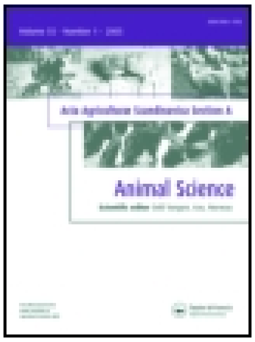

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Variables affecting herd average lifetime short-run profit in a sample of Norwegian dairy herds

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ABSTRACT
This study combined exploratory factor analysis (EFA) and Lasso regression to give a deeper insight into production-economic variables affecting short-run dairy cow lifetime profit, DCLP, at the farm level. The study rests on data on heifer growth, feeding, financial, and production variables from 13 farms. We calculated costs and income for an average animal per month and herd. Costs and income were discounted and summarized to a DCLP at time of birth, converted to profit as a monthly annuity equivalent value, MEQ. MEQ was regressed on the 53 original variables (Lasso) or on factor scores (EFA) derived from the original variables. Both EFA and Lasso regressions were used to deal with co-linearity problems. The EFA provides a higher resolution of the underlying quantities than Lasso regression. The factors improving DCLP were reduced roughage costs and high milk yield combined with the lowest possible age at first calving in the data.

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Dairy cattle; profit efficiency; Lasso regression; exploratory factor analysis

Introduction

Dairy farming contributes to society in many ways, for example by providing food security, rural viability, employment opportunities, and biodiversity. In return, society supports farmers through subsidies, while at the same time requiring that farms are run efficiently. Technical efficiency is about maximizing output for a specified set of input given the available technology, while allocative efficiency is the ability of the farmer to select the mix of input that produce a given output at minimum cost. The two terms can be combined to provide an overall economic efficiency measure. A commonly used economic efficiency measure is the gross profit function (Cherchye et al., 2010). Most previous research have shown the presence of technical inefficiency in dairy farming (see, e.g. Cabrera et al., 2010; Zhu et al., 2012; Manevska-Tasevska et al., 2016). Technical efficiency is found to be positively related to intensification (Alvarez et al., 2008; Kelly et al., 2013), the amount of purchased feed, family labor, milking frequency, and the use of a total mixed ration system (Cabrera et al., 2010). Allendorf and Wettemann (2015) concluded that increased cow losses, a high replacement rate, and a long calving interval decreased technical efficiency, whereas efficiency increased with milk yield and somatic cell count, and a lower age at first calving (AFC). Combining technical and allocative efficiency Hansen et al. (2019) showed that a low AFC, a high milk yield per cow and low use of concentrate contributed positively to farm economic efficiency.

In a recent field trial Storli et al. (2017) concluded that Norwegian Red (NR) replacement heifers are grown too slowly during the rearing period. Thus, they reach the size at which they are deemed large enough to be bred, and enter the dairy herd, unnecessarily late. Their data did not allow considering how different heifer rearing practices affected lifetime profit because the animals had only completed one lactation when the study was conducted. However, they recorded detailed information on heifer feeding (Storli et al., 2017). By combining this information with information on the same animals from the Norwegian Dairy Herd Recording System (NDHRS) and the Norwegian Dairy Herd Financial Recording database (NDFR) we could calculate income and variable costs. This is a variation of the perspective taken by Hansen et al. (2005) and Heinrichs et al. (2013). The latter authors calculated gross margin at the farm level and used data envelopment analysis (Cooper et al., 2000) to identify key economic variables for both heifers and cows. Hansen et al. (2005) utilized herd averages from the NDHRS and the NDFR databases for the years 2000–2001 comprising data from approximately 1900 farms. However, Hansen et al. (2005) did not have information on roughage intake during the heifer period, whereas this could be calculated in our

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analysis: For this, we utilized heifer growth data from repeated (8–10 times for all heifers) heart-girth measurements, and feeding data (2 times) over a 2-year period (Storli et al., 2017).

In the present study we assumed that the farmers aimed to maximize profit. We focused on short-run herd profit, where capital such as e.g. farm buildings and farmland are considered fixed quantities. This is opposed to long-run profit maximization, where labor and capital vary and may be chosen by the farmers to maximize profit. The main objective was to gain information on dairy cow lifetime profit (DCLP, see Appendix for a definition) in commercial dairy herds and to identify its economic drivers in order to enable dairy farmers to improve the economic outcome of their farms. More specifically, we aimed to identify economic drivers affecting short-run farm management practices, drivers which farmers can easily change. This was done by exploring how DCLP, converted to a monthly annuity equivalent value (MEQ), relates to 53 chosen herd variables. Many of these variables were highly colinear. To deal with the collinearity problem we applied two statistical learning techniques to estimate the economic drivers.

Materials and methods

In the present work, we performed a lifetime profit analysis by extending the data of Storli et al. (2017) with financial data from the Norwegian Dairy Herd Financial Recording database (NDFR), and the Norwegian Dairy Herd Recording System (NDHRS). The NDFR is a farm specific subscription service where member farms once a year submit their herd financial data. In return, they receive a refined analysis combining herd economic and production data. Consequently, our analysis could only be performed for NDFR member herds. We calculated DCLP in terms of the net present value at time of birth for an average individual per herd. Then, we converted DCLP to MEQ, which serves as an indicator of short-run profit.

Starting out with the 30 herds in Storli et al. (2017), where we had herd level information on feeding, and utilizing that 13 of these had herd financial data for the years 2012–2013 from being members of the NDFR, we carried out the analyses for an average individual at the herd level. The mean size of the 13 herds was 66 cow equivalents (range 34–129), which equals the sum of days in feed of cows in the herd within a year divided by 365 (TINE, 2015). This is well over the current national average of 26 cow equivalents per herd (NDHRS, 2017). However, the herds represented the three major dairy regions in Norway (six from southeast, two from southwest, and five from mid Norway). Except for the compulsory eight weeks on pasture during summer, the animals were fed a diet of roughage (mainly grass silage) and concentrates. The animals were all dual-purpose NR. All dairy cows were kept in freestalls, while some youngstock on some farms were housed in tiestalls. Calving occurred throughout the year in all herds.

