Austrian Journal of Agricultural Economics and Rural Studies, Vol. 32.6
https://oega.boku.ac.at/de/journal/journal-informationen.html
DOI 10.15203/OEGA_32.6, ISSN 1815-8129 I E-ISSN 1815-1027
OPEN ACCESS

# The empirical economic effect of dairy cow longevity in a Swiss setting

## Der empirische Effekt der Nutzungsdauer von Milchkühen auf die Wirtschaftlichkeit ausgewählter schweizerischer Betriebe

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Received: 20 Januar 2023 – Revised: 13 Juni 2023 – Accepted: 16 Juni 2023 – Published: 15 Dezember 2023

### Summary

Using regression analyses, this study investigated whether an economically optimal productive lifespan of dairy cows can be derived from Swiss farm accountancy data. By using a rich set of control variables and including a second-degree polynomial into the regression model, this study succeeded in reproducing the optimal productive lifespan of between 6 and 7 years propagated by studies based on model calculations. This is in contrast to the results of a recent empirical study that did not find a significant association between cow longevity and economic performance. By analysing different economic outcomes on the farm and production branch level, the present study was able to explain this discrepancy and succeeded in reconciling the findings from empirical research and research based on model calculations.

**Keywords:** culling, productive lifespan, milk production, profitability, Switzerland

### Zusammenfassung

Die vorliegende Studie untersuchte unter Einsatz von Regressionsanalysen, ob aus schweizerischen landwirtschaftlichen Buchhaltungsdaten die optimale Nutzungsdauer von Milchkühen abgeleitet werden kann. Unter Zuhilfenahme zahlreicher Kontrollvariablen und durch den Einbezug eines Polynoms zweiten Grades in das Regressionsmodell gelang es, die optimale Lebensdauer zwischen 6 und 7 Jahren nachzuvollziehen, welche von Studien basierend auf Modellkalkulationen propagiert wird. Dies widerspricht den Resultaten einer jüngst veröffentlichten empirischen Studie, welche keinen signifikanten Zusammenhang zwischen der Lebensdauer von Michlkühen und wirtschaftlichen Ergebnissen fand. Durch die Analyse verschiedener ökonomischer Indikatoren auf Betriebs- und Betriebszweigebene gelang es mit der vorliegenden Studie, diese Diskrepanz zu erklären und somit die Ergebnisse von empirischer Forschung und auf Modellrechnungen basierender Forschung in Einklang zu bringen.

**Schlagworte:** Merzung, Produktive Lebensdauer, Milchproduktion, Wirtschaftlichkeit, Schweiz

## 1 Introduction

Due to its impact along different dimensions of farm performance, dairy cow longevity has been studied as it relates to different scientific fields. Ecological analyses (e.g. Meier et al., 2017; Grandl et al., 2018) have demonstrated that longevity decreases greenhouse gas emissions, thereby lowering the ecological impact of dairy production. In the economic literature, the topic has also been investigated. Conceptually, a handful of factors are important, the first being the cost of rearing cattle. The longer a cow lives, the lower these costs become when distributed over all the years of a cow's life. The second factor is the milk yield of the cow. It increases with increasing lactations up to a maximum, where it begins to decline (Leiber et al., 2019). Third, health-related costs can be relevant, and tend to increase with age (Fleischer et al., 2001). Fourth, the breeding process must be considered. The shorter the lifespan of a cow, the faster the new (genetically improved) generation comes into production, which should lead to higher revenues (Mißfeldt et al., 2015). In the process of finding the optimal productive lifespan (OPL) of a cow, the goal is to find the value in which the revenues are highest in comparison to the costs.

In the prior economic literature, longevity has been analysed using different methodologies with differing – but mostly similar – results. The calculation of the OPL of a dairy cow was conceptually described by Zeddies (1973), who calculated it to be 9 lactations, at the time (see 'Übersicht 2' on page 9). Zeddies's (1973) considerations were based on the comparison between the marginal profit from keeping a cow in the herd for one additional year and the average profit (per year) of a replacement cow. More recently, Horn et al. (2012) based their analysis on panel data containing performance indicators (such as the milk yield) for individual cows kept in an organic setting. Missing information, such as the feed cost, was calculated using a bio-economic model. By grouping cows according to longevity and milk yield, they determined the economically OPL to be 6 lactations. Based on herd modelling, Markov chains and hypothetical costing, the calculations of Mißfeldt et al. (2015) resulted in a similar OLP of 7 years. The OLP increases considerably, however, to 12 years when forced culling is assumed to take place[1]. Kiefer et al. (2019) included the farmer's expectations for health-related costs in their calculations, which resulted in an OPL of 6 lactations.

