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Technical Efficiency of Dairy Farms: An Empirical Study of Producers in Poland

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Abstarct:

Purpose: *The main objective of this article was to determine the technical efficiency of Polish dairy farms in 2008-2017, taking into account the dependence on the herd size, the milk yield of cows and the effects of scale.*
Design/Methodology/Approach: *The non-parametric DEA method based on the concept of border efficiency was used to assess technical efficiency. The research uses models assuming constant (CCR) and variable returns to scale (BCC). The source of the data was information collected by the Farm Accountancy Data Network (FADN) in Poland. Data came from farms specializing dairying (type 45), with more than 15 cows.*
Findings: *The results of the conducted research indicate a higher share of efficient farms using the model assuming variable returns to scale. The average efficiency ratio increased along with the increase in the size of the herd of cows and the improvement in the milk yields of cows.*
Practical Implications: *The results of this study will be used to determine rationally the combination of inputs in dairy production. The result of these activities is an increase of efficiency and the use of economies of scale. The article clearly presents among which farm groups exists the lowest efficiency (cow herd size and milk yield).*
Originality/Value: *The study fills a gap in approach methods to conducting research on dairy farm efficiency. On the one hand, the value of the article is built by the size of observation field, on the other – dairy farms classification by cow herd size and milk yield.*

Keywords: *Returns to scale, DEA, cow herd size, milk yield, outputs, inputs.*

JEL Codes: *D24, O13, Q12, Q13.*

Paper type: *Research article.*

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1. Introduction

One of the most important production on Polish farms is cow's milk, which in 2017 accounted to 16% of the global agricultural production in Poland. Milk production at the level of 13.7 million tons allowed Poland to take the 13th place in the world and the 5th in the EU in terms of the amount of milk produced. This was the result of many changes taking place on farms, mainly related to the concentration and intensification of production. In 2007-2016, the number of farms with cows decreased by 59% (from 656 000 to 267 000) and the number of cows decreased by 20%. An important factor affecting the milk volume produced on farms was the increase in milk yield of cows by 30%. The above changes were associated with the desire to improve the efficiency of production demonstrating the ability of farms to compete on the market.

In relation to a producer, production efficiency means either maximizing production from disposed production ratios or minimizing the expenditure on a given production. It can be assessed on the basis of reference to its most effective level, the so-called unit limit. One of the methods enabling such assessment is Data Envelopment Analysis – DEA, based on a non-parametric approach to creating an efficiency curve. This method has been used many times in research on the efficiency of dairy farms, among others, by Stokes *et al.* (2007), Balcombe *et al.* (2006), Kelly *et al.* (2012), Latruffe *et al.* (2012). The results of these researches on effectiveness were quite diverse, which was related to the assumptions made in the models (Mareth *et al.*, 2016; Minviel and De Witte, 2017; Minviel and Latruffe, 2017; Špička and Smutka, 2014; Rusielik and Świtłyk, 2012). The results of the analyses prove that efficiency is related to the amount of expenditure per unit of production (Michaličková *et al.*, 2013), with farm size and production intensity (Jiang and Sharp, 2015; Ma *et al.*, 2019). Research also indicates a link between farm efficiency and milk quality (Kelly *et al.*, 2013) and animal welfare (Allendorf and Wettemann, 2015). However, the conducted research did not clearly indicate the direction and strength of the impact of subsidies on the technical efficiency of farms (Latruffe *et al.*, 2016).

The aim of the study was to determine the technical efficiency of Polish farms specialized in dairy production using the DEA method. The analysis was expanded to include the study of scale efficiency and diversification of technical efficiency in groups of farms separated according to the herd size and milk yield.

2. Material and Methods

The source of factual data was the information collected by the European system for accountancy data collection from agricultural holdings – FADN (Farm Accountancy Data Network). The field of observation of the system is only commercial farms producing about 90% of the Standard Output (SO) value in a given country, which are classified according to economic size and agricultural type. According to the indicated typology, farms described as specializing in dairying (type 45) must meet the following conditions:

- over 75% share of dairy cows in total grazing livestock;
- over 10% share of grazing livestock in total grazing livestock and forage.

Source data from the Polish FADN were verified in terms of data consistency and purposefulness. An additional selection criterion was to have at least 15 dairy cows. The conducted research so far shows that farms that do not meet this condition can be considered as not achieving the farm income at the parity level in Poland (similar to that obtained in non-agricultural activity), which at the same time prompts them to be called farms with low development capacity (non-developmental farms). As a consequence of these activities, the number of farms ranged from 869 to 1308 and changed depending on the analysed year (2008-2017).