Monthly costs and income calculations

Initially, we calculated monthly costs and income for an average individual per herd over each herd's average dairy cow's lifetime. Analyses were carried out without direct payment because state subsidies are politically determined. Fixed costs including labor costs were not included because we had a short-run perspective. Using a Microsoft Excel 2013 spreadsheet for each herd and a timeline of four periods (calf, heifer, pregnant heifer and lactation), the calculations of costs and income were carried out as follows:

Calf period

We defined the calf period as the first three mo of life. Information on the amount of milk, concentrate and roughage fed to the calves was obtained from a questionnaire answered twice by the participating farmers during the study conducted by Storli et al. (2017) (Table 1). All herds fed their calves whole milk, and costs per liter of milk was set equal to the milk price obtained by each herd (Table 2). Roughage, veterinary, and sundry costs (consumables) per herd were taken from the NDFR (Table 2). Concentrate price was obtained from the TINE OptiFôr client in the NorFôr feed evaluation system (Volden, 2011) (Table 2). A newborn heifer calf was incurred a cost of Norwegian kroner (NOK) 2500 in month one for all herds, because it is the standard value used in the NDFR (Table 2).

Heifer and pregnant heifer periods

The heifer-rearing period was divided into two parts. One from 3 mo of age to successful insemination, and one that covered pregnancy. The length of the former was derived from each herd's average AFC as given in the NDHRS (Table 1) and varied from 12 to 15 mo between herds. Costs in the two heifer periods were limited to feed, veterinary, and sundry costs. Roughage, veterinary, and sundry costs were obtained from the NDFR (Table 2). Information on the use of concentrate during the two periods was obtained from the questionnaire of Storli et al. (2017) (Table 1), and the cost of concentrate was obtained from the TINE OptiFôr (Table 2). Using the Growing cattle application of TINE OptiFôr we calculated the energy required by a heifer to reach its first calving body weight (defined as the slaughter weight of an average first parity cow in the actual herd as given in the NDHRS (Table 1) divided by an assumed dressing percentage of 0.45) at the herd's average AFC. Monthly roughage requirement in MJ net energy growth (NE_G) was obtained by subtracting the energy provided by the fed concentrate, presented as intake per day (Table 1). Roughage intake and associated costs of feeds during pregnancy were calculated in the same manner (Table 1).

Lactation period

We defined the lactation period as the entire period between herd average AFC and herd average age at culling (AAC) from the NDHRS (Table 1); this period varied from 26 to 37 mo between herds, and all herds culled their average animal during the third lactation. In our calculations we assumed a 12-mo calving interval, whereas the real calving interval for the 13 herds over 3 years was on average 11.97 mo. We further assumed the calving interval to be made up of a 305-day lactation period and a 60-day dry period. Revenues included sales of milk, sales of three calves per cow assuming NOK 2500 (the standard value in NDFR, Table 2) per newborn calf at time of calving, and the assigned herd average slaughter value of the cow at culling. The slaughter value is the product of the adult cow slaughter weight of the herd as given in the NDHRS (Table 1) times price per kg and herd obtained from the NDFR (Table 2). The monthly roughage intake was calculated as the difference between the energy required for maintenance and production given the herd's average energy corrected milk (ECM) yield per lactation month (described below) and the energy provided by the herd's average concentrate use per lactation month extracted from the NDHRS (Table 1). Energy requirement calculations were carried out using the dairy application of TINE OptiFôr. In these calculations, we used as live body weight (BW) each herd's average adult slaughter weight (Table 1) divided by the assumed dressing percentage of 0.45. Concentrate price per MJ net energy lactation (NE_L) was obtained from TINE OptiFôr and veterinary and sundry costs from the NDFR (Table 2). Herd average yield in kg ECM and kg milk per lactation month were calculated utilizing test-day records from the NDHRS on animals born from NR sires used through artificial insemination in the 13 herds after 1 January 2011. We calculated milk sale per month as average herd yields at days in milk (DIM) 15, 45, 76, 107, 137, 168, 198, 229, 259, and 290, i.e. in lactation mo 1–10, times the herds' milk price from the NDFR (Table 2). To calculate average herd yields per month,

Table 1. Herd average production variables taken either from the Norwegian Dairy Herd Recording System for cows or from the questionnaire of Storli et al. (2017), except for roughage intake for heifers, pregnant heifers and cows, which were calculated values from the TINE OptiFôr clients in NorFôr (Volden, 2011).

	Herd												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Production variables													
Age at culling, mo	55	62	54	61	55	60	54	57	51	55	52	58	64
Age at first calving, mo	26	26	24	25	24	26	27	26	25	27	25	26	27
1st parity slaughter weight, kg	252	284	254	252	271	252	256	276	246	247	262	242	247
Adult slaughter weight, kg	277	302	261	296	286	273	268	280	255	253	269	255	258
Milk, liters, calf, d^{-1}	3.4	6.0	3.8	2.8	5.4	4.4	4.2	3.3	4.5	8.0	4.0	3.8	3.6
Concentrate[a], calf, MJ·d^{-1}	5.6	12.2	8.9	6.1	6.1	7.0	7.0	7.4	12.2	8.6	7.7	8.6	9.9
Roughage, calf, MJ·d^{-1}	12.6	10.1	10.2	12.1	14.1	11.2	11.1	10.9	8.0	10.0	11.0	10.0	9.6
Concentrate, heifer, MJ·d^{-1}	7.6	11.8	10.6	0.0	3.7	4.4	3.0	10.8	12.5	11.2	12.2	10.7	6.5
Roughage, heifer, MJ·d^{-1}	30.5	31.1	27.6	38.0	37.1	33.2	36.1	30.9	24.7	26.4	27.3	26.1	31.9
Concentrate, pregnant heifer, MJ·d^{-1}	1.5	4.2	1.6	0.5	0.3	4.4	0.7	3.1	2.3	6.4	3.5	0.5	3.2
Roughage, pregnant heifer, MJ·d^{-1}	54.9	57.9	56.3	56.4	60.8	52.2	56.1	57.6	53.7	46.5	53.0	54.3	52.0
Concentrate, cow, MJ·d^{-1}	46.9	47.9	56.0	46.2	36.9	40.3	39.2	50.0	54.4	56.1	53.2	55.4	47.3
Roughage, cow, MJ·d^{-1}	71.2	84.8	77.4	86.2	80.2	81.2	73.5	78.7	68.4	71.7	74.7	72.1	68.2
Lifetime milk yield, kg[b]	19,640	27,985	24,506	27,384	19,738	24,004	16,723	23,559	18,460	20,869	19,978	24,443	22,785

[a]MJ = Net energy growth for calves and heifers, net energy lactation for cows.
[b]Herd average lifetime milk yield from a test-day model based on monthly test-day yields.

