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MEASUREMENT OF EFFICIENCY OF DIDACTIC ACTIVITIES OF PUBLIC UNIVERSITIES OF TECHNOLOGY IN POLAND: DIRECTIONAL DISTANCE FUNCTION WITH UNDESIRABLE OUTPUT APPROACH

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Abstract. *Purpose* – The conducted research aimed at estimating the technical efficiency of didactic activity in the group of universities of technology in Poland using the non-parametric Data Envelopment Analysis (DEA) method.

Research methodology – The measurement was based on the model of directional distance function with undesirable output under variable return-to-scale and output-oriented (DDF BadOutput-V-O).

Findings – The research allowed to group universities in 2010 and 2015 into three categories, i.e. efficient universities and universities above and below the average efficiency. It has been shown that it is justified to use alternative models of efficiency measurement covering different perspectives. The application of the model from a financial and employment perspective showed significant differences in performance levels in some cases.

Research limitations – This study only looks at universities of technology, so the future study should be extended to other universities and compare efficiency of higher education with the level of study effectiveness (dropout rate education, graduation rates).

Practical implications – The use of the DDF model with undesirable output allowed to obtain results closer to the actual conditions of teaching in public universities than in the case of using classic DEA models, wich only take the desired output into accoount.

Originality/Value – The originality of the work lies in the use of a more general and flexible DDF approach than the classical DEA models, which made it possible to estimate the efficiency of universities taking into account the desirable (positive) and undesirable (negative) output.

Keywords: higher education, efficiency, DEA, DDF, undesirable output.

JEL Classification: I22, I23.

Introduction

Higher education in 2018 has undergone another reform aimed at increasing quality. It is, therefore, reasonable to assess the effects of the previous system changes in higher education in 2011. The assumptions to the Act on Higher Education of 2011 indicated that "the

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proposed changes are primarily of a pro-quality nature and lead to an improvement in the efficiency of spending public funds on higher education" (Ministerstwo Nauki i Szkolnictwa Wyższego [MNiSW], 2009, p. 22). The aforementioned problem has still not been adequately resolved because, in the justification to the draft law on higher education and science from 2017, attention is drawn, inter alia, on "unsatisfactory quality of higher education" (MNiSW, 2017, p. 3). In addition, it is indicated that (MNiSW, 2017, p. 1) "systemic problems in the area of higher education (...) negatively affect (...) the level of education of students and doctoral students. This is a premise for the reform (...), including changes in the functioning of the system, management, financing and assessment of the quality of the university's activities". Nor can one disagree with Leja (2002, p. 16), who emphasizes that "assessing institutional efficiency in higher education is necessary primarily because the financial (public) funds are allocated on the basis of indicators characterizing university achievements and activities". The above-selected assumptions of the two reforms of the academic education system correspond to the requirements for management control of public entities in terms of efficiency and effectiveness of operations in accordance with art. 68 of the Public Finance Act (Ustawa z 27 sierpnia 2009 r.). These considerations indicate that the problem of measuring the effectiveness of higher education in the field of education is very important and requires in-depth research in this field.

The purpose of this research was to assess the level of technical efficiency of teaching activities of universities of technology using the DEA method, taking into account the desired and undesirable output of the educational process.

The article consists of six parts. After the introduction, the second part reviewed the literature on the study of the efficiency of higher education. The next methodical part presents both the essence of measuring efficiency using DEA models that were used in the research and characterizes the empirical research. The fourth part presents the variables adopted for the study, and the next section presents the results of empirical research. The article concludes with conclusions and proposals for further research within the considered topic.

1. Review of the scientific literature

A query in Polish and foreign literature shows that the non-parametric DEA (Data Envelopment Analysis) method (Charnes et al., 1978; Banker et al., 1984) is primarily used to measure the efficiency of higher education. The parametric SFA (Stochastic Frontier Analysis) method is much less frequently used, which dates back to the late 1970s (Aigner et al., 1977; Meeusen & van den Broeck, 1977).

