Dairy Cattle Culling Patterns, Explanations, and Implications

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ABSTRACT

Culling patterns in the Upper Midwest and Northeast regions were examined from Dairy Herd Improvement records from 1993 through 1999. There were 7,087,699 individual cow lactation observations of which 1,458,936 were complete. A probit regression model was used to determine how individual cow and herd characteristics affected the likelihood of a cow being culled. The model predicted whether individual cows were culled each month. With a combination of observable cow and herd characteristics, as well as variables to capture state, year, and farm effects, the model was able to explain, with a 79.5 and 79.9% accuracy rate, individual cow cull decisions in the Upper Midwest and Northeast regions, respectively. Summer (–11.5% in the Upper Midwest; –6.4% in the Northeast) and fall (–18.7% in the Upper Midwest; –7.9% in the Northeast) calving vs. spring calving, higher than average milk production (–1.7% per hundredweight in the Upper Midwest; –0.5% in the Northeast), higher than average protein content (–0.2% per additional percentage milk protein in the Upper Midwest; –0.1% in the Northeast), higher milk production persistency (–2.1% per additional percent persistent in the Upper Midwest; –1.8% in the Northeast), and expansion (during the early years following the expansion) were associated with a reduced likelihood of a cow being culled. Lower than average fat content (0.04% per additional percentage butterfat in the Upper Midwest; 0.02% in the Northeast), and higher than average somatic cell count (8.8% for each unit increase in somatic cell count score in the Upper Midwest; 7.8% in the Northeast) were associated with an increased likelihood of a cow being culled. The study results are useful in describing patterns of culling and relating them to cow, herd, geographic, and time variables and can act as a benchmark for producers.

Key words: culling, economics, management

INTRODUCTION

Culling is the act of identifying and removing a cow from a herd and, assuming a constant or expanding

herd size, replacing the cow with another cow, often a first-lactation heifer. The culling rate describes the percentage of cows removed from a herd. Understanding culling rates is important for managing dairy production response and profitability. When dairy farm managers cull cattle too often or too quickly, replacement expenditures are excessive. When managers keep cattle for too long, milk production, reproduction, or genetic improvement may be impaired.

High replacement costs and low milk prices tend to focus attention on culling decisions and optimal culling rates, as high replacement costs during periods of small profit margins make nonoptimal culling rates expensive. Past research has consistently estimated optimal herd-level culling rates ranging from 19 to 29% (Rogers et al., 1988; Bauer et al., 1993; Stott, 1994; Jones, 2001). Actual average annual culling rates are often above even this range. For example, the average annual culling rate for Upper Midwest DHIA herds in 2001 was 38% (Quaife, 2002). Because many dairy advisors, farm organizations, and agricultural lenders feel that the discrepancy between estimated optimal culling rates and observed culling rates is too large, dairy farmers are often advised to reduce culling rates.

Holding herd size constant, dairy cow replacement decision models instruct the manager to cull an incumbent cow when the challenger replacement cow is expected to generate more profit (Dijkhuizen et al., 1985). Without a challenger, the incumbent cow is appropriately culled when she is no longer profitable. Traditionally, an examination of culling patterns has included “voluntary” and “involuntary” culls. Culling due to low production, cow aggression, or when a cow is sold to another farm for dairy purposes is referred to as voluntary culling. Involuntary culling is all other factors including sales due to illness, injury, infertility, or death. If all culling decisions are voluntary, the manager can make decisions that maximize profit. Thus, it is important to understand how culling affects production, how many cattle are culled, why cattle are culled, and how management programs affect culling rates.

There are several examples of research on culling reasons, which are useful for identifying explanatory variables and comparing results. For example, Milian-Suazo et al. (1989) examined 34 New York dairy herds

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to explore the influence of production and disease on culling. They found that lower milk per calving-interval day, shorter previous lactation, and summer calving were associated with those cows sold for dairy purposes. Bascom and Young (1998) summarized reasons why farmers culled cows on 27 herds in New Hampshire, Vermont, and Massachusetts. They found that reproduction was the primary reason for culling, followed by production and mastitis. Higher producing herds were more likely to cull a cow for abortion and reproduction, but less likely to cull for mastitis. Smith et al. (2000) examined 11,250 herd summary records from states east of the Rocky Mountains to determine the effect of region, herd size, and milk production on cows leaving the herd. Low-producing herds reported a lower percentage of cows leaving than higher producing herds. High-producing herds reported more cows leaving for reproduction, mastitis, feet and legs, and disease than lower producing herds. Small herds reported more cows leaving for reproduction and mastitis than larger herds. Past research has largely focused on culling factors and patterns at the herd level. In contrast, we examine culling at a cow level.

We analyze DHI records for 5 Upper Midwest states and 5 Northeast states from 1993 through 1999 to determine the percentage of cattle culled each year, why cattle were culled, and when cattle were culled within a lactation. Probit regression models were used to determine how individual cow and herd characteristics affected the likelihood of an individual cow being culled.

MATERIALS AND METHODS

Culling rate was defined as cows sold due to low milk production, failing health, or poor reproduction plus mortalities as a percentage of total average milking and dry cows. This excludes cows "sold for dairy" because these sales should not be considered a problem. Selling heifers as replacements indicates a successful breeding and heifer-raising program coupled with a controlled culling situation. The culling rate value used is sometimes referred to as a herd turnover rate without the sold for dairy component.