All these analyses calculating the OPL were based on assumptions regarding costs, revenues and possibly other economically relevant aspects (such as the feed intake) that influence the OPL. Vredenberg et al. (2021) overcame this drawback by directly analysing the accountancy data of Dutch dairy farmers. In this way, the actual costs and revenues can be observed from the data without the need for assumptions. Based on 855 herds analysed over 10 years, they found that the gross margin is not significantly associated with the age of culled cows. This result contrasts with findings of the previously cited studies that propagated an OPL of at least 6 years and could be supported by different explanations. First, it is possible that the model calculations miss significant aspects of the production system, and, therefore, the results from these calculations do not reflect the real profit function of dairy production. Second, the assumed and observed costs and revenues in German, Austrian and Dutch dairy farming differ. On the other hand, the focus of Vredenberg et al. (2021) on the gross margin has possibly led to this finding, as the gross margin only partly includes the cost of rearing cattle if it is done on the farm, because parts of these costs are related to labour, machinery or buildings. Therefore, the full effect of decreased rearing costs would not be captured by the gross margin. In addition, Vredenberg et al. (2021) applied a linear model without polynomials of independent variables, thus allowing only for a strictly monotonic relationship between the productive lifespan (PL) and the gross margin. This is in contrast to what previous studies have found. They recommended a specific PL, implying that neither a shorter nor a longer PL would be optimal. In a regression setting, this can be modelled by adding polynomials of the PL to the set of independent variables.

The present study analysed the relationship between the PL of dairy cows and the economic outcome on the herd-level by means of a regression model based on real accountancy data (without further assumptions regarding costs and revenues). It differs from the analysis by Vredenberg et al. (2021) in that it integrated a second-degree polynomial of the PL into the set of independent variables. To consider all relevant costs, the analysis focused on the remuneration per family work unit as the most indicative economic figure and compared the results to an analysis focusing on the gross margin. In this way, this study aimed to explain the discrepancies between findings from empirical research and research based on model calculations.

## 2 Data and Methods

This analysis is based on the accountancy data from 278 conventional Swiss dairy farms that delivered their data to the farm accountancy data network in the year 2020 (organic farms excluded because of the small number of farms). For the given year, these farms delivered additional data, such as the number of cows replaced. Based on this information, the average PL per farm (or herd) was calculated as the inverse of the cow replacement rate. On average, the analysed sample included 35.3 livestock units of cattle (standard deviation (SD): 17.5 livestock units), of which 81% were dairy cows (SD: 8%). The PL per farm is 4.8 years, on average (SD: 1.7 years), with a milk yield of 7,080 kg of milk per cow and year (SD: 1,240 kg per cow and year). Roughly half of the farms housed their cows in tie stalls with bucket or pipe milking systems. Approximately one quarter each of the farms were located in the plains zone, mountain zone 1 and mountain zone 2; 18% were located in the hills region (for additional explanation on zones, see Table 1).

1 An assumption often ignored in preceding analyses taking it for granted that the life of any cow can be prolonged without restrictions.

The effect of the PL on the profitability of farms was studied using a regression framework. For the interpretability of the results, a linear model was chosen. Importantly, to allow for non-monotonic effects, a second-degree polynomial of the PL was part of the set of independent variables. To control for the potential confounding effects, a rich set of control variables was included in the model (Table 1). To analyse the effects of PL on the different profitability indicators, three regression models with different dependent variables were evaluated: the remuneration per annual family work unit (RAFWU) on the farm level, the gross margin per livestock unit (GMLU) in the dairy production branch and the gross margin per kg of milk sold (GMkg) by the dairy production branch. The RAFWU is defined as the agricultural income from the farm minus the cost for the farm's equity, divided by the number of annual family work units. The gross margin includes revenues (mainly from milk and animals sold) and variable costs (mainly for concentrates, bought animals, veterinarian and medicines and artificial insemination) on the level of the dairy production branch.