Both methods determine the level of efficiency of the audited entity in relation to the efficiency limit. It should be remembered, however, that DEA, unlike SFA, is a deterministic method and does not include the so-called random component, making it more susceptible to measurement errors. Besides, DEA estimates the level of efficiency based on other units in the study group, rather than an independent model in the form of production functions or costs, as in the case of SFA (Brzezicki & Prędki, 2018).

Nevertheless, the multitude of models that make up the DEA methodology makes it most commonly used to measure efficiency in higher education. Therefore, when reviewing the literature on the subject, the focus was mainly on this method. Studies on the efficiency of higher education using the DEA method are carried out at several levels: from international comparisons of higher education systems (Wolszczak-Derlacz, 2015), to the national level of all 59 public universities (Ćwiąkała-Małys, 2010; Świtłyk, 2013) or selected groups universities (Rusielik, 2010; Szuwarzyński & Julkowski, 2014; Brzezicki & Wolszczak-Derlacz, 2015; Brzezicki, 2017), up to the faculties of one (Pietrzak & Brzezicki, 2017) or several universities (Pietrzak, 2016).

It is widely accepted that the main areas of activity of universities include: didactics and the scientific sphere. However, more and more often you can see that universities from scientific and culture-forming institutions "(...) they are clearly transforming into enterprises and even industrial universities" (Czerepaniak-Walczak, 2013, p. 11).

Therefore, the literature on the subject began to use the concept of "entrepreneurial university" to define a university that functions in many areas, actively and flexibly adapt to the changing market and its needs, is constantly looking for new development opportunities and treats its stakeholders as clients (Wójcicka, 2006). According to the entrepreneurial university paradigm, the university's areas of activity are teaching, research and cooperation with the socio-economic environment. Bearing these areas in mind, it can be seen in the literature that some of the authors only deal with research on the efficienty of didactics (e.g. Brzezicki & Wolszczak-Derlacz, 2015; Świtłyk, 2013), and some analyse both didactics and scientific research (e.g. Wolszczak-Derlacz & Parteka, 2011). However, more and more often, the authors try to capture data from all three areas of higher education (e.g. Pietrzak & Brzezicki, 2017).

In the case of analysing didactic activity, the number of students, graduates (Ćwiąkała-Małys, 2010) was included on the results side, and for scientific activity - the number of publications, citations (Wolszczak-Derlacz, 2013), and in relation to activities for the socio-economic environment - the number of research projects, the value of grants (Pietrzak & Brzezicki, 2017; Wolszczak-Derlacz, 2013). However, expenditures were assumed to include the number of academic teachers (Brzezicki & Wolszczak-Derlacz, 2015; Pietrzak & Brzezicki, 2017; Wolszczak-Derlacz & Parteka, 2011), other employees (Brzezicki & Wolszczak-Derlacz, 2015; Rusielik, 2010), the value of revenues (Brzezicki & Wolszczak-Derlacz, 2015; Wolszczak-Derlacz & Parteka, 2011) and various types of costs, e.g. consumption of materials and energy, external services, etc. (Rusielik, 2010; Świtłyk, 2013). However, the most commonly used input variables in the field of teaching include the number of academic teachers, other employees, the number of students, graduates and various financial categories.

As has already been mentioned earlier, various statistical and financial data were used to test efficient using the DEA method. However, it should be noted that in the case of didactic activity, the carrier of non-material educational services are people, while the very effect of the educational process is stretched in time, which is why it is subject to various perturbations (see Pietrzak, 2016). This causes some problems when defining the effects of the area related to education because depending on the purpose of the analysis, students (e.g. Rusielik, 2010) and once graduates (e.g. Wolszczak-Derlacz, 2013) were accepted as the product of the activity.

