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Survival analysis of dairy cows in the Netherlands under altering agricultural policy

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ABSTRACT

Culling of underperforming dairy cows by replacement heifers is a fundamental part of Dutch dairy farm management. Changes in national agricultural policies can influence farmers' culling decisions. The objective of this study was to analyse the relevancy of cow-level risk factors for survival of Dutch dairy cows under perturbations due to national policy changes related to the -milk quota abolishment of 2015 and the phosphate regulations since 2017. For this purpose, an accelerated failure time model was fitted on-longitudinal dairy cows' data at national level covering the period 2009−2019. The associated cow-level risk factors for culling such as lactation value (relative production level), parity number, rolling average of inseminations over all parities, very high fat-protein ratio (highFPR) and very low fat-protein ratio (lowFPR) in early lactation, test-day somatic cell count, were fitted in the model. Along with these, a factor representing three target policy periods, namely Milk Quota period (MQ), Post-Milk Quota period (PMQ) and Phosphate regulation period (PH) were fitted. The mean survival age for all producing cows was 441 weeks overall. The predicted median survival time for the policy periods MQ, PMQ and PH were 273 weeks, 271 weeks and 256 weeks, respectively. Risk factors such as lactation value, parity and highFPR, rolling average of inseminations over all parities were positively associated with survival time in all three policy periods. Risk factors such as test-day somatic cell count and lowFPR were negatively associated with survival time in all three policy periods. In conclusion, this study demonstrated the differences in survival of Dutch dairy cows in response to changing agricultural policy. The association of cow-level risk factors for culling was consistent across the three evaluated policy periods.

1. Introduction

Replacement of dairy cows is a fundamental part of dairy farm management. The replacement decisions involve removal of underperforming dairy cows and subsequent replacement by suitable heifers. On average, 25–30 % of Dutch dairy cows are replaced annually (Nor et al., 2014; CRV, 2018) indicating a cow-longevity of 6–7 years (Nor et al., 2014) which is much lower than the natural biological longevity. A large part of cow replacements involves voluntary culling of producing cows for slaughter/ salvage, which is defined as exit of producing dairy cows from the herd as a consequence of farmers' decision (Fetrow et al., 2006). This culling for slaughter on individual cow level was shown to be associated with older parity/ age, older age at first calving, calving complications and longer calving intervals, lower relative production level, and health indicators like high somatic cell count in milk, very high or very low fat-protein ratios in early lactation, etc. (Schukken et al., 2003; Huijps et al., 2008; Nielsen et al., 2010; Pritchard et al., 2013; Gussmann et al., 2019; Rilanto et al., 2020). These factors can be termed as associated risk factors for slaughter at cow level.

Changes in national agricultural policies can influence farmers' culling decisions. Dairy farmers might change their strategy either in anticipation or to mitigate the effects of changes in the country's

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Abbreviations: MPR, Milk Production Registration; LV, Lactation Value; FPR, Fat-Protein Ratio; MQ, Milk Quota; PMQ, Post-Milk Quota; PH, PHosphate regulation; SCC, Somatic Cell Count; AFT, (Accelerated Failure Time model; AIC, Akaike Information Criterion; 95% CI, 95% Confidence Interval; SARA, Sub-Acute Rumen Acidosis.

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agricultural policies. For example, the implementation of the EU milk quota regulation in 1984 initially caused a dramatic decrease in herd size and average herd age indicating higher replacement rates in EU nations such as the Netherlands (van Arendonk and Liinamo, 2003), whereas the abolishment of the same quota system in 2015 lifted this serious production limitation, resulting in increased herd sizes (CRV, 2018). Also, since 2017, a legal constraint has been set in the Netherlands on the amount of phosphate produced per farm (MLNV, 2017) which incentivised a reduction in the dairy herd sizes, increasing the importance of high production levels among cows and their potential replacements (Jongeneel et al., 2017; McCullough, 2018). Failure to respond to such policy changes might negatively affect the future profitability of the dairy farms (McDonald et al., 2013).

So, in combination with the changing policy climate, the culling strategy of dairy farms operates in a dynamic environment where the relevance of cow-level associated risk factors and replacement criteria might change periodically. Literature on risk factors influencing culling decisions and their trade-offs representing the changed Dutch farming policy climate is, however, lacking. Most studies conducted to analyse relevant risk factors in the Netherlands were, for instance, performed during the milk quota system (Sol et al., 1984; Nor et al., 2014). There is a need for a study on the effects of policy and associated risk factors related to the slaughter (voluntary culling) of dairy cows. The objective of this study was to analyse the relevancy of cow-level risk factors for lifetime survival of Dutch dairy cows representing production, reproduction and health performances under perturbations due to national policy changes related to the -milk quota abolishment of 2015 and the phosphate regulations since 2017. For this purpose, a parametric survival model at national level was fitted on-longitudinal dairy cow data covering the period 2009–2019.

