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TECHNICAL EFFICIENCY OF DAIRY FARMS IN 2008-2017

EFEKTYWNOŚĆ TECHNICZNA GOSPODARSTW MLECZNYCH W LATACH 2008-2017

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Summary: The aim of the study was to determine the technical efficiency of farms specialising in milk production (type 45) using the DEA method. The research covered the period 2008-2017. Data for calculations were collected using the indirect observation method based the data from the Polish FADN Cfor2008-2017 as the source of actual data. 11055 dairy farms were included in the study. Dairy farms with fewer than 15 cows were excluded from the study. The DEA method uses an approach that minimizes inputs and the CCR and BCC models. In the description of the results, the surveyed farms were divided into three groups: effective farms for which the technical efficiency coefficient was 100%, farms close to effective, in which the technical efficiency coefficient was within <90<100% and ineffective farms, in which the analysed coefficient was smaller than 90%. In the analysis of the results of the given dairy farms, the farms were divided according to their economic size, cow herd size and milk yield.

Keywords: DEA method, technical efficiency, production of milk.

Streszczenie: Celem badań było określenie efektywności technicznej gospodarstw wyspecjalizowanych w produkcji mleka (typ 45) z zastosowaniem metody DEA. Badania obejmowały lata 2008-2017. Dane do obliczeń zebrano, posługując się metodą obserwacji pośredniej i wykorzystując jako źródło danych aktualnych dane z polskiego FADN za lata 2008-2017. Z badań wyłączono gospodarstwa mleczne, które posiadały poniżej 15 krów. W metodzie DEA zastosowano podejście minimalizujące nakłady i modele CCR i BCC. W opisie wyników badane gospodarstwa podzielono na trzy grupy: gospodarstwa efektywne, dla których współczynnik efektywności technicznej wynosił 100%, gospodarstwa zbliżone do efektywnych, w których współczynnik efektywności technicznej mieścił się w granicach <90<100%, i gospodarstwa nieefektywne, w których analizowany współczynnik był mniejszy niż 90%. W analizie wyników danych gospodarstw mlecznych dokonano podziałów gospodarstw według ich wielkości ekonomicznej, wielkości stada krów, wydajności mlecznej.

Słowa kluczowe: metoda DEA, efektywność techniczna, produkcja mleka.

1. Introduction

Polish agriculture makes a major contribution to global agriculture, including European Union agriculture. Its importance can be measured by the ranking of Poland in the production of agricultural products in the world and in the European Union. In the world, Poland holds the 16th place in the production of wheat (1.5% share in the global production), 2nd in production of rye (19.5%), 4th in oats (5.6%), 8th of potatoes (2.4%), and the 6th in sugar beets (5.2%). In the production of meat and milk, Poland ranks 12th in the world, with a share of (1.5%) and (2.1%), respectively, and 43rd in the number of cattle (0.4%) and 15th in that of pigs (1.2%).

In 2017 in the European Union, Poland's agriculture was 5th in terms of arable land, 4th in wheat production (7.8%), 2nd in rye production (36.2%), 1st in oats production (18.2%), 2nd in potato production (15%), 3rd in sugar beet (12.0%) and rapeseed (12.4%) production, 4th in cow's milk (9.7%) and meat (10.5%) production, 6th in the cattle (6.8%) and pig population (7.7%) (CSO 2018).

Animal production in Poland is of great importance. Its share in the structure of global production of agriculture in 2008-2017 increased from 43.8% (2008) to 51.5% (2017). The share of animal production in the production of goods in the analysed period increased from 55.0% (2008) to 60.7% (2017). The share of trade production of cattle, calves and milk in total in the total trade goods production ranged from 24.0% (2008) to 26.5% (2017) (gov.pl, 2009, 2018).

According to Ziętara (2013), the importance of milk production in Poland also results from the fact that, according to the data of the general agricultural census, cattle production was carried out in 2010 in 454,000 farms and provided upkeep for about 2 million inhabitants of rural areas. It should also be emphasized that milk is an important raw material for the processing industry, where 36,000 employees are involved in the production of dairy products in Poland. The value of sold production of the dairy industry in 2017 amounted to PLN 30325.7 million, and the share in the value of Polish exports of these products is 1.1% (gov.pl 2019).

The key issue in maintaining the competitive position of Polish agriculture is the problem of the management efficiency of individual types of farms. The aim of the study was to determine the technical efficiency of farms specialising in milk production (type 45) using the DEA method. The studies covered the period 2008-2017.

In the world economic and agricultural literature, studies of technical efficiency of agriculture, including the technical efficiency of dairy farms, are very popular. Similar studies were conducted, for example, by Ma et al. (2018), Skevas et al. (2018), Singbo and Larue (2015), Darku et al. (2015), Latruffe et al. (2012), Balcombe et al. (2006). Research on the technical efficiency of the agricultural environment, agriculture and farms in Poland was carried out by, among others, Rusielik and Świtłyk (2002), Świtłyk (1999, 2011), Góral (2014), Kasztelan (2003). The issue of dairy farm efficiency in their studies was undertaken by, among others, Parzonko (2002), Szewczyk (2010), Marzec and Pisulewski (2013, 2014, 2015), Rusielik and Świtłyk (2012).

2. Factual material and research methods

Data for calculations were collected using the indirect observation method, using data from the Polish FADN for 2008-2017 as a source of actual data. The actual data concerned farms specializing in dairy farming (type 45). After analysing the data, 11055 dairy farms were accepted for the study. Dairy farms with less than 15 cows were excluded from the study.