Table 2. Average costs per animal per herd and unit prices in Norwegian kroner (NOK) as given in the Norwegian Dairy Herd Financial Recording database, except for type of concentrates obtained from Storli et al. (2017) with prices from the TINE OptiFôr client in NorFôr (Volden, 2011).

	Herd												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Costs													
Recruitment, in 1000 NOK	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Veterinary, calves and heifers, mo^{-1}	49.3	78.3	78.8	40.0	45.9	63.1	56.5	60.0	77.0	79.8	41.3	75.6	68.3
Veterinary, cows, mo^{-1}	103.2	155.9	124.3	75.3	95.0	120.5	105.3	94.5	135.5	73.7	107.4	87.3	109.9
Sundry, calves and heifers, mo^{-1}	13.1	15.0	8.0	22.8	12.6	10.8	6.0	16.9	10.9	10.9	31.9	22.1	12.9
Sundry, cows, mo^{-1}	124.3	122.8	93.1	80.2	44.1	50.9	32.8	88.3	50.7	68.4	71.8	44.5	52.5
Roughage[a], MJ^{-1}	0.228	0.197	0.279	0.446	0.391	0.247	0.480	0.487	0.264	0.404	0.618	0.493	0.446
Concentrate, calves, MJ^{-1}	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592
Concentrate, heifers, MJ^{-1}	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575
Concentrate, cows, MJ^{-1}	0.587	0.608	0.608	0.608	0.861	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.587
Unit prices													
Newborn calf, in 1000 NOK	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Milk[b], $liter^{-1}$	4.83	4.56	5.05	4.97	5.34	4.88	4.85	4.96	4.80	4.77	4.83	4.87	4.57
Meat, kg^{-1}	44.15	40.20	44.34	35.19	43.68	39.90	42.57	43.22	43.20	42.86	43.19	40.90	41.77

[a]MJ = Net energy growth for calves and heifers, and net energy lactation for cows.
[b]Equal to cost per liter of milk fed to calves.

we used a test-day model per lactation with fixed regression coefficients of 1st to 3rd order Legendre polynomials, and random regression coefficients of 0 to 2nd order, as we have previously described in detail (Storli et al., 2017). Over the last two decades, Legendre polynomials have frequently been used to model lactation curves (Schaeffer, 2016), and we used the SAS® MIXED procedure (SAS/STAT software; SAS inc., Cary, NC) for this purpose. Heterogeneous and independent variances were assumed for three periods of lactation (1–50, 51–150 and >150 DIM).

Dairy cow lifetime profit

Monthly costs and income were discounted and summarized to a DCLP corresponding with the starting point of the investment period, i.e. the birth of a heifer calf. This was done in each of the 13 herds using the following expression (see, e.g. Konstantin & Konstantin, 2018):

$$\mathrm{DCLP} = \sum_{t=0}^{T}\left[\frac{(I_t - E_t)}{(1+r)^t}\right] + \frac{S}{(1+r)^T} \quad (1)$$

where I is monthly revenue, E is monthly cost, t is a monthly index, r is the discount rate, set to 3.5% p.a., corresponding to the current short-term nominal credit rate for agriculture in Norway. S is the slaughter value of the cow when culled, and T is the herd average lifetime in mo. Variables contained in I are sales of newborn calves and milk, those in E are costs of buying a new replacement calf as well as feed, veterinary, and sundry costs. For further details on costs and revenues we refer to Appendix.

Profit as monthly annuity equivalent value

Using expression (2) below, we converted the DCLP for the average dairy cow in a given herd into a monthly annuity equivalent value (MEQ), as described for example by Konstantin and Konstantin (2018). This conversion standardizes the DCLP, which is necessary because of the unequal length in herd average lifetime. The MEQ is the monthly amount of cash demanded by the farmer to render him/her indifferent whether to choose the MEQ or the uneven cash flow from the heifer investment over the same period. If rearing of a new heifer calf starts immediately after a cow is culled, and this is a perpetual swirl of events, the MEQ is the value generated each month as the opportunity cost of capital, calculated as:

$$\mathrm{MEQ} = \mathrm{DCLP}\left(\frac{r*(r+1)^T}{(1+r)^T - 1}\right) \quad (2)$$

where DCLP, r, and T are defined as in expression (1).

Variables associated with the monthly annuity equivalent value

With the relatively high number of possible explanatory variables compared to the number of observations, as in this study, statistical learning methods have advantages compared with conventional statistical methods. One approach is to use a shrinkage method such as the Lasso regression (least absolute shrinkage and selection operator) (Hastie et al., 2009). In Lagrangian form the lasso problem can be written:

$$\hat{\beta}_{\text{lasso}} = \text{argmin}_{\beta}\left\{\frac{1}{2}\sum_{i=1}^{N}\left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j\right)^2 + \lambda\sum_{j=1}^{p}|\beta_j|\right\}$$

The Lasso uses $\sum_{j=1}^{p}|\beta_j|$ as penalty, and λ controls the amount of shrinkage. The Lasso regression fits a model involving all p predictors, but shrinks the coefficient estimates towards zero. Some estimates are forced to be exactly equal to zero, yielding a sparser model. Thus, the Lasso performs variable selection, which is useful to exclude the least important variables from a multiple regression model.

