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The efficiency of scientific activities and technology transfer in higher education in Poland[3]

Introduction

Since the 1980s, knowledge, innovation, and technology transfer have been recognised as the most important factors of growth, socio-economic development and the competitiveness of highly developed countries. These resources have become even more significant in the recent years of this century with increased globalisation and competition and the desire of many developing countries (including BRICS) and recently considered developed countries (e.g., Poland) to advance their development in terms of civilisation and technology (Kirby, El Hadidi, 2019; Rossoni et al., 2023).

The presented challenges require new solutions from societies that arise in national (NIS), regional (RIS) (Łącka, Brzezicki, 2021), and local innovation systems (LIS). The efficiency and productivity of these systems determine the possibility of overcoming challenges, reducing barriers, and taking advantage of development opportunities in the modern economy. Poland, for several years, has been trying to make changes in the functioning of its national innovation system (Łącka, Brzezicki, 2021) and its components within the higher education sector (Łącka, Brzezicki, 2020). The goal is to increase the role of universities in the technology transfer process between science, industry and society within

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the so-called third (Compagnucci, Spigarelli, 2020) and even fourth mission of the university (Lucovics, Zuti, 2015). This requires cooperation within helix models from the simplest form (the so-called triple helix) to developed models of cooperation between science and business (quadruple and quintuple helix models) (Yoda, Kuwashima, 2019; Łącka, 2020). According to Osuch-Rak, "studies on technology transfer largely focus on the subject of academic entrepreneurship originating from universities and colleges" (2017, p. 133).

Over the last decade, the Polish higher education system has been changed and reformed several times (2011, 2018) to adapt it to new social and economic conditions and expectations, both domestic and international ones. The introduced changes concerned didactic activity and many other issues, such as evaluating scientific publications, commercialising research, university funding algorithms, scientific development, activities of academic bodies, and many other problems. In 2011, the Ministry of Science and Higher Education in Poland (MSHE) developed and implemented a central integrated system for the activities of higher education and science in Poland, which is called "POL-on". On the basis of data in the POL-on system on teaching, scientific and implementation activities, decisions were made on the implemented scientific policy of the state.

In 2012, the MSHE established a list of scientific journals with the number of points awarded for publications in these journals. Meanwhile, the articles outside the MSHE list were rated the lowest. The introduction of the list of journals was one of the elements of higher education reform in Poland introduced in 2011.

It is also worth noting that for several years now, one can observe an increased interest in the MSHE and the promotion of the idea of knowledge and technology transfer to the economy among universities through numerous financial programmes addressed to the academic community. This is reflected in the state's introduction to the evaluation of scientific units (including universities) of an assessment of knowledge and technology transfer from the world of science to the economy (Ministry of Science and Higher Education, 2020).

Therefore, it is reasonable to conduct research to measure and assess the efficiency of scientific research and technology transfer to the economy through higher education institutions. The objective of the article is to assess the efficiency of scientific activity and technology transfer to the economy by public universities in Poland and to formulate recommendations for state policy to increase the effectiveness of the technology transfer process by them.

Literature review

Due to their scientific and research potential, universities are a source of knowledge and technologies that should be used in the modern world for socio-economic development (Amry et al., 2021; Barra et al., 2021). Scientists show

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less interest in researching the efficiency of university technology transfer (UTT) using quantitative and qualitative methods (e.g., Anderson et al., 2007; Kim et al., 2008; Tseng, Raudensky, 2014). An important contribution to the presentation of the effects of university technology transfer offices in the Republic of Korea is the research of Han (2018). Stochastic Frontier Analysis was used to study the efficiency in this regard. In recent years, more and more scientists from various countries have undertaken research on technology transfer carried out by universities and its determinants. A synthetic discussion of the scope of these studies, based on a literature review, is presented in the study by Rybnicek and Königsgruber (2019), de Wit-de Vries *et al.* (2019), Padilla Bejarano *et al.* (2023) and O'Dwyer *et al.* (2023).