Data

Data were supplied by Dairy Records Management Systems (DRMS, Raleigh, NC). The data contained production records of participating DHI dairy farms in the Northeast region [Maine, New Hampshire, Pennsylvania, and Vermont (1993 to 1999); and New York (1996 to 1999)] and the Upper Midwest region [Illinois, Iowa (1996–1999), Indiana (1993–1999), Michigan (1997–1999), and Wisconsin (1995–1999)] from 1993 through

1999 for individual cow records and 1995 through 1999 for herd level records in participating states. Data from 1995 through 1999 were used to capture the largest possible number of herd-related characteristics. The total numbers of herds with complete records for 1995 were 6,264 (about 9% of all operations with milk cows in those states; USDA–National Agricultural Statistics Service, Milk Production Report). Other years and corresponding herd numbers with records were 14,028 herds in 1996; 18,290 herds in 1997; 20,132 herds in 1998; and 19,464 herds in 1999. These values represented approximately 22, 31, 33, and 35% of operations with milk cows in those states for 1996 through 1999, respectively (USDA-NASS, Milk Production Report). Herds could enter or exit at any time; thus, the data are an unbalanced panel from a herd perspective. We controlled for this in the estimation with a fixed-effects variable for herd. There were 7,087,699 individual cow lactation observations in the original data set.

Explaining Cow Cull Probability

For each cow and decision period, the decision-maker has a choice: the cow can be culled or retained. With a discrete, binomial choice, a nonlinear probability regression model was used for analysis. Specifically, a probit model was used to predict the probability that the cumulative effect of the explanatory variables had exceeded the threshold value for a cow to be culled. The probit model takes the form:

$$P(\text{Cull} = 1) = \beta_0 + (\beta_1 X_1 + \dots + \beta_n X_n),$$

where $P(\text{Cull} = 1)$ refers to the predicted probability (0 or 1 for a given cow and lactation) that a culling event occurs in that lactation, β_0 is the intercept, and $\beta_1, \dots, \beta_n$ are coefficients relating to $x_1, \dots, x_n$, which are a set of independent variables that may influence whether a cull will occur. The marginal effect of the n th parameter in a probit model is calculated as $\beta_n \Phi(Y_i)$, where β_n is the coefficient of the n th parameter, Φ is the standard normal density function, and Y_i refers to the regression result at mean values (Gujarati, 1995). The SAS statistical software (SAS Institute, 2002) was used to calculate coefficients and resulting marginal effects. The probability threshold of a positive event was set at 0.6.

A variety of individual and herd-level characteristics contribute to a cow being culled. From the previous literature (Dijkhuizen et al., 1985; van Arendonk and Dijkhuizen, 1986; Rogers et al., 1988; Milian-Suazo et al., 1989; Delorenzo et al., 1992; Bascom and Young, 1998; Smith et al., 2000; Weigel et al., 2003), we identified a number of characteristics that were expected to

influence the culling decision. Factors that influence culling decisions were categorized as relating to cow, herd, location (state or region), or time. Cow-related characteristics included calving season: spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), or winter (December, January, and February), of the current lactation, lactation number (quadratic), milk production (kg), fat (%), protein level (%), persistency (%), as well as SCC score relative to the herd average, services per conception relative to the herd average, and breed. Persistency percentage is an index based upon each cow's current projected 305-d mature equivalent (**305ME**) production compared with her projected 305ME production on the previous test day. A persistency value greater than 100 indicated that the lactation curve of the cow was more persistent than the average for her breed, age, and season of freshening. The formula to calculate persistency percentage is: (new projection/last month's projection) $\times$ 100 (DRMS, 1999). The SCC difference measure was calculated by subtracting the herd average SCC in cells/mL from the individual cow's SCC. Herd characteristics included whether the herd had breed-registered cows, herd size, whether the herd was in or recently had a herd expansion, and proportion of replacement heifers to milk cows. Two groups of 5 expansion dummy variables were designed to test the hypothesis that expansion was positively correlated with the likelihood of a cow being culled. The first expansion group, "small" expansions, included herds that increased herd size by between 20 and 300%. Dummy variables for this expansion group represented the first through fifth years during or following a herd expansion. The second group of expansions, "large" expansions, consisted of those farms that expanded by more than 300%. A dummy variable was also assigned to represent the first through fifth years during or following a large expansion. An explanatory variable, "heifer ratio current or lagged" representing the ratio of the number of heifers over 13 mo of age (corresponding to cattle that can be expected to calve within 10 to 13 mo) to the average annual milking and dry cow herd size (heifer ratio), was used to determine the effect that the number of available replacements had on the likelihood of a cow being replaced. One current period and a 1-yr lagged ratio were used. State level milk-to-feed and cull cow-to-replacement heifer price ratios for each month were included. The milk-to-feed price ratios were constructed from USDA reports for each state by month. This price ratio represents number of pounds of 16% mixed dairy feed equal in value to 1 pound of milk. All milk prices were from the *Agricultural Prices Monthly* publication (USDA-NASS). A representative feed price was constructed using prices of corn, alfalfa hay, and

soybeans obtained from *Agricultural Prices Monthly* (USDA-NASS). In a few cases, prices were not available for a particular state (for example, a New Hampshire milk price). In these cases, the closest available neighboring state price was utilized (Vermont milk price for New Hampshire). Similarly, cull cow-to-replacement heifer price ratios for each month by state were calculated from *Agricultural Prices Monthly* data (USDA-NASS). Both of the price ratios are proxies for the contemporaneous dairy economic conditions under which a farmer made culling decisions. A state dummy variable captured other characteristics such as weather and geography unique to that state. A year variable captured potential time effects. Finally, a fixed-effect dummy variable was included for each farm observation to capture management and other unobservable characteristics. These characteristics are summarized in Table 1 and discussed in detail below.