The selection of input variables for the study of dairy farms was made according to the formal criterion, using the backward stepwise regression method. It was assumed that the variables included in the model represent the main decision areas in the researched farms. As a result of the calculations, the following list of variables for dairy farms was obtained:

Output: the sum of the sales value: cows' milk and milk products, beef and veal and total subsidies − excluding those on investment (PLN),

Inputs: utilized agricultural area (ha), number of dairy cows (LU), sum of costs incurred for crop-yielding input (seeds and seed potatoes, own seeds and seed potatoes, fertilizers, plant protection) (PLN), costs of feed for grazing livestock (PLN), other livestock specific costs (PLN), machinery and building current costs (PLN), energy costs (PLN), and depreciation cost (PLN).

The value of the determination coefficient R2 for the model built for dairy farms was 0.82 - 0.84 in individual years of the study. This shows that the farm models are well adapted.

The data covered the period 2008-2017. Table 1 contains descriptive statistics of the surveyed farms and the abbreviations used in the text.

Table 1. Descriptive statistics on variables used for the efficiency measurement

Specification	Abbreviations	Mean	Standard deviation	Coefficients of variation
Economic size (€)	ES	65353.7	23635.1	36.2
Milk yield (l)	MY	5581.3	1576.9	28.3
Utilised agricultural area (ha)	UAA	31.6	15.3	48.4
Number of dairy cows (LU)	COWS	25.2	8.4	33.2
Sum of the sales value: cows' milk and milk products, beef and veal and total subsidies − excluding those on investment (PLN)	STS_AP	269541.8	132589.2	49.2
Sum of costs incurred for crop-yielding inputs (PLN)	C_CYI	23805.2	16735.0	70.3
Costs of feed for grazing livestock (PLN)	C_FEED	53969.3	36534.5	67.7
Other livestock specific costs (PLN)	OC__DAP	9008.3	7554.2	83.9
Machinery and building current costs (PLN)	MC_M&B	12745.4	9827.3	77.1
Energy costs (PLN)	ENERGY	17558.3	10443.2	59.5
Depreciation costs (PLN)	DEPREC	35925.0	21376.9	59.5
Number of observations		11055		

Source: own study.

The technical efficiency measurement was performed using the method included in the boundary analysis, i.e. the non-parametric Data Envelopment Analysis (DEA) method. For the DEA method, the CCR model was used assuming the fixed scale effects (Charnes, Cooper, and Rhodes, 1978) and the BCC model assuming the variable scale effects (Banker, Charnes, and Cooper, 1984).

The DEA method used the approach minimizing the expenditure. In the description of results, the surveyed farms were divided into three groups: effective farms for which the technical efficiency coefficient was 100%, farms close to effective, in which the technical efficiency coefficient was within <90<100%, and inefficient farms in which the analysed coefficient was smaller than 90%. In the analysis of the results of the given dairy farms, the farms were divided according to their economic size, herd cow size, and milk yield. The following application software packages were used in the development of factual data*: Statistica ver. 13.1* and *Frontier Analyst ver. 4.2.0.*

The DEA CCR and BCC models use one of the most popular techniques proposed in the work "Production Frontiers" (Färe, Grosskopf, and Lovell, 1995). In order to calculate the technical efficiency, the concept of measuring efficiency presented by Coelli, Prasada Rao and Battese in their publication "An introduction to efficiency and productivity analysis" was used (Coelli, Prasada, and Battese, 1998). This concept assumes that two components affect the total economic efficiency: technical efficiency and allocation efficiency. In the method used, technical efficiency is defined as the relation of actual productivity to the highest possible productivity. Based on the data, it is possible to estimate the efficiency curve determined by effective objects. Beyond this curve, there will be objects showing a certain degree of inefficiency and this degree can be calculated using this curve. The general assumption of this method is that the efficiency of a given production factor is the quotient of a given input to the intended effect and, developing it into a multidimensional situation, it can be assumed that having s – effects and m – input efficiency, it takes the form of:

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

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

Reducing the inputs and effects 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 effect weights and input weights are optimized variables.

Charnes, Cooper and Rhodes in the publication "Measuring the efficiency of decision making units" presented a way to solve this function using the linear programming method (Charnes, Cooper, and Rhodes, 1978).

3. Research results

Figures 1 to 3 present the average examined features of dairy farms over time. The value of revenues from sales with subsidies increased in the analysed time period from 235869.1 PLN (2008) to 324912.3 PLN (2017), i.e. by 37.0%.