However, as emphasized by Brzezicki (2017), graduates are naturally identified with the final education process, so their choice is logical and closer to the actual assessment of teaching activities. At the same time, one cannot disagree with Szuwarzyński (2006, p. 217–218), who indicates that “It is often assumed that a product is a graduate, but no one specifies how he obtained the diploma. Is it by the deadline or a year or two later? (...) These are also products that can be compared with defective products in a production company. They entail specific costs ... ”. Considering the fact that the Ministry of Science and Higher Education is both the owner of public universities and the main one financing the education service by means of a didactic subsidy, it is very important for as many people as possible to complete education in the nominal time provided for the education process and be able to move from the educational to the economic sphere by undertaking work. Taking into account both the perspective of the Ministry of Science and Higher Education, which expends specific public funds, including for didactic activities and for the universities themselves, which resources are used in the education process, it should be assumed that the most important thing is that the expenditure allocated for this purpose is used rationally and effectively (in accordance with the assumptions of management control) in the nominal time foreseen for studies for a given educational cycle.

When analysing methodologically the research conducted using the DEA method, devoted to Polish higher education, a particular relationship was noticed. Two standard radial CCR and BCC models (e.g. Ćwiąkała-Małys, 2010; Świtłyk, 2013) are usually used for the study, with few exceptions in the form of, e.g. SBM (Rusielik, 2010; Szuwarzyński & Julkowski, 2014; Brzezicki, 2017), non-radial SBM network model (Pietrzak & Brzezicki, 2017), hybrid model with undesirable output (Brzezicki, 2018). Meanwhile, studies in foreign literature are increasingly appearing in which a new approach is used to assess efficiency using the directional distance function model (DDF), or the idea is used as the basis for building a new, much more advanced research methodology. Among the works in this area, it is worth mentioning (Barra & Zotti, 2016; Daraio et al., 2015; Yang et al., 2018; Villano & Tran, 2019). However, only Barra and Zotti (2016), using the function of directional distance, drew attention in their research to the so-called undesirable effects of didactic activity, taking into account a simple relational indicator of student resignation between the first and second year of study.

According to the authors' knowledge, the aforementioned problem signalled theoretically by Szuwarzyński (2006) regarding the time of obtaining a diploma by higher education graduates, and the related issue of undesirable output of didactic activity, were first taken in Poland empirically by Brzezicki and Rusielik (2017), who included the number of students after the last year without a diploma, similar to Brzezicki (2018). This topic was also developed by Szuwarzyński (2018), who adopted the student resignation rate between the first and second year of studies as an undesirable output, adopting the research convention of Barra and Zotti (2016). However, all the quoted studies do not fully cover the issue of the undesirable output of teaching in higher education.

This gaps in knowledge found the authors will try to fill empirically later in the article. To date, no analysis has been made in Poland of the issue to which Szuwarzyński (2006) drew attention, using a new approach to efficiency testing using the directional distance function. In addition, delimiting this to the desired output of teaching activities when the graduate graduated in regular time and undesirable (negative) output of these activities if he exceeded the nominal period of study, which is a practical fulfilment of the assumptions of management control.

2. Research methodology

As noted in the previous part of the work, the DEA method is used to study the efficienty of higher education more often than other methods. The beginnings of the DEA method go back to the article by Charnes, Cooper and Rhodes (1978), which presents the first DEA model called CCR, from initials of authors' surnames, assuming a constant return to scale. However, the paper (Banker et al., 1984) presents the second, basic BCC model, in which variable return to scale was adopted.

The progress in measuring efficiency, caused by the use of a more general and flexible approach, which is the Directional Distance Function (DDF), has made this approach increasingly used to measure the efficiency of business entities under the DEA methodology. Färe and Grosskopf (2000), presenting the relationship between the Shephard distance function (1953, 1970), whose idea is used in radial models, and the directional distance function proposed by Chambers, Chung, and Färe (1996), indicate that it is an important tool in production theory. The Shephard distance function is a special case of the directional distance function. Färe and Primont (2006) argue that the functions of directional distance can be considered as an alternative to appropriate concepts for measuring radial efficiency.

