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EFFICIENCY AND TECHNICAL PROGRESS IN AGRICULTURAL PRODUCTIVITY IN THE EUROPEAN UNION

EFEKTYWNOŚĆ I POSTĘP TECHNICZNY W KSZTAŁTOWANIU PRODUKTYWNOŚCI ROLNICTWA UE

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Summary: The aim of this study was to estimate changes in total productivity in agriculture of the EU, the EU 15 and the EU 10 countries and to determine to what extent these changes resulted from technical progress and to what extent from changes in production efficiency. The time frame of analyses concerned 2006-2017, the spatial scope involved both the EU, the EU 15 (the so-called "old EU countries"), the EU 10 ("the new EU countries") and individual EU countries. The subjective scope of the survey covered selected farms from the EU countries representing from 4 045 300 to 5 295 930 farms in the EU countries depending on the year. The data from the Farm Accountancy Data Network (FADN), a European system for accountancy data collection from agricultural holdings, were used. Total factor productivity (TFP) was evaluated using the Malmquist productivity index and non-parametric data envelopment analysis (DEA). The research found that over the period 2006-2017 the average level of positive changes of total factor productivity was similar in the old and new EU countries. At the same time, the increase in total productivity in the EU was mainly the result of an increase in efficiency, in the EU 15 it was the effect of positive changes in efficiency, while in the EU 10 it was due to both efficiency gains and technical progress. In 2006-2017, the greatest changes in technical progress were observed in the Czech Republic, and the highest increase in the efficiency of agricultural production in Ireland, while the decrease in the efficiency of agricultural production and technical regress of agriculture occurred only in Spain and Austria.

Keywords: agriculture, total factor productivity (TFP), efficiency, technical progress, the European Union, Data Envelopment Analysis.

Streszczenie: Celem artykułu było określenie zmian w całkowitej produktywności rolnictwa w krajach UE, UE 15 i UE 10 oraz wskazanie, w jakim stopniu zmiany te wynikały z postępu technicznego, a w jakim ze zmian w efektywności produkcji. Zakres czasowy analiz to lata 2006-2017, zakres przestrzenny dotyczył UE, UE 15 (tzw. starych krajów członkowskich), UE 10 (tzw. nowych krajów członkowskich) i poszczególnych krajów UE. Zakres podmiotowy badania obejmował reprezentatywne gospodarstwa rolne, które reprezentowały w zależności od roku od 4 045 300 do 5 295 930 gospodarstw rolnych w krajach UE. W analizach zastosowano dane FADN – Europejskiego Systemu Rachunkowości Rolnej. Całkowitą produktywność rolnictwa (TFP) oszacowano, obliczając indeks Malmquista z użyciem metody DEA. Udowodniono, że w latach 2006-2017 przeciętne zmiany produktywności rolnictwa w starych i nowych krajach UE były zbliżone. Jednocześnie wzrost całkowitej produktywności w UE był efektem wzrostu efektywności, w krajach UE 15 − rezultatem poprawy efektywności, a w krajach UE 10 wynikał ze wzrostu efektywności i z postępu technicznego. W latach 2006-2017 największe zmiany postępu technicznego obserwowano w Czechach, a zmiany wzrostu efektywności produkcji rolnej − w Irlandii. W tym samym czasie spadek efektywności produkcji rolnej i regres techniczny rolnictwa wystąpiły w Hiszpanii i Austrii.

Słowa kluczowe: rolnictwo, całkowita produktywność rolnictwa, efektywność, postęp techniczny, Unia Europejska, *Data Envelopment Analysis.*