The relationship between MEQ and the 53 recorded and estimated variables given in Table 3 was explored as follows: Initially, we standard normalized the variables with the PROC STDIZE procedure in SAS® followed by the SAS® PROC GLMSELECT procedure with the Lasso selection option with the LSCOEFFS sub-option. This sub-option uses Least Angle Regression (LAR) to determine the sparse model and ordinary least squares regression to obtain the regression coefficients and associated test statistics. The LAR algorithm searches solutions over a set of λ values (Hastie et al., 2009). The Schwarz Bayesian information Criterion was used as stop criterion. Then, we performed an exploratory factor analysis (EFA) using the PROC FACTOR procedure in SAS®. In a setting with many production-economic parameters affecting the profit of a dairy operation, EFA with principal components (see, e.g. Johnson & Wichern, 2002) can be an efficient means to reduce dimensionality and identify underlying patterns (Atzori et al., 2013). This is a multivariate method used to interpret the correlation structure among the 53 variables and to estimate their factor scores for subsequent regression analysis. The EFA is based on the factor model in which the observations are postulated linearly dependent upon the matrix product of unobservable factors and their factor loadings, in addition to an error term (see, e.g. Johnson & Wichern, 2002). Factor loadings indicate to what degree they relate to a factor and range from 0 to 1. *A priori* to the analysis, we only considered to interpret loadings ≥ |0.40| (Pett et al., 2003). To extract factors, we used the principal component method where each variable's largest absolute correlation with any other variable was used as the prior communality estimate. The number of factors was determined by withholding factors with eigenvalues greater than 1, known as the

Table 3. Description of the 53 variables used to explain the monthly annuity equivalent value (MEQ).

No.	Variable	Description
1	Cows	Number of herd cow-years, equal to sum of cow-days divided by 365, from NDHRS
2	AFC	Age at first calving, mo
3	FC_BW	Estimated first calving BW, kg
4	AAC	Age at culling, mo
5	Slwt	Carcass weight at slaughter, kg
6	C_mfeed	Milk feed costs, calf, 0–3 mo[a]
7	C_conc	Concentrate costs, calf, 0–3 mo
8	C_RG	Roughage costs, calf 0–3, mo
9	C_Vet	Veterinary costs, calf, 0–3 mo
10	C_sun	Sundry costs, calf, 0–3 mo
11	H_conc	Concentrate costs, heifer, 3 mo to pregnancy
12	H_RG	Roughage costs, heifer, 3 mo to pregnancy
13	H_Vet	Veterinary costs, heifer, 3 mo to pregnancy
14	H_sun	Sundry costs, heifer, 3 mo to pregnancy
15	PH_conc	Concentrate costs, pregnant heifer
16	PH_RG	Roughage costs, pregnant heifer
17	PH_Vet	Veterinary costs, pregnant heifer
18	PH_sun	Sundry costs, pregnant heifer
19	L1_conc	Concentrate costs, cow, lactation 1
20	L1_RG	Roughage costs, cow, lactation 1
21	L1_Vet	Veterinary costs, cow, lactation 1
22	L1_sun	Sundry costs, cow, lactation 1
23	L1_income	Milk income, cow, lactation 1
24	L2_conc	Concentrate costs, cow, lactation 2
25	L2_RG	Roughage costs, cow, lactation 2
26	L2_Vet	Veterinary costs, cow, lactation 2
27	L2_sun	Sundry costs, cow, lactation 2
28	L2_income	Milk income, cow, lactation 2
29	L3_conc	Concentrate costs, cow, lactation 3
30	L3_RG	Roughage costs, cow, lactation 3
31	L3_Vet	Veterinary costs, cow, lactation 3
32	L3_sun	Sundry costs, cow, lactation 3
33	L3_income	Milk income, cow, lactation 3
34	Sl_income	Carcass value, cow^{-1}
35	ADG1	ADG, g/d, 5–10 mo (Storli et al., 2017)
36	ADG2	ADG, g/d, 10–15 mo (Storli et al., 2017)
37	ADG3	ADG, g/d, 15–21 mo (Storli et al., 2017)
38	CR	Culling rate, from NDHRS
39	SqADG1	$(\text{Variable } 35)^2$
40	SqADG2	$(\text{Variable } 36)^2$
41	SqADG3	$(\text{Variable } 37)^2$
42	ADG_tot	Weighted ADG, g/d, 5–21 mo, (5/16 variable 35)+(5/16 variable 36)+(6/16 variable 37)
43	RC_mo_BC	Rearing costs per mo birth to calving, Σ variables 6–18/AFC
44	RC_mo_LT	Rearing costs per mo life, Σ variables 6–18/AAC
45	RC_mo_PLT	Rearing costs per mo productive life, Σ variables 6–18/(AAC-AFC)
46	SI_I_mo_LT	Carcass income per mo life, variable 34/AAC
47	SI_I_mo_PLT	Carcass income per mo productive life, variable 34/(AAC-AFC)
48	L1_C_mo	Lactation 1 costs per mo, Σ variables 19–22/12
49	L1_I_mo	Lactation 1 milk income per mo, variable 23/12
50	L2_C_mo	Lactation 2 costs per mo, Σ variables. 24–27/12
51	L2_I_mo	Lactation 2 milk income per mo, variable 28/12
52	L3_C_mo	Lactation 3 costs per mo, Σ variables. 29–32/(AAC-AFC-24)
53	L3_I_mo	Lactation 3 income per mo, variable 33/(AAC-AFC-24)

Note: Variables 2–53 are herd averages, and L3-variables are affected by culling, which takes place in 3rd lactation for all herds.
[a]All income and cost variables in Norwegian kroner.

Kaiser–Guttman criterion (O'Rourke & Hatcher, 2013). A promax rotation was chosen to better facilitate the interpretation of the factors. The variance explained by each factor was calculated by summarizing the squared loadings of the factor and dividing by the total number of variables (here 53). Finally, we tested the identified, independent factor scores, with mean zero and variance one, for their effect on MEQ. We applied the SAS® PROC GLMSELECT procedure with forward selection of variables ($P \leq .05$, for entry into the model).

