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How Do Herd's Genetic Level and Milk Quality Affect Performance of Dairy Farms?

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ABSTRACT

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The effects of genetic level and output quality characteristics on technical efficiency (TE) of dairy farms were studied. The average total relative breeding value (RBV) at herd level was considered a parameter of the genetic level and production potential of the main input (dairy cows), while somatic cell count (SCC) and milk composition characterise the quality of the main output (milk) of dairy farms. The analysis was carried out in two stages: data envelopment analysis was used in the first stage and fractional regression model in the second stage, combining the data collected by the Estonian Farm Accountancy Data Network with the data from the Estonian Livestock Performance Recording Ltd. The results showed that the TE of fully efficient dairy farms is positively affected by the total RBV ($P < 0.05$), number of dairy cows in the herd ($P < 0.05$), and negatively affected by the SCC ($P < 0.001$) and costs of purchased feed per kg of produced milk ($P < 0.01$). Among the inefficient farms, the TE was positively affected by the lifetime daily milk yield ($P < 0.05$), and average milk fat ($P < 0.1$) and protein ($P < 0.05$) contents. The results confirm our hypothesis that the genetic level of dairy herd and milk quality have a positive effect on the TE of dairy farms.

Keywords: genetic level; dairy farm; technical efficiency; data envelopment analysis; fractional regression model

Dairy sector is one of the most important sectors in Estonian agriculture. In 2017, milk accounted for 27.0% of the value of agricultural output. In the past 15 years, the structure of dairy farms has changed significantly. In 2000–2017 (as of Jan 14, 2018), the number of dairy herds registered for milk recording decreased by 82.4%, from 3211 to 564. The number of herds with up to 100 dairy cows plummeted by 86.6%, while the herds of over 100 cows suffered a loss of 31.7% (Estonian Livestock Performance Recording Ltd. 2018). Since 2001, when the EU pre-accession programme SAPARD was launched, Estonia has witnessed a rapid development in the construction and modernisation of cowsheds, as well as the adoption of total mixed ration feeding. According to Luik and Viira (2016), in 2012, approximately 54% of Estonian dairy cows were housed in cowsheds built or renovated in 2002–2012.

The structural change towards larger and more modern dairy farms has been associated with improved productivity in Estonian dairy sector (Jansik et al. 2014; Kimura and Sauer 2015). In 2000–2016, the productivity of dairy cows saw a substantial increase of 89.5% from 4660 to 8833 kg per cow. Although the number of dairy cows de-

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creased by 34.1%, total milk production stepped up by 24.1% from 629 600 to 781 399 t (statistics for 2017 – www.stat.ee). In the same period, the average annual growth in milk yield constituted 3.9% for the Estonian Holstein (EHF) cows and 4.1% for the Estonian Red (ER) breed. Higher milk yield has been seen as one of the factors behind the increase in the share of the EHF cows, from 70.3% in 2000 to 80.4% in 2016 (Estonian Livestock Performance Recording Ltd. 2018).

When comparing the dairy cows born in 2000 with those born in 2013, it appears that the main genetic trait that characterises the milk production potential, the average relative breeding value (RBV) for milk increased by an average of 2.0% per annum in EHF cows, while in ER cows, the average annual improvement was 1.5% (Figure 1). The increase in the RBV for milk largely explains (in case of EHF, R^2 = 0.95, in case of ER, R^2 = 0.96) the growth in the average milk yield. Therefore, in addition to the improved housing conditions for dairy cows, upgraded feeding systems, and an increase in the share of EHF cows in the total dairy herd, the rapid improvement in the average milk yields could be associated with the genetic progress of dairy cows.

Investments into new or modernised cowsheds and milking technology, as well as the decreased number of very small farms have contributed to improved milk hygiene. In 2000–2016, the milk quality measured by somatic cell count (SCC) improved, whereas the nationwide average SCC decreased from 402 SCC × 10^3/ml to 282 SCC × 10^3/ml. In 2003, 40.9% of the collected milk was of the elite grade, in 2017 elite grade milk accounted for 68.8% of the purchased milk (statistics for 2017 – www.stat.ee).

While the productivity of dairy cows has markedly improved, some negative aspects, such as increased culling rate and decreased number of lactations per lifetime of dairy cows that increase herd replacement costs, have become evident. The culling rate increased from 27.4 to 35.6% and the average productive lifetime decreased from 3.0 to 2.4 lactations between 2000 and 2016. In addition, average milk fat content decreased from 4.29% in 2000 to 4.00% in 2016, while average milk protein content increased from 3.28% to 3.36% (Estonian Livestock Performance Recording Ltd. 2018).

