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Dairy Farm Culling Decisions: How do milk price, heifer price and carcass price effect optimal replacement decisions?

Merzungsentscheid auf Betriebsebene: wie beeinflussen Milchpreis, Färsenpreis und Schlachtpreis die optimale Ersatzrate?

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Summary

This study investigates the optimal replacement policy for dairy herds, considering changes in price parameters and their impact on the percentage of cows with a negative Cow Value. The Cow Value calculates the value of a cow and its replacement based on a Markov Chain model. Simulations explore how milk, heifer, and carcass prices influence replacement decisions in 181 Swiss herds of different breeds. Results indicate that external factors significantly affect optimal replacement rates, with lower milk prices and lower replacement costs favoring more frequent replacement. Brown Swiss and Holstein have higher optimal replacement rates compared to Simmental, Swiss Fleckvieh and Original Brown. Additionally, average milk yield plays a crucial role, suggesting that farms with high yielding cows should consider lower replacement rates to increase revenue.

Keywords: dairy cow, optimal replacement rate, bio economic model, herd management, culling

Zusammenfassung

Diese Studie untersucht die optimale Bestandsergänzungsrate für Milchviehherden und berücksichtigt dabei den Einfluss verschiedener Preisparameter. Die Berechnung erfolgt auf Basis eines Markov-Kettenmodells anhand des Kuheigenwerts, welcher den Wert einer Kuh und ihrer Ersatzfärse berücksichtigt. Mithilfe von Simulationen wird untersucht, wie Milch-, Färsen- und Schlachtpreise die Ersatzentscheidungen in 181 Schweizer Herden verschiedener Rassen beeinflussen. Die Ergebnisse deuten darauf hin, dass externe Faktoren die optimale Austauschrate signifikant beeinflussen, wobei tiefere Milchpreise und niedrigere Ersatzkosten einen verstärkten Austausch begünstigen. Rasseunterschiede sind erkennbar, wobei Brown Swiss und Holstein im Vergleich zu Simmental, Swiss Fleckvieh und Original Brown höhere optimale Austauschraten aufweisen. Darüber hinaus spielt die durchschnittliche Milchleistung eine entscheidende Rolle, was darauf hindeutet, dass Betriebe mit hochleistenden Kühen durch eine niedrigere Ersatzrate den wirtschaftlichen Ertrag steigern könnten.

Schlagworte: Milchvieh, optimale Bestandsergänzungsrate, bioökonomisches Modell, Herdenmanagement, Merzung

1 Introduction

The replacement of dairy cows and its implications on the length of the productive life are subject of extensive discussions reaching far beyond the dairy industry. These discussions include considerations ranging from economic viability of farms to environmental impacts posed by dairy cattle, animal welfare concerns raised by the public, and the regulatory framework influenced by subsidies and laws (De Vries, 2020; Heikkila et al., 2008; Bergeå et al., 2016; De Vries and Marcondes, 2020; Owusu-Sekyere et al., 2023; Kulkarni et al., 2021). An extended productive life is considered potentially beneficial in many aspects, offering a mutually beneficial outcome for all stakeholders (Dallago et al., 2021; Vredenberg et al., 2021; Schuster et al., 2020). Studies suggest that despite significant recent increases in the breeding trait longevity, the span of productive life have only marginally increased (De Vries and Marcondes, 2020; Bergeå et al., 2016). On farm replacement decisions are often driven by fertility issues or claw and udder diseases, but in the following study we are focusing on the market impact on dairy cow replacement.

The lack of improvement of longevity could possibly be attributed to economic considerations and to production systems that favor shorter lifespans. For certain farms, income from dairy production might not increase due to extended longevity because of higher health costs (Vredenberg et al., 2021). Milk and carcass prices, and the cost of acquiring replacement heifers also have a significant influence on the replacement decisions of cows in a dairy herd (Arendonk, 1985; De Vries and Marcondes, 2020; Garcia, 2001). Low milk price encourages extended cow retention to minimize replacement costs, but only if accompanied by good health (Garcia, 2001). Milk yield peaks at the age-related performance maximum around the fourth lactation can lead to higher milk production at the farm although younger cows may have higher genetic potential (Groenendaal et al., 2004). The carcass price varies by breed, carcass weight, and age. Dual-purpose breeds often realize higher returns than dairy breeds (Bazzoli et al., 2014). If the replacement of a cow with a heifer leads to a net loss, the inclination is to retain the cow for a longer duration and replace it at a later stage. The magnitude of this net loss directly influences the economic motivation to extend longevity. Conversely, if the replacement process results in either no net loss or even yields a profit, the prospect of replacement becomes more appealing.