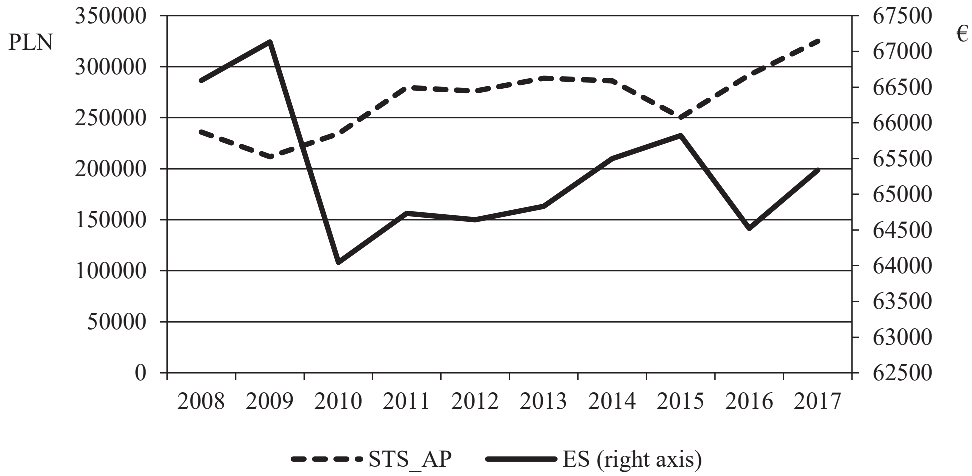

Fig. 1. Sum of the sales value: cows' milk and milk products, beef and veal and total subsidies – excluding those on investment and the economic size of the examined dairy farms between 2008 and 2017 (PLN)

Source: own study.

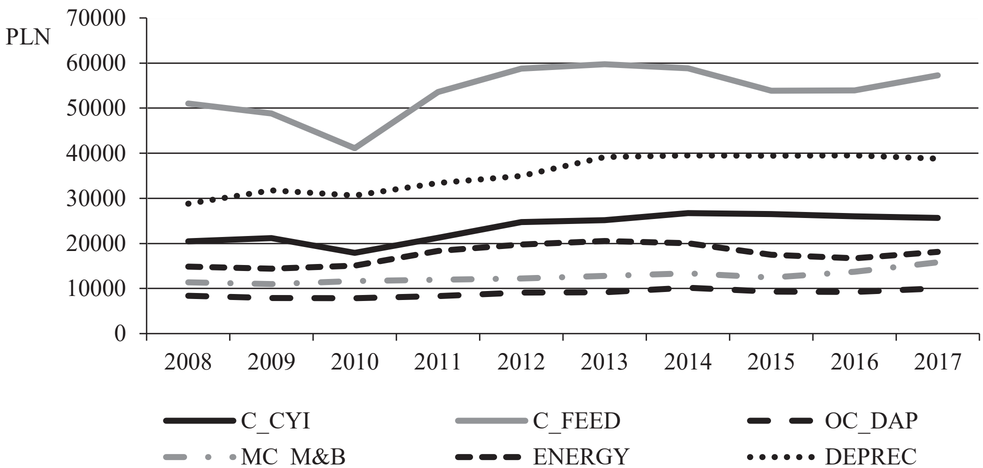

Fig. 2. Cost components adopted into the dairy farm model in 2008-2017

Source: own study.

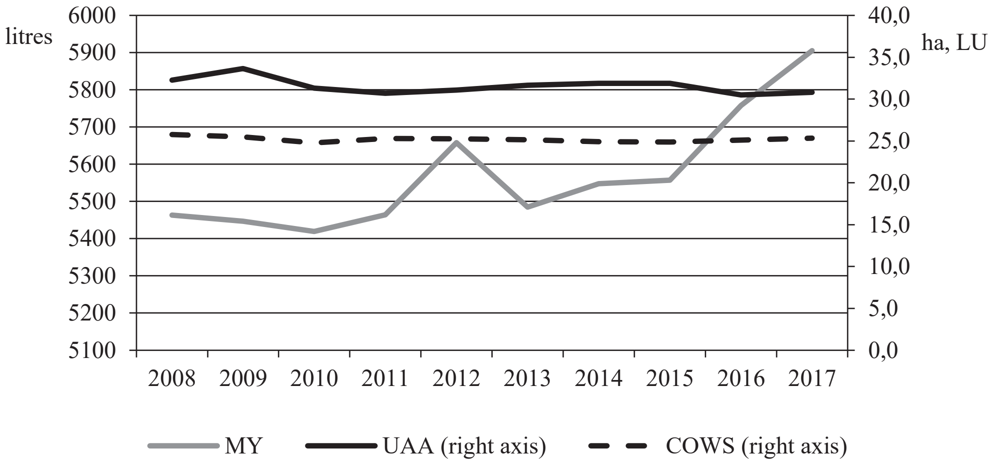

Fig. 3. Milk yield, utilised agricultural area and cow herd size on dairy farms

Source: own study.

In turn, the economic value of farms dropped from 69590.7 euros (2008) to 65336.1 euros (2017).

The costs of crop-yielding inputs increased from 20474.7 PLN in 2008 to 25621.0 PLN in 2017, i.e. by 25.1%. Feed costs increased from 51023.5 PLN in 2008 to 57291.4 PLN in 2017, i.e. by 12.3%. Other animal production costs increased from 8399.9 PLN in 2008 to 10049.7 PLN in 2017, i.e. by 19.6%. The costs of maintaining buildings and machinery in the period under analysis increased by 38.9%, from the level of 11378.0 PLN (2008) to 15811.4 PLN (2017). Energy costs in 2008-2017 increased by 21.9% from 14860.0 PLN in 2008 to 18115.2 PLN. The depreciation costs increased by 34.8% from 28807.8 PLN in 2008 to 38822.2 PLN in 2017.

The milk yield of cows in 2008-2017 increased by 442 litres (by 8.1%). The size of cow herds in the analysed years stabilized at the level of 25 animals/farm, and that of the utilised agricultural area farm in 2017, compared to 2008, decreased by 1.4 ha and at the end of the period amounted to 30.8 ha (decreased by 4.5%).