Low milk prices that were present for two years since the import ban enforced by the Russian Federation in August 2014 imposed strong pressure on the viability of Estonian dairy farms. Elimination of EU milk quotas in April 2015 has brought about structural adjustment in the whole EU dairy

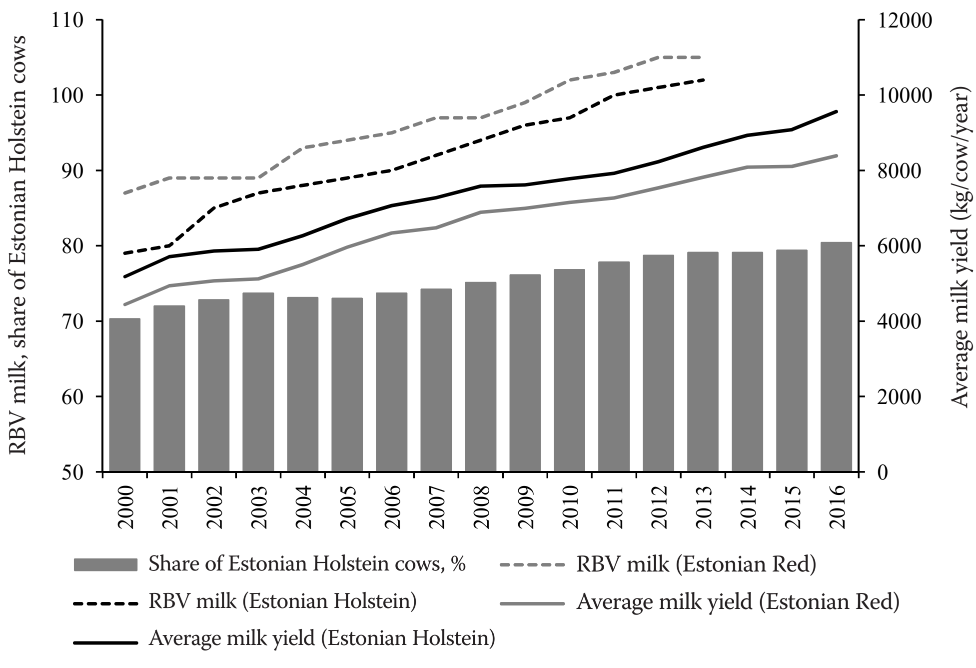

Figure 1. Relative breeding value of milk and average milk yield of Estonian Holstein and Estonian Red cows, and share of Estonian Holstein cows from 2000 till 2015
source: Estonian Livestock Performance Recording Ltd. (2018)

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sector. Improvements in productivity and technical efficiency (TE) are one of the key aspects in maintaining the competitiveness of dairy farms, while productivity can be defined as the quantity of production (output) divided by the quantity of input. Farrell (1957) defined the TE in two ways: as the ability of a farm to produce the maximum feasible output with a given bundle of inputs, or as the ability of a farm to use minimum inputs to produce a given level of output. Therefore, managers of dairy farms constantly need to seek ways to improve the TE of their farms along with productivity.

Breeding becomes more and more important in this process for several economic reasons. The main purpose of breeding programmes is to improve milk yield, milk fat, and protein contents, herd health and fertility, and achieve a smooth lactation curve. All these parameters affect the economic results of a dairy farm. Roibas and Alvarez (2010, 2012) found that the genetic potential of a herd contributes significantly to the profitability of dairy farms measured by milk sales minus variable costs, and milk fat and protein content that enables farms to receive higher milk prices, and that the increase in milk yield due to higher genetic index was greater in larger farms. They conclude that if milk prices are to remain low in the future, farmers need to use improved genetic breeds in order to retain profitability. In the study of Steine et al. (2008), seven breeding goals out of ten (milk, meat, mastitis resistance, fertility, udder, temperament and legs) had a significant positive effect on farm profits (value of milk, meat and subsidies minus costs of forage and concentrates). Ramsbottom et al. (2012) observed that the herd level economic breeding index was positively related to the net margin and gross revenue per cow and per litre of milk. Therefore, one could presume that the animals' genetic level (RBV) in combination with other production inputs affect the TE of dairy farms.

The objective of a performance evaluation is to evaluate the current farm operations internally and to benchmark them against similar farms or farm operations externally in order to identify the best practice. Such best practice can be empirically identified, and the efficient frontier can be estimated based on the observations at one farm over time or at similar farms in a specific time period (Zhu 2009). Productivity and TE are easy to calculate if there is only one output and one input. However, there are usually no such production units that produce only one output with one input. Therefore, in TE studies of agricultural producers, popular methods are those that allow to use several inputs and outputs in different units (e.g. Davidova and Latruffe 2007; Luik et al. 2009, 2011; Allendorf and Wettemann 2015).