For both Lasso and EFA the coefficient of determination of prediction was computed using PROC REG in SAS® as:

$$R_p^2 = 1 - \frac{\text{PRESS}}{\text{SS}_{\text{tot}}}$$

where $\text{PRESS} = \sum_{i=1}^{n} (y_i - \widehat{y_i})^2$, $\widehat{y_i}$ is the predicted MEQ-value for herd i, and SS_{tot} is the total sum of squares. The R_p^2 is an estimate of the fraction of variance in MEQ explained by the model in the prediction of missing observations under leave-one-out cross-validation.

Results

Table 4 gives rearing and production costs in addition to milk and slaughter income for the average animal in each herd discounted to a present value at time of birth. The table also shows the calculated DCLP and MEQ values per herd. The mean MEQ value was NOK 761.8, with large variation between herds (range 325–1198) as was the case for most variables in Table 4.

The Lasso selected 4 of the 53 variables in Table 3. The model was significant ($F = 18.4$) and explained 85% of the variance (adjusted $R^2 = 0.85$, Table 5). The four variables were rearing costs per month of productive lifetime, roughage costs for heifers from 3 mo of age until pregnancy, AFC, and 1st lactation milk income per mo. The coefficient of determination of prediction (R_p^2) was 0.58 (Table 5).

The EFA identified nine factors (Table 6), with respectively 18, 16, 14, 10, 13, 8, 4, 9, and five variables with loadings above |0.4|. Table 5 shows the results from an ordinary least-squares regression with forward selection of the nine factor scores on MEQ. The models' F was 21.4 and adjusted $R^2 = 0.77$. Two factors, one discussed below as a factor related to roughage costs and a second combining high milk yield and calving at an early age, were chosen by the model. The (R_p^2) was 0.66 (Table 5).

Discussion

An important finding from this pilot study was the considerable variation in DCLP and MEQ values between the herds (Table 4). Consequently, the material should make it possible to identify causes of differences in profit.

The Lasso regression identified 4 variables that affected MEQ (Table 5) with an adjusted R^2 of 0.85. Although this illustrates a statistically good model fit, the chosen variables are not straightforward to interpret at a practical level. Therefore, to get a more fine-grained picture of the underlying explanatory patterns, we performed an EFA and regressed the factor scores on the MEQ.

The EFA revealed nine factors with eigenvalues above 1 (Table 6). Five (variables # 8, 12, 16, 20, and 25, Table 6) of 18 variables with loadings > |0.4| included in factor 1 had a direct relation to roughage costs in the entire

Table 4. Herd average costs and income discounted to present value, with dairy cow lifetime profit (DCLP) and monthly annuity equivalent (MEQ); all in Norwegian kroner per animal per herd.

	Herd												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Rearing costs													
New calf	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Milk feed	1486	2499	1770	1286	2649	1975	1846	1511	1970	3484	1765	1706	1505
Concentrate	2348	4120	2887	405	1136	2102	478	3446	3789	4282	3637	3089	2684
Roughage	6371	5669	7078	13,533	11,846	6981	13,153	13,964	6384	9924	15,604	12,704	12,686
Veterinary	1237	1964	1829	967	1066	1583	1137	1505	1860	2076	997	1898	1778
Sundry	329	376	187	551	293	270	120	424	263	284	770	556	335
Lactation costs													
Concentrate	21,742	28,379	27,858	27,440	26,707	22,559	21,045	25,532	23,598	25,928	23,927	29,218	27,694
Roughage	12,749	16,179	17,683	37,269	26,540	18,376	28,837	32,229	12,879	22,019	34,043	30,768	29,364
Veterinary	2670	4957	3340	2400	2636	3629	2808	2606	3164	1838	2602	2482	3575
Sundry	3215	3903	2503	2558	1223	1533	874	2435	1184	1705	1740	1266	1708
Income													
Calves born	6729	6729	6767	6748	6767	6729	6709	6729	6748	6709	6748	6729	6709
Milk	84,469	112,972	110,763	120,716	94,050	103,696	85,059	103,791	79,551	88,688	86,455	105,555	91,890
Slaughter	10,476	10,193	9941	7970	10,701	9198	9801	10,307	9545	9288	10,038	8857	8996
DCLP	47,027	59,348	59,838	46,525	50,989	57,539	19,717	34,674	38,252	30,646	15,656	34,954	23,765
MEQ	926	1046	1198	833	1004	1045	395	660	807	603	325	655	407

Table 5. Estimates (SE) of regression coefficients as obtained by either Lasso or Exploratory Factor Analysis (EFA) on respectively, the 53 original variables or the underlying factor scores.

Step	Source	Estimate	SE	SBC	F	P	Adjusted R^2	R_p^2
0	Intercept	761.8	–	148.1	0	–	–	–
1	RC_mo_PLT[a]	−147.2	–	139.8	14.2	–	0.52	–
2	H_RG[b]	−84.8	–	138.2	10.8	–	0.62	–
3	AFC[c]	−83.1	–	130.5	18.0	–	0.81	–
4	L1_I_mo[d]	70.7	–	128.1	18.4	–	0.85	0.58
0	Intercept	761.8	37.0	–	0	–	–	–
1	Factor 1[e]	−231.1	39.4	–	11.2	0.006	0.46	–
2	Factor 7[f]	157.3	39.2	–	16.1	0.002	0.77	0.66

Notes: In Lasso, a hybrid version of Least Angle Regression (ordinary least-squares for determination of coefficients in a second step) was used, while EFA utilized forward selection of variables. In Lasso, the Schwarz Bayesian information Criterion (SBC) was used to select the final model, while forward selection with level of significance for entry into the model of 0.05 was used for EFA. In each step, the variable added with the models' F, the variables' P, and the adjusted R^2-values are given where relevant. In the last step the predicted R^2 (R_p^2) is given.
[a]RC_mo_PLT = rearing costs per mo productive life.
[b]H_RG = Roughage costs, heifer, 3 mo to pregnancy.
[c]AFC = Age at first calving, mo.
[d]L1_I_mo = Lactation 1 milk income per mo.
[e]Factor 1 = Cost factor related to roughage costs.
[f]Factor 7 = Factor combining high milk yield and early calving.