As already mentioned, the function of the directional distance was formally presented for the first time by Chambers, Chung, and Färe (1996, 1998), who used the work of Luenberger (1992a, 1992b, 1995) and redefined his benefit function and shortage function as measures of efficiency, introducing a new distance function for this purpose, which they called the directional distance function. In addition, they demonstrated the fact that the directional distance function covers other classic cases, including Shephard's entry and exit functions. The advantage of the directional distance function is that it can be estimated using the same linear programming techniques that are used in the DEA methodology.

The classic approach within the DEA methodology allows determining the effectiveness of the tested unit based on the efficiency criterion assuming that the production of a larger number of products (regardless of whether they meet expectations or not), using smaller resources is better than generating a smaller number of products. However, the above principle does not quite work in business practice because it does not include undesirable (defective) products of activity that occur during the production process. Most often, the company tries to produce as many desired products as possible and the least undesirable (e.g. due to a production error) that do not meet expectations. Therefore, the economic unit, called DMU (Decision Making Unit), whose production technology allows to generate more desirable products, in line with expectations and less undesirable (defective), using fewer resources, will be more efficient.

Only Chung (1996) and Chung, Färe, and Grosskopf (1997) presented the possibilities of using the directional distance function in the situation of both desirable and undesirable output of the enterprise's activity. The model of the directional distance function with undesirable output (DDF BadOutput) is based on the assumption that each DMU unit subjected to the test produces both the desired and unwanted output from the given inputs. This means that three groups of variables are used to estimate efficiency, i.e. input as well as desirable and undesirable (defective) output.

The following symbols have been adopted: input vector in the form of $x \in R_+^N$, undesirable output $b \in R_+^I$, and desired $y \in R_+^M$, then the production technology can be described as:

$$T = \left\{ \left(x, y, b \right) : x \, \text{can produce} \left(y, b \right) \right\}. \tag{1}$$

The directional distance function is based on scaling the relevant directional vectors $g = \left(-g_x, g_y, -g_b \right) \in R_+^I \times R_+^S \times R_+^K$, which correspond to the individual variables, i.e. inputs ($-g_x$) and desirable (g_y) and undesirable ($-g_b$) outputs. The directional distance is determined by the formula (Barra & Zotti, 2016, p. 171):

$$\vec{D}\left(x, y, b, g_x, g_y, g_b \right) = sup\left\{ \beta : \left(x - \beta g_x, y + \beta g_y, b - \beta g_b \right) \epsilon T \right\}, \tag{2}$$

where β represents the distance between the observation for a given unit and the point on the efficient frontier, taking into account the direction vector determining the direction in which efficiency is measured.

The directional distance function with undesired output, assuming a variable return to scale (BadOutput-V), can be estimated within the framework of the DEA methodology, for the object number o = 1, ..., n, as follows:

$$\begin{gathered} \max \beta_o ; \\ \sum_{j=1}^{n} \lambda_{jo} x_{ij} \le x_{io} - \beta g_{xio} ; \\ \sum_{j=1}^{n} \lambda_{jo} y_{sj} \ge y_{so} + \beta g_{yso} ; \\ \sum_{j=1}^{n} \lambda_{jo} b_{kj} = b_{ko} - \beta g_{bko} ; \\ \sum_{j=1}^{n} \lambda_{jo} = 1 ; \\ \lambda_{jo} \ge 0, i = 1, \ldots, I; s = 1, \ldots, S; j = 1, \ldots, n; k = 1, \ldots, K , \end{gathered} \tag{3}$$

where λ_{jo} is the intensity factor. However, the condition $\sum_{j=1}^{n} \lambda_{jo} = 1$ indicates that the measurement of efficiency will take place under the assumption of a variable return to scale.

The β value is a measure of the inefficiency of the DMU being assessed. Therefore, if for a given DMU unit, the value β = 0 means that the tested entity is efficient, while the measure β > 0 indicates the inefficiency of the object. In order to determine the unit's efficiency as suggested by Ray (2008), subtract the inefficiency index (β) calculated using the directional distance function (DDF), i.e. the level of efficiency = (1–β), from a value of 100% efficiency. The procedure presented by Ray (2008) was used in this study.