One such method is the nonparametric piecewise linear programming method proposed by Farrell (1957), which received wider attention when Charnes, Cooper and Rhodes used the term Data Envelopment Analysis (DEA) for the first time in 1978 (Coelli et al. 2005). DEA can identify the efficient units, and results for inefficient units will show by how much each input can be reduced, or output increased, to produce an optimal output (Cooper et al. 2004). The advantages of DEA lie in its simplicity, diversity, its lack of a need for a specific functional form for relating inputs to outputs, and the fact that inputs and outputs can be measured in different units.

The main reason for choosing DEA over the Stochastic Frontier Analysis (SFA), which is a widely used parametric approach in dairy farm efficiency analyses (e.g. Cabrera et al. 2010), is the advantage that DEA allows to estimate the efficient frontier without knowing whether an output is a linear, quadratic, exponential or some other function of inputs (Coelli et al. 2005). Nevertheless, the DEA method does have some disadvantages. Namely, it is sensitive to measurement errors (Coelli et al. 2005) but, if the data are verified and the results are correctly interpreted, its advantages outweigh its disadvantages.

In order to comprehend the determinants of TE, the effects of contextual and environmental variables (variables over which manager has little or no control) need to be studied. In order to examine the effects of contextual and environmental variables on the TE of Estonian dairy farms, the recommendations of Coelli et al. (2005) and Banker and Natarajan (2008) to use a two-stage approach were followed. The first-stage analysis employed DEA and traditional inputs and outputs explained in the section Materials and Methods. In the second-stage of the analysis, the TE scores from the first stage were regressed against the contextual and environmental variables, as well as the indicators of milk quality and the herd's genetic level.

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The fractional regression model (FRM) was used in the second-stage analysis, as suggested by Papke and Wooldridge (1996), and Ramalho et al. (2010). The FRM helps overcome some of the problems related to the Tobit regression that is a limited dependent variable regression method frequently used in the second stage of DEA analyses (Hansson and Ohlmer 2008; Allendorf and Wettemann 2015). DEA estimates the TE scores in the interval (0, 1). However, zero values are usually not found. According to Ramalho and Ramalho (2011), the two-limit Tobit model should only be applied when there are observations in both limits. The FRM allows the accumulation of non-trivial probability mass at one end of the distribution, which is often the case in DEA. In addition, the FRM is more effective in analysing one- and two-part models, which is useful if the probability of observing a DEA score of unity is relatively large, or if the sources of farm efficiency differ from those of farm inefficiency. The first stage of the FRM uses a binary choice model, where the binary indicator has values of 0 for inefficient farms and of 1 for efficient farms. The second stage of the model is the fractional section that is estimated using only the sub-sample of inefficient farms (TE score < 1). DEA in combination with the FRM has not been used widely in recent agricultural studies, but taking into account its advantages, the FRM was considered more suitable than the widely used regressions Tobit and OLS.

Our hypothesis is that the average total RBV of the herd and better milk quality have a positive effect on the TE of dairy farms. Therefore, in order to improve TE, dairy farm managers should pay more attention to improving these indicators.

MATERIAL AND METHODS

The study focuses on integrating information about the genetic level of dairy herds, milk quality, and farm accounts in farm TE analysis. Annual farm level data from 2012 collected by the Estonian Farm Accountancy Data Network (FADN) (www.maainfo.ee) were used to calculate the TE scores of Estonian dairy farms. The FADN dataset provides information on production outputs, labour and capital inputs, variable and fixed costs, agricultural area, number of cows, and other relevant farm income and cost figures. The farm level RBV, milk production and quality data, and herd replacement statistics, were available for all Estonian dairy farms that participated in milk recording (Estonian Livestock Performance Recording Ltd. 2018; see also www.jkkeskus.ee). After integrating the FADN and milk recording datasets, data from 106 dairy farms was used in the analysis. The total number of cows in these farms was 20 797, from which 15 561 (74.8%) were of EHF breed.

To evaluate the TE of farms, the output-oriented variable returns to scale (VRS) model was used. A set of n farms was considered in order to express mathematically the VRS model (1). Each farm used m inputs to produce s outputs. Specifically, farm j used x_{ij} input i and produced y_{rj} output r. The TE measure, according to the VRS model, can be formulated as:

$$\theta^* = \max \theta \qquad (1)$$

subject to

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{i0},\ i = 1, 2, ..., m$$

$$\sum_{j=1}^{n} y_{ij}\lambda_j \geq \theta\, y_{r0},\ r = 1, 2, ..., s$$

$$\lambda_j \geq 0,\ j = 1, 2, ..., n$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

where:

θ = scalar

x, y = input and output quantities

λ = vector describing the contribution of the benchmark farms to the virtual farm on the frontier

Using the variables λ and θ, the model is solved once for each farm by looking for the largest radial contraction of the input vector x_i within the technology set. The obtained value of θ^* is the efficiency score for the n^{th} farm, with a value of 1, indicating a point on the frontier and hence a technically efficient farm (Coelli et al. 2005; Zhu 2009). The DEAP Version 2.1 software was used to evaluate the efficiency scores.