Considering all explanatory variables, the estimated probability of cow i in herd j for month s of year t takes the form:

$$\begin{aligned}
 P(\text{Cull} = 1)_{ijtsr} = & \beta_0 + \beta_1 (\text{Year})_t \\
 & + \beta_2 (\text{Farm})_j + \beta_3 (\text{Calving season}) + \beta_4 (\text{Lactation})_{it} \\
 & + \beta_5 (\text{Lactation}_{it})^2 + \beta_6 (\text{Milk difference})_{ijt} \\
 & + \beta_7 (\text{Fat difference})_{ijt} + \beta_8 (\text{Protein difference})_{ijt} \\
 & + \beta_9 (\text{Persistency difference})_{ijt} + \beta_{10} (\text{SCC difference})_{ijt} \\
 & + \beta_{11} (\text{Services/conception difference})_{ijt} + \beta_{12} (\text{Breed})_i \\
 & + \beta_{13} (\text{Registered herd})_j + \beta_{14} (\text{State}) \\
 & + \beta_{15} (\text{Herd size})_{it} + \sum_{r=1}^5 \delta_r (\text{Small expansion}) \\
 & + \sum_{r=1}^5 \gamma_r (\text{Large expansion}) + \sum_{t=0}^{-1} \phi_t (\text{Heifer ratio})_{jt} \\
 & + \sum_{s=-1}^{-12} \lambda_s (\text{Milk-to-feed price ratio})_s \\
 & + \sum_{s=-1}^{-12} \eta_s (\text{Cull-to-heifer price ratio})_s,
 \end{aligned}$$

where s represents months prior to the current month for the variables that enter with a lag and r is the number of years following an expansion. Thus, the estimation is a cow model with explanatory variables that capture herd- and cow-specific characteristics. The farm fixed effect (β_2) captures characteristics unique to that operation that are not captured by other exogenous right-hand side variables. The estimated farm fixed effects are not reported below because there is one for

Table 1. Name and related descriptions of independent variables used in regression analysis to predict probability of a cow being culled

Variable	Description
Year t	Cow observation was in year t; 1 = yes, 0 = no, where t = 1996, 1997, 1998, or 1999.
Farm j	Cow observation was from farm j; 1 = yes, 0 = no.
Calving season	1 if true for winter (December, January, February), summer (June, July, August) or fall (September, October, November); spring (March, April, May) = omitted, 0 = otherwise.
Lactation	Current lactation number.
Lactation squared	Current lactation value squared.
Milk difference	305-d mature equivalent (305ME) milk hundredweight difference from herdmates.
Fat difference	305ME percentage fat difference from herdmates.
Protein difference	305ME percentage protein difference from herd-mates.
Persistency difference	Persistency compared with herd.
SCC difference	Persistency % = (new projection/last month's projection) $\times$ 100
Services/conception difference	Cow SCC less average herd SCC
Breed	Difference between previous lactation services per conception and the previous lactation services per conception of cattle in its herd and age group (grouped as lactations 1, 2, or 3+).
Registered herd	1 if true for Guernsey, Jersey, or other (Holstein omitted). 0 = otherwise.
State	1 if true for each of the 10 states. 0 = otherwise.
Herd size	Indicates the average number lactating and nonlactating cows that were in the herd.
Herd size squared	Average number milking and dry cows squared.
Small expansion, year r	Cow observation was from a farm that was in year of or following an expansion of more than 20%, but less than 300%; 1 = yes, 0 = no, where r = 1 through 5.
Large expansion, year r	Cow observation was from a farm that was in the year of or following an expansion of more than 300%; 1 = yes, 0 = no, where r = 1 through 5.
Heifer ratio	Current and 1-yr lagged variables measuring the proportion of the number of dairy replacement heifers herd greater than 13 mo of age relative to the number of the milking and dry cow herd size on the observation farm.
Milk-to-feed price ratio, month s	Milk-to-feed price ratio during lactation month s = 1 through 12+.
Cull cow-to-replacement heifer price ratio, month s	The cull cow to replacement heifer price ratio during lactation month s = 1 through 12+.

each herd and individual values are only of relevance to the operation in question.

Individual cow data was available from 1995 through 1999. The estimation was performed for each region to examine how each parameter differed between the 2 regions rather than having the regional differences absorbed by each state-independent variable. Using data from Upper Midwest DHIA dairy farms in Illinois, Indiana, Iowa, Michigan, and Wisconsin, there were 1,126,610 useable observations (cow lactations) in which 335,711 culling events and 790,899 nonevents occurred. The estimation had an R^2 of 0.28. The model was able to successfully classify 79.5% of the Upper Midwest culling events and nonevents.

To calculate the marginal effects of the independent variables on the probability of a cull, the model was designed to provide a culling probability for a baseline situation. The baseline situation for the Upper Midwest estimation was a first-lactation Holstein cow calving in Indiana in the spring of 1995. The farm from which this representative Upper Midwest cow came was equal in size to the sample average herd size of 193 cows and had not undergone an expansion before or during the 1995 through 1999 period. The representative farm had

a current year heifer ratio that was equal to the sample average of 0.50. For the baseline Upper Midwest situation, there was a 26.1% chance that a first-lactation, average-producing Holstein cow would be culled during or at the termination of the first lactation on that particular farm in Indiana. The marginal effects that are reported below should be interpreted as the change in probability of a culling when that factor changes relative to the baseline cow all other factors held constant.

Using data from Northeast DHIA dairy farms in Maine, New Hampshire, New York, Pennsylvania, and Vermont, there were 225,987 culling events and 106,339 culling nonevents that took place. The probit model correctly predicted 79.9% of the cull decisions. The estimation had a R^2 of 0.28. The baseline situation for the Northeast estimation was a first lactation Holstein cow calving on a particular farm in Vermont in the spring of 1995. The farm from which this representative cow came was equal in size to the sample average herd size of 200 cows and had not undergone an expansion before or during the 1995 through 1999 period. The representative farm had a current year heifer ratio that was equal to the sample average of 0.48. For the baseline Northeast farm situation, there was a 36.8% chance

that a first-lactation, average-producing Holstein cow would be culled during or at the termination of the first lactation on a particular farm in Vermont.