The determination of technical efficiency was based on the concept of its measurement presented by Coelli *et al.* (1998). It assumes that total economic efficiency is determined by technical and allocation efficiency, where technical efficiency is determined by the quotient of actual and the highest possible productivity. In addition, based on a specific set of data, one can specify an efficiency curve that will include objects with a certain degree of inefficiency that can be estimated using this curve.

To determine technical efficiency, the non-parametric Data Envelopment Analysis (DEA) method was used with the application of two input-oriented models (effectiveness is achieved by reducing expenditure while maintaining a certain level of results):

- CCR model assuming constant returns to scale;
- BCC model assuming variable returns to scale.

In the indicated models, it is assumed that the efficiency of a given production ratio is the quotient of a given input to the intended effect (Charnes *et al.*, 1978), and developing this into a multidimensional situation, it can be assumed that having *s* – outputs and *m* – inputs, the efficiency takes the form:

$$\frac{\sum_{r=1}^{s} u_r y_r}{\sum_{i=1}^{m} v_i x_i} = \frac{u_1 y_1 + u_2 y_2 + \ldots\ldots + u_s y_s}{v_1 x_1 + v_2 x_2 + \ldots\ldots + v_m x_m}, \tag{1}$$

where: y_r – output value, u_r – output weight, x_i – input value, v_i – input weight.

Reducing inputs and outputs to synthetic quantities makes it possible to calculate the technical efficiency coefficient. The linear programming task is solved for each object and the calculated efficiency coefficient is in the form of a maximized objective function, where outputs weights and input weights are optimized variables. Charnes *et al.* (1978) presented a way of solving this function using the concept of Farell and Fieldhouse (1962), who were the first to attempt to use linear programming to measure efficiency (Førsund and Sarafoglou, 2002; Chang and Guh, 1991). Detailed information on the DEA method has been presented, among others, in the publications by Banker *et al.* (1984), Cooper *et al.* (2006), Zijiang (2006), Kočišová (2016), Parichatnon *et al.* (2018).

Effectiveness testing requires proper selection of variables. For this purpose, a backward stepwise regression method was used, thanks to which a list of variables representing the main decision areas in the researched farms was obtained (Table 1). The value of the determination coefficient R^2 was 0.82-0.84 (depending on the analysed year), which indicates that the variables were well adapted to the models used in the effectiveness test.

Table 1. *Variables used in testing the efficiency of farms specializing dairying*

Outputs	Inputs
1. Sum of returns of sales, direct payments and subsidies (PLN).	1. Utilised Agricultural Area (ha). 2. Dairy cows (LU). 3. Specific forage costs (seeds and plants, fertilisers, crop protection) (PLN). 4. Purchased concentrates (PLN). 5. Other specific livestock costs (PLN). 6. Machine and building upkeep (PLN). 7. Energy (fuels, electricity) (PLN). 8. Depreciation (PLN).

The analysis of the research results was based on the criteria for the size of the herd of cows and milk yield with the identification of three groups of farms:

- efficient farms with a technical efficiency ratio of 100%;
- farms close to efficient farms with a technical efficiency ratio in the range of 90-100%;
- inefficient farms where the technical efficiency ratio was less than 90%.

3. Results

The average values describing farms specializing dairying show that in the years 2008-2017 there was an over 7% increase in milk yield in the examined farm population, which in 2017 was close to 5.900 litres (Table 2). This situation took place while maintaining an almost identical level of other organizational parameters such as the area of arable land or the size of a dairy herd (approx. 26). Farms with 15 to 132 dairy cows can be found among the examined facilities, which affects the amount of costs incurred and revenues generated. Their diversity is reflected by the high value of the coefficient of variation, which gives the opportunity to determine the differences in efficiency between farms with different yields and dairy cow herd size. When analysing the cost categories adopted for research, it is worth noting that, despite the change in average values over time, their structure (the share of individual cost categories in the total costs assumed for the effectiveness test) was almost identical. Cattle feeding costs and depreciation constituting on average over 70% of the total costs assumed as expenditure to determine the efficiency of dairy farms dominated in it.

