately 180 000 states, so in principle a set of 180 000 linear equations should be solved involving the inversion of a matrix of the dimension 180 000 \( \times \) 180 000. However by using a technique called hierarchic Markov processes developed by Kristensen (1988; 1989) the number of equations to be solved are reduced to 6.

The direct calculation of net returns has the advantage over stochastic simulation by random number generation that it reduces the calculations drastically and avoids the problem of variation in simulation results without reducing the stochastic elements in any way. Differences between returns from policies are therefore absolutely precise and not influenced by random variation.

The prices and other conditions used in the calculations are shown in Table 1.

RESULTS AND DISCUSSION

The technical and economic impacts of the replacement policies are shown in Table 2. Policy 3a, which is optimal in the absence of a quota, is characterized by a very intensive culling for milk yield and reproductive performance. Thus the average milk yield is 6.6% higher than under Policy 2 where no culling for milk yield and almost no culling for length of calving interval takes place. The more intensive culling under Policy 3a is also illustrated by the fact that the average stage of lactation for replacement (voluntary and involuntary) is 7 weeks earlier than under Policy 2.

Table 1. Conditions used in the calculation of net returns

<table>
<thead>
<tr>
<th>Prices (Dkr)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (kg FCM)</td>
<td>2.40</td>
</tr>
<tr>
<td>Basic food (SFU)</td>
<td>1.30</td>
</tr>
<tr>
<td>Food for milk production (SFU)</td>
<td>1.45</td>
</tr>
<tr>
<td>Calf</td>
<td>1 400.00</td>
</tr>
<tr>
<td>Heifer</td>
<td>9 000.00</td>
</tr>
<tr>
<td>Young cow (kg live weight)</td>
<td>11.50</td>
</tr>
<tr>
<td>Older cow (kg live weight)</td>
<td>11.00</td>
</tr>
<tr>
<td>Interest rate (corrected for tax and inflation, %)</td>
<td>3</td>
</tr>
<tr>
<td>Herd level of milk yield (week 1-40, 1st lact.)</td>
<td>5 800.00</td>
</tr>
</tbody>
</table>
Policy 3b, which is optimal under a quota, is in fact not very different from Policy 2. The average milk yield is only 1.4% higher and the average stage of lactation for replacement is only 3 weeks earlier than under Policy 2. Thus the culling for milk yield and reproductive performance is much less intensive under Policy 3b compared to 3a.

If we turn to the economic results, it appears that in the situations without a milk quota Policy 3a is evidently better than the others. The net returns to housing, labour and management are 3.3% higher than for Policy 1, which ranks second. The results in absolute figures are not directly comparable to those of Dijkstra & Stelwagen (1988) because they included housing costs in the calculations. Since, however, the housing costs are independent of the replacement policy, the differences between net returns from different policies may be compared.

In this study the difference between Policy 3 and Policy 1 equals 308 Dkr per cow per year. The corresponding difference in the study of Dijkstra & Stelwagen was 33 Dfl. or approximately 125 Dkr per cow per year (under “average” level of reproductive performance). Thus the benefits from policy 3 seem to be larger under Danish conditions than under Dutch in the absence of a milk quota. The reason for this is probably, that under Danish conditions the optimal replacement rate (as well as observed rates) is considerably higher than in most other countries due to a relatively high value of culled cows.

Under a quota the impression is fundamentally different. Naturally Policy 3b is the most profitable, but the benefits compared to Policy 2 are less than 1% in net returns to housing, labour and management. It is therefore evident that the costs of a decision support system for culling must be very low in order to be profitable. A rough estimate of the maximum costs is approximately 45 Dkr per cow per year.

Policies 1 and 2 primarily affects herd profitability by preventing low milk yield per cow per year to result from long calving intervals. In policy 3a and 3b, the yield ability of individual cows is also taken into account, which leads to a more efficient selection. But with a smaller marginal value of average milk yield under quota, the benefits become smaller.

As it appears from Table 2 the mutual ranking of Policies 1 and 2 depends on the

<table>
<thead>
<tr>
<th>Policy</th>
<th>1</th>
<th>2</th>
<th>3a</th>
<th>3b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield, kg/cow/year</td>
<td>7 082</td>
<td>6 896</td>
<td>7 350</td>
<td>6 991</td>
</tr>
<tr>
<td>Average time for replacement, weeks after calving</td>
<td>25</td>
<td>28</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Annual replacement rate</td>
<td>50</td>
<td>35</td>
<td>59</td>
<td>38</td>
</tr>
<tr>
<td>Net returns to housing, labour and management</td>
<td>Dkr/cow/year, abs.</td>
<td>9 236</td>
<td>9 150</td>
<td>9 544</td>
</tr>
<tr>
<td>Dkr/cow/year, rel.</td>
<td>100.0</td>
<td>99.1</td>
<td>103.3</td>
<td>(100.9)</td>
</tr>
<tr>
<td>Net returns to housing, labour and management</td>
<td>Dkr per 1 000 kg milk, abs.</td>
<td>1 304</td>
<td>1 327</td>
<td>(1 299)</td>
</tr>
<tr>
<td>Dkr per 1 000 kg milk, rel.</td>
<td>100.0</td>
<td>101.8</td>
<td>(99.6)</td>
<td>102.2</td>
</tr>
<tr>
<td>Number of cows assuming quota, relatively</td>
<td>100.0</td>
<td>102.7</td>
<td>96.4</td>
<td>101.3</td>
</tr>
</tbody>
</table>

" Policy 3a is an optimal policy without a quota, and policy 3b is optimal under a quota.

* Includes involuntary replacements.
presence or absence of a milk quota. The reason for this is intimated by the technical results which show that Policy 1 in its consequences is quite similar to Policy 3a, and Policy 2 is quite similar to Policy 3b. The net returns per 1000 kg milk under policy 3a is 1299 Dkr. This amount is the expected net revenue to be gained if the optimal policy from a situation without a milk quota is used under a quota. It should be noticed that under a quota the returns from policy 3a are lower than even those from Policy 1 and considerably lower than those from Policy 2. These results show that a decision support system based on maximization of net revenue per cow will directly misinform the dairy farmer if used under a quota.

CONCLUSIONS

In the absence of a milk quota there are considerable benefits from using an efficient selection of cows with the highest expected milk yield, but under a quota the benefits are negligible if compared to the very simple policy of only replacing cows which fail to conceive within 238 days. If a system based on calculations assuming no quota is used under a quota the dairy farmer will be directly misinformed. Decision support systems for culling should be specifically designed for the quota situation, where reductions of costs are the most important means for improving herd net returns. Emphasis should therefore be put on information that support reductions on average costs of keeping a cow by replacing, for example, cows with a high risk of diseases.

REFERENCES