2. Material and methods

2.1. Data

Anonymized production data on individual Dutch dairy cow-level were obtained from the Cattle Improvement Cooperative- CRV (CRV Holding BV, the Netherlands). This data comprised of 4 subsets, containing (1) Milk Production Registration (MPR) test records, (2) cow removal/exit records, (3) lactation records and (4) insemination records (see Table 1 for details). The data spanned the years 2009–2019 and included information on approximately 80 % of all the milk-producing cows in the Netherlands. The raw data files included repeated measures of 6,033,922 dairy cows from 19,885 farms.

Only data from commercial farms were selected. A commercial Dutch dairy farm was defined as a farm having (a) records (being active) for at least 5 years between 2009 and 2019, (b) an average of at least 30 producing cows (with a minimum of 25 in any given year) and (c) an average of 4 test-day observations per year for all cows (with a minimum of 3 observations in any given year) (Table 2). Furthermore, for farms that ended their farming operation, the records from the year of closure were omitted. Cow-level records containing missing birth dates, missing test-day records on selected variables as well as records containing unrealistic and misprint values were omitted. Records on cows that changed farms more than twice in their production lifetime were also excluded because it was analytically complicated to follow them throughout their life. This concerned only a small proportion of the total number of cow records ($<$0.1 %), as resale of producing cows is rare in the Dutch dairy sector. Cows which were exported to other countries were excluded from the data as information on their survival was not available. The four data (sub)sets were merged at cow level in a single final dataset, consisting of repeated records on 4,779,676 dairy cows from 13,936 commercial farms.

Table 1
Summary of raw data in the study.

No.	Names of Data (sub)sets	Contents
1	Milk Production Registration (MPR data)	Records of producing cows on test-day milk, test-day fat%, test-day protein%, test-day somatic cell count, number of lactations, parity, etc.
2	Animal removal/ exit from herd records (Exit data)	Exit date of animals, code of exit (dead, alive/no exit, slaughter, export)
3	Lactation records data (Lactation data)	Cow-level lactation summary of 305-milk, 305-fat, 305-protein, calving date, etc. (per parity)
4	Insemination records (Insemination data)	Records of insemination dates per parity, total inseminations, type of insemination, etc.

Table 2
Data editing steps with number of animals and number of farms retained in each step.

Editing step	Action	Number of animals	Number of farms
0	Raw data from 2009–2019 as received	6,033,922	19,885
1	Select commercial farms a Farms active $>$ 5 years between 2009–2019 b Average number of producing animals per farm $>$ 30 (with more than 25 in any year) c Farms with more than 4 test-days on average per year	5,681,833	15,916
2	Merge 4 data subsets (animals with observations in all four datasets retained) Cows which were exported to other countries were excluded from the data.	5,289,957	14,618
3	Filter/ select final data a Remove records of cows with missing data on selected variables and remove complete records of cows with missing birthdate b Remove production records of cows with questionable (unrealistic) records (e.g., parity = 60) c Remove complete records of animals that were sold multiple times (animals on $>$ 2 farms before exit) ±	4,779,676	13,936

± Excluded cows for this reason amounted to 0.1 % of total cows in the raw data (6,033,922).

2.2. Data transformation and variable selection

Based on the literature, variables reported as risk factors for culling were selected from the merged data. The final factors and their levels are presented in Table 3. Parity was categorised into 4 levels, Lactation value (LV), which denotes the relative milk production level of a cow in a herd was categorised in 3 levels. Details on how LV is calculated can be found at CRV (2020). Fat and protein percentages in the first 100 days of lactation were converted to fat-protein ratios (FPR). FPR < 1 has been considered as an indicator of Sub-Acute Rumen Acidosis (SARA) in early lactating cows (Enemark, 2008). However, based on expert opinion from the authors, a lower value of FPR < 0.9 was selected as lower threshold for normal ratio. Similarly, as FPR > 1.5 has been considered an indicator for subclinical ketosis (Duffield et al., 1997; Čejna and Chládek, 2005), it was selected as an upper threshold for normal ratio. The proportion of test-days with ratios above 1.5 and below 0.9 were determined in each parity per cow, representing very high and very low FPR, respectively. The two factors representing very high and very low FPR were split in two levels representing small proportion (less than 50 %) and large proportion (more than/ equal to 50 %) of low/high-FPR values in first 100 lactation days. Individual somatic cell count on test-day of more than 200,000 cells/ ml can be indicative of subclinical mastitis (De

Table 3
Selected risk factors and their levels and numbers.