Technology transfer can be understood in a narrow and broad sense. Perceiving technology transfer narrowly, we say that it trades in patents, utility models, licenses and know-how. This is also the mechanism leading to the dissemination of technology. In a broader sense, technology transfer includes the creation of knowledge, the transfer of technology and its acceptance and implementation by the end user. In this case, technology is understood as the result of the use of: scientific knowledge (e.g., resulting from research and development work carried out at universities), practical knowledge (know-how), appropriate technical equipment, and methods of process implementation and organisation (e.g., spin-offs), which through the appropriate structure and systems contained in it is able to ensure optimal use of technology. In this approach, an important role in the process of technology transfer is played by scientific and research units which, while implementing the third mission of the university, create new solutions or cooperate in this area with the industry (Osuch-Rak, 2017; Perkmann et al., 2021; Sharma, 2022).

In Poland, this issue is even less explored, and there is a lack of research allowing the measurement and evaluation of the efficiency of technology transfer processes in university-type HEIs of different natures (universities, technical, medical, economic, agricultural, and military HEIs) and from different sectors (public and private).

Researching the achievements of academic centres usually comes down to selecting the appropriate input and output data and then measuring efficiency using various quantitative methods. In this approach, university activity is seen as a process by which inputs are transformed into outputs. From the review of educational research in the world by De Witte and López-Torres (2017), it can be concluded that they are very diverse in various respects. However, research on the efficiency of universities is most often performed using the non-parametric DEA method or the parametric Stochastic Frontier Analysis (SFA). The Rhaiem (2017) analysis shows that more research is carried out with DEA than with SFA.

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The authors studying the efficiency of higher education used very different DEA models (Table A1 in Appendix), ranging from classic (CCR, BCC, SBM) to advanced (DDF, network DEA, dynamic SBM) models. Scientists chose the DEA model for analysis based on the research concept and the purpose of the research. Each model has different analytical possibilities, which were used depending on the research needs, e.g., the network DEA model allows for consideration of the network of connections, and the dynamic SBM model allows for inter-periodic variables. Some authors used a two-stage analysis to study higher education. In the first stage, the efficiency indicators were calculated using the DEA method, and in the second stage, regression was used to determine the factors influencing the efficiency level.

Typically, inputs were accepted as the number of academic staff or research and development (R&D) staff, funds for R&D, room space or fixed assets, and outputs included the number of publications or citations, patents, and grants. In the R&D activity of universities, some authors considered the number of publications, while others considered the number or the value of financial grants. However, Gralka *et al.* (2019) suggest that these two outputs can be included interchangeably in research. The authors (Gralka et al., 2019) argue that most publications are financed by grants, so these two variables are closely related. It is worth noting that most of the authors who study the efficiency of higher education (e.g., Foltz et al., 2012; Visbal-Cadavid et al., 2017; Wolszczak-Derlacz, 2018) in one model consider data related to teaching activity (e.g., the number of students or graduates) and R&D activity (e.g., the number of publications) or technology transfer (e.g., the number of the patents) and primary research (e.g., the number of journals, citations), which is a fundamental limitation, as it is not known which activity affects the efficiency level of a particular university to a greater extent. Some authors notice this problem. Therefore, they use a two-stage network DEA model (Yang et al., 2018), in which the first stage is related to basic research and the second to technology transfer. A few authors (e.g., Wolszczak-Derlacz, 2013; Chuanyi et al., 2016; Łącka, Brzezicki, 2020) use two separate empirical models adopting other variables. Wolszczak-Derlacz (2013) separately estimated the efficiency of scientific and implementation activities of 31 public higher education institutions in Poland (mainly universities and polytechnics) in 2001-2008. The author's study found that polytechnics (technical universities) were more efficient than universities in terms of scientific and implementation activities. However, since the Wolszczak-Derlacz (2013) study, several systemic changes have been introduced, including a comprehensive evaluation of the scientific activity of HEIs, the creation of a point system for ranking scientific journals, and a system for reporting the effects of the higher education and science system (POL-on), which could have improved the situation of HEIs. It is worth noting that Angori *et al.* (2023) analysed the evolution of basic, mission-oriented and applied research

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at European universities from 1978 to 2015. The results of the study indicate that over the years, patents from publicly funded academic research have become more basic research-oriented and basic research has become more mission-oriented at HEIs. Applied research, on the other hand, has declined since the late 1990s. Accordingly, the following research hypotheses were formulated for this study.

H1: All surveyed HEIs are more efficient in basic research than in technology transfer to the economy.