Table 2. *Characteristics of studied farms in selected years of the analysis*

Variable (per farm)	Mean	Standard deviation	Median	Coefficient of variation (%)
2008 (n=1075)				
Milk yield (litres/cow/year)	5 462,5	1 354,8	5 372,6	24,8
Utilised Agricultural Area (ha)	32,2	17,1	28,5	53,1
Dairy cows (LU)	25,8	9,8	23,5	38,1
Sum of returns of sales, direct payments and subsidies (thous. PLN)	235,8	124,0	206,0	52,6
Specific forage costs (seeds and plants, fertilisers, crop protection) (thous. PLN)	20,4	15,5	16,9	75,7
Purchased concentrates (thous. PLN)	50,9	36,9	41,3	72,6
Other specific livestock costs (thous. PLN)	8,4	6,9	6,5	82,4
Machine and building upkeep (thous. PLN)	11,4	9,9	8,6	87,1
Energy (fuels, electricity) (thous. PLN)	14,9	9,8	12,5	66,2
Depreciation (thous. PLN)	28,8	17,7	24,4	61,3
2012 (n=941)				
Milk yield (litres/cow/year)	5 656,7	1 551,6	5 534,0	27,4
Utilised Agricultural Area (ha)	31,1	14,4	28,2	46,4
Dairy cows (LU)	25,2	8,0	23,5	31,6
Sum of returns of sales, direct payments and subsidies (thous. PLN)	276,1	129,5	246,1	46,9
Specific forage costs (seeds and plants, fertilisers, crop protection) (thous. PLN)	24,7	17,6	20,5	71,2
Purchased concentrates (thous. PLN)	58,7	38,3	49,0	65,2
Other specific livestock costs (thous. PLN)	9,1	7,4	6,9	81,9
Machine and building upkeep (thous. PLN)	12,2	9,3	10,0	76,5
Energy (fuels, electricity) (thous. PLN)	19,8	10,8	17,5	54,4
Depreciation (thous. PLN)	35,0	20,4	30,2	58,4
2017 (n=1308)				
Milk yield (litres/cow/year)	5 868,2	1 716,8	5 708,9	29,3
Utilised Agricultural Area (ha)	30,7	14,9	27,6	48,4
Dairy cows (LU)	25,2	8,3	23,2	32,9
Sum of returns of sales, direct payments and subsidies (thous. PLN)	322,9	148,8	289,7	46,1
Specific forage costs (seeds and plants, fertilisers, crop protection) (thous. PLN)	25,6	16,8	22,0	65,8

Purchased concentrates (thous. PLN)	56,5	37,3	47,8	66,0
Other specific livestock costs (thous. PLN)	9,9	8,4	7,1	85,0
Machine and building upkeep (thous. PLN)	15,9	11,9	13,4	74,7
Energy (fuels, electricity) (thous. PLN)	18,1	10,5	15,4	58,3
Depreciation (thous. PLN)	38,4	22,1	34,3	57,5

As a result of the application of the model assuming constant returns to scale (CCR) for testing the effectiveness, it can be observed that in each surveyed year approximately 10% of all surveyed farms were efficient (Table 3). Farms in the group close to efficient were characterized by a similar share. The calculations carried out showed that the average efficiency ratio in the CCR model were within the limits of 69.0-76.2%. This means that the model has a slight dispersion of the technical efficiency ratio. This slight variability of the efficiency ratio has also occurred in the model assuming variable returns to scale (BCC). However, the elements differentiating the results obtained for the BBC and CCR models were the number of efficient and close to efficient farms, as well as the average technical efficiency ratio for 2008-2017. The data in Table 3 shows that in the BCC model, the percentage of efficient farms ranged from 14% to 20%, while the average technical efficiency ratios were in the range of 81.8-85.5%.

Table 3*. Technical efficiency ratio of farms specializing dairying and their coefficients of variation in 2008-2017*

Year	Number of farms	Efficient farms (%)		Farms close to efficient (%)		Average technical efficiency (%)			Coefficient of variation (%)		
		CCR	BCC	CCR	BCC	CCR	BCC	SCALE	CCR	BCC	SCALE
2008	1075	9	20	11	21	75,9	85,5	89,0	18,8	14,0	13,4
2009	1154	6	14	6	18	71,1	82,3	86,9	20,5	15,7	15,3
2010	922	11	19	9	21	76,2	85,1	89,7	19,0	14,1	12,9
2011	869	10	18	10	18	75,7	84,0	90,3	19,5	15,0	13,0
2012	941	9	21	8	18	75,2	84,3	89,5	19,2	15,2	13,0
2013	1187	9	17	8	17	73,2	82,8	88,7	20,1	15,7	13,7
2014	1180	9	19	9	20	74,8	84,9	88,3	19,2	14,0	13,8
2015	1168	8	18	5	16	69,0	81,8	84,8	23,4	17,0	17,4
2016	1251	10	16	9	18	75,7	83,4	91,0	18,4	14,8	12,2
2017	1308	8	15	9	18	75,0	83,2	90,4	18,6	15,0	12,4