RESULTS AND DISCUSSION

Culling Statistics

Across all 10 states over the 7-yr period, the average culling rate including cattle sold for dairy was 35.1%. When cows "sold for dairy" were removed from the DHIA culling records, the average culling rate for the 10 states during the 1993–1999 period of 31.6% was closer to the estimated optimal culling rates.

Northeast state herds had average cull rates ranging from 29 to 31% (Table 2). This average was lower than Upper Midwest region herds, which averaged 33 to 35%. Consistent with results of Smith et al. (2000), average annual culling rate increased with rolling herd average milk production. The average annual culling rate reached a plateau for herds producing more than 9,545 kg of milk at just over 32%. Average culling rate increased with herd size. Farms with a herd size of less than 150 cows had an average annual culling rate of 31.4%. The largest size group, herds with more than 600 cows, had the highest average culling rate of 36.8%.

Table 3 displays the percentage of culled cattle removed for particular reasons by state. The most common reasons for culling across all 10 states were "injury or other", reproduction problems, low production, mastitis, and mortality. These patterns were similar when examined by state. "Reproduction" and "injury or other" were the first and second most common reasons for culls in every state with the exception of Michigan, where production was the most common reason for culling. "Injury or other" was especially common in New York; "Sold for dairy" was the most common in Wisconsin.

Examining culling reason by herd size revealed that the primary reason for cattle being culled on farms with less than 300 cows was injury, with reproduction being the second most common reason (Table 4). Injury culls decreased as herd size increased, but the largest herds still had injury as the most common reason for culling. Larger herds experienced relatively more feet and leg problems as well as mortalities. In general, the lactation-specific total culling rate, health culling rate, and the mortality rate increased through the 10th lactation (Table 5). This pattern was essentially unchanged when sorted by breed, herd size, and milk production.

Cull rates by month were bimodal occurring most frequently at the beginning or end of lactation. The majority of cattle that died during a lactation did so in early lactation. Forty-two percent of the cattle that died did so within the first 60 d of the lactation. The majority of cattle culled due to health reasons were culled at the

Table 2. Average culling rates (%) with SD by year, state, milk production level, and herd size

	Average culling rate including "sold for dairy"		Average culling rate without "sold for dairy"	
	% ¹	SD	%	SD
Year				
1993	36.9	17.4	33.0	12.5
1994	34.8	16.6	31.2	11.9
1995	33.9	16.8	30.2	12.1
1996	33.1	16.5	30.0	12.1
1997	34.7	18.2	31.4	14.0
1998	34.9	15.6	31.9	12.3
1999	35.4	17.4	31.6	12.5
Northeast region				
New Hampshire	33.9	19.5	29.1	12.6
Vermont	32.6	16.6	29.1	11.4
Maine	36.3	22.8	31.4	15.8
New York	33.5	16.2	30.3	12.0
Pennsylvania	32.9	13.3	30.5	11.4
Upper Midwest region				
Indiana	38.9	21.3	33.2	13.9
Illinois	33.6	12.7	33.6	12.7
Michigan	37.7	15.4	35.1	12.7
Wisconsin	38.2	40.4	34.8	38.6
Iowa	37.9	26.3	34.9	24.8
Breed				
Holstein	34.8	17.2	31.9	14.2
Jersey	33.0	22.1	27.2	15.3
Brown Swiss	38.0	57.0	30.9	53.9
Guernsey	45.3	30.1	42.0	23.2
Ayrshire	37.0	24.3	29.6	17.9
Milking Shorthorn	36.5	26.7	26.7	13.1
Milk production level (RHA ²)				
≤8,182 kg	34.6	23.1	30.8	19.0
8,183 to 9,545 kg	34.8	16.4	31.9	13.6
9,546 to 10,909 kg	35.5	15.9	32.2	9.8
10,910 to 12,272 kg	37.2	19.2	32.3	11.7
≥12,273 kg	40.9	22.7	32.2	13.6
Herd size				
<150 cows	35.0	20.1	31.4	16.2
150 to 300 cows	35.1	10.9	33.4	9.2
301 to 450 cows	35.6	11.3	34.0	8.5
451 to 600 cows	35.5	8.6	34.2	8.4
>601 cows	38.3	15.8	36.8	14.3

¹These averages are across all states by year, all years for the states, and both years and states for the breed, production, and herd size categories.

²RHA = Rolling herd average milk production.

end of lactation and over one-third of the cattle culled for health reasons were removed in lactation month 11 or beyond. Natzge (2002) reported that most cattle are culled during the first 20-d period following the first 21 d after calving. The within-lactation culling pattern was determined for nondeath health culls and mortalities.