The most commonly used inputs in the TE analyses of dairy farms are the number of cows, area of agricultural land, labour, feed, and capital (e.g. Davidova and Latruffe 2007; Rasmussen 2010). In specialised dairy farms, there is a strong correla-

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tion between the number of dairy cows and milk output (R^2 = 0.984 in our sample); also, there is a strong correlation between the number of dairy cows and total sales revenue (R^2 = 0.970 in our sample). Milk revenue is the main source of income for specialised dairy farms. Due to the strong correlation between the number of cows and milk (total sales) revenue, the number of dairy cows was not included in the DEA analysis.

There is one aggregated output in the model, which is the total sales revenue of milk and dairy products, live animals, other agricultural production and services provided for other farmers (y_1). The model has five variables as inputs. Land (x_1) is measured as the farm's total utilised agricultural area in ha. Labour (x_2), measured in annual working hours, includes both paid and unpaid labour that has contributed to the work on the farm during the accounting year. Feed costs (x_3) include purchased feed (mostly concentrates). Total intermediate consumption (x_4) includes total specific costs and overheads (machinery and buildings, current costs, energy, contract work, and other direct inputs). Capital costs (x_5) include the depreciation of machinery and buildings. Table 1 provides the descriptive statistics on the outputs and inputs used in the DEA analysis.

The marked range of different variable values (e.g. minimum and maximum values for land size differ 64 times) can be explained by the dualistic farm structure in Estonia.

While farm accounts data are often used to determine the TE scores, in some studies, the contextual and environmental variables are gathered via additional surveys (e.g. Allendorf and Wettemann 2015). The following herd characteristics have previously been used in the studies of TE of dairy farms: age at first calving (Hansson and Ohlmer 2008; Allendorf and Wettemann 2015), calving interval (Hansson and Ohlmer 2008; Allendorf and Wettemann 2015), and length of dry period (Hansson and Ohlmer 2008).

In the second-stage analysis, the factors that affect the TE scores are divided into two groups: (*i*) herd related factors (difference in total RBV, cow's productive period, lifetime daily milk production per cow, number of dairy cows, farm manager's age, purchased feed); (*ii*) milk quality related

Table 1. Descriptive statistics of the variables for Data Envelopment Analysis and the second-stage analysis

	Unit	Min	Max	Mean	SD	Median
Output and inputs in Data Envelopment Analysis						
Total sales revenue (y_1)	Euro	20 587	3 237 984	569 663	723 503	189 818
Land (x_1)	ha	37	2 365	589	639	265
Labour (x_2)	h	2 150	141 500	26 985	32 436	9 163
Purchased feed costs (x_3)	Euro	1 399	404 349	89 297	100 129	39 993
Total intermediate consumption (excluding purchased feed) (x_4)	Euro	22 135	2 399 563	452 332	552 723	180 681
Costs of the capital (x_5)	Euro	1 246	926 248	119 522	172 147	39 422
Variables in the second-stage fractional regression model analysis						
Technical efficiency score of variable returns to scale model (TE_VRS)	score	0.464	1.000	0.863	0.143	0.910
Total relative breeding value (RBV_total)	points	–19.900	6.200	–1.983	3.758	–1.300
Productive period of dairy cows (Prod_per)	months	17.901	85.998	44.529	13.552	41.672
Milk production per cow's lifetime (Milk_day)	kg/day	4.874	15.653	11.057	2.178	11.100
Somatic cell count (SCC)	10^3/ml	121.000	918.000	341.415	130.134	319.000
Milk fat content (Milk_fat)	%	3.320	5.330	4.119	0.257	4.120
Milk protein content (Milk_protein)	%	3.080	3.510	3.341	0.087	3.340
Dairy cows *n* (Cow)	*n*	8.000	912.000	196.198	225.790	80.500
Purchased feed (concentrates) cost per kg milk (Purch_feed)	Euro/kg	0.008	0.158	0.065	0.036	0.065
Age of farm manager (Age)	years	20.000	79.000	51.311	11.952	52.000

SD = standard deviation

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factors (SCC, milk fat and protein content). The descriptive statistics of the explanatory variables are given in Table 1. Based on the strongest correlation with the TE score (R^2 = 0.430), the total RBV was selected as the indicator of the herd's genetic potential in the second-stage analysis. This selection was somewhat expected, since total RBV is composed of the breeding values of milk production (50%), udder health (25%), and conformation (25%) (Uba 2006).