Factor	Abbrev.	Explanation	Levels	No. of test-day records
Lactation value	LV	Relative milk production level on test-day in comparison to the herd average of 100. Three levels represent less than 90, between 91 and 110, more than 110 L V.	below average	26,023,175
			average	65,532,040
			above average	22,950,930
Parity	–	Parity number of cows	1 st parity	34,517,660
			2nd parity	28,438,152
			3–4th parities	35,092,020
			> 4 parities	16,458,313
Very high-fat protein ratio	highFPR	Indicator for subclinical ketosis, reflected by the proportion of tests in first 100 days of lactation resulting in FPR > 1.5	< 50 %	112,705,286
			≥ 50 %	1,800,859
Very low-fat protein ratio	lowFPR	Indicator for Sub-acute Rumen Acidosis. reflected by the proportion of tests in first 100 days of lactation resulting in FPR < 0.9	< 50 %	114,436,777
			≥ 50 %	69,368
Test-day somatic cell count (x 1000)	SCC	Somatic cell count in thousands per millilitre of milk on test-day	< 200	91,912,692
			≥ 200 and < 600	15,257,987
			≥ 600 and < 1000	3,202,567
			≥ 1000	4,132,899
Insemination	Insem	Rolling average of total number of inseminations over all parities	< 2	63,753,449
			≥2 and < 5	47,408,119
			≥ 5	3,344,577
Policy periods	Period	Time periods of test-day records MQ (Milk quota): 2009–2013, PMQ (post-milk quota): 2014–2016, PH (Phosphate regulation): 2017–2019	MQ	49,613,372
			PMQ	33,652,664
			PH	31,240,109

Vliegher et al., 2005). Individual somatic cell counts in test-day milk were classified in 4 levels with the first level (< 200,000 cells/mL) acting as reference. The 4 levels were created deliberately to check if the farmers distinguish between not just high SCC but also very high levels of SCC on individual cow level. Number of inseminations per parity were converted to rolling average of inseminations over all parities up to the current parity number. So, 1st parity cows had the rolling average equal to their absolute insemination number, whereas all the subsequent parities had rolling averages equal to the mean of all previous inseminations with the number of inseminations for that parity. The rolling average number of inseminations over all parities was classified in 3 levels. A factor for policy periods was generated based on calendar year representing three target policy periods, namely Milk Quota period (MQ), Post-Milk Quota period (PMQ) and Phosphate regulation period (PH).

The data were transformed into survival data in counting process format with start time, stop time and event variables (e.g. removal/exit) representing left-truncated (initial start time was the difference between the test date and birth date of the cows), and interval-censored repeated measures data (Fig. 1) according to Klein and Moeschberger (2006). Each interval represented the time period between two test-days of MPR recording. Start and stop times for the intervals were represented in weeks of survival. Event “1″ represented removal of cows from MPR records as where the cow can be considered as “slaughtered” or “dairy sale” (sold alive to another herd) and the event of “0″ represented cows which were still producing, censored, or those which were involuntarily culled (euthanasia/ died naturally) during the period between 2009 and 2019. Factors were time-varying variables with observations for each survival interval between two subsequent test-dates of MPR recording. Test-date independent variables such as parity, Insem, Policy period were repeated for each test-date interval that had the same observation.

2.3. Statistical analysis

Time-varying effects or hazards of associated risk factors can be analysed with censored longitudinal survival data by appropriate parametric survival models (Klein and Moeschberger, 2006). Given the nature of the data, a parametric survival model with appropriate distribution for survival time was chosen. Parametric survival model assumes a specific distribution for time-to-event or survival time that is analysed linearly against covariates or in this case, factors with distinct levels. Interval censored data of cows can be utilized in such a model along with time-dependent factor levels (Klein and Moeschberger, 2006; Kleinbaum and Klein, 2010). Several parametric models with different underlying distributions for time-to-event (the dependent variable) were tested. Out of these tests, the lognormal Accelerated Failure Time (AFT) model was selected based on a visual conformation of the residuals and expected residual distribution as well as lowest Akaike-Information Criterion (AIC) as seen in Table A, Appendix 1. Logarithm of time-to-event was linearly regressed against these associated time-dependent factor-levels which were assumed to linearly increase or decrease time-to-event based on their effect.

Selected relevant factors (Table 3) were added to the model as fixed time-varying effects along with a random (shared variance) term to correct for effects within farms by clustering,

$$\log T_{ij} = \beta X_{ij} + \varepsilon_{ij}$$

Where, T_{ij} represents the time-to-event in ith cluster and jth cow-level observation, β is a vector of time ratio estimates, X_{ij} is a matrix of factor levels with “i” clusters and “j” observations of cows per cluster and ε_{ij} are random errors within cluster (not independent inside cluster). This structure represents correcting for cluster dependence by marginalizing the Time ratio (TR) estimates similar to the method used in Fan and Datta (2011).