Table 1: Independent variables and their potential impact on the economic outcome

| **Herd structure and herd performance** | |
|---|---|
| **Variable** | **Potential impact mechanism** |
| Number of livestock units in the dairy production branch | Economies of scale. The higher the number of animals, the lower costs per unit tend to be (Hoop et al., 2015). |
| Share of dairy cows in herd (%) | Proxy to determine whether rearing is outsourced. This can change the cost-revenue structure of a farm. |
| Average productive lifespan of cows in the herd (in years; linear and quadratic term) | Describes the time from giving birth to the first calf until the culling of the cow. The quadratic term should allow to find the OPL (if present in the data). |
| Milk yield (in kgs per cow and year) | High milk yield leads to high revenues. Management of high-performance herds can be challenging. |
| Dairy cattle breed (yes, no) | Dairy breeds: Holstein, Jersey, Brown Swiss (with focus on dairy), Fleckvieh (with focus on dairy) and others, according to the opinion of the farm manager participating in the survey. Dual-purpose breeds: Original Braunvieh, Simmentaler, Swiss Fleckvieh and other dual-purpose breeds, according to the farm manager. |
| **Feeding** | |
| **Variable** | **Potential impact mechanism** |
| Concentrate input (in kgs per cow and year) | Concentrate intensity of milk production. When it is low, more milk comes from roughage. This can influence profitability (Ertl et al., 2014). |
| Number of grazing days of each cow (in the herd) per year | Grazing can lower the cost for machinery and buildings. On the other hand, it requires time for grazing management. |
| Production of milk for non-pasteurised cheese (yes, no) | Prohibits silage feed. Hay can be more expensive. On the other hand, farms tend to receive a better milk price. |
| Seasonal calving (yes, no) | Harmonizes the feed requirements of cows and grass growth over the course of the year, thereby minimising the amount of feed that must be conserved (→ cost savings). |
| **Miscellaneous farm characteristics and production conditions** | |
| **Variable** | **Potential impact mechanism** |
| Share of revenues from milk and cattle in total revenues of the farm (%) | Dairying provides comparatively low incomes (Hoop et al., 2021). Therefore, a larger share of other (more profitable) branches could increase the farm-level income. On the other hand, the focus on the dairy production branch could increase its efficiency and, therefore, profitability. |
| Lease cost per hectare (CHF / ha) | Farms owning less land, therefore having to lease land, could have an economic disadvantage. |
| Bucket or pipe milking system (yes, no) | The milking system can influence building and labour costs. Most farms having bucket or pipe milking systems have tie stalls. |
| Share of pastures and meadows in total agricultural area (%) | This variable is meant to capture the variability that is not captured by the production zones (see below). |
| Hill zone (yes, no) | In Switzerland, each farm is assigned to a production zone, the plain zone being the most favourable in terms of production conditions. The hill zone is one degree less favourable, which could influence profitability. |
| Mountain zone 1 (yes, no), 2 (yes, no), 3 (yes, no), 4 (yes, no) | The mountain zones are even less favourable than the hill zone. The higher the number, the harsher the production conditions (climate and/or topography). |

| Characteristics of the farm manager | |
|---|---|
| **Variable** | **Potential impact mechanism** |
| Age of the farmer (years) | Younger farmers could have higher incomes because they are more innovative. Older farmers could have higher income because they are more experienced. |
| Farmer is a member of a breeding association (yes, no) | Possibly, farmers being members of a breeding association have higher incomes because of better management. On the other hand, focusing on breeding could lower their profitability because profitability is not their first priority. |
| Education: Vocational examination / farm manager school; yes, no) | This level of education is above the basic vocational training of farmers. Therefore, it could lead to higher income. |
| Education: Master's examination or higher (yes, no) | This level of education is above the vocational examination. Therefore, it could lead to even higher income. |

Source: own considerations, 2023. References added where appropriate.