H2: Technical universities are more effective in technology transfer and universities are more effective in basic research.

All studies performed using classical and advanced DEA models assume that the values of the variables must be positive. This is the basic principle of the DEA method and its fundamental limitation. In economic practice, it happens that resources are used, but no positive effects are obtained, or even losses are incurred, i.e., negative values were obtained, such as the payment of compensation for a defective product that caused damage to the recipient. In either case, the owner of the enterprise sustains losses. In such cases, researchers would often either rescale the data by adding large values to make all the data positive or by adding minimal values to negative data, thereby obtaining positive values. However, this often led to surprising results. Therefore, a solution was sought to enable efficiency testing based on positive and negative data simultaneously. Several DEA models have appeared in the literature that address the above issues. This study uses one of them, which is discussed in detail later in the article.

RESEARCH METHODOLOGY

The Polish higher education system is complex. Most of the 133 public higher education institutions are subordinated to the Ministry of Science and Higher Education (95). Whereas the rest (38) to other ministries depending on their profile, e.g., medical universities (10) are supervised by the Ministry of Health (Brzezicki, 2019). In Poland, HEIs are mainly classified according to their authority to confer doctoral degrees. The word “university” may be used in the name of a university whose organisational units have the authority to confer doctoral degrees in at least ten disciplines. The word “university” supplemented with another adjective or adjectives to define the profile of the university may be used in the name of a higher education institution whose organisational units are authorised to confer at least six doctoral degrees, including at least four in the sciences covered by the university’s profile. Different types of higher education institutions engage in R&D activities in very different ways, which is reflected in various numbers of projects and values of funds allocated for this purpose (Table 1).

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Table 1. Number of projects and the value of funds allocated for research or development work in 2016 for the implementation of projects by type of university [PLN]

Type of university	Value of projects [PLN]	Number of projects
University	848,029,997.30	8644
Technical University	771,715,862.30	6151
Medical University	221,873,717.30	1219
University of Agriculture / Nature	107,884,809.20	903
Military University	72,139,282.45	256

Note: Universities ranked from the highest to the lowest value of funds.

Source: (Ministry of Science and Higher Education, 2019a).

The leading position of the ranking is occupied by universities, followed by technical and medical universities. It is worth noting that military universities implemented significantly fewer research projects than other universities. Their value was equal to that of technical universities. Universities get different results depending on the nature of the research (e.g., different scientific publications or patents). Therefore, it is reasonable to measure them separately; it will be possible to check which universities specialise in one or the other R&D activity, which would not be possible if one model was used.

On the other hand, comparing the results of both models will make it possible to check how universities related to the other less efficient activity – at what level they generated effects. It was decided to use the suggestions of Gralka *et al.* (2019) when studying the efficiency of university R&D activities in the future and in addition to taking into account scientific publications, to pay more attention to technology transfer, as well as to the relationship between the specificities of different types of universities and their level of efficiency. Therefore, the study distinguished between scientific activities related to scientific publications and practical activities aimed at transferring knowledge to the economy. Separate empirical models (Table 2) were created for both R&D activities of the university: M1 (scientific activities) and M2 (technology transfer).

In consideration of the findings provided by the literature review, it was decided to adopt the following set of outputs (Table 2) for the M1 model: the number of books (y_1), chapters (y_2) and weighted average of articles (y_3). In the case of the number of articles, the weighted average (y_3) was adopted, reflecting the time and effort of the authors to create a given type of article. The above approach has been used many times in the study of higher education, e.g., in the work of Visbal-Cadavid *et al.* (2017). For the M2 model, the following outputs were adopted: patent applications to the Polish and foreign patent office (y_4) and patents obtained from the Polish and foreign patent office (y_5). Two inputs were adopted in both models (M1–M2), but one is the same in the two models, and the

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other is different. Fixed asset value (x_2) given by universities for various purposes, and captured in different reports, is identical. Additionally, the variable enables the assessment of the university's size and material wealth. However, in the case of the second input, a distinction was made, resulting from the provisions of the law on higher education and a different way of reporting by universities to Statistics Poland and the MSHE. It is presumed that when an employee is employed full-time at a university, the university is the employee's primary place of employment. Within the scope of duties of academic staff employed in the groups, including scientists and academics, one of the duties is to conduct scientific activities in the form of, e.g., scientific publications and participation in scientific conferences.