Table 2 presents the average results of technical efficiency coefficients calculated for individual DEA models. The average efficiency coefficients calculated for the CCR model ranged from 69.0% (2015) to 76.2% (2010), in the BCC model, the technical efficiency coefficients ranged from 81.8% (2015) to 85.5% (2008), and the efficiency coefficients of the scale ranged from 84.8% (2015) to 91.0% (2016).

In the CCR model, the number of effective farms in 2008-2017 ranged from 70 (2009) to 120 (2016), and the share of these farms in the general population from 6% (2008) to 11% (2010). The total number of inefficient farms in the analysed years ranged from 755 to 1202, i.e. from 85.1% to 98.3% of the total population of farms. The number of farms included in the group close to effective was from 61 (2015)

Table 2. DEA results for the dairy farms between 2008-2017

Technical efficiency coefficients (%)			
Year	CCR	BCC	SCALE
2008	75.9	85.5	89.0
2009	71.1	82.3	86.9
2010	76.2	85.1	89.7
2011	75.7	84.0	90.3
2012	75.2	84.3	89.5
2013	73.2	82.8	88.7
2014	74.8	84.9	88.3
2015	69.0	81.8	84.8
2016	75.7	83.4	91.0
2017	75.0	83.2	90.4
Coefficients of variation *v* (%)			
2008	18.8	14.0	13.4
2009	20.5	15.7	15.3
2010	19.0	14.1	12.9
2011	19.5	15.0	13.0
2012	19.2	15.2	13.0
2013	20.1	15.7	13.7
2014	19.2	14.0	13.8
2015	23.4	17.0	17.4
2016	18.4	14.8	12.2
2017	18.6	15.0	12.4

Source: own study.

to 117 (2008), which constituted from 5.2% to 10.9% of the studied group, and the number of ineffective farms ranged from 694 (2011) to 1085 (2017), which constituted from 79.9% to 83.0% of all farms.

In the BCC model, the number of ‘effective farms’ in the analysed period was from 165 (2009) to 221 (2014) farms, and the total number of ‘ineffective farms’ from 706 to 1106, including farms included in the group of farms ‘close to effective’ was from 160 (2011) to 239 (217). The number of farms included in the group of inefficient farms ranged from 546 (2010) to 867 (2017). Effective farms constituted from 14.3% (2009) to 20.8% (2012), and total ineffective farms ranged from 75.0% to 87.9%, including the share of farms of the group close to effective was from 15.9% (2015) to 21.4% (2010), and the share of ineffective farms constituted from 59.1% (2008) to 66.5% (2015).

In the scale efficiency model, the number of farms characterized by the optimal scale of operations was from 76 (2009) to 126 (2016), which constituted from 6.6% to 11.5% of all farms. The group of farms classified as ineffective farms totalled from 749 to 1333 farms, including the group of farms classified as farms close to effective ranged from 452 to 732 farms, and the number of the group of ineffective farms ranged from 297 (2011) to 605 (2015). In the total population structure, the share of ineffective farms totalled from 88.5% (2010) to 93.4% (2009), including ineffective farms from 32.5% (2016) to 51.8 (2015), and the share of farms close to effective was from 40.2% (2015) to 57.4% (2016). When discussing the results of scale efficiency, attention should be paid to the high average scale efficiency coefficients, which indicates the exhaustion of scale effects on the surveyed farms.

Variation coefficients (*v*) for individual DEA models were, respectively: for the CCR model from 18.4% (2016) to 23.4% (2015), for the BCC model from 14.0% (2008, 2014) to 17.0% (2015), for the scale efficiency model from 12.2% (2016) to 17.4% (2015).

Figures 4 to 6 present the results of studies of individual DEA models depending on the economic size of farms, milk yield of cows and the size of the herd of cows. Figure 4 presents the CCR technical efficiency coefficients depending on the economic size of the farm.

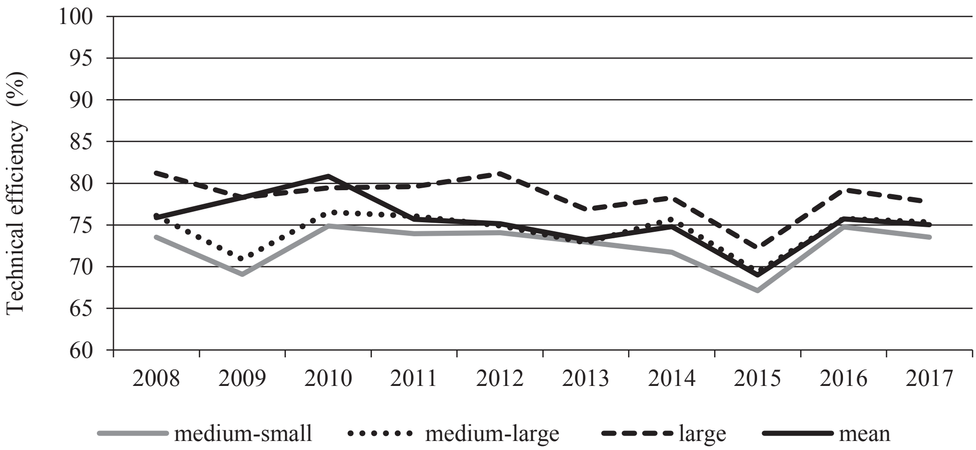

Fig. 4. CCR technical efficiency and the economic size of farms

Source: own study.