Table 2: Coefficient estimates from the three regression models explaining the remuneration per annual family working unit (RAFWU), the gross margin per livestock unit (GMLU) and the gross margin per kg of milk sold (GMkg) by means of different farm, herd and farmer characteristics

| | RAFWU | | GMLU | | GMkg | |
|---|---|---|---|---|---|---|
| | **Coef.** | **P val.** | **Coef.** | **P val.** | **Coef.** | **P val.** |
| **Intercept** | **-83,012** | 0.011 | **-2047.0** | 0.007 | **90.0** | <0.001 |
| **Livestock units dairy branch** | **1,077** | <0.001 | 3.6 | 0.148 | 0.1 | 0.355 |
| **Share of dairy cows in herd (%)** | 254 | 0.227 | **24.5** | <0.001 | **-0.4** | 0.007 |
| **Productive lifespan (years)** | **8,277** | 0.028 | 102.9 | 0.231 | 0.8 | 0.733 |
| **Productive lifespan$^2$** | **-654** | 0.031 | -9.2 | 0.185 | -0.1 | 0.568 |
| **Milk yield (1000 kg · cow$^{-1}$·year$^{-1}$)** | **3,680** | 0.013 | **354.4** | <0.001 | **-2.7** | 0.005 |
| **Dairy cattle breed (0, 1)** | 4,346 | 0.180 | 130.9 | 0.078 | 3.6 | 0.091 |
| **kg concentrates · cow$^{-1}$·year$^{-1}$** | **-16** | 0.002 | **-0.5** | <0.001 | **0.0** | 0.013 |
| **No. of grazing days · year$^{-1}$** | **140** | 0.021 | 2.7 | 0.051 | **0.1** | 0.029 |
| **Milk for non-pasteurised cheese (0, 1)** | **13,522** | <0.001 | **541.0** | <0.001 | **7.1** | <0.001 |
| **Seasonal calving (0, 1)** | **10,029** | 0.022 | 132.8 | 0.183 | 5.6 | 0.052 |
| **Share of milk & cattle in total revenues (%)** | -212 | 0.124 | **7.4** | 0.019 | 0.1 | 0.211 |
| **Lease cost per hectare (CHF · ha$^{-1}$)** | -3 | 0.497 | 0.0 | 0.599 | 0.0 | 0.762 |
| **Bucket or pipe milking system (0, 1)** | **8,592** | 0.008 | -95.3 | 0.197 | -2.0 | 0.336 |
| **Share of pasture & meadows (%)** | 293 | 0.189 | 2.6 | 0.616 | 0.2 | 0.137 |
| **Hill zone (0, 1)** | 7,734 | 0.101 | 196.5 | 0.069 | 3.8 | 0.226 |
| **Mountain zone 1 (0, 1)** | 2,157 | 0.659 | 5.7 | 0.960 | -1.1 | 0.738 |
| **Mountain zone 2 (0, 1)** | -3,114 | 0.576 | 28.7 | 0.822 | -2.2 | 0.552 |
| **Mountain zone 3 (0, 1)** | 842 | 0.921 | **542.4** | 0.006 | 8.9 | 0.112 |
| **Mountain zone 4 (0, 1)** | 2,019 | 0.856 | **535.1** | 0.036 | **24.0** | 0.001 |
| **Age of farm manager (years)** | -2 | 0.989 | -3.1 | 0.336 | -0.1 | 0.154 |
| **Member of breeding association (0, 1)** | -2,523 | 0.628 | 122.2 | 0.307 | 2.4 | 0.475 |
| **Education: vocational exam. (0, 1)** | 346 | 0.950 | -219.5 | 0.082 | -1.3 | 0.720 |
| **Education: master's ex. or higher (0, 1)** | 4,427 | 0.201 | 50.5 | 0.524 | 0.0 | 0.984 |
| **Adjusted R$^2$** | 0.41 | | 0.59 | | 0.23 | |

Coef.: coefficient estimate from the regression model.
P-val.: probability that the null hypothesis is true, stating that the coefficient is zero.
Source: own calculations based on the analysed sample of Swiss farms, 2020.