Since the objective of this study was to analyse the associated factors for lifetime survival of cows under policy perturbations, the model was structured in a way that it provided estimates on parity, lactation value, very low fat-protein ratio, very high fat-protein ratio, test-day somatic cell count and rolling average of inseminations over all parities, inside each level of the policy periods. This was achieved by fitting the main effects of all factors and subsequently by fitting interaction of policy period factor with other factors. Consequently, the model was refined by using the AIC-based stepwise backward selection protocol. The final model was defined as follow,

$$\begin{aligned} Y => \log(Ftime) \sim\ & \mu + LV + Parity + SCC + lowFPR + highFPR + Insem \\ +Period + Period\ & : LV + Period : Parity + Period : SCC + Period \\ & : highFPR + Period : lowFPR + Period \\ & : Insem + cluster(Farm) + e \end{aligned}$$

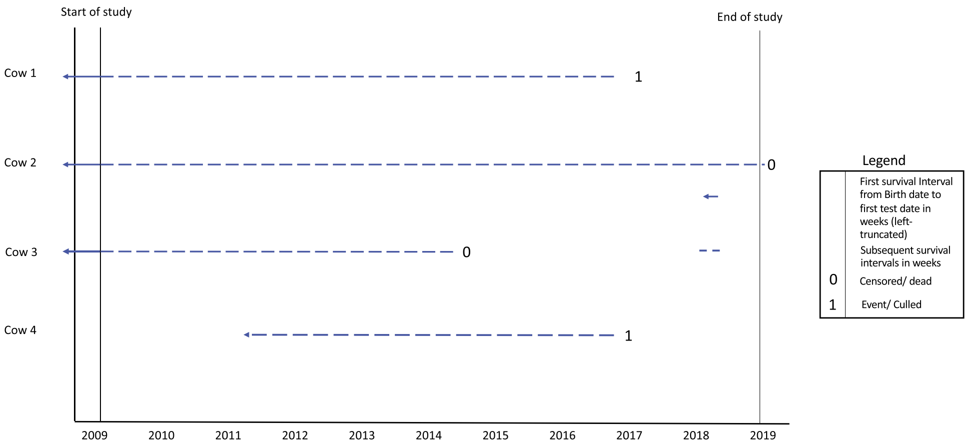

Fig. 1. Explanation of survival analysis data$^{\pm}$. $^{\pm}$Cow 1 represents a left-truncated cow (i.e., was already producing within the herd before the recording period) that has a culling event, Cow 2 represents a left-truncated cow that gets censored at end of study (e.g., no event registered during the recording period), Cow 3 represents a left-truncated cow that is censored before the study ends and Cow 4 represents a cow which starts producing within the study and has an event before the end of the study ends.

Where, '*Ftime* ' represent time-to-event, *LV*, *Parity*, *SCC lowFPR*, *highFPR*, *Insem*, *Period* represent the factors as denoted Table 1 and '*cluster*(*Farm*) ' denote the cluster effects of the farms in which cows are producing and '*e*' represents the residual term. In this model, the ' *Ftime* ' is representative of survival intervals between previous and next test date in the MPR records. The interaction terms represent the proportion of effect of the factors under different policy periods (*Period*). Estimates of the factor levels were calculated 'inside' the levels of the *Period* term with their standard errors.

To further explore the survival of the individual cows under different policy periods, the predicted survival times in weeks were drawn for all combinations of the factor levels. However, in order to analyse the culling in this survival time, the predicted log-survival times of only the 1st parity cows were retained as the survival of other parities is influenced by survival in previous parities making it difficult to interpret the predicted log-times.

All analyses were done using R-studio v 3.6.3 (R Core Team, 2020) with packages 'survival', 'data.table', 'dplyr', 'survminer' and dependencies therein. Model diagnostics were analyzed graphically using 'AFTtools' and 'forestplot' packages in R. 'The computational capacity needed for such a big data analysis was achieved by utilizing the High-Performance Computing facility at Utrecht Bioinformatics Center (HPC, 2020).

3. Results

3.1. Descriptive statistics

The data spanned from year 2009–2019 with a maximum of 13,590 farms and minimum of 11,737 farms per year (Table 4). However, the majority of the selected farms (~78 %) continued production for the entire span of 11 years. Producing cows from the selected herds in the MPR data were tested on average 10 times per year.

Table 4
Recorded number of commercial farms and producing cows between 2009 and 2019.

Year	Cows	Farms
2009	1,308,083	13,375
2010	1,371,412	13,450
2011	1,405,444	13,531
2012	1,443,133	13,590
2013	1,492,813	13,453
2014	1,536,476	13,407
2015	1,600,403	13,355
2016	1,695,173	13,176
2017	1,634,629	12,732
2018	1,529,185	12,244
2019	1,388,810	11,737

Between 2010 and 2019, 337,754 new primiparous cows were introduced to the farms with a maximum of 396,909 cows in year 2016 and a minimum of 253,251 cows in year 2019 (Fig. 2). Similarly, on average 268,206 cows had an event i.e., they were slaughtered or sold (dairy sale) with a maximum of 338,076 and a minimum of 230,002 cows in years 2017 and 2015, respectively (Fig. 2). Based on this information and data on herd sizes, the average overall removal rates per year were calculated (Fig. 3) per policy period. From Fig. 3, it was clear that the year 2015 had the lowest removal rate (during PMQ), while year 2019 had the highest removal rate (during PH). Fig. 4 shows the distribution of cows per parity over the years 2009−2019, indicating an initial increase in first parity animals during PMQ, followed by a gradual decrease during PH, indicating an increase in average herd age (e.g., a larger proportion of older animals).