Swiss dairy farms show a very high level of diversity. The main factors that contribute to this diversity are small-scale production systems, different regions and feeding regimes as well as different breeds and herd sizes, additionally there is a very diverse cost-revenue structure across farms, these differences also facilitate very different replacement decisions (AGRIDEA, 2022, 2023).

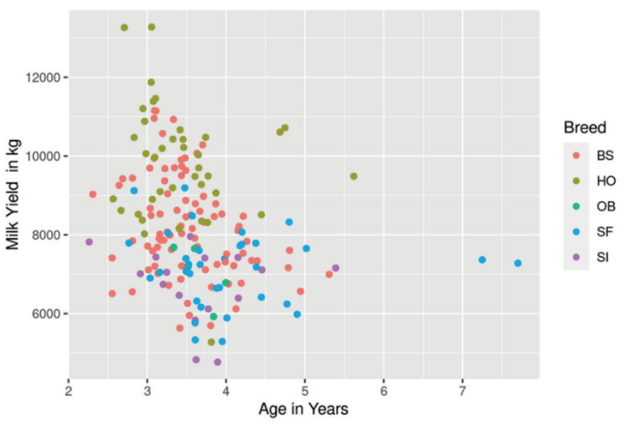
The on farm replacement decision is complicated as its financial implications are often not apparent (Vredenberg et al., 2021; De Vries and Marcondes, 2020). To help farmers with replacement decisions Cabrera (2012) and Kelleher et al. (2015) introduced tools based on Markov chain models, which assign every cow in the herd a monetary value. To accommodate the diversity of Swiss dairy farming a similar tool was developed by Schlebusch et al. (2024) introducing the Cow Value (CV). This tool predicts a monetary value (CV) in Swiss Francs (CHF) for each cow in the herd based on its projected lifespan and the expected average monthly revenue for that remaining lifespan. The CV tool uses a model containing a wide range of farm data, including prices for milk yield and more. In this study, we employ the CV tool in a simulation study to examine how variations in milk price, carcass price, and heifer prices can impact the optimal on-farm replacement strategy. We investigate how parameter changes impact the order of cows in a herd according to the CV. Such changes would subsequently affect the economically optimal replacement decisions. Furthermore, we analyze if and which farm characteristics influence the cow replacement rate as well as how the farms can react to the parameter alterations.

2 Materials and Methods

2.1 Data and configurable parameters

In order to assess the impact of different farm characteristics as well as different cost and price structures, the optimal replacement rate for all cows in 181 herds, including 86 Brown Swiss, 5 Original Brown, 40 Holstein, 16 Simmental, and 34 Swiss Fleckvieh herds with changing production parameters are calculated. The herds were selected to depict different farm types commonly present in Switzerland according to herd size, average age, and milk yield. In figure 1, the average age and the milk yield per standard lactation as well as the distribution of breeds of the herds is shown. The data was made available by the Arbeitsgemeinschaft Schweizerischer Rinderzüchter (ASR) and only farms with a least 15 cows were chosen. The farm level data includes individual cow milk yield, protein and fat contents, somatic cell count, lactation number, month in milk, pregnancy month, and breeding values for milk and aggregate genotype.

Figure 1 Average age and milk yield of 181 herds shown for the breeds Brown Swiss(BS), Holstein(HO), Original Brown(OB), Swiss Fleckvieh(SF) and Simmental(SI)



Source: Own compilation based on data from the Arbeitsgemeinschaft Schweizerischer Rinderzüchter, 2023.

Table 1 The parameters used to calculate different rankings

Parameter	Unit	Low		Medium		High
Milk Price	Fr./kg	0.5	0.6	0.7	0.8	0.9
Heifer Price	Fr./Heifer	3000	3250	3500	3750	4000
Carcass Price	Fr./kg	6	7	8	9	10

Sources: Own variation of prices based on price data of Agridea 2022; 2023.

Table 2 All prices and costs as well as other important information

	Variable	Value	Unit
Milk price payment scheme	Baseline protein	3.3	%
	Baseline fat	4	%
	Content payment protein	0.05	CHF/0.01%
	Content payment fat	0.04	CHF/0.01%
Costs	Veterinarian	17	CHF/Month
	Insemination	53	CHF/Insemination
	Feed price	0.35	Fr./kg
Replacement	Life weight cow	650	kg
	Carcass weight cow	325	kg

Sources: Agridea 2022; 2023.