The highest efficiency rates in this model was characteristic for farms included in the group of ‘large farms’. In this group of farms, CCR technical efficiency coefficients in the period under study ranged from 77.7% (2017) to 81.2% (2008). In the group of medium-large farms, the CCR technical efficiency coefficients ranged from 69.4 (2015) to 76.5% (2010). From 2011, the technical efficiency coefficient for the analysed model coincided with the average values calculated for the general population. The lowest CCR technical efficiency coefficients were recorded in the group of medium-small farms. The CCR technical efficiency coefficients for this group of farms ranged from 67.1% (2015) to 74.9% (2010).

Figure 5 presents the results of research between the BCC technical efficiency coefficients and the economic size of the dairy farms under study.

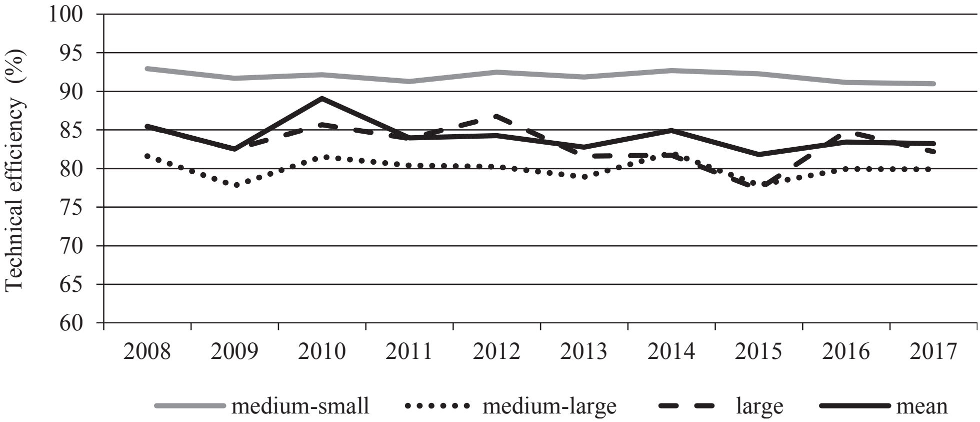

Fig. 5. BCC technical efficiency and the economic size of farms

Source: own study.

In this efficiency model, medium-small farms are characterized by the highest technical efficiency ratios, which ranged from 91.0% (2017) to 92.9 (2008). In large farms, the BCC technical efficiency coefficients were recorded from 77.3% (2015) to 86.8% (2012), while farms from the group of medium-large farms had the lowest BCC technical efficiency coefficients, which ranged from 77.8% (2009) to 82.0 (2014).

Figure 6 presents the scale efficiency coefficients depending on the economic size of farms. The highest scale efficiency coefficients were recorded in the group of large farms and ranged from 93.1% (2010) to 96.0% (2014).

In the group of 'medium-large' farms, the scale efficiency coefficients ranged from 88.9% (2015) to 94.7 (2016). In the group of 'medium-small' farms, the scale efficiency coefficient in the analysed period ranged from 72.5% (2015) to 81.8% (2016).

Figures 7 to 9 present the relations between the calculated technical efficiency models (CCR, BCC, scale) and the milk yield of cows. In the CCR efficiency model (Figure 7), the highest (except for 2008) technical efficiency coefficients were for farms with the highest milk yield (> 8000 l/cow). The technical efficiency coefficients in this group of farms ranged from 70.5% (2008) to 89.4% (2011). The lowest technical efficiency coefficients were noted in farms with the lowest milk yields of cows (<4000 l). The CCR technical efficiency coefficients on these farms ranged

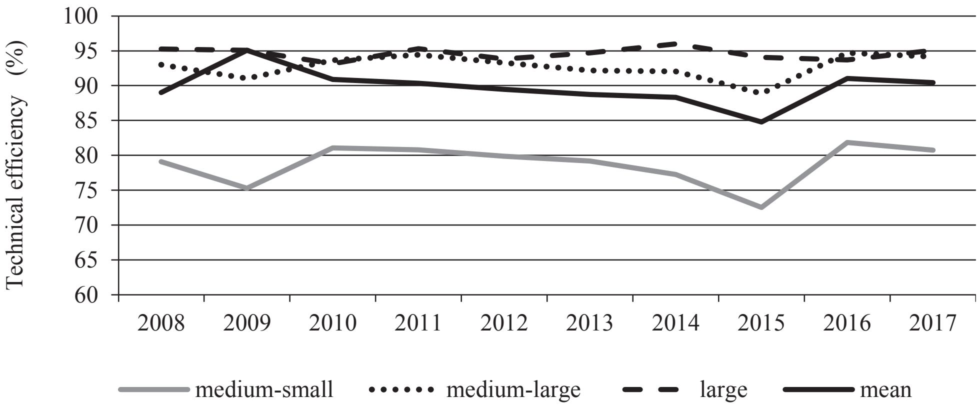

Fig. 6. Scale efficiency and the economic size of farms

Source: own study.

from 65.3% (2009) to 75.1% (2008). In the group of farms with a cow milk yield of 4000-6000 l, the CCR technical efficiency coefficients ranged from 65.8% (2015) to 76.1% (2008). On farms with a milk yield of 6000-8000 l, the CCR technical efficiency coefficients ranged from 73.5% (2015) to 80.2% (2014).