1. Introduction

The development of agriculture determines its competitiveness and one of the most appropriate measures of competitiveness of agricultural sector is productivity [Guth, Smędzik-Ambroży 2019; Chryniewicz et al. 2016]. The European Commission additionally underline that this is the most reliable long-term competitiveness indicator [European Commission 2009]. Maintaining a high level of productivity in agriculture is also one of the key prerequisites for the transition from industrial to sustainable development of agriculture [Czyżewski, Smędzik-Ambroży 2017; Medina, Potter 2017; Rizov et al. 2013; Smędzik-Ambroży 2016; Smędzik-Ambroży 2018a; Smędzik-Ambroży 2018b]. The effects of agricultural management, just as in non-agricultural sectors, are determined by the way the factors of production are used. The input–output relation is one of the main economic characteristics of production processes. The improvement of this relation is an endogenous fundamental source of maximizing the producer's goal function. However, this improvement should be observed when values are expressed in constant prices [Bezat-Jarzębowska et al. 2012]. The same applies to situations in which total factor productivity (TFP) is assessed [Latruffe 2010]. In the context of the production function, the technical efficiency of production is also considered. This is a situation in which the producer, when maximizing the production effect, will not put more factors into production than necessary. Establishing relations in this area between different entities enables the application of a non-parametric Data Envelopment Analysis (DEA) method, which is based on linear mathematical programming and the estimation of the efficiency limit. Within the examined research sample, the one whose efficiency is the highest (benchmark) is indicated. It is treated as a reference for other units whose efficiency indicators are estimated in relation to this frontier [Charnes et al. 1994; Smędzik-Ambroży 2017].

The 2004 enlargement of the European Union, the process of integration and implementation of the Common Agricultural Policy created an opportunity for new member states to improve their competitiveness in the agricultural sector. This can be manifested by a decrease in the differences in agricultural productivity between the EU 15 and the countries that joined the European Union in 2004 (the EU 10). The period of more than 15 years since the greatest integration process in the history allows one to expect that the level of total factor productivity in agriculture of old and new members will have converged towards each other. It would suggest also an increase in territorial cohesion in the agricultural productivity of the EU countries. While the mere statement of this fact is cognitively important, it is significant to determine to what extent these changes resulted from technical progress and to what extent from the changes in production efficiency constituting the added value of the research. Therefore, the main objective of the research is to estimate the changes in agricultural total factor productivity in the EU 15 and the EU 10 countries and to determine to what extent these changes resulted from technical progress and to what extent from changes in production efficiency.

The issues of agricultural productivity are discussed in literature. However, the results of the conducted research depend on the choice of the productivity measures, the time scope of the analysis or the characteristics of the surveyed entities. Within the framework of studies related to the European Union, the authors point out that new and old member states differ significantly in terms of agricultural productivity, whilst in new EU countries agricultural productivity was relatively lower than in the old ones [Kijek et. al. 2019]. At the same time, higher productivity changes were identified for new member states [Domańska et al. 2014; Hamulczuk 2015; Baráth, Fertő 2017]. The identified differences in level and changes in productivity are, in turn, a premise for research on the existence of convergence process in this area. Among studies on EU agriculture it is worth noting the papers by Hamulczuk [2015], Staniszewski [2015], Baráth and Fertő [2017], Kijek et al. [2019]. Studies devoted to the evaluation of total factor productivity and its decomposition for the EU countries are rather limited [Coelli, Rao 2005; Domańska et al. 2014; Baráth, Fertő 2017]. In addition to differences in agricultural productivity from the EU 15 and EU 12 countries, the impact of subsidies from the common agricultural policy on differences in agricultural productivity from areas differing in resource conditions in country scale is also examined. Such studies for Poland, with particular regard to the regional scale, were conducted by Smędzik-Ambroży [2017] and Guth and Smędzik-Ambroży [2017].

2. Material and methods of the research

The main goal of the research was achieved in two stages and the analysis was based on the non-parametric DEA (Data Envelope Analysis) method. In the first stage, total factor productivity indexes for individual countries and the EU, the EU 15 and the EU 10 groups in 2005-2017 were calculated. Changes of TFP were expressed in the Malmquist productivity indices as Fare et al. [1994] proposed (see formula (1)).

$$M_I(x^{t+1}, y^{t+1}, x^t, y^t) = \sqrt{\frac{D_I^t(x^{t+1}, y^{t+1})}{D_I^t(x^t, y^t)} \times \frac{D_I^{t+1}(x^{t+1}, y^{t+1})}{D_I^{t+1}(x^t, y^t)}} \tag{1}$$

where: M_I – the Malmquist TFP index, input oriented; x^t, x^{t+1} – vectors of inputs in t and $t+1$ periods; y^t, y^{t+1} – vectors of outputs in t and $t+1$ periods; $D_I^t(x^t, y^t)$ – input distance function at t, the maximum proportional decrease of the input vector y^t, given outputs x^t; $D_I^t(x^{t+1}, y^{t+1})$ – input distance function at $t+1$ assuming technology from t, defined as the maximum proportional change in inputs required to make (x^{t+1}, y^{t+1}) feasible in relation to the technology at t; $D_I^{t+1}(x^t, y^t)$ – input distance function at t assuming technology from $t+1$; $D_I^{t+1}(x^{t+1}, y^{t+1})$ – input distance function at $t+1$.