rearing period and in the first and second lactation (but not in lactation 3, see factor 2 below). Another six variables had a strong indirect relation to roughage costs (variables # 43–45, 48, 50, and 52, Table 6). Three of the remaining seven factors loaded positively on sundry costs in the rearing period (variables # 10, 14, 18, Table 6), while veterinary costs loaded negatively, especially in lactation 1 and 2 (variables # 9, 17, 21, and 26), which suggests that a high roughage intake results in reduced veterinary costs. One possible consequence of a low roughage intake is rumen acidosis, see, e.g. Kleen et al. (2003). Thus, we interpret factor 1 as mainly related to roughage costs. Clearly, there was a larger variation in roughage costs than in the other cost variables (Table 4), illustrated for example by a coefficient of variation (CV) as large as 34% for dairy cows compared with a CV of only 11% for concentrates. The significant effect of the roughage costs factor on MEQ (P = .006, Table 5) combined with the negative regression coefficient means that increased roughage costs, i.e. cost per MJ times roughage intake, would significantly reduce profit. This is consistent with the findings of Heinrichs et al. (2013) who reported the variation in feed costs to account for around 75% of heifer-rearing costs, or 15–20% of total milk production costs (Heinrichs, 1993). In the present study, total feed costs made up as much as 89% of variable costs of rearing, of which 69% were roughage costs (Table 4). Had fixed costs, e.g. for housing, been included in the analysis these percentages would obviously have decreased and results approached those of Heinrichs (1993) and Heinrichs et al. (2013). Our study further showed that the variation in the roughage costs factor explained more (46%) of the variation in MEQ than the roughage costs considered by Hansen et al. (2005) (some 20–25%), most likely because we were able to calculate the roughage intake. Thus, we had far more detailed information on roughage costs than what Hansen and coworkers could obtain, which was solely based on roughage unit price extracted from the NDFR. Additionally, the roughage costs used by Hansen et al. (2005) was contained in a number of their variables, as was also discussed by the authors. This clearly demonstrates that the results are highly dependent on the assumptions made in the economic analysis, but also shows that the roughage costs are a major determinant of MEQ in dairy production. Roughage costs are also the cost the farmer can influence the most. However, our high marginal R^2-value (0.46) from this factor could also result from the fact that roughage costs in the NDFR data used in our calculations included for example machinery-, harvesting-, and storage costs. Nevertheless, one unit (1 SD) change of the factor score would change MEQ by 231 NOK per animal and month. This compares well with the MEQ-range given in Table 4, underpinning the importance of keeping roughage costs low to improve dairy profit. A high score of the roughage costs factor would be due to either a high roughage intake or a low cost per MJ of roughage. To reduce roughage costs, we would advise farmers to produce high quality roughage at a low cost per MJ. A recent study on 184 Norwegian dairy farms showed that a high harvesting capacity in MJ of roughage harvested per hour, a high roughage yield and dry matter content together with a high quantity of roughage harvested per farm reduced roughage costs per MJ (Hansen, 2019).

Factor 7 loaded strongly positive on variables related to lactation 1 income (variables # 23, and 49, Table 6), but also had a high negative loading on AFC (variable # 2, Table 6). The latter relation means that calving at a younger age would lead to earlier return on investment, which is synonymous with reduced effect of discounting. Thus, we interpret factor 7 as discounted income from milk, i.e. a factor combining high milk yield and early return on investment (early calving). This could be obtained by farmers applying a well-planned heifer rearing strategy (see, e.g. Salte et al., 2020). The scores for this factor regressed positively on our indicator of profit, MEQ ($P = .002$, Table 5). One SD increase of the factor score would increase MEQ by 157 NOK per animal and month. Our results are in line with the results of Pirlo et al. (2000), Hultgren et al. (2011), and Heinrichs et al. (2013). In an economic context our result corresponds with a shorter cash conversion cycle, which is known to positively affect profitability (Ebben & Johnson, 2011; Enqvist et al., 2014). The cash conversion cycle is a measure referring to the time between a producers' disbursement when buying raw

Table 6. Promax-rotated principal component estimates of factor loadings of the 53 variables on basis of a 9-factor model with eigenvalues > 1.