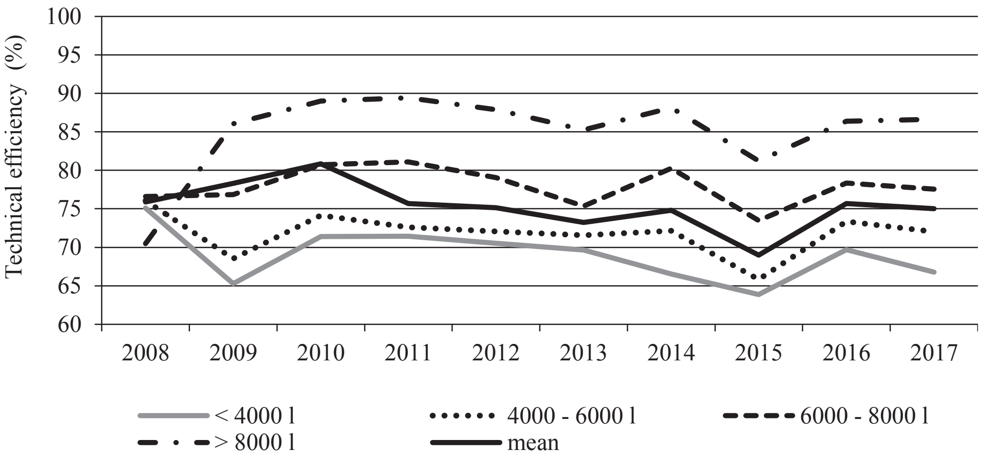

Fig. 7. CCR technical efficiency and cow milk yield

Source: own study.

Figure 8 presents the relations between the BCC technical efficiency coefficients and the milk yield of cows. The highest BCC technical efficiency coefficients were recorded on farms with the highest milk yield of cows (>8000 l). The BCC technical

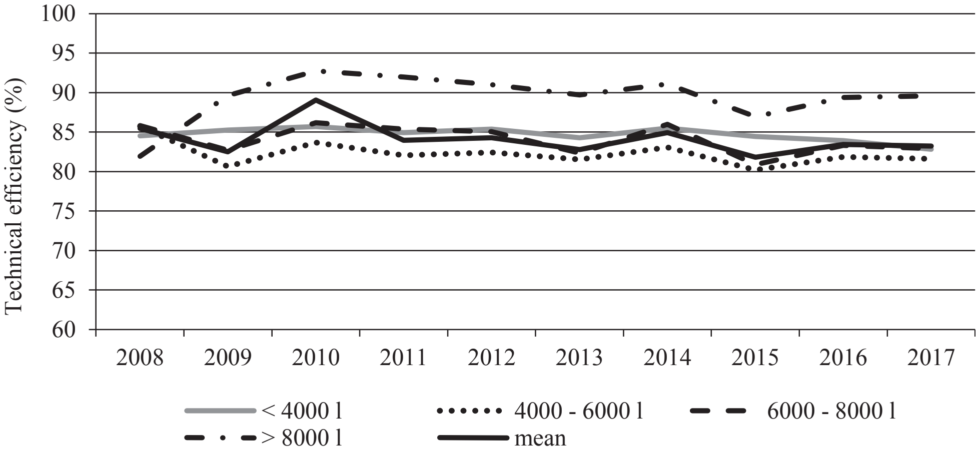

Fig. 8. BCC technical efficiency and cow milk yield

Source: own study.

efficiency coefficients in this group of farms ranged from 89.6% (2008) to 92.7% (2010). In the remaining groups of farms, distinguished according to milk yield, the coefficients were similar to each other and ranged from 80.7% (2009) to 84.9% (2014).

Figure 9 presents the results of studies on the scale efficiency and milk yield of cows. The highest scale efficiency coefficients were recorded in dairy farms with milk yields over 8000 l per cow. Scale efficiency coefficients on these farms ranged

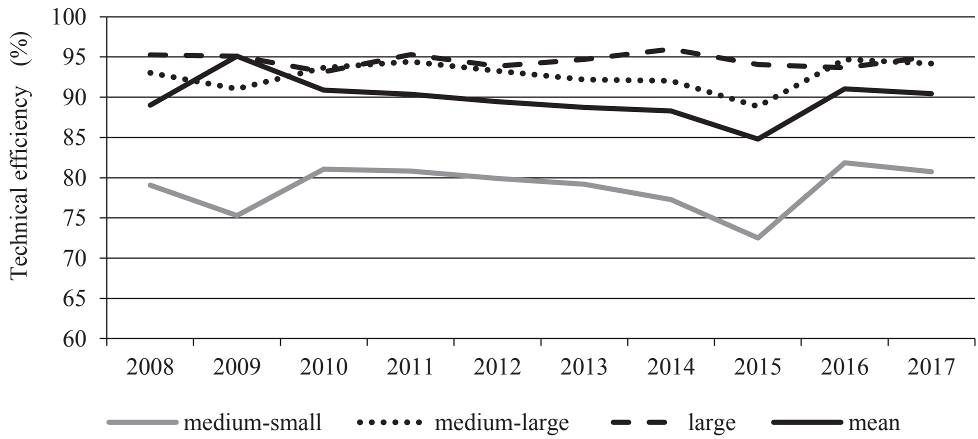

Fig. 9. Scale efficiency and cow milk yield

Source: own study.

from 86.9% (2008) to 97.2% (2011), while the lowest scale efficiency coefficients were characteristic for farms with the lowest milk yields. On these farms, they ranged from 76.9% (2009) to 89.0 (2008). On farms with capacities from 4000 to 6000 l, the scale efficiency coefficients ranged from 82.8% (2015) to 91.0% (2016). On farms with cow capacities from 6000-8000 l, the scale efficiency coefficients were at the level from 89.0% (2008) to 94.2% (2016).