The Malmquist index is a relative measure of productivity which represents the productivity of the production point (x^{t+1}, y^{t+1}) relative to the production point (x^t, y^t). A value greater than 1 will indicate positive TFP growth from period t to period t+1. Otherwise, there is a decrease in the productivity of the production point (x^{t+1}, y^{t+1}) relative to the production point (x^t, y^t).

In the second stage of the research, the previously calculated Malmquist productivity indices were decomposed (see formula (2)).

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \times \left[\left(\frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{2}$$

The value outside the brackets represents the technical efficiency change (the change in the distance between a given combination of inputs and the optimal combination minimizing the size of inputs for a given size of effects, between periods t and $t+1$). The geometric mean in brackets determines the technological progress between period t and $t+1$ (change in the optimal combination). As in the case of the Malmquist indexes, values above 1 mean an increase in efficiency or technical progress from period t to period $t+1$. On the other hand, values below 1 mean a decrease in efficiency or technical regress from period t to period $t+1$.

The decomposition of the Malmquist productivity indices made it possible to determine to what extent changes in agricultural total factor productivity in the analysed countries resulted from the implementation of technical progress, and to what extent from the changes in production efficiency in the agricultural sector. TFP indices were decomposed for both the analysed groups of countries and individual member countries.

The research was carried out for the period of 2006-2017. Since the relative measure of productivity is being evaluated, the first year of research was 2005, as it was the first all-year round of the EU membership for all the countries covered by the survey. The countries that joined the EU after 2004 were excluded, as the DEA method requires the research sample to be unmodified and stable throughout the research period. Adding a new object to the sample changes the results of the analysis because of their relative nature [Cvetkoska, Savić 2017], therefore such EU countries as Bulgaria, Croatia and Romania were excluded from the analyses. As a consequence, two groups of countries were examined. The first one, defined as the EU 15 countries (the so-called old member states), comprises Belgium, Netherlands, Luxembourg, France, Germany, Italy, the United Kingdom, Denmark, Ireland, Greece, Spain, Portugal, Finland, Austria and Sweden. The second one, called the EU–10 countries (the so-called new member states), covers the Czech Republic, Poland, Slovakia, Lithuania, Latvia, Estonia, Hungary, Slovenia, Cyprus and Malta.

A set of appropriate measures was used to estimate total factor productivity. On the input side, these were respectively land, labour and capital. Land input means the stocks of utilized agricultural area in hectares, agricultural labour force input is measured in annual work unit (AWU) and capital is expressed as the value of fixed assets less the value of land in euros. The value of total agricultural production in euros was assumed as the effect (output). The data came from the European Union Farm Accountancy Data Network (FADN), and thus concerned the value of inputs and outputs per one representative agricultural farm from particular EU countries in each of the years in 2005-2017. Depending on the year, these farms represent from 4 045 300 to 5 295 930 farms of all the farms in the EU countries.

In order to exclude the impact of prices on productivity differences among the EU countries, the value of total agricultural production and the value of capital input were (in each year of the period considered) adjusted by purchasing power parity published by Eurostat. In the case of this indicator, prices in each of the member countries are adjusted to the average prices in the entire European Union. Labour force and land inputs were expressed in physical units, so there was no need to adjust them. At this point it should be noted that the advantage of the DEA method in analysing agricultural efficiency is, among others, the possibility of using inputs and outputs nominated in different units. In the interpretation of the results the average values for both individual countries and the EU, the EU 15 and EU 10 were used.

3. Research results

3.1. Productivity of agriculture in the EU, EU 15 and EU 10

The empirical studies carried out on the representative sample of FADN farms show that total factor productivity in the EU increased slightly (the index was 1.03) during the investigated period (see Table 1). The same average level of the TFP growth was identified for the other analysed groups of countries, i.e. the EU 15 and the EU 10 in the period 2006-2017. A decrease in the TFP in the EU took place in 2009, 2013 and 2016. In the case of the EU 10, the total factor productivity decline occurred in 2006, 2009, 2013 and 2016 and was higher than the downturn in productivity observed for the EU 15 in 2009 and 2013, respectively.