3.2. Survival analysis using AFT model

Table 5 shows the effects of associated risk factors in the final model under the specified policy periods in terms of differences in survival time in weeks. All effects of the associated factors were based on 95 % confidence intervals. The output of estimates in TR can be seen in the Table B of Appendix 1.

In terms of differences between the policy period, the median survival of the cows decreased by 2.7 weeks and 15.3 weeks in PMQ and PH, respectively, compared to MQ (Table 5). Hence, the lowest median survival for cows under policy period was found in PH period. Based on the results of the lognormal AFT model (Table 5), it was shown that estimated survival increased with higher parities, above average LV, higher proportion of HighFPR and higher Insem of the cows and lower SCC and lower proportion of lowFPR within all three policy periods. The effect of Parity and inseminations over all parities (Insem) were directly related to age of the cows (see Discussion).

The overall estimated mean survival for all producing cows in the data, based on the model, was 441 weeks (± 1 week). The predicted median survival time for the policy periods MQ, PMQ and PH were 273 weeks, 271 weeks and 256 weeks, respectively. Focusing on 1st parity cows, in all three periods, the lowest predicted survival time was for a combination of below average LV, small proportion of highFPR values, high proportion of lowFPR values, high SCC and less than 2 Insem from the same model. Similarly, the highest predicted survival time for 1st parity cows was for a combination of factor levels such as above average LV, large proportion of highFPR values, small proportion of lowFPR values, low SCC ($<$ 200,000 cells/mL) and more than 5 Insem (> 5) for all three policy periods.

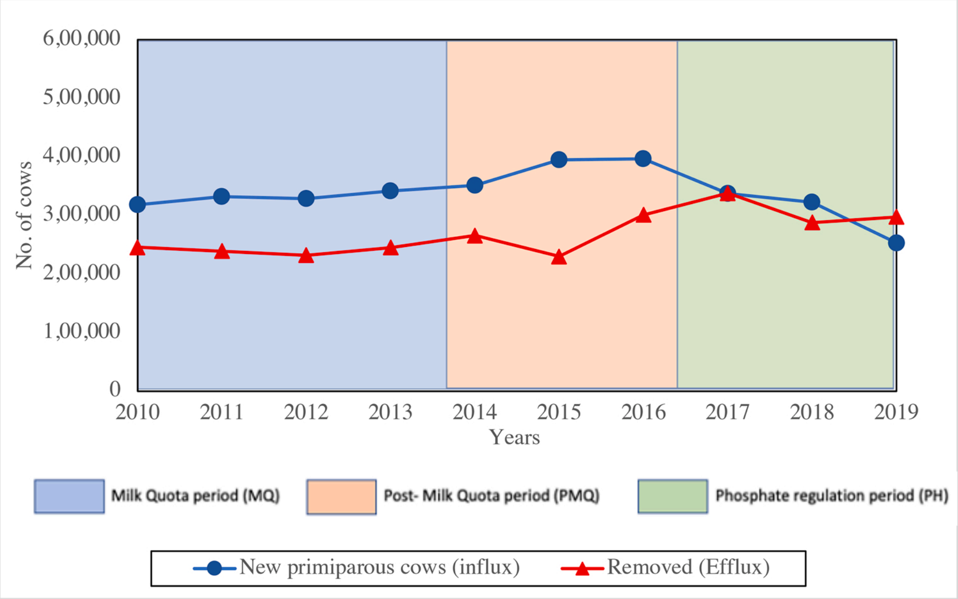

Fig. 2. Recorded number of Influx and Efflux of cows from farms in years 2010 to 2019.
Note: influx-efflux figures for year 2009 are not displayed as they were biased due to left-truncation of cows that were already producing. X- axis divided in three policy periods viz., Milk Quota (MQ, 210–2013), Post-Milk Quota (PMQ, 2014–2016) and Phosphate regulation (PH, 2017–2019).