There are two major dairy breeds in Estonia: EHF and ER. The RBV scores of these breeds are not directly comparable. Therefore, the herd level average RBV difference (dRBV) from the RBV national average was determined for each breed as follows:

$$dRBV_{i,j} = \overline{RBV_{i,j}} - \overline{RBV_j} \quad (2)$$

where:
i = farm
j = breed

The herd level average RBV difference from the national average is the weighted average RBV difference of both breeds:

$$dRBV_i = \sum_j dRBV_{i,j} \times \frac{cows_{i,j}}{cows_i} \quad (3)$$

where:
$cows_j$ = number of cows from the respective breed.

It is assumed that a higher total RBV reflects the better ability of dairy cows to convert feed into milk and the better milk hygiene; therefore, it should positively affect the farm TE. It is expected that longer productive periods of dairy cows and higher lifetime daily yields per cow have a positive effect on the TE of farms through lower herd replacement costs. It is assumed that better milk quality (lower somatic cell counts) and higher fat and protein contents in milk enable farms to market a higher proportion of the milk produced and receive a higher price for their milk, which in turn produces a positive effect on the farm TE. It is also presumed that larger farms are more efficient than smaller farms, and the same applies to farms with lower costs of purchased feed concentrates per 1 kg of milk. Furthermore, it was assumed that farms with younger managers are more efficient.

Upon comparing the specification tests of the different models, it was decided to base the analysis on the cloglog model, which was not rejected by any of the specification tests (of one- and two-part models) and had the highest R^2 value. In the first part of the two-part model, observations (farms) were divided into two groups based on their efficiency score: efficient (TE = 1) and inefficient (TE < 1) (i.e. it is a binary dependent variable model). The second stage of the two-stage model assesses how the explanatory variables affect inefficient farms (TE < 1). The 'frm' package of the R programme was used to estimate the parameters in the second-stage analysis.

RESULTS

The VRS value equal to 1 (100%) means that the farm is technically efficient and it is producing the maximum outputs per given inputs. According to VRS model, 33% of the dairy farms were technically efficient (Table 2). The average VRS score of dairy farms was 0.863. The most critical group of dairy farms (VRS < 0.59) contained 6 farms (5.7%).

From Table 2 it appears that the sales revenues per cow, average milk yield per cow, and total number of dairy cows were larger in those farms with a higher TE. In addition, more efficient farms used less agricultural land and labour per cow. Purchased feed (concentrates) costs and total intermediate consumption per dairy cow were higher in the least efficient and most efficient farm groups.

The results of the one-part FRM model (Table 3) showed that the estimated coefficient of the herd's average total RBV was positive but statistically insignificant. Farms with a longer productive lifetime of dairy cows showed lower TE ($P < 0.1$). In addition, milk production per day of a cow's lifetime had a positive and statistically significant effect on the farm TE ($P < 0.05$).

Of the factors that characterise the quality of milk, the somatic cell count (SCC) in milk had a statistically significant ($P < 0.01$) negative correlation on the farm TE – the higher the SCC (the poorer the milk hygiene), the lower the farm's TE. Milk fat content (%) had a significant ($P < 0.1$) positive effect on the farm TE. While the regression coefficient of milk protein content was also positive, its correlation with the farm TE was not statistically significant.

The size of the farm was a statistically significant ($P < 0.1$) factor that positively affected the TE,

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Table 2. Distribution of technical efficiency (TE) scores in the variable returns to scale (VRS) model and descriptive statistics of output and inputs per dairy cow

VRS TE score	Farms		Average cows *n*/farm	Total sales revenue (y_1) (Euro/cow)	Land (x_1) (ha/cow)	Labour (x_2) (h/cow)	Purchased feed costs (x_3)	Total inter-mediate consumption (x_4)	Costs of the capital (x_5)	Average annual milk yield (kg/cow)
	n	%					(Euro/cow)			
< 0.59	6	5.7	67	2188	4.7	155.7	595.4	2734	501.0	6171
0.60–0.69	7	6.6	98	1965	3.0	114.7	617.6	1855	417.7	6602
0.70–0.79	21	19.8	160	2364	3.4	161.2	518.6	2139	485.1	6857
0.80–0.89	16	15.1	143	2507	3.0	140.1	510.9	1963	416.1	7141
0.90–0.99	21	19.8	223	3083	2.9	126.1	679.7	2323	530.4	7843
1.00	35	33.0	267	3216	2.8	135.6	632.9	2464	418.9	7658

i.e. if the farm grows in size, so does its TE. The cost of purchased feed (concentrates) per kg of produced milk had a significant ($P < 0.05$) negative effect on the farm TE. This implies that farms that produce most of their feedstuffs themselves are more efficient. The estimated coefficient of farm manager's age was negative, but this estimate was statistically insignificant in the given model.