Culling Probability Estimation Results

The data set in this study was large and the standard errors were small resulting in significant effects of many independent variables. Statistical significance does not necessarily translate to practical, economic

Table 3. Percentage of cows culled by reason for culling across states for DHI herds in 10 states

Culling reason	All states	NH	VT	ME	NY	PA	IN	IL	MI	WI	IA
Sold for dairy	7.7	8.6	8.7	8.1	6.0	6.7	10.5	8.6	6.9	12.7	7.8
Production	12.8	8.4	14.5	9.4	6.0	18.8	16.7	10.0	19.7	9.5	11.8
Reproduction	18.9	20.9	19.3	18.9	16.1	21.9	22.4	22.4	17.6	15.0	18.2
Injury/other	26.9	25.7	23.9	31.1	43.1	20.0	18.3	18.3	16.6	28.1	20.1
Died	10.6	11.5	7.9	10.6	10.6	8.4	10.6	11.5	14.3	9.6	12.6
Mastitis	12.1	16.0	14.1	12.0	9.9	14.2	13.6	12.7	10.3	8.6	13.9
Feet and legs	4.4	4.5	6.5	4.2	3.7	5.5	4.8	3.7	3.7	3.4	2.7
Disease	3.0	2.8	2.2	3.1	2.9	2.8	1.7	4.3	3.9	2.6	4.4
Udder	3.6	1.8	2.9	2.6	1.6	1.8	1.7	8.4	7.0	10.4	8.5
Health culls as a percentage of all culls ¹	79.5	83.1	76.8	82.5	88.0	74.5	72.9	81.4	73.4	77.8	80.4

¹Health culls include those due to udder and mastitis problems, lameness and injury, disease, and reproduction problems but not death.

significance and the results must be interpreted with care. Managers and advisers must consider what can be changed, what the costs and resource use will be, and what the potential benefit could be. A small percentage increase in risk of culling may be economically significant in a management sense, if a quick and inexpensive correction is available. The results presented here provide benchmarks and guidelines for producers.

Table 6 displays the coefficient estimate results for the culling probability model estimated with data from the Upper Midwest region. Table 7 shows the same estimation estimated with data from the Northeast region. As discussed above, the marginal effects should be interpreted as the change in probability of a culling when that factor changes relative to the baseline cow all other factors held constant.

Calving season variables played a significant role in contributing to the likelihood of a cow being culled. As compared with the spring calving season, calving in summer or fall decreased the likelihood of a cow being culled in both regions. Given these results, if a manager was only interested in culling rate reduction, he might

prioritize the breeding program to have proportionally more cattle calve in fall followed respectively by summer and then spring. Other factors, such as milk and input price seasonal movements should be considered before engaging in such calving scheduling. Because proportionally more cattle are culled in winter and spring, producers may consider synchronizing first-lactation cow calving to counterbalance the increased culling likelihood for winter- and spring-calving cattle. Climatic differences characterizing season (spring, summer, winter, and fall) affect cow health, milk production level, feed availability, milk price, and thus, profitability. Delorenzo et al. (1992) found that seasonal variations in milk production, conception, and milk price affected the profit-maximizing replacement decisions of Florida herds. For example, a cow that calves in late spring, enters peak milk production, and is bred during the hottest part of the year may not achieve as high peak milk production or breed back as quickly as its herdmates that calve in other seasons.

Lactation number captured cow age, whereas lactation squared was included to capture the potential that

Table 4. Percentage of cows culled by reason for culling across herd size groups for DHI herds in 10 states¹

Reason	Herd size (cows)				
	0 to 150	151 to 300	301 to 450	451 to 600	601+
Sold for dairy	8.3	5.0	4.3	3.4	6.5
Low production	12.8	12.7	12.9	13.6	13.4
Reproduction	19.5	18.1	16.9	15.7	13.4
Injury/other	27.4	25.8	24.4	22.9	23.3
Died	9.7	13.1	14.4	14.5	16.4
Mastitis	11.7	13.3	14.4	14.7	13.4
Feet and legs	3.6	7.0	7.2	8.7	8.2
Disease	2.8	3.4	4.2	5.0	3.5
Udder	4.1	1.6	1.4	1.6	1.9
Health culls as a percentage of all culls ²	78.9	82.3	82.8	83.1	80.0

¹The 10 states with DHI records analyzed include Illinois, Indiana, Iowa, Michigan, Maine, New Hampshire, New York, Pennsylvania, Vermont, and Wisconsin.

²Health culls include those due to udder and mastitis problems, lameness and injury, disease, and reproduction problems but not death.

Table 5. Percentage of milking and dry cows culled, percentage of cows culled for health reasons, and mortality rate by lactation for DHI herds in 10 states¹

Lactation	All culls ²	Health cull rate ³	Mortality rate
1	17.9	13.1	1.9
2	31.3	23.2	3.4
3	37.3	28.0	4.5
4	42.9	32.5	5.4
5	47.3	35.9	6.0
6	51.1	39.0	6.3
7	54.4	41.6	6.6
8	57.2	43.8	6.6
9	60.2	46.3	6.9
10+	61.8	46.3	7.5

¹The 10 states with DHI records analyzed include Illinois, Indiana, Iowa, Michigan, Maine, New Hampshire, New York, Pennsylvania, Vermont, and Wisconsin.

²Includes all culls except those associated with cattle being sold to other farms for dairy purposes.

³Health culls include those due to udder and mastitis problems, lameness and injury, disease, and reproduction problems but not death.

the likelihood of being culled may have increased at a decreasing rate. In this study, each lactation subsequent to the first increased the probability of a culling more than 20% in the Northeast region and more than 30% in the Upper Midwest region. This increase in likelihood occurred at a decreasing rate as the lactation number was positive, whereas lactation squared was negative. Past research has shown that the incidence of culling increases with age. Dutch data used by van Arendonk and Dijkhuizen (1986) confirmed that the probability of an animal being culled due to health reasons (injury, disease, SCC, and reproduction) increased with age.

The herd production level of Dutch dairy farms (van Arendonk and Dijkhuizen, 1986) and United Kingdom dairy herds (Stott, 1994) did not affect the optimal cow longevity and culling rate. Rogers et al. (1988) found that larger milk yields supported only slightly higher culling rates for dairy farms in the United States. Weigel et al. (2003), however, reported a positive correlation between involuntary culling of high-producing cows, defined as cattle within the top 20% of their herd in terms of milk production. Based on these past models, the relative productivity of an individual cow compared with its herd mates should affect the probability of whether that cow is culled. Because US milk producers are paid based on milk components, differences in fluid milk production, butterfat production, and milk protein production were utilized to examine milk production effects. The 305ME milk, fat, and protein are production measurements that standardize production per cow so that the values represent the production as if all of the cattle were the same age, from the same

location, milked twice a day, and had calved during the same season (DRMS, 1999).