## 3 Results

Table 2 contains the coefficients from the three regression models explaining the RAFWU, the GMLU and the GMkg by means of different farm, herd and farmer characteristics. According to the regression models, the PL is not related to the profitability on the production branch level, that is, the coefficients for the GMkg and GMLU are not significantly different from zero. In contrast, there is a significant association between the PL and RAFWU ($P < 0.05$). Figures 1, 2 and 3 describe the marginal effects of the RAFWU, GMLU and GMkg, respectively. As can be seen, according to the regression model, the OPL with regard to the RAFWU is 6.3 years, whereas the median PL in the sample is 4.5 years, resulting in a foregone remuneration of approximately 2,200 Swiss Francs per annual family work unit (CHF/AFWU) for the median farm. The further away from the OPL, the larger the foregone RAFWU, as is the case for the 5% quantile in the sample distribution: Such a farm could increase the remuneration of family members by 8,900 CHF/AFWU (+22%) were the PL increased to the optimal level.

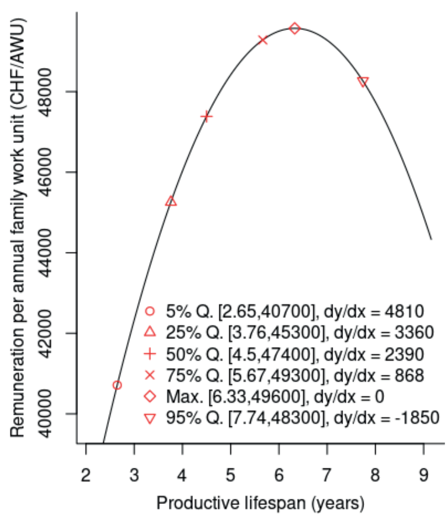



Figure 1: Marginal effects of productive lifespan on remuneration per annual family work unit. Source: regression coefficients from Table 2.

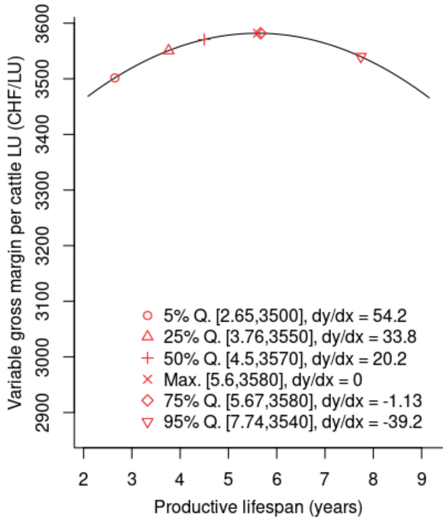



Figure 2: Marginal effects of productive lifespan on gross margin per cattle livestock unit. Source: regression coefficients from Table 2.

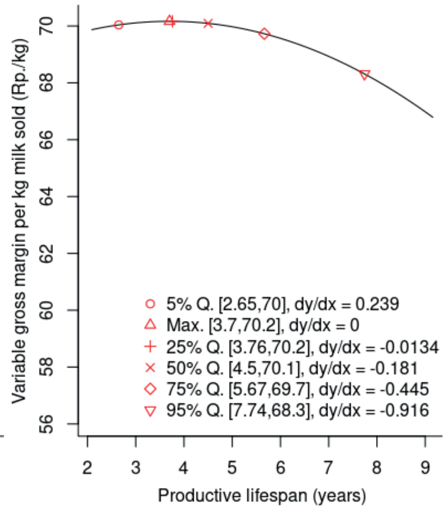



Figure 3: Marginal effects of productive lifespan on gross margin per kg milk sold. Source: regression coefficients from Table 2.

As the relative scale of the y axis is the same in Figures 1, 2 and 3, it can be seen that the relationship between the PL and the GMLU or GMkg is weak compared to the case of the RAFWU. For instance, by increasing the PL from the 5% quantile to the optimal value, the GMLU would increase by only 2%. In the case of the GMkg, it would change by less than 1%. However, because of the non-significance of the coefficients of the GMLU and GMkg, their marginal effects should be interpreted with caution. Therefore, it is questionable whether the OPL, with regard to these variables, can be determined at all.

To perform a sensitivity analysis with regard to the two distinguished types of cattle breeds (dairy and dual-purpose), a second regression model was estimated where the PL interacted with the cattle breed. Because only the breed dummy changed markedly, Table 3 only shows the coefficients of this dummy and the newly introduced interactive terms. Even though the coefficient of the linear term for the dairy breed is higher than the linear term without interactions in the first model (10,758 with interactions, 8,277 without interactions), the P-value of the corresponding coefficient is not significant, which is probably due to the reduced number of observations (only 84 farms with dairy breeds). From Table 2 to Table 3, the coefficient of the dairy breed dummy switched to a negative value. Acting as an intercept, this dummy seems to compensate for the high coefficient of the linear interactive term mentioned above.