Table 1. The changes in total factor productivity in agriculture in the EU, EU 15 and EU 10 in 2006-2017

Groups	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2006-2017
EU	1.02	1.15	1.03	0.86	1.11	1.10	1.06	0.98	1.01	1.01	0.98	1.04	1.03
EU 15	1.04	1.10	1.01	0.89	1.12	1.08	1.06	0.99	1.01	1.00	1.00	1.05	1.03
EU 10	0.99	1.22	1.07	0.80	1.09	1.13	1.05	0.96	1.00	1.03	0.96	1.04	1.03

Source: own calculation based on FADN.

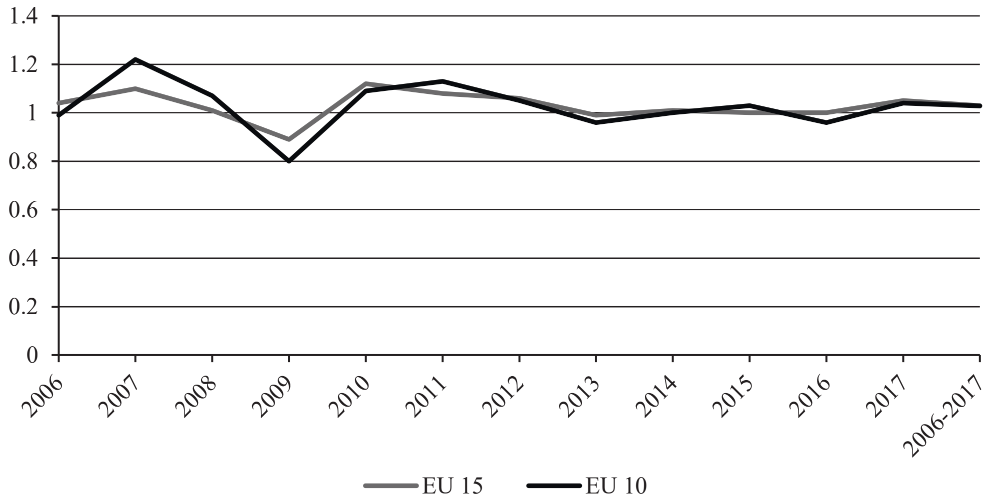

Fig. 1. The changes in total factor productivity in agriculture in the EU 15 and EU 10 in 2006-2017

Source: own elaboration based on FADN.

It is worth noting that although the average TFP growth rate was at the same level for the EU 15 and the EU 10 in 2006-2017, the level of changes of these indicators differed in particular years. The greatest differences were observed in 2006-2009, that is in the first years after the EU enlargement in 2004 (see Table 1 and Figure 1). It can be assumed that the productivity of agriculture in the EU 10 was more sensitive in comparison to the EU 15 at that time. This could be connected with the fact that the instruments of agricultural sector support were implemented in the new member states and to the lesser resilience of the agricultural farms to the financial crisis. In the following years, changes in total agricultural productivity in both the EU 15 and the EU 10 were almost at the same level.

It can be said that the accession of the EU 10 countries in 2004 had a positive impact on changes of the total factor productivity in those members. The positive effects of this accession are visible six years after 2004, in the form of the equalization of changes of total factor productivity of farms in the EU 10 and the EU 15 countries. When assessing changes in productivity, it is also important to analyse their sources. Therefore a further part of the research, based on a decomposition of the TFP indices, is dedicated to answer the question whether the changes in the TFP were the result of efficiency changes or technical changes.

3.2. Efficiency, technical progress and productivity in the EU, EU 15 and EU 10

Analysis of components of the Malmquist TFP index points towards the relatively small increase in technical efficiency in the EU, the EU 15 and the EU 10 over the period 2006-2017. The average change of efficiency was at the same level around 1.02 in each analysed group of countries (see Table 2).