As expected, the difference in milk production between a cow and its herd mates significantly affected the probability of a cow being culled. A cow that produced one additional hundredweight more than the average 305ME milk yield was 1.7% less likely to be culled than the average producing cow in the Upper Midwest region and about 0.5% less likely to be culled in the Northeast region. Cattle whose average difference in 305ME protein was 0.5 kg higher than the average producing cow were less likely to be culled in both regions. It is logical that cattle producing more milk and more protein than their herd mates are more profitable, all else being equal, and should remain in the herd longer than less profitable cattle. Counter to expectations, higher fat production increased the likelihood of a cow being culled, but the effect was small. This may result from managers trying to emphasize milk and protein production when making decisions. Prior to multiple component pricing, dairy farmers primarily were paid on fluid milk, butterfat, and SCC. Currently farmers are paid for fluid, butterfat, milk protein, SNF, and SCC. Thus, managers may now place more emphasis on components other than butterfat.

It was expected that more persistent cows have an increased probability of remaining in the herd as the less persistent cow will be less likely to cover variable costs in late lactation. Cows that were one persistency percentage higher than the average producing cow were about 2% less likely to be culled in both regions. Lactational persistency percentage is a DHI measure that compares the persistency of a cow with those of her herd mates. Dijkhuizen et al. (1985) determined that it became more advantageous to retain a long-open cow and continue breeding the animal as persistency increased.

Cattle with higher SCC score than the average were 1% more likely to be culled than the cow represented by the baseline situation. This is not surprising because high SCC scores decrease both the milk price per hundredweight as well as the amount of milk produced per cow (DRMS, 1999). In the United States, milk processors pay producers a premium for low SCC and discount prices for high SCC. As an individual cow SCC score increases relative to the rest of the herd, that cow becomes less profitable due to treatment costs, lost production, and quality discounts.

The number of services per conception in the previous lactation was associated with a decreased likelihood of a cull in the Upper Midwest (although the effect was small) region, but increased the likelihood of a cull in the Northeast region. Reproduction was the primary reason for culling cows (Bascom and Young, 1998). Cas-

Table 6. Estimates and marginal effects of explanatory variables on the likelihood of a cow being culled in Upper Midwest herds

Parameter	Estimate	SE	$P > t $	Marginal effect (%)
Intercept	2.308	0.1595	<0.001	
1996	0.161	0.0304	<0.001	21.02
1997	0.308	0.0087	<0.001	41.67
1998	0.224	0.0071	<0.001	29.71
1999	0.155	0.0067	<0.001	20.18
Winter calve	-0.014	0.0070	0.049	-1.70
Summer calve	-0.095	0.0065	<0.001	-11.48
Fall calve	-0.158	0.0078	<0.001	-18.66
Lactation	0.236	0.0029	<0.001	31.42
Lactation squared	-0.014	0.0004	<0.001	-1.77
Milk difference	-0.004	0.0001	<0.001	-1.70
Fat difference	0.0003	1.5×10^{-5}	<0.001	0.04
Protein difference	-0.0013	3.5×10^{-5}	<0.001	-0.16
Persistency difference	-0.0168	4.5×10^{-5}	<0.001	-2.08
SCC difference	0.0692	0.0009	<0.001	8.81
Services/conception difference	0.0268	0.0011	<0.001	-0.64
Guernsey	0.1768	0.0364	<0.001	23.20
Jersey	-0.1619	0.0208	<0.001	-19.08
Other colored breed	-0.0480	0.0140	<0.001	-5.88
Illinois herd	-0.5684	0.1657	<0.001	-56.57
Michigan herd	0.2110	0.1108	0.057	27.93
Wisconsin herd	-0.8340	0.1828	<0.001	-73.12
Iowa herd	-0.3448	0.1285	0.007	-37.83
Registered herd	-0.0011	0.0132	0.934	-0.13
Herd size	0.0004	0.0001	<0.001	0.05
Herd size squared	-1.47×10^{-7}	1.33×10^{-8}	<0.001	0.00
Small expansion	-0.0983	0.0574	0.087	-11.85
Small expansion year 2	-0.0537	0.0567	0.343	-6.58
Small expansion year 3	-0.1382	0.0579	0.017	-16.42
Small expansion year 4	-0.0696	0.0573	0.224	-8.47
Small expansion year 5	-0.0955	0.0575	0.097	-11.52
Large expansion	-0.1216	0.1084	0.262	-14.54
Large expansion year 2	-0.2493	0.1066	0.019	-30.32
Large expansion year 3	-0.0171	0.1040	0.870	-2.11
Large expansion year 4	-0.0454	0.1042	0.663	-5.57
Large expansion year 5	0.0178	0.1003	0.076	23.41
Heifer ratio current	0.0228	0.0117	0.051	0.03
Heifer ratio lagged	-0.0013	0.0073	0.854	0.00
MFR ¹ 1	-0.0336	0.0076	<0.001	-4.13
MFR 2	-0.0131	0.0079	0.098	-1.63
MFR 3	-0.0034	0.0076	0.661	-0.41
MFR 4	-0.0595	0.0076	<0.001	-7.27
MFR 5	-0.0230	0.0076	0.003	-2.85
MFR 6	-0.0723	0.0070	<0.001	-8.80
MFR 7	0.0166	0.0039	<0.001	2.08
MFR 8	-0.0038	0.0039	<0.001	-0.47
MFR 9	-0.0087	0.0038	0.324	-1.24
MFR 10	-0.0117	0.0039	0.021	-1.46
MFR 11	-0.0093	0.0038	0.003	-1.15
MFR 12	0.0185	0.0036	0.013	2.32
CRR ² 1	0.1150	0.1328	<0.001	0.15
CRR 2	0.1019	0.1694	0.386	0.13
CRR 3	-0.8020	0.1704	0.548	-1.00
CRR 4	-0.9962	0.1766	<0.001	-1.24
CRR 5	-0.6836	0.1717	<0.001	-0.85
CRR 6	-1.3021	0.1712	<0.001	-1.61
CRR 7	-0.1880	0.1723	0.275	-0.23
CRR 8	0.5058	0.1794	0.005	0.63
CRR 9	-1.2826	0.1906	<0.001	-1.59
CRR 10	-0.5314	0.1960	0.007	-0.66
CRR 11	0.3371	0.2012	0.094	0.42
CRR 12	1.0774	0.1548	<0.001	1.35
R ²	0.28			
Percentage correct predictions	79.5			