Figure 10 presents the dependence of CCR technical efficiency depending on the size of the cow herd. The size of the CCR technical efficiency coefficients depends on the size of the cow herd. The highest CCR technical efficiency coefficients were recorded in the group of farms with the largest cow herds. In 2008-2016 they amounted from 82.5% (2015) to 91.9 (2012). In the last year of the study, the CCR technical efficiency coefficient in this group of farms dropped to 73.9%. On farms with 30-45 cows in a herd, the technical efficiency coefficients ranged from 73.3% (2009) to 76.8% (2017). In the group of farms with the smallest cow herds of 15-30 cows, the CCR technical efficiency coefficients ranged from 68.2% (2015) to 75.7% (2016).

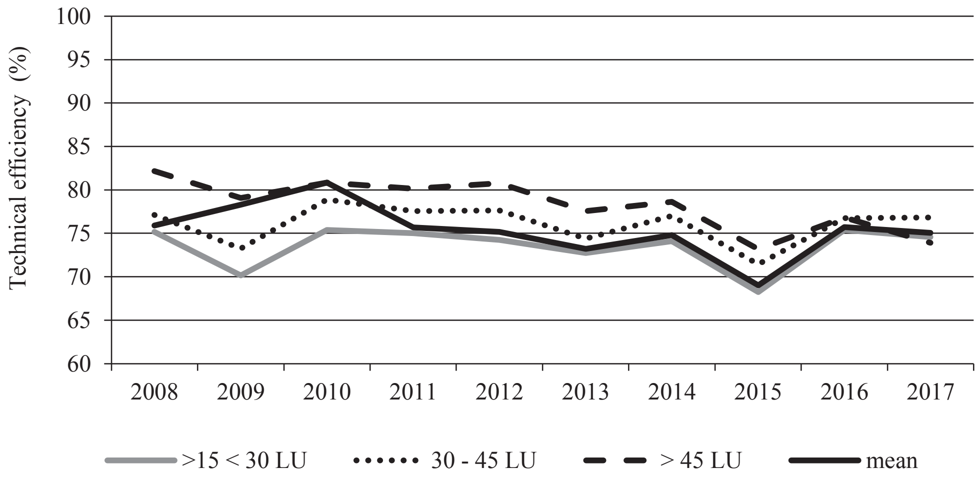

Fig. 10. CCR technical efficiency and cow herd size on dairy farms

Source: own study.

Figure 11 shows the results of the BCC model depending on the size of the cow herd. In this model, farms with the largest cow herds (>45 cows) showed the highest BCC technical efficiency coefficients. In the analysed period they ranged from 79.6% (2017) to 91.9% (2012). Farms with cow herds of 15-30 cows showed BCC technical efficiency coefficients from 83.8% (2009, 2015) to 86.8% (2007). On farms with 30-45 cows in a herd, they ranged from 74.3% (2015) to 81.0% (2010).

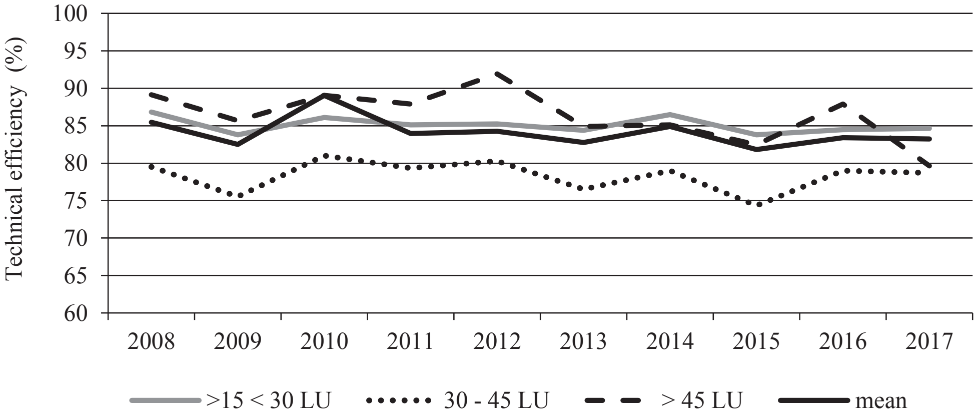

Fig. 11. BCC technical efficiency and cow herd size on dairy farms

Source: own study.

Figure 12 presents the study results on the relations of efficiency coefficients of the scale and the size of the cow herd. The highest scale efficiency coefficients were recorded on farms with 30-45 cows in a herd. The scale efficiency coefficients on these farms ranged from 96.1% (2015) to 97.8% (2011). Farms with the largest cow herds (> 45 cows) were characterized by lower scale efficiency coefficients than the farms with 30-45 cows in a herd. They ranged from 88.3% (2012) to 93.6% (2017). For farms with the smallest cow herds (15-30 cows), the scale efficiency coefficients were the lowest and ranged from 81.7% (2015) to 91.0% (2016).