In addition to determining the technical efficiency ratio, the scale efficiency was calculated and it was found that:

- in most of the analysed years, about 10% of farms were characterized by the optimal size of inputs and obtained effects;
- in most of the analysed years, about 60% of all farms had a scale efficiency ratio of over 90%;

- the surveyed farms specializing dairying were characterized by a scale efficiency ratio ranging from 84.8% to 91%, which means that on average inefficient farms could reduce their size by 9 to 15% (depending on the year under study) without affecting their result.

3.1 Technical Efficiency and the Herd Size

For the technical efficiency study, due to the number of cows on dairy farms, the population was divided into four groups (Table 4). Assuming constant returns to scale in the CCR model, the average technical efficiency ratio slightly increased as the herd size increased on farms. In the structure of farms, the share of efficient entities was also higher among farms with bigger herd size and ranged from 5% on farms below 20 cows to 14% on farms with more than 40 cows.

Table 4. *Technical efficiency in groups of farms specializing dairying based on the herd size*

Year	Number of farms	Efficient farms (%)		Farms close to efficient (%)		Average technical efficiency (%)			Coefficient of variation (%)		
		CCR	BCC	CCR	BCC	CCR	BCC	SCALE	CCR	BCC	SCALE
< 20 LU											
2008	355	5	30	10	36	73,2	93,0	78,6	19,6	7,4	16,6
2012	299	10	32	7	34	74,4	92,9	79,9	19,7	7,5	16,3
2017	416	9	25	10	36	74,8	92,1	81,0	19,7	7,7	16,1
20-29,9 LU											
2008	447	11	13	11	13	76,7	82,0	93,1	18,3	13,3	7,9
2012	401	11	13	7	9	74,2	79,7	92,7	20,0	15,2	9,1
2017	557	7	8	7	9	74,5	79,4	93,5	18,0	13,4	8,1
30-40 LU											
2008	183	8	13	11	13	76,8	79,0	97,0	18,6	17,1	5,6
2012	185	6	14	12	12	77,4	79,8	97,1	17,2	17,2	3,9
2017	249	8	11	8	9	75,7	77,1	98,1	18,3	17,8	2,8
> 40 LU											
2008	90	14	34	13	16	80,7	86,0	94,1	16,5	15,9	7,2
2012	56	9	41	9	7	78,5	85,4	92,5	16,6	17,8	7,4
2017	86	10	26	10	15	77,4	82,6	94,3	18,0	19,5	6,2

The assumption of variable returns to scale in the BCC model indicates a higher percentage of efficient farms than in CCR model. The highest average efficiency indicators were achieved by farms with the smallest herd size (over 92%) and additionally the coefficient of variation in this group of farms was the lowest. Research indicates the relationship between the average scale efficiency and the average herd size in the analysed groups of farms. The average scale efficiency was the highest in farms with over 30 cows in a herd.

The basic reasons for farm inefficiency in terms of the costs incurred for production inputs include, first of all, higher costs associated with feed production and higher depreciation on inefficient farms. Efficient farms were characterized by a higher milk yield of cows compared to inefficient farms, which was mainly reflected in sales revenues per cow.

3.2 Technical Efficiency and Milk Yield

When analysing the obtained results, due to the milk yield criterion, five farm groups were separated (Table 5). Because the studied groups contain a differentiated number of objects, relative values were also used in the presentation of results. Calculation of technical efficiency using the CCR model showed that the average technical efficiency ratio are increasing in subsequent groups of farms with higher milk yield. In the group of farms where milk yield did not exceed 4 thousand litres efficiency ratio was from 66.8% to 70.5%, and on farms with a yield exceeding 8 thousand litres efficiency were higher than 85%. The obtained research results also show that in the CCR model, the share of efficient farms in the group in which the milk yield was higher than 8 thousand litres was (in most cases) more than twice as large as in other groups.