¹MFR = Milk-to-feed price ratio for lactation month s.²CRR = Cull cow-to-replacement heifer price ratio for month s.

Table 7. Estimates and marginal effects of explanatory variables on the likelihood of a cow being culled in Northeast herds

Parameter	Estimate	SE	$P > t $	Marginal effect (%)
Intercept	-0.2236	0.3305	0.499	
1996	0.1536	0.0113	<0.001	16.09
1997	0.1733	0.0101	<0.001	18.19
1998	0.2980	0.0074	<0.001	31.64
1999	0.2098	0.0062	<0.001	22.11
Winter calve	0.0489	0.0082	<0.001	5.04
Summer calve	-0.0627	0.0078	<0.001	-6.35
Fall calve	-0.0781	0.0095	<0.001	-7.89
Lactation	0.1996	0.0026	<0.001	21.01
Lactation squared	-0.0069	0.0003	<0.001	-0.63
Milk difference	-0.0045	0.0001	<0.001	-0.46
Fat difference	0.0002	1.5×10^{-5}	<0.001	0.02
Protein difference	-0.0011	3.2×10^{-5}	<0.001	-0.11
Persistence difference	-0.0171	4.7×10^{-5}	<0.001	-1.75
SCC difference	0.0756	0.0009	<0.001	7.84
Services/conception difference	0.0376	0.0010	<0.001	3.88
Guernsey	0.3085	0.0446	<0.001	32.78
Jersey	-0.1125	0.0163	<0.001	-11.29
Other colored breed	-0.0556	0.0176	0.002	-5.65
New Hampshire herd	0.0513	0.3219	0.874	4.49
Maine herd	0.0435	0.3641	0.905	5.29
New York herd	0.4011	0.3309	0.226	42.82
Pennsylvania herd	0.7837	0.3237	0.016	82.78
Registered herd	0.0146	0.0147	0.321	1.50
Herd size	0.0013	0.0001	<0.001	0.13
Herd size squared	-8.56×10^{-7}	5.28×10^{-8}	<0.001	0.00
Small expansion	-0.2969	0.0687	<0.001	-28.54
Small expansion year 2	-0.2328	0.0677	<0.001	-22.74
Small expansion year 3	-0.2078	0.0680	0.002	-20.42
Small expansion year 4	-0.0769	0.0667	0.249	-7.77
Small expansion year 5	-0.1826	0.0676	0.007	-18.05
Large expansion	-0.3313	0.0978	<0.001	-31.56
Large expansion year 2	0.0031	0.0924	0.974	0.31
Large expansion year 3	-0.2456	0.0984	0.013	-23.92
Large expansion year 4	-0.0732	0.0930	0.431	-7.41
Large expansion year 5	-0.0670	0.0933	0.473	-6.79
Heifer proportion current	0.0145	0.0083	0.079	0.01
Heifer proportion lagged	-0.0001	0.0056	0.989	0.00
MFR ¹ 1	0.0785	0.0086	<0.001	8.14
MFR 2	-0.0514	0.0106	<0.001	-5.22
MFR 3	-0.0393	0.0107	<0.001	-4.00
MFR 4	0.0046	0.0119	0.698	0.47
MFR 5	-0.0309	0.0118	0.009	-3.12
MFR 6	-0.0461	0.0120	<0.001	-4.68
MFR 7	-0.0055	0.0125	0.659	-0.57
MFR 8	-0.0152	0.0115	0.188	-1.56
MFR 9	-0.0189	0.0117	0.108	-1.93
MFR 10	-0.0659	0.0114	<0.001	-6.67
MFR 11	0.0249	0.0111	0.024	2.56
MFR 12	0.0506	0.0092	<0.001	5.23
CRR ² 1	0.4492	0.1610	0.005	0.46
CRR 2	0.3015	0.2211	0.174	0.31
CRR 3	0.5300	0.2395	0.027	0.54
CRR 4	0.1137	0.2252	0.614	0.11
CRR 5	-0.0811	0.2126	0.703	2.64
CRR 6	-0.0449	0.2193	0.838	-0.05
CRR 7	-1.5193	0.2178	<0.001	-1.55
CRR 8	0.0622	0.2049	0.761	0.06
CRR 9	-0.5102	0.2043	0.013	-0.52
CRR 10	0.5705	0.2137	0.008	0.58
CRR 11	0.5625	0.2418	0.020	0.58
CRR 12	1.2309	0.1741	<0.001	1.26
R ²	0.28			
Percentage correct predictions	79.9			

¹MFR = Milk-to-feed price ratio for lactation month s.²CRR = Cull cow-to-replacement heifer price ratio for month s.

sell (2002) noted that cows that conceive more readily than their herdmates remain in the herd longer. Difference in services per conception from the prior lactation between a cow and her herdmates in the same lactation was used to represent individual cow reproductive efficiency. van Arendonk and Dijkhuizen (1985) hypothesized that a cow that had difficulty conceiving in the previous lactation may be viewed more critically during the present lactation.