Table 3: Coefficient estimates for the interactive terms between the productive lifespan and the cattle breeds, as well as for the dairy breed dummy

| | RAFWU | | GMLU | | GMkg | |
|---|---|---|---|---|---|---|
| | Coef. | P val. | Coef. | P val. | Coef. | P val. |
| **Dairy breed (0, 1)** | -22,489 | 0.278 | 28.6 | 0.952 | 0.2 | 0.988 |
| **Productive lifespan (years), dairy breed** | 10,758 | 0.088 | 62.2 | 0.667 | 0.7 | 0.860 |
| **Productive lifespan², dairy breed** | -788 | 0.144 | -5.6 | 0.648 | -0.1 | 0.815 |
| **Productive lifespan (years), dual-purpose breed** | 1,254 | 0.816 | 27.3 | 0.825 | -0.7 | 0.833 |
| **Productive lifespan², dual-purpose breed** | -81 | 0.861 | -2.8 | 0.789 | 0.1 | 0.834 |
| **Adjusted R²** | 0.41 | | 0.59 | | 0.23 | |

Other variables (see also Table 2) were left out for the sake of brevity, as their coefficients barely changed.
Source: own calculations based on the analysed sample of Swiss farms.

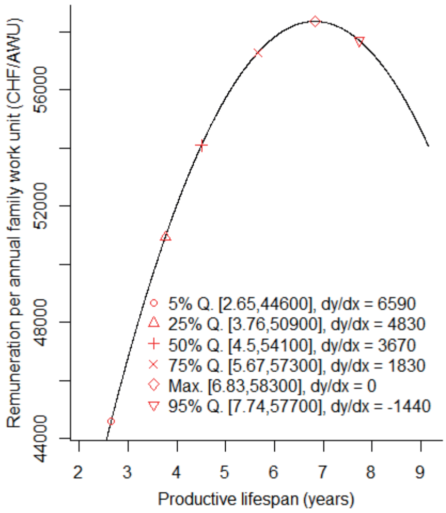



Figure 4: Marginal effects of productive lifespan on remuneration per annual family work unit for dairy breeds. Source: regression coefficients from Table 3.

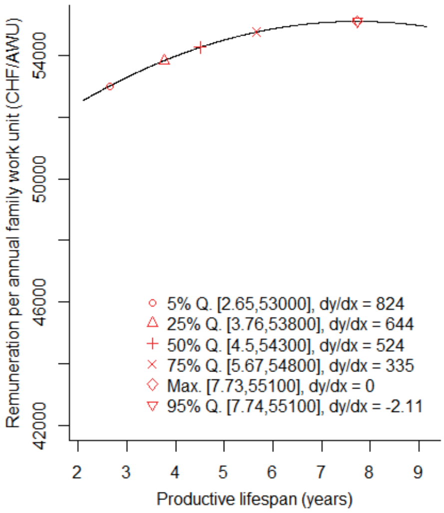



Figure 5: Marginal effects of productive lifespan on gross margin per cattle livestock unit for dual-purpose breeds. Source: regression coefficients from Table 3.

The marginal effects of the PL with regard to the RAFWU are shown in Figures 4 and 5. For dairy breeds, the effect of the PL on the RAFWU is more pronounced compared to the first regression model and compared to the dual-purpose breeds. The OPL for dairy breeds was estimated at 6.8 years. Based on the coefficients for the dual-purpose breeds, increasing the PL from the 5% quantile (i.e. from 2.65 years) to the optimum would increase the RAFWU by only 4%. Therefore, the OPL that was estimated at 7.7 years seems to be of less relevance for profitability. In its qualitative visual appearance, the effect of the PL on the GMLU and GMkg is similar for dairy and dual-purpose breeds and differs little from the curves shown in Figures 2 and 3, hence, the corresponding plots are not shown explicitly. For the sake of brevity, the effect of the control variables will not be described.