Table 2. Summary of inputs and outputs for the study

Specification	Variable	Source	Unit
Model 1	M1: Scientific activities	DEA: SBM	
Inputs	x_1 – Full-time academic staff	MSHE	Number
	x_2 – Fixed asset value	MJ (2019)	Value PLN
Output	y_1 – Books	MSHE (2019b)	Number
	y_2 – Chapters	MSHE (2019b)	Number
	y_3 – Weighted average of articles	MSHE (2019b)	Number
Model 2	M2: Technology transfer	DEA: BP–SBM	
Inputs	x_3 – R&D personnel	HEI	Number
	x_2 – Fixed asset value	MJ (2019)	Value PLN
Output	y_4 – Patent applications to the patent office	HEI	Number
	y_5 – Patents obtained from the patent office	HEI	Number

Note: MSHE – Ministry of Science and Higher Education, MJ – Ministry of Justice, HEI – higher education institutions.

Source: own study.

The groups of employees mentioned above constitute the total of full-time academic teachers employed at educational institutions. Universities provide data on the number of people employed full-time at the MSHE. However, in reports on the R&D activities of universities, which are submitted for statistical purposes to Statistics Poland, universities indicate the total number of R&D employees, as the information mainly concerns the transfer of technology and knowledge to the economy. Therefore, this report also mentions technical staff, other staff and academic teachers. Thus, in the M1 model, the input full-time academic staff (x_1) was assumed, and in the M2 model, R&D personnel (x_3). The literature (de la Torre et al., 2017) points to the problem of allocating resources among the three different activities of universities, especially in terms of personnel. However, in

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Poland, for the purposes of the Ministry of Science and Higher Education and public statistics, universities separately report their scientific activity related to scientific publications, and implementation activity related to patents filed and obtained. Therefore, an approach based on two separate DEA models can be used in Poland.

Most of the data for the study was obtained from the MSHE and HEIs based on an application for access to public data. Since it was decided to analyse the situation of Polish universities after the first significant reform of higher education was introduced in 2011 and before the second reform of 2018, the data from 2016 were selected, which should illustrate the results of the first reform. The reform initiated in 2011 has been fully implemented, and its results can be assessed in the following years. The most recent second higher education reform has not yet been fully implemented. Therefore, it is justified to analyse the situation of higher education institutions after implementing the first reform and before introducing the second.

It was decided that the study would cover the two largest groups of universities spending the highest amounts of funds allocated to research or development (Table 1), i.e., universities and technical universities, which together constitute 36 units out of 59 public academic universities independently supervised by the MSHE. Thus, the group's homogeneity of the surveyed units will be maintained. It will also be possible to analyse the efficiency level in relation to the specificity of various types of universities, as indicated by Gralka *et al.* (2019). The complete data from 2016 was obtained for 34 universities for the empirical study (Table A2 in Appendix). The majority of the research sample comprises technical universities (18 units) and a smaller proportion of universities (16 units).

Permanent changes to the higher education system in Poland were also conducive to undertaking research, mainly using the DEA method (Brzezicki, 2020). The article by Charnes *et al*. (1978), in which they presented its first CCR model (from the authors' names), is based on radial efficiency and constant return to scale (CRS). The second BCC model with variable returns to scale (VRS) was presented by Banker *et al.* (1984). The above models are based on radial efficiency; therefore, Tone (2001) suggested the SBM (Slacks-Based Measure) model, based on non-radial efficiency, if individual inputs and outputs have a different impact on the efficiency of an economic entity. The above models are standard DEA models based on which newer, more complex models were developed.