The estimates of the two-part model (Table 4) indicate that the total RBV had a significant ($P < 0.05$) positive effect in determining the technically efficient (TE = 1) farms, but it did not have a statistically significant effect on the TE in the group of technically inefficient (TE < 1) farms (second part of the model). However, the average partial effects of total RBV were positive and statistically significant ($P < 0.05$), implying that an increase in the total RBV by one point increases the TE score by 0.0284 points on average. While the productive period had a significant negative effect on the farm TE in the one-part model, its effect on the TE was insignificant in the two-part model. Average milk production per day of a cow's lifetime did not have a significant effect in determining technically efficient farms in the first part of the two-part model. However, in the second part, it had a significant ($P < 0.05$) positive effect on the farm TE among inefficient farms.

Of the milk quality and composition indicators, SCC had a statistically significant ($P < 0.001$) nega-

Table 3. Factors affecting technical efficiency of dairy farms according to the results of the one-part cloglog model

	Estimate	SD	*t*-Value	Pr (> |*t*|)	Average partial effects
Intercept	–2.7115	2.0021	–1.35	0.176	
Total relative breeding value (RBV_total)	0.0240	0.0150	1.57	0.111	0.0058
Productive period of dairy cows (Prod_per)	–0.0066	0.0037	–1.78	0.075†	–0.0016
Milk production per cow's lifetime (Milk_day)	0.0566	0.0240	2.36	0.018*	0.0137
Somatic cell count (SCC)	–0.0012	0.0004	–2.78	0.005**	–0.0003
Milk fat content (Milk_fat)	0.3309	0.1880	1.76	0.078†	0.0803
Milk protein content (Milk_protein)	0.7363	0.5251	1.40	0.161	0.1788
Dairy cows *n* (Cows)	0.0005	0.0003	1.78	0.076†	0.0001
Purchased feed (concentrates) cost per kg milk (Purch_feed)	–3.5025	1.4112	–2.48	0.013*	–0.8500
Age	–0.0025	0.0037	–0.67	0.504	–0.0006
Observations *n*			106		
R^2			0.381		

SD = standard deviation, Pr = probability

†$P < 0.1$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

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Table 4. Factors affecting technical efficiency of dairy farms according to the results of the two-part cloglog-cloglog model

	First part (Binary component: cloglog)				Second part (Fractional component: cloglog)				Average partial effects
	estimate	SD	*t*-value	Pr (> |*t*|)	estimate	SD	*t*-value	Pr (> |*t*|)	
Intercept	−3.2500	9.9749	−0.32	0.745	−3.9703	1.8130	−2.19	0.029*	
Total relative breeding value (RBV_total)	0.1791	0.0779	2.30	0.022*	0.0083	0.0133	0.63	0.532	0.0284**
Productive period of dairy cows (Prod_per)	−0.0217	0.0220	−0.98	0.326	−0.0038	0.0031	−1.21	0.227	−0.0037
Milk production per cow's lifetime (Milk_day)	0.0593	0.1161	0.51	0.609	0.0531	0.0256	2.07	0.038*	0.0141
Somatic cell count (SCC)	−0.0088	0.0025	−3.51	0.000***	−0.0004	0.0004	−0.98	0.328	−0.0014***
Milk fat content (Milk_fat)	1.3012	1.0302	1.26	0.207	0.2900	0.1503	1.93	0.054†	0.2278
Milk protein content (Milk_protein)	0.0769	2.5955	0.03	0.976	0.9985	0.4732	2.11	0.035*	0.1039
Dairy cows *n* (Cows)	0.0023	0.0010	2.41	0.016*	0.0003	0.0003	0.99	0.324	0.0004**
Purchased feed (concentrates) cost per kg milk (Purch_feed)	−19.2198	7.1995	−2.67	0.008**	−1.3428	1.3201	−1.02	0.309	−3.0936**
Age	0.0110	0.0177	0.62	0.536	−0.0052	0.0036	−1.45	0.148	0.0012
Observations *n*	106				71				
R^2	0.362				0.322				

SD = standard deviation, Pr = probability
†$P < 0.1$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

tive effect on the TE in the first part of the two-part model. Among technically inefficient farms, the SCC did not have significant effects on farm TE. Average partial effects revealed that reducing SCC in milk by 100×10^3/ml would result in an increase in farm TE by 0.14 points ($P < 0.001$). Milk fat content had a statistically weak ($P < 0.1$) positive effect on farm TE among the inefficient farms. The effect of milk protein content on the TE of dairy farms was statistically significantly positive ($P < 0.05$). However, average partial effects of both milk composition indicators were statistically insignificant.

While the number of dairy cows had a significant positive ($P < 0.05$) effect on the TE in the first part of the two-part model, its effect on the TE of inefficient farms was insignificant. However, its average partial effects were statistically significant ($P < 0.01$). Increasing the number of dairy cows by 100 would see the TE improved by 0.04 points.