The model (3) in general is characterised by a lack of orientation (non-oriented), unlike many "classic" DEA models, including CCR and BCC. By adapting for the purposes of this article the research convention of Barra and Zotti (2016), consisting in taking into account relevant desirable and undesirable output of didactic activity, it was decided to use the so-called output-oriented radial DDF model with the variable return to scale [DDF BadOutput-V-O]. The lack of orientation, which characterises the initial model, is therefore abandoned (3). This is a particular case of the model (3), which assumes $g = \left(-g_x, g_y, -g_b\right) = \left(0, y_o, -b_o\right)$:

$$\max \beta_o ;$$
$$\sum_{j=1}^{n} \lambda_{jo} x_{ij} \le x_{io} ;$$
$$\sum_{j=1}^{n} \lambda_{jo} y_{sj} \ge \left(1+\beta\right) y_{s0} ;$$
$$\sum_{j=1}^{n} \lambda_{jo} b_{kj} = \left(1-\beta\right) b_{ko} ; \qquad (4)$$
$$\sum_{j=1}^{n} \lambda_{jo} = 1 ;$$
$$\lambda_{jo} \ge 0,\ i = 1,\ldots,I;\ s = 1,\ldots,S;\ j = 1,\ldots,n;\ k = 1,\ldots,K .$$

In order to properly perform the test using the DEA method, it is necessary to both determine the appropriate number of decision units (in relation to the total number of inputs and output), as well as to select them correctly to ensure the homogeneity of the analysed group of objects. Therefore, purposeful selection of objects subjected to analysis was made, adopting a group of 18 public technical universities supervised by the Ministry of Science and Higher Education (MNiSW): U1 – West Pomeranian University of Technology in Szczecin, U2 – Warsaw University of Technology, U3 – Białystok University of Technology, U4 – University of Technology and Humanities in Bielsko-Biała, U5 – Częstochowa University of Technology, U6 – Gdańsk University of Technology, U7 – Silesian University of Technology in Gliwice, U8 – Kielce University of Technology, U9 – Koszalin University of Technology, U10 – Cracow University of Technology Tadeusza Kościuszki, U11 – AGH University of Science and Technology, U12 – Lublin University of Technology, U13 – Łódź University of Technology, U14 – Opole University of Technology, U15 – Poznan University of Technology, U16 – Kazimierz Pulaski University of Technology and Humanities in Radom, U17 – Rzeszow University of Technology, U18 – Wroclaw University of Technology.

3. Variables adopted for empirical study

The basis for the selection of variables for the study was the purpose of this work to analyse the efficiency of teaching activities in a situation of both positive and negative output. In addition, attention was also paid to data used in the literature by other authors. The primary resources of universities include financial resources and employees. Therefore, they focused on defining inputs. Thus, the number of academic teachers (full-time and part-time) converted into full-time jobs was assumed as the first circulation – X1. The second and last expenditure was the total value of teaching income in a given year – X2.

Turning to the effects of teaching, two output were adopted, one desired (positive) and the other undesirable (negative). The total number of students (full-time and part-time) after the last year without a diploma who did not complete education in the nominal period, was used to define the undesirable output of didactic activity – B1. However, the total number of graduates (full-time and part-time, including foreigners) – Y1, who are naturally identified with the final education product, was adopted as the desired output of the educational process.

Two empirical models (M-1, M-2) were adopted for the study, consisting of one input and two output (Table 1). Only the number of academic teachers (X1) was assumed for expenditure in the first empirical model (M-1), while the second model (M-2) included only the total value of teaching income (X2). The adoption of such a research convention results from the fact that the highest share in teaching income is a subsidy from the state budget, the amount of which depends, among others on the number of teaching staff. Therefore, there is a certain correlation between variables, so to eliminate it, one variable was adopted in both empirical models. On the other hand, the same variables characterizing the undesirable and desired output of didactic activities were adopted as output in the considered models, in the form of the number of students after the last year without a diploma (B1) and the number of graduates (Y1). It was assumed that a higher education institution whose production technology allows it to obtain more good output and less undesirable in terms of didactic activity is more technically efficient than other units.