In recent literature, several DEA models can be found that measure the efficiency of an entity based on positive and negative data. Pastor and Ruiz (2007) and Kaffash *et al.* (2018) conducted a brief literature review of negative data in DEA models. Four DEA models and their various modifications are often mentioned in the literature: range directional model (RDM), slacks-based measure model (SBM), variant of radial measure (VRM) and semi-oriented radial

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measure (SORM). Even though radial models have a long history and theoretical foundations presenting efficiency measurement utilising the DEA method, the non-radial models (e.g., SBM) much better reflect the practice of economic entities using, e.g., different levels of inputs for generating outputs. The author of the SBM model (Tone, 2001) and other co-authors (Tone et al., 2020) created the base point slacks-based measure model (BP-SBM), which makes it possible to include both positive and negative data. It is worth noting that Tone (2011) had presented dealing with non-positive data in the SBM models earlier. The authors' literature review shows, firstly, that the efficiency of higher education has not been measured using the DEA model in the case of negative data or no output obtained from the inputs used for that purpose. Secondly, in the research conducted so far, the authors included data from several areas of activity (teaching, research, and technology transfer) in one model, which made it impossible to determine the impact of individual actions on the efficiency of a higher education institution. Therefore, a separate assessment of the efficiency of technology transfer and basic research in two, not one model, will determine more precisely which university is more efficient in each activity. However, this, in turn, will indicate their specialisation in activities related to the adopted development strategy of a given higher education institution. The established literature gap will be filled with the present study.

After defining the variables and accepting 34 universities for analysis, the research framework was presented. Firstly, non-radial models (e.g., SBM) better reflect the situation of economic actors than radial models (e.g., CCR), which, depending on the orientation, assume a proportional reduction of inputs or proportional increase of outputs. In non-radial models, individual inputs and outputs have a different impact on the level of efficiency of an economic entity. Secondly, Cooper *et al.* indicate that "If the data set includes numeric values with a large difference in magnitude, e.g., comparing big companies with small ones, the VRS model may be a choice" (Cooper et al., 2007, p. 344). The data of universities accepted for the study differ in size. Third, the university aims to generate the maximum number of results (publications and patents) rather than reduce employees and fixed asset value. Therefore, it was decided to use non-radial SBM output-oriented (O) models with variable-returns-to-scale (VRS or V) for the study.

The empirical research was divided into two stages. In the first stage, the efficiency of scientific activities in higher education (M1) was measured using the standard SBM (the output-oriented SBM under variable-returns-to-scale SBM-O-V) model (Tone, 2001). Each university admitted to the study published several publications of a given type (books, chapters, and articles). There are no zero or negative values in the M1 model. Therefore, there is no need to use any other model than SBM.

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In the second stage, the BP-SBM model (Tone et al., 2020) was used to measure the efficiency of technology transfer by universities (M2). In some universities, human, financial, and material outlays were used, but no results were obtained in the form of reported or obtained patents. Therefore, in the case of universities with no output, the number 0 was changed to a constant negative value, as it is a loss of the unit's resources. It is worth emphasising that the BP-SBM (the output-oriented BP-SBM under variable-returns-to-scale BP-SBM-O-V) model is compatible with the classic SBM model (Tone, 2001), which determined its use in the study.

Using the SBM and BP-SBM models makes it possible to conduct comparative studies of various areas of activity of the same economic entity, even in the absence of outputs or in the case of their negative value, which is a significant advantage over other DEA models.

Results and discussion

The average efficiency results for individual groups of universities in both empirical models (M1–M2) are presented in Table 3. The average efficiency measures for all universities show that they were more efficient in scientific activities (M1) than in technology transfer (M2). The difference between the M2 (0.40) and M1 (0.76) models is almost twice as big. When comparing the groups of universities, it can be noticed that universities were more efficient in the M1 model (0.91) and technical universities in the M2 (0.65) model. However, it should be noted that the difference in efficiency between the two groups of universities in the M2 (0.52) model is almost twice as big as in the M1 model (0.28). It is also worth noting that in the group of technical universities, there is a more substantial differentiation of efficiency results (st. dev.) in both empirical models (M1–M2) than in the case of universities. The results of technical universities' efficiency are almost identical in both models (M1: 0.63 and M2: 0.65), which cannot be said about universities whose scores are highly different (M1: 0.91 and M2: 0.13). Thus, technical universities are similarly oriented towards basic research (M1) and technology transfer (M2). In contrast, universities are almost entirely oriented towards basic research and the theoretical dimension of knowledge (M1). The literature (Bonaccorsi et al., 2006) indicates that the scientific and implementation activities of HEIs up to a certain point can coincide, resulting in a mutually self-reinforcing process, but after a certain level, too strong a focus of HEIs on implementation activities can lead to lower scientific performance, in which case the relationship is in the shape of an inverted U.