Cost of purchased feed per kg of produced milk had a statistically significant ($P < 0.01$) negative effect on the TE of dairy farms in the first part of the two-part model. In the second part of the model, it did not have a significant effect. Average partial effects reveal that reducing the cost of purchased feed per one kg of produced milk by 0.01 Euro would bring about a 0.031 points higher TE score ($P < 0.01$). Age of the farm manager did not have any significant effects on the TE of dairy farms, neither in the first or second part of the two-part model.

DISCUSSION

According to the DEA results, the farms with more dairy cows are more efficient. The sales revenue per cow and milk yield per cow were also higher in high efficiency groups. In addition, less agricultural land and labour per cow were used in the high efficiency groups. Therefore, the results of the DEA analysis were in accordance with the expectations.

There were some significant results from the one-part FRM model. The longer productive lifetime of dairy cows had a negative effect on the TE, while the effect of the lifetime daily milk production was positive. This suggests that farmers should not simply aim for a longer productive lifetime or

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larger milk yield when striving for more efficient milk production, but they should maximise the average milk output per day of a cow's lifetime. Higher SCC in milk had a negative effect on the farm TE. In the analysis of North Rhine-Westphalian dairy farms, Allendorf and Wettemann (2015) reached the same conclusion. High SCC in milk causes milk to have a lower marketability and a lower price, resulting in low milk sales revenue and, in turn, a lower TE. High SCC (poor milk hygiene) could also indicate the lower managerial competence of the farm manager. The SCC in milk produced in Estonia has decreased in recent years (Estonian Livestock Performance Recording Ltd. 2018). To some extent, the decline in SCC can be attributed to the widespread introduction of modern technology and improved housing conditions. Of the two milk composition indicators, only milk fat had a positive effect on the Farm TE in the one-part FRM model. As explained by Roibas and Alvarez (2010; 2012), higher milk fat content enables farms to receive higher price for their milk, thereby improving their economic performance.

The size of dairy farms had a statistically significant positive impact on efficiency. The relationship between the size of the farm and its TE is explained by the scale effect. When the farm increases in size, so does its potential to use existing resources in increasingly optimal ways. Vasiliev et al. (2008, 2011) and Luik et al. (2009) addressed the differences between the TE in smaller and larger farms in Estonia. Tauer and Mishra (2006) and Lawson et al. (2004) also found that the size of the farm has a positive effect on efficiency due to increased cost-efficiency. The size has an important effect on productivity growth. Kimura and Sauer (2015) found that the total factor productivity growth was higher in larger Estonian dairy farms. This is in line with the trends in the structure of dairy farms: the number of small farms is decreasing rapidly.

The cost of purchased feed (concentrates) per kg of produced milk has a statistically significant negative effect on farm TE in the one-part FRM model. This suggests that in the sample farms, increase in the cost (and consumption) of feed concentrates is not accompanied by the equivalent or even higher increase in the output, and farms should seek to reduce their purchased feed costs in order to improve their TE.

Lawson et al. (2004) and Tauer and Mishra (2006) discovered that companies with younger managers are more efficient. Sipilainen et al. (2009) pointed out that the increasing age of the farm manager increases inefficiency, due to decreased investments in both physical and human assets. However, in this study, the farm manager's age had statistically insignificant effect on the farm TE.

Based on the two-part FRM model, it is concluded that there are differences in the significance of factors that determine fully efficient dairy farms and the TE in the group of inefficient farms. The significant determinants of fully efficient dairy farms included total RBV, SCC, and the number of cows and purchased feed costs.

In the group of inefficient dairy farms, the total RBV, SCC, number of dairy cows, and cost of purchased feed per kg of produced milk had no statistically significant effect on the farm TE. However, the average milk production per day over a cow's lifetime and milk fat and protein contents had a significant positive effect on the farm TE. Therefore, differentiating between fully efficient farms and technically inefficient farms in the two-part FRM model showed that there are differences between the determinants of TE in the two sub-groups of fully efficient and inefficient farms.

CONCLUSION

The results of this study show that the TE of fully efficient dairy farms was positively affected by the following factors: a higher total RBV, a lower cow's productive lifetime, a higher lifetime daily milk production, better milk hygiene (lower SCC). In the group of inefficient farms, those farms that achieved higher average milk fat and protein contents were technically more efficient. Among the characteristics of a farm and its management, the number of dairy cows (farm size) and the cost of purchased feed per kg of produced milk had a significant effect on the farm TE.

Therefore, the study confirmed the hypothesis that the genetic level of dairy herd and milk quality positively affect the TE of dairy farms. RBV embodies important information about the farm (productivity potential of the herd) and about the farm manager (knowledge and skills in selecting the breeding material). Future studies could consider the significance of this latter aspect.

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REFERENCES

Allendorf J.J., Wettemann P.J.C. (2015): Does animal welfare influence dairy farm efficiency? A two-stage approach. Journal of Dairy Science, 98, 7730–7740.