Table 1. Accepted inputs and output in empirical models (source: authors' calculations)

Name of the variable	M-1	M-2
X_1 – number of academic teachers (full-time and part-time)	+	–
X_2 – total value of teaching income	–	+
B_1 – number of students (full-time and part-time) after the last year without a diploma	+	+
Y_1 – number of graduates (full-time and part-time)	+	+

Statistical data used in the study were taken from the publication "Higher education – basic data" (MNiSW, 2010, 2015) published by the Ministry of Science and Higher Education, and financial data from reports on the implementation of the material and financial plan of individual universities published in the public judicial and economic monitor (MS, 2010–2015). The adoption of data from 2010 and 2015, makes it possible to illustrate the situation before and after the introduction of the reform of higher education in Poland in 2011.

4. Results and discussion

Table 2 presents a summary of results of measuring the efficiency of teaching activities in 2010 and 2015 for the M-1 model (regarding the number of employees) and the M-2 model (related to the total value of teaching income).

Table 2. The efficiency of educational activities of public technical universities in 2010 and 2015 (source: authors' calculations)

Year	2010		2015		2010	2015
Model	M-1	M-2	M-1	M-2	Difference [(M-1)– (M-2)]	
U1	0.87	0.87	0.50	0.50	–0.01	0.00
U2	0.95	0.95	0.71	0.71	0.00	0.00
U3	1.00	1.00	0.64	0.66	0.00	–0.03
U4	1.00	1.00	1.00	1.00	0.00	0.00
U5	1.00	1.00	0.58	0.79	0.00	–0.21
U6	0.62	0.60	0.83	0.77	0.02	0.06
U7	1.00	1.00	0.89	0.90	0.00	–0.01
U8	0.74	0.58	0.89	0.97	0.16	–0.08
U9	1.00	1.00	0.68	0.84	0.00	–0.16
U10	0.76	0.76	0.73	0.75	0.00	–0.02
U11	0.78	0.78	1.00	1.00	0.00	0.00
U12	0.55	0.56	0.71	0.70	0.00	0.01
U13	0.71	0.71	0.58	0.55	0.00	0.03
U14	1.00	0.99	1.00	1.00	0.01	0.00
U15	1.00	1.00	0.88	0.90	0.00	–0.02
U16	0.92	1.00	1.00	1.00	–0.08	0.00
U17	0.88	0.81	1.00	1.00	0.06	0.00
U18	1.00	1.00	0.87	0.84	0.00	0.03
Minimum	0.55	0.56	0.50	0.50		
Average	0.88	0.87	0.81	0.83		
Maximum	1.00	1.00	1.00	1.00		
Std. deviation	0.15	0.16	0.17	0.16		

The average technical efficiency in 2010 was 0.88 for the M-1 model, while for the M-2 model, it was 0.87. In turn, in 2015 it was respectively 0.81 for the M-1 model and 0.83 for the M-2 model. It can be stated that in 2015 the overall level of efficiency decreased by a few percentage points. In 2010, the lowest efficiency indicators for both models were recorded at the Lublin University of Technology, while in 2015 it was the West Pomeranian University of Technology.

Analysing the differences between the model covering the number of academic teachers (M-1) and the model covering the value of teaching income (M-2), it can be stated that in 2010 in three universities these differences were significant. The biggest difference between the analysed models was found at the Kielce University of Technology, and it was about 16%. In turn, at the University of Technology and Humanities in Radom this difference was –8%, and at the Rzeszów University of Technology 6%. Generally, it can be stated that the differences between the analysed models (apart from the cases mentioned) are small. This confirms the calculated average efficiency level of both models. It is worth noting that only in the case of the University of Technology and Humanities in Radom the M-2 model had a higher indicator level than the M-1 model. In turn, in 2015, the differences between the two models were definitely larger. The level of performance indicators for the M-2 model is higher than for the M-1 model. In some cases, these differences are very significant, e.g. at the Częstochowa University of Technology, they amounted to –21%, and at the Koszalin University of Technology –16%. It can be stated that 2015 is definitely more diverse in this respect than in 2010.