## 4 Discussion

The regression model including the interaction between the PL and the cattle breed revealed interesting differences in the effect of the PL on the RAFWU. First, the effect of the PL on the RAFWU is smaller for dual-purpose breeds. This could be explained by the fact that the net cost of cow replacement is lower in dual-purpose production systems because culled cows generate more revenue. Also, because the milk yield of dual-purpose breeds is lower in absolute terms, it varies less between lactations. Second, even if the value is subject to uncertainty, the calculated OPL is higher for dual-purpose breeds. Again, this could be caused by the net cost of cow replacement and the development of the milk yield over different lactations. In addition, dual-purpose breeds may be healthier in higher lactations[2]. Finally, production systems using dual-purpose cows can have similarities to suckler cow production systems, which seek to maximise meat production from the offspring while keeping the mother in production as long as possible[3].

Regardless of the type of cattle breed, the results of this study demonstrate that the OPL derived from the Swiss farm-level accountancies (6.3 years with regard to RAFWU for the full sample; 6.8 years for dairy breeds; uncertain estimate of 7.7 years for dual-purpose breeds) is similar to the OPL calculated by Horn et al. (2012; OPL = 6 lactations), Mißfeldt et al. (2015; OPL = 7 years)[4] and Kiefer et al. (2019; OPL = 6 lactations), even though the results refer to different production systems (Austria, Germany, Switzerland, conventional, organic)[5]. Based on the present analysis, it can be assumed that Vredenberg et al. (2021) did not find a significant association between profitability and PL, because they focused on the GMkg, which does not take into account important cost positions, such as the cost for labour, machinery or buildings. Therefore, the findings by Vredenberg et al. (2021) do not necessarily contradict the present and other studies in the literature.

The significance of the PL with regard to the RAFWU suggests that the farm-internal costs for rearing cattle play an important role, while the effect of the higher milk pro-

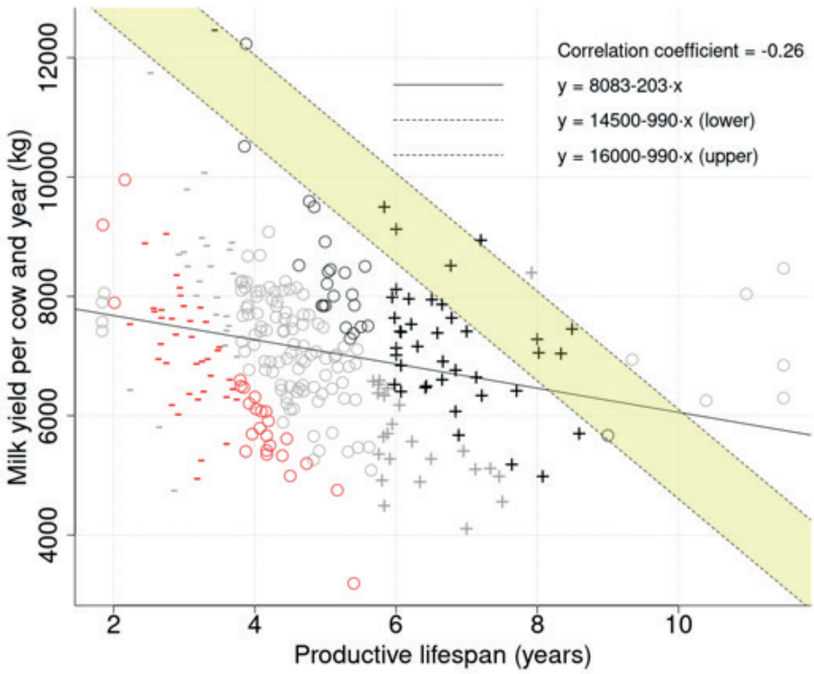
2 All these aspects influence the marginal profit from keeping a cow in the herd and the average profit (per year) of a replacement cow.

3 Stated differently, each animal used to replace a cow results in foregone revenue. Therefore, the cow replacement rate should be kept low.

4 For the comparison with Mißfeldt et al. (2015), the OPL not considering forced culling must be used.

5 In some publications, the OPL is expressed in number of years, and, in others, it is expressed in number of lactations, which should not differ significantly, assuming a standard lactation of 305 days and a dry period of 60 days.