Table 2. Technical efficiency changes in agriculture in the EU, EU 15 and EU 10 in 2006-2017

Groups	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2006-2017
EU	1.01	1.07	0.86	1.14	1.16	1.08	1.05	0.97	0.96	0.97	0.98	1.01	1.02
EU 15	1.03	1.07	0.91	1.04	1.18	1.04	1.07	0.97	0.96	0.98	0.96	1.03	1.02
EU 10	0.97	1.08	0.79	1.29	1.12	1.14	1.02	0.97	0.95	0.97	1.01	0.97	1.02

Source: own calculation based on FADN.

Based on the conducted research, it can be concluded that in 2006-2017 changes in agricultural efficiency in the EU 10 and the EU 15 were similar as for the total factor productivity. This is particularly evident after 2012 (see Figure 2). The biggest differences in changes in technical efficiency were evident in 2008 and 2009, when the decrease and increase in efficiency were, respectively, greater in farms in the EU 10 group compared to the EU 15 countries.

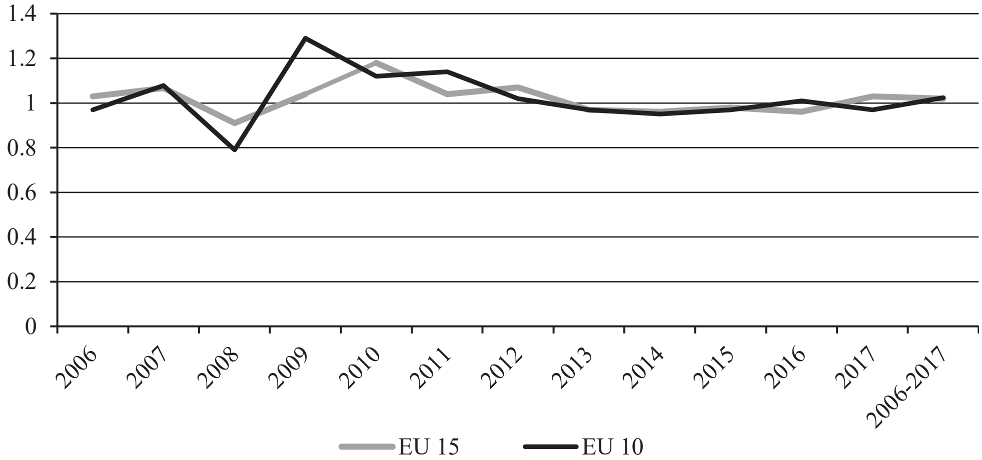

Fig. 2. Technical efficiency changes in agriculture in the EU 15 and EU 10 in 2006-2017

Source: own elaboration based on EUFADN.

The conducted study demonstrates that there was no significant shift in technical changes in the analysed farms in the EU countries between 2006 and 2017 (see Table 3). This was also the case for the EU 15, but at the same time little progress was recorded in the EU 10 group, while the average rate of technical change was 0.01 higher than unity. Positive changes have been observed particularly since 2011, when technical change indicators in agriculture in the EU 10 were above unity each year, meaning technical progress. The only exceptions were 2013 and 2016, when there was no technical progress or regress in agricultural farms. Technical agricultural progress in the new countries was particularly marked in 2014 (see Figure 3 and Table 3). Contrary to the positive alteration in the EU 10 group, there were no adequate changes that would allow to point to the technical progress or technical regress in agriculture in the EU 15 (the indicator was 1.00 in 2006-2017, see Table 3).

Table 3. Technical progress/regress in agriculture in the EU, EU 15 and EU 10 in 2006-2017

Groups	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2006-2017
EU	1.00	1.00	0.98	1.00	1.00	1.01	0.99	1.00	1.04	1.00	1.00	1.00	1.00
EU 15	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.99	1.01	1.00	1.00	0.98	1.00
EU 10	0.99	1.01	0.95	1.00	1.00	1.01	1.02	1.00	1.09	1.01	1.00	1.01	1.01

Source: own calculation based on FADN.