In the next step, an attempt was made to group the analysed universities in terms of the efficiency indicator level. The universities were divided into three groups. Group A, i.e. efficient universities where the level of the efficiency ratio is 1.0. Group B, where the level of efficiency is above the average for a given year and model, and group C where the efficiency is below this average. The results of the grouping are included in Table 3.

Table 3. Grouping of public technical universities in 2010 and 2015 (source: authors' calculations)

Model	M-1	M-2	M-1	M-2
Year	2010		2015	
U1	C	B	C	C
U2	B	B	C	C
U3	A	A	C	C
U4	A	A	A	A
U5	A	A	C	C
U6	C	C	B	C
U7	A	A	B	B
U8	C	C	B	B
U9	A	A	C	B
U10	C	C	C	C
U11	C	C	A	A
U12	C	C	C	C
U13	C	C	C	C
U14	A	B	A	A
U15	A	A	B	B
U16	B	A	A	A
U17	B	C	A	A
U18	A	A	B	B
Group	Numerosity			
A	8	8	5	5
B	3	3	5	5
C	7	7	8	8

Based on the grouping results, it was noticed that there are differences in the level of efficiency between the analysed years. In 2010, there were eight efficient universities, three colleges in group A and seven colleges in group B. In 2015, there were five efficient colleges, in group B there were also five colleges and eight universities in group C.

Only one university was recorded, which was fully efficient both in the case of two empirical models and in both analysed years. This university was the University of Technology and Humanities in Bielsko-Biała. There were also three universities, which in each of the analysed cases belonged to group C. They were the University of Technology in: Cracow, Lublin and Łódź.

Only two universities, i.e. Białystok University of Technology and Częstochowa University of Technology "fell" from the efficient A group to the least efficient C group between the analysed years. You can also include the Koszalin University of Technology. However, in the case of AGH, there was a transition from group C to group A. A similar situation occurred at the Rzeszów University of Technology.

In other cases, transfers between the groups occurred from group A to B or from group B to C. Comparing the analysed years; one can notice a tendency to move to a lower efficiency category.

Conclusions

In this study, the level of efficiency of teaching activities of universities in individual years has been analysed. The use of the DDF model with undesirable output allowed to obtain results closer to the actual conditions of teaching in public universities than in the case of using classic DEA models, which take into account only the desired output.

On the other hand, the use of two alternative models, in which in one case the number of teachers (M-1) was adopted as an input, and in the other the value of teaching income (M-2) allows to determine the differences in the results obtained for some universities. This indicates the validity of using alternative models to assess the efficiency of individual universities. Such extended analysis, carried out from different perspectives, gives a complete picture of the examined level of efficiency.

The analysis showed that the average level of the efficiency ratio in 2015 decreased compared to 2010 by 4–6 percentage points. The number of universities considered efficient also decreased. Among the analysed universities, only the University of Technology and Humanities in Bielsko-Biała showed full technical efficiency in all analytical variants. On the other hand, three universities were noted, which in all analyses were below average efficiency.

Future research directions should take into account the quality of academic education and the links between education and the labour market. The second important research direction should be analysis, which affects the efficiency of studying and reducing the number of people who do not finish education in the nominal duration.

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Author contributions

ŁB developed the research concept and wrote the following parts of the article: Introduction, Review of the scientific literature, Research methodology, Variables adopted for empirical study. ŁB was responsible for data acquisition and efficiency assessment. RR was responsible for analysing the results and writing the following parts of the article: Results and discussion, Conclusions.

Disclosure statement

Authors declare they haven't any competing financial, professional, or personal interests from other parties.

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