The focus of this study lies on variable economic parameters in the model that are known to influence optimal replacement decisions like milk price, carcass prices for cows, and the cost of a replacement heifer (Arendonk, 1985; De Vries and Marcondes, 2020). Every parameter is split into 5 values – from low to high. These parameter values are based on common industry values like the label, the animal welfare standard, the processing and quality (Agridea 2022, 2023). Between all parameters and their respective prices, 125 different combinations are possible. The configurations are based on own variation of the prices based on the price data from Agridea 2022, 2023. Accordingly, 125 different optimal replacement rates are calculated for each herd.

2.2 Calculation of the optimal replacement rate based on the Cow Value model

The optimal replacement rate is determined by assessing the proportion of animals exhibiting a negative CV. The CV model employs the Markov Chain method to predict the expected lifespan of each cow in a herd. This predicted lifespan is then combined with a contribution margin for each cow, which is based on factors such as milk yield, milk price, and other relevant variables. Subsequently, the model compares the contribution margin of each cow in the herd with that of its potential replacement heifer, the difference between the two is the CV. A positive CV implies that it is economically advantageous to retain the cow. Conversely, a negative CV indicates that replacing the cow with a young heifer is a more optimal economic decision. For a more comprehensive understanding and additional references, please consult Schlebusch et al. (2024).

Default values for expenses, prices, and pertinent information are established based on industry-wide average benchmarks, as outlined in Table 2, the live and carcass weight are assumed to be the same over all breeds to ensure that differences between breeds aren't just based on different weights.

2.3 Analysis of the impact of prices and herd characteristics on the optimal replacement rate

In total we test 125 different configurations. One configuration consists of a combination of the parameters for milk price, heifer price and carcass price. We calculate the share of animals with a negative CV for each possible configuration for 181 herds. The share of animals with a negative CV is equivalent to the optimal replacement rate.

To quantify the dependence of the optimal replacement rate on different herd characteristics and price configurations we employ the mixed effects model. The model was implemented and estimated in R using the package "lmerTest" (R Core Team, 2024; Kuznetsova et al., 2017). Adapted from Bell and Jones (2015), it looks as follows:

Equation 1 $$Y_{\mathrm{hc}} = \beta_0 + \beta_1(x_{\mathrm{hc}} - \bar{x}_h) + \beta_2 z_{\mathrm{h}} + (u_{\mathrm{h}} + e_{\mathrm{hc}})$$

γ_{hc} is the share of cows to be replaced (in herd h with configuration c), β_0 is the intercept, β_1 contains the coefficients for the variables χ that differ between different configurations (i.e. for χ_{hc} minus the herd average $\overline{\chi_h}$), β_2 contains the coefficients for the configuration-independent herd characteristics z_h, u_h is the random-effect on the herd level and e_{hs} is the error term on the level of each single configuration (per herd). As described above, the variables χ changed per configuration are the milk price, the heifer price and the carcass price. Trying to bring the heifer and the carcass price to a similar scale in order to simplify the comparison between different coefficients, we multiplied the carcass price per kg with the weight of a carcass (325 kg, see Table 2). A list of all variables at herd level (z) is contained in Table 5 in the results section and is not listed here for the sake of brevity.

Deviating from Bell and Jones (2015), we dropped the term $\beta_3\ \overline{\chi}_h$ from the model because it does not differ between herds or configurations. Still, this model has advantages over a fixed effects model because it is able not only to capture the effect of configured prices χ, but simultaneously the effect of herd characteristics z that do not differ between different configurations. In addition, a standard OLS model should not be used in this setting as it is not able to differentiate between the farm and the configuration level.

3 Results

Table 3 provides an overview of the summary statistics of the rate of cows to be replaced across all herds and variants. The average rate of cows to be replaced is 14%, with a median of 7.4%. The first quartile is at 1.3% and the third at 21.1%. The replacement rate varies from a minimum of 0% to a maximum of 100%. Different breeds show variations in replacement rates. Holstein and Swiss Fleckvieh have similar values. The Brown Swiss breed has a higher average and median share of cows to be replaced than the other breeds. Simmental has lower values compared to the other breeds, with a mean of 10.89%.

For milk prices, the average replacement rate ranges from 13.72% to 14.63%, with medians between 5.56% and 9.09%. Lower milk prices result in greater variance, while higher prices reduce variance. Regarding heifer prices, as prices increase, the percentage of cows to be replaced decreases, along with variability. For carcass prices, low prices lead to fewer replacements, while higher prices increase the replacement rate.

In Table 4 the descriptive statistics for the herd variables are shown.