No.	Variable[a]	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
1	Cows	−0.02	−0.01	0.16	0.21	0.08	0.70	0.14	0.07	−0.33
2	AFC	0.02	0.12	0.25	−0.36	0.12	−0.22	−0.62	−0.01	0.12
3	FC_BW	0.01	0.09	−0.05	0.06	0.20	0.89	0.09	0.18	0.14
4	AAC	−0.14	0.95	0.04	−0.16	0.42	0.03	−0.15	0.14	−0.03
5	Slwt	−0.22	0.23	−0.19	0.12	0.39	0.85	0.00	0.28	0.11
6	C_mfeed	−0.11	−0.24	0.44	−0.28	−0.11	0.28	−0.01	−0.18	−0.18
7	C_conc	−0.27	0.05	0.82	0.32	−0.24	0.10	−0.10	0.10	0.24
8	C_RG	0.90	−0.08	−0.57	−0.07	−0.14	−0.14	0.09	−0.21	−0.18
9	C_Vet	−0.42	0.01	0.90	−0.08	−0.28	−0.05	−0.04	−0.04	0.16
10	C_sun	0.74	0.13	−0.16	0.51	0.11	−0.23	0.37	0.44	−0.27
11	H_conc	0.05	−0.27	0.80	0.38	−0.12	0.02	0.17	0.43	−0.22
12	H_RG	0.86	0.19	−0.47	−0.21	−0.06	−0.26	−0.03	−0.21	−0.17
13	H_Vet	−0.33	0.17	0.92	−0.05	−0.07	−0.11	0.00	0.14	−0.12
14	H_sun	0.71	0.19	−0.06	0.49	0.15	−0.26	0.35	0.49	−0.33
15	PH_conc	−0.06	0.00	0.63	−0.15	0.36	0.06	−0.11	0.20	−0.11
16	PH_RG	0.93	−0.08	−0.43	0.00	−0.24	−0.20	0.07	−0.22	−0.08
17	PH_Vet	−0.42	0.01	0.89	−0.08	−0.28	−0.05	−0.03	−0.04	0.16
18	PH_sun	0.74	0.13	−0.16	0.51	0.11	−0.23	0.38	0.44	−0.27
19	L1_conc	0.28	−0.14	0.58	0.48	−0.36	−0.50	0.29	0.46	−0.13
20	L1_RG	0.94	−0.07	−0.42	−0.16	−0.19	−0.17	0.15	−0.22	−0.10
21	L1_Vet	−0.59	−0.01	0.45	0.51	0.16	0.51	−0.20	0.13	0.47
22	L1_sun	−0.28	0.12	0.16	0.18	0.15	0.26	0.24	0.90	0.01
23	L1_income	0.07	0.12	0.15	−0.02	−0.13	−0.05	0.93	0.38	0.12
24	L2_conc	0.17	−0.19	0.26	0.00	−0.84	−0.15	0.05	−0.23	0.09
25	L2_RG	0.91	−0.13	−0.44	−0.14	−0.24	−0.21	0.05	−0.21	0.12
26	L2_Vet	−0.56	−0.10	0.34	0.40	0.06	0.50	−0.36	0.00	0.66
27	L2_sun	−0.28	0.10	0.14	0.16	0.13	0.27	0.21	0.90	0.07
28	L2_income	0.10	−0.07	−0.10	−0.20	−0.44	−0.17	0.35	0.03	0.76
29	L3_conc	−0.05	0.80	−0.08	−0.17	0.20	0.34	0.36	−0.01	−0.24
30	L3_RG	0.36	0.84	−0.34	−0.08	0.17	−0.23	0.20	0.04	−0.20
31	L3_Vet	−0.38	0.82	0.22	0.11	0.43	0.36	−0.10	0.21	0.11
32	L3_sun	−0.29	0.73	0.12	0.05	0.29	0.32	0.15	0.59	0.12
33	L3_income	−0.10	0.91	−0.11	−0.10	0.35	0.17	0.34	0.18	−0.11
34	Sl_income	−0.19	−0.54	0.01	0.22	0.01	0.75	−0.14	0.06	−0.06
35	ADG1	0.03	−0.15	−0.01	0.97	0.08	0.14	−0.01	0.13	−0.12
36	ADG2	−0.36	0.37	−0.13	0.06	0.95	0.22	−0.23	0.02	−0.23
37	ADG3	−0.11	0.62	−0.18	−0.70	0.51	0.09	0.16	−0.24	−0.11
38	CR	0.16	−0.59	−0.19	−0.15	−0.17	0.20	−0.31	−0.54	0.45
39	SqADG1	0.08	−0.19	0.00	0.97	0.07	0.12	0.00	0.14	−0.13
40	SqADG2	−0.37	0.36	−0.12	0.05	0.95	0.21	−0.22	0.00	−0.21
41	SqADG3	−0.08	0.61	−0.20	−0.67	0.54	0.07	0.17	−0.22	−0.11
42	ADG_tot	−0.22	0.61	−0.22	−0.08	0.84	0.24	0.04	−0.13	−0.25
43	RC_mo_BC	0.94	−0.10	−0.02	0.07	−0.23	−0.14	0.23	−0.07	−0.29
44	RC_mo_LT	0.92	−0.37	0.04	0.05	−0.30	−0.17	0.13	−0.10	−0.22
45	RC_mo_PLT	0.86	−0.52	0.07	0.03	−0.33	−0.19	0.05	−0.11	−0.15
46	Sl_I_mo_LT	−0.03	−0.87	−0.03	0.25	−0.22	0.45	−0.01	−0.05	−0.03
47	Sl_I_mo_PLT	0.04	−0.96	0.01	0.17	−0.29	0.26	−0.12	−0.07	0.05
48	L1_C_mo	0.97	−0.12	−0.11	0.12	−0.32	−0.32	0.28	0.09	−0.12
49	L1_I_mo	0.07	0.12	0.15	−0.02	−0.13	−0.05	0.93	0.38	0.12
50	L2_C_mo	0.87	−0.17	−0.32	−0.09	−0.45	−0.19	0.06	−0.20	0.20
51	L2_I_mo	0.10	−0.07	−0.10	−0.20	−0.44	−0.17	0.35	0.03	0.76
52	L3_C_mo	0.80	−0.57	−0.21	0.14	−0.42	−0.08	0.30	−0.19	−0.09
53	L3_I_mo	0.30	−0.84	0.02	0.16	−0.40	−0.01	0.41	−0.03	0.02
Variance explained, %		12.96	10.09	6.99	5.34	6.89	5.25	4.26	4.49	3.36

Note: Factor loadings > |0.4| are underlined.
[a]Variables described in Table 3.

materials for production and the collection of cash when selling the finished product. This is comparable to invest in a heifer calf to collect future revenues from milk and meat production. Among the 13 herds, the average AFC varied from 24 to 27 months of age (Table 1), and our result points to an economic advantage of approaching an AFC of 24 months.

The first factor that did not significantly ($P > .05$) affect MEQ, but which we still chose to discuss since it might take effect with a larger number of herds under study is factor 2. This factor loaded positively on variables related to costs and milk income in lactation 3, AAC, and an increased growth rate during the first pregnancy that could produce a larger animal (variables # 29–33; 4; and 37, respectively, Table 6). However, it loaded negatively on variables related to the slaughter value of the cow, the culling rate, and costs and income per month in lactation 3 (variables # 34 and 46–47; 38; 52 and 53, respectively, Table 6). Bearing in mind that the average cow was culled during third lactation in all herds, we consider factor 2 to be mainly a profit factor in third lactation related to both costs and income. With increased AAC, which is negatively related to culling rate, more NR cows are likely to be overconditioned. Thus, they would obtain a lower slaughter value, which could explain the negative loading. In addition, older cows are more prone to disease as is illustrated by the high factor loading for veterinary costs in the third lactation (variable # 31, Table 6). This could incur treatment costs (see, for example, Heringstad et al., 2004; NDHRS, 2017). Looking at AAC Heikkila et al. (2008) obtained an economic optimum of 3.7–3.8 lactations per cow, which at the time was some 1.5 lactations more than the average cow longevity in Finland. However, this was in a situation with a lower meat price than the current Norwegian one. This implies that the high Norwegian meat price relative to the milk price is a driver for earlier culling, and a possible reason why we could not disclose any effect of productive lifetime. Additionally, delayed culling in third lactation would save total recruitment costs from the reduced housing area needed for the heifer cohort. The EFA suggested a possible positive covariation between growth rate during first pregnancy and AAC (both with positive loadings on the factor). This relationship could be explored by combining the growth data from Storli et al. (2017) with herd lifetime information for these animals that will shortly be available from the NDHRS.