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Table 3. Mean of efficiency in 2016, by the group of higher education

Model	M1			M2		
Group	Univer.	Technical	All	Univer.	Technical	All
Mean	0.91	0.63	0.76	0.13	0.65	0.40
St. dev.	0.15	0.27	0.26	0.10	0.33	0.36

Note: St. dev. – Standard Deviation, Univer. – Universities, Technical – Technical Universities, All – All 34 higher education institutions

Source: own elaboration.

Figure 1 presents the results of the efficiency of individual universities in both empirical models (M1–M2). The following variables were assigned to the studied universities: U1–U34 (Table A2 in Appendix) to present the results in a graphical form. Table A2 in the appendix contains detailed results of efficiency for individual universities. In the M1 model, there were more than twice as many efficient universities as in the M2 model – 14 and 6 units, respectively.

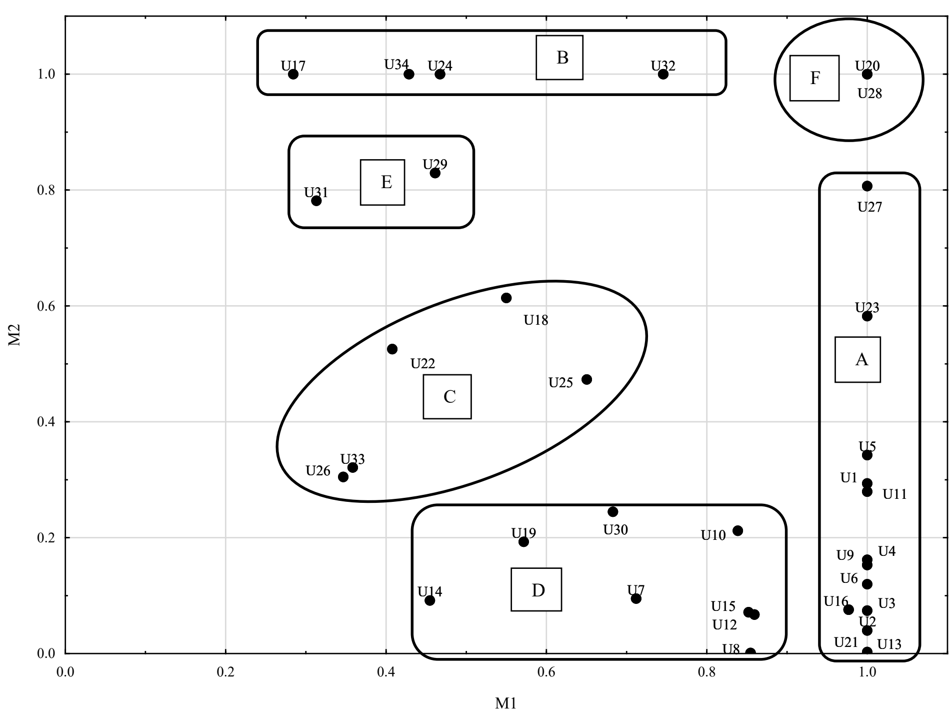

Figure 1. Indicators of efficiency in 2016

Source: own elaboration.

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Therefore, it is much more challenging to achieve complete 100% efficiency in technology transfer (M2) than in scientific activities (M1). The University of Technology and Humanities in Bielsko-Biała (U20) and the Lublin University of Technology (U28) turned out to be 100% efficient universities in 2016 in both empirical models (M1–M2). The least efficient university in the M1 model among all respondents was the West Pomeranian University of Technology in Szczecin (U17), and in the M2 model, the Cardinal Stefan Wyszyński University in Warsaw (U13). The universities with the lowest efficiency level in particular groups of universities are also worth mentioning. The lowest efficiency index value among all universities was achieved by the University of Zielona Góra (U14) in the M1 model and the Cardinal Stefan Wyszyński University in Warsaw (U13) M2 model. However, on the other hand, among all technical universities, the West Pomeranian University of Technology in Szczecin (U17) turned out to be the least efficient in the M1 model, and the Częstochowa University of Technology (U21) in the M2 model. However, it should be emphasised that both the Cardinal Stefan Wyszyński University in Warsaw (U13) and the Częstochowa University of Technology (U21) achieved a total 100% efficiency in the M1 model, although in M2, they obtained the lowest results in their groups.