In Table 5, the coefficients from the random effects model are shown. The model demonstrates the effect of different parameters on the share of cows to be replaced. The effect sizes for the parameters milk price, heifer price, and carcass price (which were changed in 125 combinations for each herd) all show significant effects. The marginal R-squared of the model, that is the part of the variance explained by the fixed effects, is 0.56. Considering also the random effects, the explained variance amounts to 0.72.

Table 3 The summary of the share of cows to be replaced differentiated by Breed Brown Swiss (BS), Holstein (HO), Original Brown (OB), Swiss Fleckvieh (SF) and Simmental (SI), as well as milk price, carcass price and heifer price

		Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Summary Breed	ALL	0.00%	1.30%	7.41%	14.00%	21.05%	100.00%
	BS	0.00%	2.44%	9.52%	16.34%	24.14%	100.00%
	HOL	0.00%	1.12%	5.17%	11.49%	17.15%	95.45%
	OB	0.00%	0.00%	6.67%	12.12%	15.69%	93.75%
	SF	0.00%	0.00%	5.36%	12.77%	18.18%	100.00%
	SI	0.00%	0.00%	3.70%	10.89%	14.81%	95.83%
Summary milk price in CHF	0.5	0.00%	0.00%	5.56%	14.63%	20.90%	100.00%
	0.6	0.00%	0.00%	6.25%	14.01%	20.83%	100.00%
	0.7	0.00%	1.32%	7.41%	13.72%	20.83%	96.77%
	0.8	0.00%	2.11%	8.11%	13.74%	21.05%	93.55%
	0.9	0.00%	2.76%	9.09%	13.89%	21.21%	88.89%
Summary heifer price in CHF	3000	0.00%	8.00%	21.74%	26.61%	40.00%	100.00%
	3250	0.00%	3.85%	12.50%	18.53%	28.79%	96.77%
	3500	0.00%	1.52%	7.41%	12.20%	18.75%	88.89%
	3750	0.00%	0.00%	3.85%	7.76%	11.11%	88.89%
	4000	0.00%	0.00%	2.33%	4.90%	6.82%	66.67%
Summary carcass price in CHF	6	0.00%	0.00%	0.00%	3.37%	4.17%	55.56%
	7	0.00%	0.00%	3.03%	5.66%	8.11%	66.67%
	8	0.00%	2.00%	6.86%	10.63%	15.79%	88.89%
	9	0.00%	5.77%	14.63%	19.08%	28.57%	90.32%
	10	0.00%	14.29%	27.27%	31.26%	44.44%	100.00%

Source: own calculations based on the analyzed sample of Swiss farms, 2023.

Table 4 The descriptive statistics of the herd variables

Variable	1st Qu.	Median	3rd Qu.
Animal Count	27	36	53
Average Age	3.15	3.493	3.88
Share of animals in first and second lactation	41.94	50.65	58.82
Aggregate Genotype	1053	1084	1125
Breeding Value Milk	114.9	222.4	356.2
Milk Yield	7157	8198	9194
Protein Content	3.34	3.44	3.54
Fat Content	3.97	4.074	4.23
Somatic cell count	83590	100359	123802
Replacement rate	1.299	7.407	21.053

Source: own calculations based on the analyzed sample of Swiss farms, 2023.

Table 5 The regression on the cows to be replaced by different coefficients

	Estimate	Std. Error	t value	Pr(>|t|)	Sign
Intercept	1.26	18.30	0.07	0.945	
***x* variables from different configurations**					
Milk price (CHF·kg^{-1})	-1.75	0.44	-3.98	<0.001	***
Heifer price (CHF·heifer^{-1})	-0.02	0.00	-123.09	<0.001	***
Carcass price (CHF per 325 kg carcass)	0.02	0.00	157.15	<0.001	***
***z* variables describing the herd**					
Herd size (number of dairy cows)	0.03	0.01	3.10	0.002	**
Aggregate genotype (base 1000 points)	0.02	0.01	1.37	0.171	
Milk yield (kg·cow^{-1}·lactation^{-1})	-1.46	0.54	-2.70	0.008	**
Protein content (%)	-5.61	4.55	-1.23	0.220	
Fat content (%)	3.99	2.83	1.41	0.161	
Somatic cell count (100‘000 cells per kg milk)	8.32	1.77	4.71	<0.001	***
Holstein dummy	-2.65	1.81	-1.46	0.145	
Original brown dummy	-4.87	3.34	-1.46	0.147	
Swiss Fleckvieh dummy	-3.39	1.63	-2.08	0.039	*
Simmentaler dummy	-3.67	2.25	-1.63	0.104	

* Significant on the 0.05 level
** Significant on the 0.01 level
*** Significant on the 0.001 level

Source: own calculations based on the analyzed sample of Swiss farms, 2023.