Banker T., Natarajan R. (2008): Evaluating contextual variables affecting productivity using data envelopment analysis. Operations Research, 56, 48–58.

Cabrera V.E., Solis D., del Corral J. (2010): Determinants of technical efficiency among dairy farms in Wisconsin. Journal of Dairy Science, 93, 387–393.

Coelli T.J., Rao D.S.P., O'Donell C.J., Battese G.E. (2005): An Introduction to Efficiency and Productivity Analysis. Springer US.

Cooper W.W., Seiford L.M., Zhu J. (2004): Handbook on Data Envelopment Analysis. Springer US.

Davidova S., Latruffe L. (2007): Relationships between technical efficiency and financial management for Czech Republic farms. Journal of Agricultural Economics, 58, 269–288.

Estonian Livestock Performance Recording Ltd. (2018): Results of Animal Recording in Estonia 2017. Eesti Põllumajandusloomade Jõudluskontrolli AS, Tartu, Estonia.

Farrell M.J. (1957): The measurement of productive efficiency. Journal of the Royal Statistical Society, Series A, 120, 253–290.

Hansson H., Ohlmer B. (2008): The effect of operational managerial practices on economic, technical and allocative efficiency at Swedish dairy farms. Livestock Science, 118, 34–43.

Jansik C., Irz X., Kuosmanen N. (2014): Competitiveness of Northern European dairy chains. MTT Economic Research, Agrifood Research Finland, Publications 116, Helsinki, Finland.

Kimura S., Sauer J. (2015): Dynamics of Dairy Farm Productivity Growth: Cross-Country Comparison. OECD Food, Agriculture and Fisheries Paper No. 87. OECD Publishing, Paris, France.

Lawson L.G., Bruun J., Coelli T., Agger J.F., Lund M. (2004): Relationships of efficiency to reproductive disorders in Danish milk production: a stochastic frontier analysis. Journal of Dairy Science, 87, 212–224.

Luik H., Viira A.-H. (2016): Feeding, milking and manure systems in Estonian dairy barns. Agraarteadus: Journal of Agricultural Science, 27, 92–107.

Luik H., Seilenthal J., Varnik R. (2009): Measuring the input-orientated technical efficiency of Estonian grain farms in 2005–2007. Acta Agriculturae Scandinavica, Section C – Food Economics, 6, 204–210.

Papke L.E., Wooldridge J.M. (1996): Econometric methods for fractional response variables with an application to 401 (K) plan participation rates. Journal of Applied Economics, 11, 619–632.

Ramalho E.A., Ramalho J.J.S. (2011): Alternative estimating and testing empirical strategies for fractional regression models. Journal of Economic Surveys, 25, 19–68.

Ramalho E.A., Ramalho J.S.S., Henriques P.D. (2010): Fractional regression models for second stage DEA efficiency analyses. Journal of Productivity Analysis, 34, 239–255.

Ramsbottom G., Cromie A.R., Horan B., Berry D.P. (2012): Relationship between dairy cow genetic merit and profit on commercial spring calving dairy farms. Animal, 6, 1031–1039.

Rasmussen S. (2010): Scale efficiency in Danish agriculture: An input distance-function approach. European Review of Agricultural Economics, 37, 335–367.

Roibas D., Alvarez A. (2010): The impact of genetic progress on the profits of dairy farmers. Journal of Dairy Science, 93, 4366–4373.

Roibas D., Alvarez A. (2012): The contribution of genetics to milk composition: evidence from Spain. Agricultural Economics, 43, 133–141.

Sipilainen T., Kortelainen M., Ovaska S., Ryhanen M. (2009): Performance of Finnish dairy farms and its determinants: A comparison of parametric, semiparametric, and nonparametric methods. Acta Agriculturae Scandinavica, Section C – Food Economics, 6, 173–184.

Steine G., Kristoffersson D., Guttormsen A. (2008): Economic evaluation of the breeding goal for Norwegian Red dairy cattle. Journal of Dairy Science, 91, 418–426.

Tauer L.W., Mishra A.K. (2006): Dairy farm cost efficiency. Journal of Dairy Science, 89, 4937–4943.

Uba M. (2006): Developments in genetic evaluation of dairy herds. Tõuloomakasvatus, 4, 23–26. (in Estonian)

Vasiliev N., Astover A., Motte M., Noormets M., Reintam E., Roostalu H., Matveev E. (2008): Efficiency of Estonian grain farms in 2000–2004. Agricultural and Food Science, 17, 31–40.

Vasiliev N., Suuster E., Luik H., Varnik R., Matveev E., Astover A. (2011): Productivity of Estonian dairy farms decline after accession to the European Union. Agricultural Economics – Czech, 57, 457–463.

Zhu J. (2009): Quantitative Model for Performance Evaluating and Benchmarking. Springer International Publishing.

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