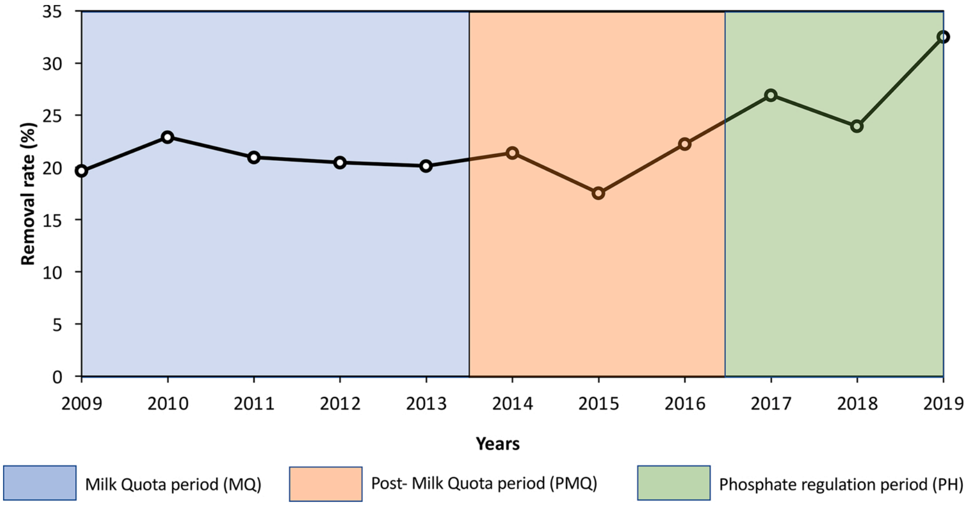

Fig. 3. Average removal rate including slaughter and dairy sale of Dutch dairy cows between 2009 and 2019.

4. Discussion

The objective of this study was to analyse the relevancy of cow-level risk factors for survival of Dutch dairy cows representing production, reproduction and health performances under perturbations due to national policy changes related to the -milk quota abolishment of 2015 and the phosphate regulations since 2017. In this study, large scale, national level data was utilized for the analysis. This enabled very precise estimations of associated effects of the relevant factors with small (95 %) confidence intervals. It was shown that there are some differences in the estimated survival of cows between the three policy periods Milk-Quota period, Post-Milk Quota period and Phosphate regulation period. Differences in estimated survival based on the associated risk factors were, however, limited between the policy periods. Consequently, there were no changes in the ‘pattern’ of estimated survival under the levels of associated risk factors within different policy periods. This showed that there were no differences in the relevancy of associated risk factors between the three policy periods. Based on this observation, it was theorized that the criteria used by farmers for culling decisions did not vary between policy changes but might have been more ‘strictly’ applied to select cows for culling.

4.1. Policy periods

It was seen that the removal rate (which includes slaughter and dairy sale of cows) was stable prior to 2014 (Fig. 4). Also, the influx of new cows (primiparous cows) in the producing herd was stable indicating a stable removal vs influx rate during the years 2009–2013 (Fig. 3). From the AFT model (Table 3), the average estimated survival of cows in MQ was highest compared to PMQ and PH policy periods. This is in contrast to the expectation of having an increased survival after the abolishment of the milk quota (PMQ), due to an increase in herd size. During PMQ (2014–2016), the influx of new animals increased, whereas the removal rate decreased to its lowest value in 2015 (Figs. 3 and 4). These changes in influx and efflux reflect the response of farmers to the abolishment of milk quota, which resulted in a herd expansion. However, the AFT