The results of this study demonstrate that the average increase in agricultural productivity in the EU (index 1.03, see Table 1) in 2006-2017 was mainly positively affected by improved efficiency (index 1.02, see Table 2) with no changes in technical

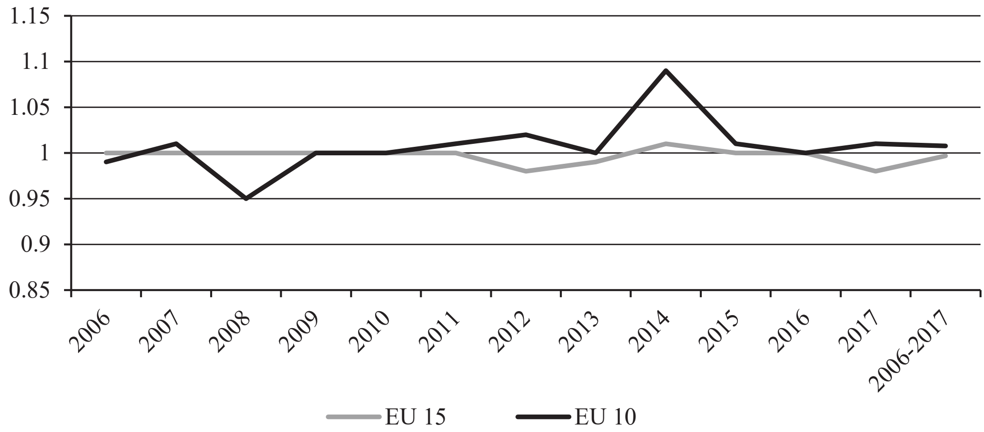

Fig. 3. Technical progress/regress in agriculture in the EU, EU 15 and EU 10 in 2006-2017

Source: own elaboration based on FADN.

progress (index 1.00, see Table 3). At the same time, similar average annual TFP growth was observed in both the EU 15 and the EU 10. These results are partly consistent with the research by Domańska et al. [2014]. According to their results the Malmquist TFP increased in the EU–27 in 2007–2011, mainly due to positive changes in technical efficiency. In turn, the influence of technical changes was relatively low and negative. In a study by the European Commission [2016], total factor productivity increased in the EU 28 in 2005-2015, albeit at a slower rate in recent years then in the past. Both in the EU 15 and the EU 13 the TFP growth increased although the EU 13 growth rates were relatively higher. In turn, according to Baráth, Fertő [2017], the TFP estimated for the EU countries slowly decreased in 2004-2013, but for the new member countries productivity was much higher and was in a growing trend. According to Kijek et al. [2019], the level of relative TFP index was lower but positive in the new member states compared to most of the EU 15 countries. It should be emphasized that the differences in the research results can be explained by the different scope of research in relation to the number and features of entities, the time of examination and the applied productivity measures.

As our research reveals, the increase in agricultural productivity in the EU 15 resulted only from an improvement in efficiency, while in the case of the EU 10 the increase in TFP was affected both by positive efficiency changes and technical progress. It can be assumed that this was a result of the implementation of the instruments supporting the agricultural sector within the CAP in new members. Public expenditure on the agricultural sector (i.e. the modernisation of agricultural holdings, purchase of new machinery and equipment, training activities) contributed to the dissemination of technical progress and, consequently, to the improvement of agricultural productivity [Headey et al. 2010; Rizov et al. 2013; Dudu, Kristkova 2017].

3.3. Efficiency and technical progress in the EU countries

The last part of the study is devoted to an assessment of the components of the TFP indices changes in individual countries of the European Union over the period 2006-2017 (see Figure 4).