The average first-lactation cow in Illinois, Iowa, and Wisconsin was less likely to be culled than similar cattle in Indiana, whereas a Michigan cow was more likely to be culled. The state differences were dramatic in the Upper Midwest region suggesting that infrastructure, economic, climatic, and geographic influences captured by the state variables were significant in explaining the likelihood of a cull. In contrast to the Upper Midwest results, the probability of a culling did not differ significantly across Northeast region states from the base Vermont case with the exception of Pennsylvania (where a culling was much more likely).

The effect of herd size on the likelihood of a cow being culled was significant, but small on a per-cow basis. Culling rates for herds with 600 or more cows were larger than the culling rates for herds with fewer than 100 cows, but that the difference was only 2% (Quaiffe, 2002). Weigel et al. (2003) found that high-producing cattle were more likely culled in larger herds due to herd health problems than in smaller herds.

The effect of expanding on the likelihood of culling was mixed. For the smaller category of expansions (an increase in herd size of less than or equal to 300%), the effect of the initial expansion year on the probability of a culling was negative, but insignificant for several years in the Upper Midwest. The time pattern for small expansions in the Northeast region was similar, but consistently more significant. For herds that had a large increase in herd size (a herd size increase of more than 300%), the first large expansion year was negatively correlated with culling likelihood, but often insignificant in both regions. Dairy farm expansion has been cited as a contributing factor increasing culling rates and high replacement heifer prices (Hoard's Dairyman, 2003). Hadley (2001) found that dairy farms in Wisconsin and Michigan actually experienced a decrease in culling rates the first 2 yr of an expansion. Weigel et al. (2003) reported that expansion dairies were more likely to involuntarily cull high-producing cattle due to health problems, but less likely to cull low-producing cattle.

The heifer proportion from last year (i.e., lagged 1 yr) was included. For herds in both regions, the effect of the current year heifer ratio on the likelihood of a cow being culled was positive, but quite small. Thus,

there was evidence suggesting that the number of heifers available had a small influence on culling rates. A manager may allow heifers to enter the herd through increased culling, selling the surplus heifers, or some combination of those actions. Radke and Lloyd (2000) asserted that many producers adjusted culling rates to accommodate the number of heifers available. If managers cull heavier to accommodate surplus heifers, this indicates that they believe it is more profitable to have the heifer enter the herd than to sell them as replacement heifers to other farms.

The milk-to-feed price ratio can serve as an important indicator of milk production profitability. As an increasing milk-to-feed price ratio represents an easier ability to cover variable costs, the marginal effect of each lactation month's milk price ratio was expected to correlate negatively with the likelihood of a cow being culled. Renkema and Stelwagen (1979) concluded that the effects of milk price on optimal replacement decisions were small for Dutch dairy farms. Later work by Rogers et al. (1988) concluded that the same was true for US dairy farms. Bauer et al. (1993) found that the optimal terminal lactation for Alberta herds was not affected by changes in milk price. Jones (2001) found that the optimal longevity for Wisconsin dairy cows changed with milk price, but only in conjunction with opposite changes in replacement heifer prices. During periods of low milk price a producer may cull an animal without a replacement if the current financial return does not exceed the variable costs associated with production. This was the case in the majority of lagged price ratios by month in both regions.

It was expected that the marginal effect of the cull cow price to replacement heifer price ratio would be positively correlated with the likelihood of a cow being culled. As with the milk-to-feed prices, the cull-cow-to-replacement-heifer price ratio marginal effects were mixed being mostly positively correlated in the Northeast region with many of the parameters insignificant in both regions. Renkema and Stelwagen (1979) found that cull cow prices had a small effect on optimal culling policies for Dutch herds. Rogers et al. (1988) showed that replacement heifer prices had a large effect on culling decisions for US dairy farm managers. Bauer et al. (1993) estimated that changes in replacement heifer prices or a large decrease in cull cow prices should have large effects on the optimal terminal lactation for Alberta producers. Stott (1994) found that the optimal herd life for cows in the United Kingdom was sensitive to changes in replacement heifer prices. As the price farmers receive for selling cull cattle increases relative to replacement heifer price, it becomes less expensive from a capital investment perspective to cull and replace a given animal.

CONCLUSIONS

Replacement heifer costs are one of the largest costs for dairy farmers. Thus, culling practices should be scrutinized to control costs and achieve profitable milk production. The culling decision is an economic comparison of the current cow to the potential replacement. Culling decisions are dynamic and must be made considering future implications of current decisions. A first step in understanding both the decision process and consequences is to understand what the culling patterns are and what factors contribute to dairy cow culling.

The largest marginal effects on likelihood of a cull were those related to lactation (cow age) and season. Summer and fall calving was associated with a smaller likelihood of a cull than spring calving. The milk market generally supplies a higher price in the fall months that encourages peak milk production in that season. Lower milk production and milk quality significantly increased the likelihood of culling the cow, although the effects were marginally small. Somatic cell count difference was the largest marginal effect and highlighted the continued importance of herd health programs. Expansion had a negative influence on the likelihood of a culling in the early years following the expansion. These results reflect the increased pressure to manage cash flow by keeping facilities at or near capacity following an expansion.

The study results are useful in describing patterns of culling and relating them to cow, herd, geographic, and time variables and can act as a benchmark for producers. Explaining discrepancies between farm management behavior and optimal culling decisions is an issue for future research.

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