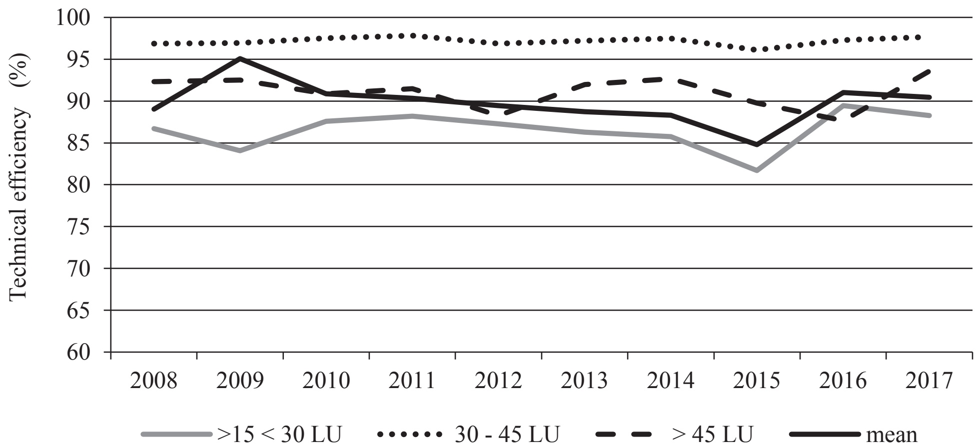

Fig. 12. Scale efficiency and cow herd size on dairy farms

Source: own study.

Figure 13 presents the results of calculations that apply only to farms included in the group of inefficient farms for which the technical efficiency coefficients do not exceed 90%.

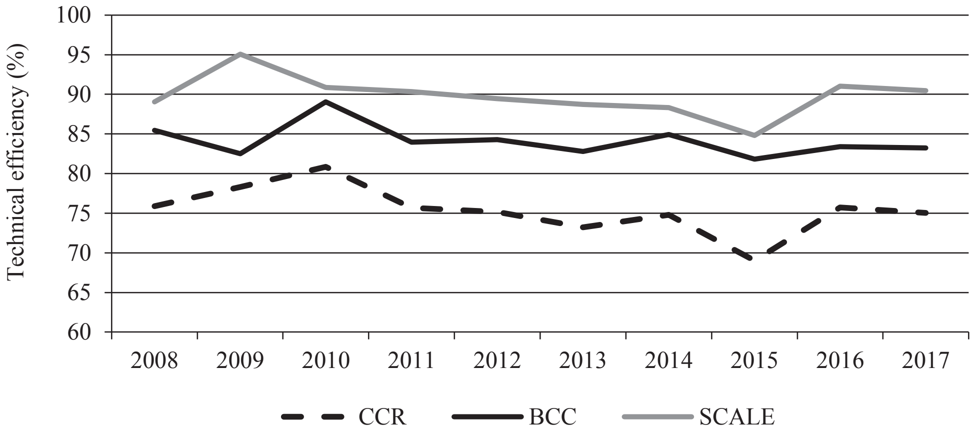

Fig. 13. Technical efficiency for inefficient dairy farms

Source: own study.

In this group of farms, CCR technical efficiency coefficients ranged from 64.7% (2015) to 73.2% (2016). The BCC technical efficiency coefficient was from 73.9% (2015) to 81.9% (2008), and scale efficiency coefficients from 73.5% (2015) to 87.2% (2010).

4. Conclusions

The research on the technical efficiency of dairy farms keeping more than 15 milk cows allows the formulation of the following conclusions:

1. The average technical efficiency coefficients in 2008-2017 calculated for the CCR model ranged from 69.0% (2015) to 76.2% (2010), in the BCC model the technical efficiency coefficients ranged from 81.8% (2015) to 85.5% (2008), and the scale efficiency coefficients ranged from 84.8% (2015) to 91.0% (2016).
2. In the group of inefficient farms (technical efficiency coefficients <90.0%), the technical efficiency coefficients of the CCR model ranged from 64.7% (2015) to 73.2% (2016). The BCC technical efficiency coefficients ranged from 73.9% (2015) to 81.9% (2008), and the scale efficiency coefficients ranged from 73.5% (2015) to 87.2% (2010).
3. When examining the relations between technical efficiency coefficients and the economic size of farms, it was found that in the DEA CCR model, the highest technical efficiency coefficients were characteristic for large farms (77.7%-81.2%),

while the lowest technical efficiency coefficients were characteristic for medium-small farms (67.1%-74.9%). In the BCC model, the highest technical efficiency coefficients were recorded on medium-small farms (91.0%-92.9%), while the lowest on medium-large farms (77.8%-82.0%). The highest scale efficiency ratios were found in large farms (93.1%-96.0%), while the lowest scale efficiency coefficients were found in medium-small farms (72.5%-81.5%).

4. Research on the relations between technical efficiency and the milk yield of cows allowed to establish that the highest technical efficiency coefficients for the CCR, BCC and scale efficiency model were recorded on farms with the highest milk yield. In the CCR model, the lowest technical efficiency coefficients and scale efficiency coefficients characterized farms with the lowest milk yields. In the BCC model, technical efficiency coefficients for the other milk yield groups were similar and ranged from 80.7% to 84.9%.

5. When analysing the relations between technical efficiency in the CCR and BCC models and the size of the cow herds, it was found that the highest technical efficiency coefficients were recorded on farms with the largest cow herds, while the lowest technical efficiency coefficients in the CCR, BCC and scale efficiency models occurred on farms with the smallest cow herds. It is noteworthy that the highest scale efficiency coefficients were found in the case of farms with cow herds of 30-45 cows.

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