An increase of the milk price by 1 CHF per kg of milk leads to an 1.75% decrease in the number of cows to be replaced. The heifer price has a negative effect of -0.02% per 1 CHF increase in heifer price. The effect of the carcass price is positive; a price increase of 1 CHF per carcass leads to a 0.02% increase in replaced cows. The average milk yield shows a significant effect on the share of cows to be replaced, with an increase of 1000 kg milk per cow and lactation resulting in a decrease of -1.46%. The somatic cell count has a significant positive effect, and an increase of 100‘000 cells would lead to an 8.32% increase in the replacement rate. With a difference of 3.39% Simmentaler Fleckvieh shows a significantly lower optimal replacement rate compared to the baseline given by the Brown Swiss breed. All other effects were not significant.

4 Discussion

Focusing on economics, our results suggest that the prices for milk, heifers and cow carcasses play an important role in the replacement decision which is in accordance with existing literature (Arendonk, 1985; De Vries and Marcondes, 2020; De Vries, 2020; Vredenberg et al., 2021). With a high heifer price, a low replacement strategy is optimal, while the opposite holds true with a high carcass price. A high milk price leads to a decrease of replaced cows, because also less productive cows stay in the herd.

In contrast to the findings of Vredenberg et al. (2021) we found that the herd size had a small significant positive effect. According to our results, herds with a high average aggregate genotype do not have significantly higher replacement rates. Because we did not measure the difference between the replacement heifer and the herd, this does not necessarily contradict the literature stating that the replacement rate should be higher, the higher the genetical improvement by the assumed replacement heifer is (Groenendaal et al., 2004; Alvåsen et al., 2018). Our result stating that an increased somatic cell count is associated with a higher replacement rate is supported by earlier studies (Rilanto et al., 2020; Kulkarni et al., 2021). Udder health issues being associated with a high cell count are a likely explanation for this result. A lower milk yield is generally associated with a higher replacement rate (Rilanto et al., 2020; Kulkarni et al., 2021; Owusu-Sekyere et al., 2023) which is also confirmed by the results in this study.

The average milk yield has a notable influence on the proportion of cows to be replaced. A higher average milk yield corresponds to a lower number of cows to be replaced, resulting in reduced replacement rates. Consequently, farms with a high average milk yield should consider replacing fewer cows to achieve an economically optimal state. This approach allows them to harness the age-related milk potential of older cows. In contrast to milk yield, neither the average effective protein nor fat content in a herd significantly impacts the percentage of cows to be replaced even though they can influence the price of milk. Unlike milk yield, both protein and fat content do not significantly increase with age. Consequently, regarding protein and fat yield, older cows do not hold a notable advantage over younger replacement heifers.

Notably, breed differences are evident, with Brown Swiss seeming to be more affected by differences in parameterization, while Original Brown, Simmental, and Swiss Fleckvieh, and to a lesser extent Holstein show lower variability in the percentage of cows to be replaced. This suggests that the economics of dairy production with cattle from the Brown Swiss breed respond more promptly to changing production parameters.

As regards the causality between the chosen and variables, it must be admitted that we cannot be sure whether the causality is only unidirectional (from to), or whether some explanatory variables in our model are also influenced by the replacement rate . For example, a high milk yield might result from a production system having a low replacement rate, or a high somatic cell count might result from a high replacement rate.

There are some limitations to this study. In real-world settings, cows are often replaced due to health or fertility issues, which this study did hardly consider (except for the somatic cell count being a proxy for udder health issues). Instead, we focused on the economic drivers of dairy cow replacement. Another important factor which influences the optimal replacement policy is the availably of replacement heifers (De Vries, 2020) which was not considered in this study, since the presumption was that exactly the number of heifers which is needed is available. This assumption may not necessarily hold true in a practical setting. Another assumption/simplification concerns differences between breeds. Due to the lack of farm-specific data for weight and other variables, we decided to keep these values constant across all breeds and herds. This simplification was made to assure that the observed results were driven by the underlying Markov chains (representing survival probabilities of different breeds) and were not merely an artefact of breed-dependent assumptions.

5 Conclusions

External price factors play an important role in determining the optimal replacement policy of a farm. An increased milk price leads to a lower optimal replacement rate. The difference between heifer prices and carcass prices has a significant influence on the optimal replacement policy. Larger herds seem to have a higher replacement rate. A higher milk yield encourages a lower replacement rate. A high somatic cell count is associated with a significantly higher replacement rate. The optimal replacement rate for the milk-pronounced breed Brown Swiss is significantly higher compared to Swiss Fleckvieh.

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