Figure 4: Relationship between productive lifespan and milk yield




Black: farms with top 75%–97.5% average lifetime milk production per cow. Red: farms with bottom 2.5–25% lifetime milk production. '+': farms with top 75%–97.5% productive lifespan. '–': farms with bottom 2.5–25% productive lifespan. Solid line: slope from linear regression (milk yield ~ productive lifespan). Dashed line: marking an area of assumed maximum combinations of lifespan and milk yield derived from the black group.
Source: analysed sample of Swiss farms, 2020.

duction by cows in higher lactations seems to be of minor importance. Otherwise, if the revenue side was the determining factor, the OPL, with regard to the GMLU and GMkg, should have been equally or similarly pronounced to the OPL, with regard to the RAFWU. Hence, if farmers relied on the variable gross margin for economic optimisation, it could explain the median PL in the sample being 4.5 years, as, for farmers, there appears to be no financial incentive to increase the PL.

In this context, it should be pointed out that, under practical conditions, there is probably a trade-off between life expectancy and milk yield, as suggested by Evans et al. (2006), who evaluated the development of these two figures over time. This would be in line with the findings by Fleischer et al. (2001), who analysed the relationship between milk yield and the incidence of diseases in dairy cows (for a list of other studies on the relation between performance and fitness traits, see Horn et al., 2012, p. 128). As stated by Mißfeldt et al. (2015), forced culling is rarely considered in model calculations determining the OPL. Therefore, these calculations are prone to overlook the real-world constraints induced by the biological nature of milk production. Thus, the reality could be that the farmer can hardly increase the average herd milk yield by increasing the average PL of cows, because this would require the selection of (more healthy) cows with lower individual milk yields, which, in turn, would lower the average herd milk yield.

This potential trade-off is shown in Figure 4 depicting the relation between the average PL and the average milk yield per farm in the analysed sample of Swiss farms. The overall relationship from a simple OLS regression ($y = 8083 - 203 \cdot x$; adj. $R^2 = 0.07$; p-value $< 0.001$) and the correlation coefficient (–0.26; p-value $< 0.001$) are negative. Also, there seems to be an area with very few observations to the right of the dashed lines. Potentially, for the analysed sample, the yellow shaded area between the dashed lines could mark the maximum possible combination of the milk yield and PL, not considering a few outliers to the right. This potential negative correlation between the average milk yield and the average PL in a herd should be analysed in more detail by future studies before concluding that farmers should increase the PL of their cows in order to increase profits.

Finally, some limitations of the present study should be pointed out. The results are based on a non-random sample from Switzerland (called 'farm management sample'; Renner et al., 2019), and, therefore, it cannot be claimed that the findings are representative of all Swiss dairy producers. For example, different producers operate with different prices for milk and cattle sold. Assuming that a farm rears its own cattle and the relative price of meat is high, the economic effect of the PL is levelled, because the farmer gets a relatively high revenue from culling the cow. Therefore, the OPL not only differs between farms but also changes over time. In addition, the OPL differs between cattle breeds with different milk yields and slaughter weights; also, it depends on the rearing costs of the farm. In the plains zone, the opportunity costs of rearing cattle tend to be higher, because the farmland is more productive. In the mountain zones, marginal areas can be used for rearing to save cost. Also, animals can be sent to alpine pastures, which is rewarded with direct payments. Unfortunately, because of the limited number of observations, it was not possible to include the interactive terms of breeds and zones with the PL in the regression model. Methodically, with regard to statistics, it must be admitted that the stable unit treatment value assumption is possibly not fulfilled, because farms having the same average PL in their herds can still have different herd structures (e.g. all cows living approximately the same number of years, or some cows being culled early and others living for many years). In addition, the average PL per farm as calculated in this study is an approximate snapshot and not 100% accurate, because fluctuations in the number of culled cows (over time) are to be expected. Also, the cow replacement rate (and thus the computed PL) is likely to be biased when the herd size of a farm is increased (e.g. after an investment) or decreased (e.g. when facing fodder shortages).

In summary, with respect to the optimal productive lifespan of dairy cows, the results of the present study based on empirical accounting data are comparable to the results of studies based on model calculations. Although the analysed dataset has some limitations, it has made it possible to show that the potential discrepancies between bio-economic models and empirical accounting data are likely to have been caused by methodological aspects, such as the chosen profitability indicator and the assumed relationship between profitability and longevity.

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