Table 5. *Technical efficiency in groups of farms specializing dairying based on the milk yield criterion*

Year	Number of farms	Efficient farms (%)		Farms close to efficient (%)		Average technical efficiency (%)			Coefficient of variation (%)		
		CCR	BCC	CCR	BCC	CCR	BCC	SCALE	CCR	BCC	SCALE
< 4000 litres											
2008	150	5	21	7	21	67,6	85,6	79,5	24,3	15,0	20,8
2012	124	11	30	6	13	70,5	85,4	82,7	23,5	16,5	15,8
2017	161	11	22	5	15	66,8	82,8	80,8	26,2	17,4	19,0
4000-4999 litres											
2008	262	6	16	5	18	70,7	82,7	85,9	19,4	15,4	14,6
2012	222	8	18	5	19	70,9	82,4	86,6	20,3	16,6	14,8
2017	261	5	12	5	18	70,0	81,7	86,3	19,4	16,2	14,3
5000-5999 litres											
2008	300	4	15	11	23	76,5	84,9	90,4	15,6	13,5	10,2
2012	248	4	16	6	18	73,1	82,4	89,3	17,7	15,5	12,7
2017	302	8	14	6	17	73,7	81,4	90,9	17,3	15,8	10,9
6000-8000 litres											
2008	324	14	24	15	21	81,9	87,0	94,1	14,7	12,4	8,0
2012	269	11	19	10	18	79,0	85,1	93,0	16,1	13,9	9,3
2017	411	7	12	9	16	77,6	83,0	93,9	14,1	13,5	8,2
> 8000 litres											
2008	39	26	51	28	26	88,1	94,0	93,6	13,6	9,6	7,9
2012	78	23	35	21	19	87,9	91,0	96,6	11,3	9,7	5,7
2017	173	17	24	21	29	86,5	89,5	96,6	11,4	10,4	4,7

The average technical efficiency ratio of the surveyed farms determined using the model assuming variable returns to scale (BCC) were above 80%. The highest percentage of efficient farms occurred in two extreme groups of farms characterized by the lowest and highest milk yield. Considering 2017, it can be pointed out that almost every fourth farm in these groups was an efficient farm. In the remaining groups of farms (yield of 4-8 thousand litres of milk) this percentage did not exceed 15%. The obtained results are characterized by small variability, which was lower than 20% and decreased together with groups of farms with increasing milk yield.

The scale efficiency ratio contained in Table 5 show the relationship between its height and average milk yield in individual farm groups. The calculated average scale efficiency value was higher in groups with higher milk yield. In the last year of the analysis on farms with a yield of up to 4 000 litres, it amounted to about 80%, while in yield exceeded 8 000 litres efficiency ratio was higher than 96%. A detailed analysis of the results obtained allows the conclusions that:

- in groups of farms where the milk yield did not exceed 8 000 litres, the optimal scale of production was characteristic for less than 10% of farms, and 65-86% of farms should increase their production (increasing scale effects);
- in the group of farms with the highest milk yield, the share of farms with an optimal production scale was close to 20%, and the number of objects that should increase or decrease production was similar and amounted to about 40%.

4. Conclusions

The conducted research on the level of technical efficiency of Polish farms specializing dairying using the DEA method allowed to diagnose their effectiveness. The results obtained for the model with constant returns to scale showed that only up to 10% of all surveyed farms incurred expenditure corresponding to the optimal expenditure to obtain the results achieved. A look at the problem of the efficiency of the studied farms by assuming that the results do not change proportionally to the expenditure incurred (BCC model) showed a double increase in the number of efficient farms compared to the results obtained using the CCR model. In the research results of many authors, one can meet the indicated relationship between the use of the BCC model for technical efficiency testing and the increase in the number of effective objects.

The article analyses the effectiveness from the point of view of two parameters of particular importance for dairy farms. The first of these was the herd size. The grouping of farms and the technical efficiency ratio obtained for them using this variable allowed to state that the efficiency of farms assuming constant returns to scale (CCR) increased with the increase in the size of the farm herd. In turn, the use of the model with variable returns to scale (BCC) showed that the average efficiency in the groups of the smallest and largest farms was at a similar, high level.

The second parameter used in the analysis of test results was the milk yield of cows. The division of the studied farms into five groups of farms and the calculations made showed that the average efficiency ratio increased with the obtained milk yield. This situation took place regardless of the model used. Nevertheless, it is noteworthy that the largest share of efficient farms among all farms in a given group occurred on farms with the lowest (less than 4 000 litres) and the highest (over 8 000 litres) milk yield.

Future research should focus on building the optimal production technology that would allow us to estimate the optimal level of inputs ensuring the highest relative efficiency. Such technology can be built for the whole group of the studied dairy farms, but this approach should be considered insufficient. Therefore, an important aspect that should interest researchers is the creation of optimal technologies for groups of farms separated by the size of a dairy cow herd and milk yield.

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