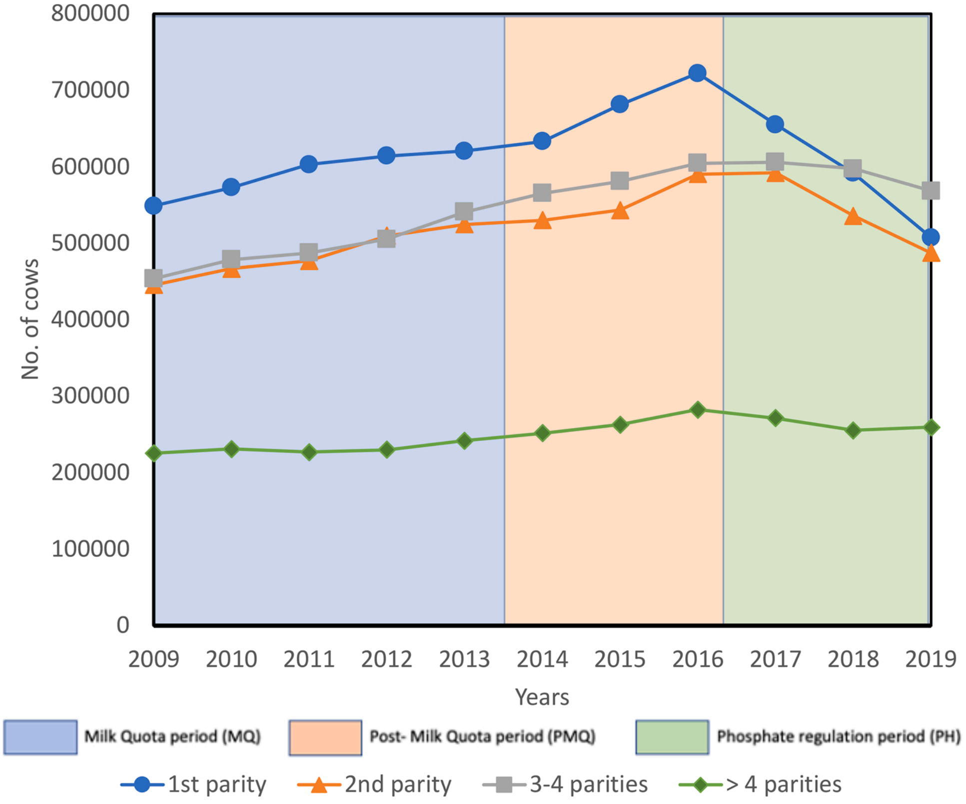

Fig. 4. Distribution of Dutch dairy cows by parity in years 2009 to 2019.

model (Table 3) showed a slight decrease in estimated survival of the cows compared to MQ. Based on this finding, it is possible that farmers favoured addition of new primiparous cows compared to decreasing the removal rate of already producing cows for herd expansion. This resulted in relative decrease in survival probability of already producing cows.

In the PH period (2017−2019), it was clearly seen that there was an increase in the average removal rate from ~ 20 % before 2017 to ~ 28 % (Fig. 4). Also, the trendlines between influx of new animals and efflux/removal of animals crossed between years 2017–2019 (Fig. 3) indicating an attempt to radically decrease the herd sizes by reducing the influx rate and increasing the removal rate. From the AFT model (Table 3), there was a clear drop in the estimated survival during the PH period indicating the above changes. Based on the results of AFT model, it was also theorized that the adjustments made by the farmers in the context of changing policy climates may not have taken place strictly within the defined bounds of particular periods, except for PH where fast changes were 'forced upon' the farmers due to an unforeseen change in policy. Thus, it was theorized that the culling pattern in terms of relevant risk factors remained stable across the changing policy periods which was against the initial expectation. Hence, under changing policy climate the perturbations caused in culling patterns of the farms could be treated as a continuum rather than discrete changes per year or per period in future research.

4.2. Relevant risk factors and modelling strategy

In this analysis, each time interval in which the survival was estimated, was bounded by two subsequent test-dates of MPR records. This survival interval represents a decision interval for farmers in which they decide to retain or cull individual cows between two test-day performances. The assumption was such that 'based on each testing interval, the decision to cull was updated'. Unlike existing literature such as Alvåsen et al. (2014); Gussmann et al. (2019) and Rilanto et al. (2020), each survival interval did not correspond to inter-calving intervals. This structuring of shorter time intervals also reduces the time lag between the time when the decision is made whether to cull or keep the cow, and the end of survival interval, giving more precise survival time estimates (test-date intervals << calving intervals).

This is a fundamental difference between survival per parity (Alvåsen et al., 2014; Rilanto et al., 2020) and lifetime survival (split in MPR test-date intervals). As a consequence, the time-varying variables have observations which vary per survival interval, except for the factors Parity and Insem.

The factors selected in this model encompassed production, reproduction and health performances based on the literature. The positive association of LV and negative association of SCC to the estimated survival from the models were in line with the findings of Bascom and Young (1998); Rilanto et al. (2020) and Gussmann et al. (2019). In early lactation, FPR of very low (FPR < 0.9) or very high (FPR > 1.5) magnitude can be indicative of underlying subacute rumen acidosis-SARA (Danscher et al., 2015; Rojo-Gimeno et al., 2018) or subclinical ketosis (Duffield et al., 1997; Van Soest et al., 2019) respectively, which increases the risk of culling and replacement. However, use of FPR for indicating underlying SARA (lowFPR) for survival analysis as associated risk factors has not been reported in previous studies.

A higher proportion of lowFPR in early lactation was negatively associated with the survival of cows as seen in Table 5. It was theorized that, the negative association of lowFPR with survival might simply be due to the fact that cows had a lower production potential along with being indicative of SARA. However, based on the results in Table 5, it is seen that highFPR had a positive association. This might be explained by the fact that high magnitude of FPR might be associated with higher production potential of the cows and hence there is a potentially high correlation between test-day milk production and higher FPR values in early lactation. A similar result was explained by Shahid et al. (2015) due to preferential treatment of high producing cows with high FPR.

Moreover, it was found that a very small number of animals showed

Table 5
Estimated differences in survival time (in weeks) based on Time Ratios (TR) of lognormal model[±].