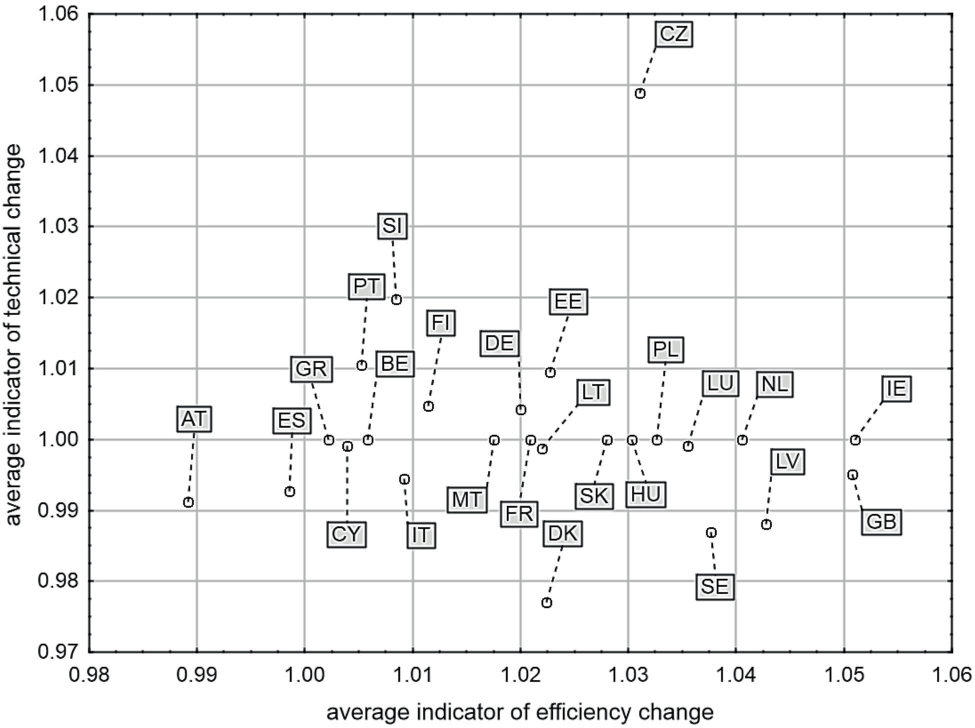

Fig. 4. Average technical change and efficiency change in agriculture in the EU countries in 2006-2017

Source: own elaboration based on FADN.

As the data show, the components of the agricultural TFP index developed differently for individual countries during the analysed period. An increase in efficiency took place in all EU 15 countries, except for Spain and Austria. The observed positive changes were relatively low, and the greatest were characterized for farms in Ireland, Great Britain and the Netherlands. At the same time, technical efficiency increased in all EU 10 countries, with the highest change in Latvia, Slovenia and Poland.

In respect to technical changes, it should be noted that the positive changes were observed only for three countries of the EU 15, namely Finland, Germany and Portugal. The average indicator of technical progress in this group of countries was relatively low and amounted to 1.01. In other countries there were no changes or there was technical regress that compensated the mentioned positive changes. Technical progress took place for three new member states, the Czech Republic, Estonia and Slovenia. The index for these three countries was 1.03 in 2006-2017. In the other new members there was neither technical progress nor regress.

Only in two EU countries, the agricultural TFP was affected by a decrease both in production efficiency and technical changes. These were Austria and Spain (see Figure 4), both belonging to the EU 15. The increase in agricultural productivity resulted from a rise in efficiency and also technical changes in six countries: the Czech Republic, Estonia, Finland, Germany, Portugal and Slovenia.

4. Conclusions

The main purpose of the research was to estimate changes in agricultural TFP indices in the EU 15 and the EU 10 countries and to indicate to what extent these changes resulted from technical progress and to what extent from efficiency changes. The research was based on the TFP Malmquist index completed with a decomposition on technical changes and efficiency changes. The authors' contribution to literature, which referred to agricultural productivity, covers mainly two issues. Firstly, the research scope encompasses the EU, the EU 15 and the EU 10 groups in the period 2006-2017 and the study based on FADN data for representative farms from these countries. Depending on the year, these farms represented from 4 045 300 to 5 295 930 farms in the EU countries. Secondly, changes in total factor productivity in agriculture and its components were assessed, not only in groups of countries, but also in individual EU countries. As far as the authors know, research in this area using FADN data has not been conducted so far.

The authors have proved that in 2006-2017 there were positive changes in agricultural productivity in the three investigated groups. At the beginning of the analysed period these changes varied for the EU 15 and the EU 10, but with time they were nearing each other. The increase in agricultural productivity in the EU was mainly the result of improved efficiency in the absence of technical changes. In the case of farms from the EU 15, the positive changes in productivity resulted only from a rise in efficiency, while for the EU 10 the increase in TFP was affected by both efficiency improvement and technical progress. This can be partly explained by the implementation of the instruments that support agriculture. They directly stimulate the growth of productivity in this sector [Dudu, Kristkova 2017] and indirectly contribute to the increase of agricultural income and sustainable development of the agricultural sector in the EU. As a consequence, it can be assumed that the EU demands to increase cohesion in the agricultural productivity between the EU 15 and EU 10 countries is being implemented. From the point of view of achieving the EU's long-term goals, this should be assessed positively.

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