In the following, the remaining non-significant factors are only summarily described in order to present a more comprehensive picture of quantities that were examined in our study. Factor 3 loaded heavily in particular on veterinary and concentrate costs during rearing (variables # 7, 9, 11, 13, 15, and 17, Table 6), but also on milk feed costs from birth to weaning (variable # 6, Table 6). This factor is thus interpreted as a herd management cost factor in early life. Factor 4 loaded the strongest on average daily BW gain (ADG) in the prepubertal period (variable # 35, Table 6), and would thus be a factor explained by early growth rate. The corresponding negative loading for growth during first pregnancy (variable # 37, Table 6) is biologically sound, because a high growth rate early in life that leads to a higher BW at e.g. time of successful insemination would reduce the need for heifers' own growth to achieve a target calving BW. The 5th factor had the highest positive loadings on post-pubertal ADG and total ADG (variables # 36, and 42, respectively, Table 6). Moreover, the factor loaded negatively on concentrate costs in lactation 2 (variable # 24, Table 6). We interpret this factor as reduced need for heifers' own growth in second lactation, resulting mainly from high post-pubertal ADG leading to a calving BW closer to mature BW. Factor 6 loaded the highest on estimated live weight at calving, carcass weight/slaughter income, and number of cows (variables # 3; 5 and 34; and 1, respectively, Table 6). A possible interpretation of factor 6 would be that it is a factor determined by cow mature BW. Factor 8 loaded the strongest on sundry costs in lactations 1, 2, and 3 (variables # 22, 27, and 32, respectively, Table 6), and is interpreted as a sundry cost factor. Finally, factor 9 loaded heavily on income in the 2nd lactation, but also on veterinary cost in 2nd lactation (variables # 28 and 26, respectively, Table 6). This might suggest that the factor is related to increased production.

Our study had more independent variables than observations, and additionally many of these variables were collinear. To alleviate this we conducted a variable reduction from the 53 inter-correlated and collinear variables down to 9 independent variables with EFA and used forward selection of variables to determine the model. Lasso also uses forward selection of variables and strives after a sparse model. Although thirteen farms are few, Monte Carlo simulation of Lasso has shown that a significant relationship found in a small sample will still be significant when the sample size increases (Riveros Gavilanes, 2020). However, there is a risk that the power in a small dataset is insufficient to disclose smaller significant effects. The significant factors related to roughage costs (factor 1) and early return on investment (factor 7), in decreasing order of importance, jointly explained 77% of the variance in MEQ values among herds. It should, however, be noted that the variance explained by each factor (Table 6) is a consequence of the number of variables mapping on that particular factor and not the importance of the variables on MEQ that has to be determined through a regression analysis. A challenge with the EFA is, however, the interpretation of the factors.

The variables identified by the Lasso (Table 5) were contained in the two factors identified by the EFA (Table 6). However, Lasso results alone would not give the same degree of understanding as obtained by EFA, especially for rearing costs per month of productive life and roughage costs from 3 mo of age to pregnancy for heifers, which both are not easily interpretable. Thus, advising farmers based on the Lasso results would be difficult because the variables lack consistency: For the first variable, the same results could be reached by changing variables contained in both the nominator and the denominator, whereas roughage costs in other periods than between 3 mo and pregnancy was not found important by Lasso. This would be expected when many explanatory variables are highly collinear, because Lasso selects one of them in favor of the others. Therefore, we are more confident with the results obtained by regression on factor scores, which gives us deeper insight into how these variables affect the DCLP. This is supported not only by EFA predicting more precisely(R_p^2, Table 5), but also because it shows a smaller loss in predictive ability than Lasso (11% vs. 27%). The factor scores in EFA absorb information from several independent variables and become more robust to observations in one single herd, whereas Lasso relies on the original variables only.

We assumed a discount rate of 3.5% p.a. If the discount rate increases, the factor combining high milk yield and early return on investment (early calving) would become more important, whereas the roughage costs factor would become less. With a decreased interest rate the opposite would occur. Another assumption was that farmers aim to maximize profit. . Other perspectives could have been taken. For example, including more fixed costs and farmers' own labor would allow exploring additional economic measures. Yet, goals and values differ among farmers; some want to keep the farm and the tradition alive, others to have an interesting work, be independent, earn money, and take care of the environment and the cultural landscape (Hansen & Greve, 2015).

Conclusions

An important finding from this pilot study was the considerable variation in DCLP and MEQ values among herds. Herd profit, defined by the monthly annuity equivalent value (MEQ), was positively affected by reduced roughage costs, which we interpret to be mostly influenced by cost per MJ. Thus, roughage costs should be kept low. The other factor found to positively affect MEQ was high milk yield combined with a lowest possible AFC, which was 24 mo in our data. This implies that the farmer should strive to keep age at first calving low without compromising first lactation milk yield.

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Appendix

Dairy cow lifetime profit, DCLP, equals discounted values of:

	Sales income from milk and livestock[1]
+	Sales income from value of newborn calves[1]
–	Variable costs (concentrate, roughage, veterinary and insemination, purchase of livestock, and consumables)
–	Rent of farmland for roughage production
–	Maintenance, insurance and depreciation of tractors and machinery used in roughage production
–	Hired labor in roughage production

[1]Income and costs associated with fattening bull calves were not included.