Factor	Estimated survival in weeks
Intercept	246.7 (244.7–248.6)
Log(scale)	+0.3
Policy Periods	
MQ[±]	Ref
PMQ	−2.7
PH	−15.3

Factor	MQ Survival time in weeks[§]	PMQ	PH
Reference (Ref)[¶]	246.7	244	231.4
Parity			
1 st parity (Ref)			
2nd parity	+85.0	+83.3	+87.0
3−4 parities	+217.4	+215.1	+222.1
> 4 parities	+459.6	+441.5	+451.2
LV			
below average	−29.8	−30.3	−29.5
Average (Ref)			
above average	+25.1	+25.2	+20.6
SCC (X 1000)			
< 200 (Ref)			
≥ 200 and < 600	−11.8	−9.7	−9.2
≥ 600 and < 1000	−18.5	−14.8	−12.3
≥ 1000	−32.4	−29.2	−24.4
highFPR			
< 50 % (Ref)			
≥ 50 %	+9.8	+9.6	+6.0
lowFPR			
< 50 % (Ref)			
≥ 50 %	−12.0	−10.9	−5.1
Insem			
< 2 (Ref)			
≥2 to 5	+18.9	+17.4	+15.3
≥ 5	+29.2	+24.6	+24.6

[§] Calculated as $e^{(\beta_0+\beta_{\text{policy}}+\beta_{\text{TR}})}$ where β_0 is the intercept, β_{policy} is the policy effect in time-to-event and β_{TR} is the time ratio of factor level to the reference. [§]95 % confidence intervals for Parity, LV, SCC, low/ highFPR and Insem were small (< ±1 week) and are not displayed in the table.

[±] Abbreviations in the table: Ref (reference level of factor), MQ (milk quota), PMQ (post-milk quota), PH (phosphate regulation), LV (lactation value), SCC (test-day somatic cell count), highFPR (very high test-day fat-protein ratio), lowFPR (very low test-day fat-protein ratio), Insem (rolling average of inseminations over all parities).

[¶] Baseline survival for each policy period. Calculated as $e^{(\beta_0+\beta_{\text{policy}})}$ where β_0 is the intercept, β_{policy} is the policy effect. All β-estimates can be found as Time ratios (TR) in Appendix 1, Table B.

high proportions of highFPR and lowFPR during their first 100 days of lactation (≤ 2% of total observations per factor; see Table 3). The imbalance in numbers of observations in each factor level were expected due to biological reasons. However, in the analysis this imbalance did not visibly affect the standard errors of the estimated time ratios.

It was found that higher parities were associated with higher survival times which was not in line with findings of Thomsen et al. (2004); Miller et al. (2008) and Rilanto et al. (2020). In this study, survival was not analysed per parity but over the entire life span (broken down into test-date intervals) under changing policy. Unfortunately, the side effect of this is that Parity factor is related to the age of the cow and hence survival estimates increase as parity increases. This can be explained by the fact that parity which serves as an indicator of age of the cow was related to the survival times. Hence, the interpretation of the parity factor estimates was not straightforward. Besides this, the event in this survival analysis was for slaughter and dairy sale, whereas natural death/ euthanasia served as censoring criteria. Since natural death or euthanasia (involuntary culling) are common for older age cows (Thomsen et al., 2004; Shahid et al., 2015), the effect of parity on the survival of cows could be counter indicative.

Similarly, it was found that a higher magnitude of Insem was associated with higher survival. However, according to the literature from Van Arendonk and Dijkhuizen (1985); Dijkhuizen et al. (1985); Sewalem et al. (2008), higher numbers of inseminations required for conception were indicative of poor reproductive performance and, hence, increased culling risk. The deviation from existing literature can be explained by the fact that in this study, the number of inseminations were coded as a rolling average over all parities, which made this factor dependent on age and parity number. As a consequence, the effect of this factor became dependent on survival time similar to parity number. One way to rectify this issue was to take insemination history (inseminations up to the last parity). However, the first parity cows which formed the majority of the culled cows were lacking this information. Moreover, Insem variable is used as a surrogate to “farmers’ confidence in the performance of the cow” since cows which show potential benefit may be inseminated more times by the farmer in order to retain them. Thus, Insem was reflective of the decision that farmer has already made to retain the cow for next lactation and did not reflect on the performance before the farmer’s decision. Thus, the results of this study indicated the associations of relevant risk factors of culling but did not provide insight into the actual culling decision processes and motivations of the farmers.

Besides this, other fertility indicators such as prolonged lactation, age of first calving, etc. were not analysed in this study due to data constraints. Also, data on disease indicators for important production diseases such as clinical mastitis, lameness diseases, etc. were not available which are important risk factors for slaughter as well as involuntary culling (Bascom and Young, 1998; Rajala-Schultz and Gröhn, 1999; Gröhn et al., 2005; Olechnowicz and Jaskowski, 2011).

In conclusion, this study demonstrated the differences in survival of Dutch dairy cows in response to changing agricultural policy. It was also shown that the relevance of cow-level risk factors for culling did not change under changing agricultural policy.

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2021.105398.

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