It was decided to use the approach presented by Santos *et al.* (2022), who divided university researchers into three clusters, conducting basic research, experimental research and dealing with two at the same time, but at the university level, in order to identify clusters of universities oriented towards basic research (publication of scientific papers) and development and implementation work (patents). Graphical presentation of the results in a two-dimensional space (Figure 1) made it possible to identify 6 different efficiency groups of higher education institutions:

1. Group A – clearly oriented towards scientific activities (M1),
2. Group B – clearly oriented towards technology transfer (M2),
3. Group C – similarly oriented towards scientific activities (M1) as it is towards technology transfer (M2),
4. Group D – more oriented towards scientific activities (M1) than technology transfer (M2),
5. Group E – more oriented towards technology transfer (M2) than scientific activities (M1),
6. Group F – maximum-oriented technology transfer (M2) and scientific activities (M1).

Group A comprises the largest number of universities (13), and the second-largest group is D (8), followed by C (5), B (4), E (2) and F (2). The individual efficiency groups indicate both what strategies are implemented by universities and which R&D activity is treated as their priority. HEIs with similar performance results in one or both models (M1–M2) can significantly increase their R&D

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performance by entering into collaborations, and the resulting group performance will be even across all units. On the other hand, classified efficiency groups determine optimal development directions and strive for 100% efficiency. The two most numerous groups (A and D) indicate the general rule that the studied HEIs mostly follow. Universities in group A achieved the maximum 100% efficiency in the M1 model. However, it can be seen that they are starting to strive towards efficiency in model M2 as indicated by the distribution of units, with individual colleges higher on the M2 axis setting the direction for most of the other units. By contrast, group D is firmly committed to efficiency in the M1 model, only slightly engaging its resources to generate outputs in the M2 model. The results show that universities first strive for total 100% efficiency in scientific activities (M1), and after obtaining it, they turn their attention towards technology transfer (M2). Such activities have substantive justification, as the MSHE, apart from teaching activities of individual universities, has assessed scientific and research activity, paying attention to the publishing activity of units.

On the other hand, based on this evaluation, the MSHE awarded academic categories linked to both the amount of funding awarded and the university's prestige. The opposite strategy concerning groups A and D was implemented by universities in groups B and E, which first sought to achieve total efficiency in the M2 model and, after obtaining it, increased the efficiency in the M1 model. Conversely, strategies of the middle development path were implemented by universities in group C. It is also worth analysing the situations of universities and technical universities in the respective performance groups separately. The separation of the results into the two types of universities indicated that almost the entirety of groups A and D consist exclusively of universities (apart from the two technical universities in groups A and D). In contrast, the remaining groups, B, C, E and F, consist entirely of technical universities.

The results in the M1 model clearly show that universities are almost exclusively focused on scientific activities. Meanwhile, in the case of technical universities, the situation is more complex, as they achieved higher efficiency in technology transfer (M2) than universities. Still, equally often, they obtained medium or high-efficiency results in the field of scientific activities (M1). Their efficiency in scientific activities (M1) was varied and depended on individual technical universities. The results obtained in the present study agree with those of Werker and Hopp (2020), who, based on a survey of three leading European technological universities, studied the impact of research orientation and networks of researchers on their productivity. According to the Werker and Hopp (2020) study, only a small group of scientists who are able to successfully balance research and applications have been reported. However, the vast majority of scientists focus on either basic or applied research. These scientists face a trade-off between scientific publication and innovation.

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However, the mere calculation of the efficiency level does not exhaust the discussed topic. Therefore, it was decided to use the research approach of Tseng and Raudensky (2014) to present other variables that may affect the university's research and development activities. For the purpose of finding out to which R&D activities universities allocate funds to, the following classification was used. Research and development (R&D) activity in Poland has been divided into three main areas (Figure 2) (Łącka, Brzezicki, 2020): basic research (fundamental), applied research (applied and industrial), and industrial research (development work). The main area of spending funds by both public universities is basic research (Figure 2), which provides new knowledge without the necessity to use it in practice.

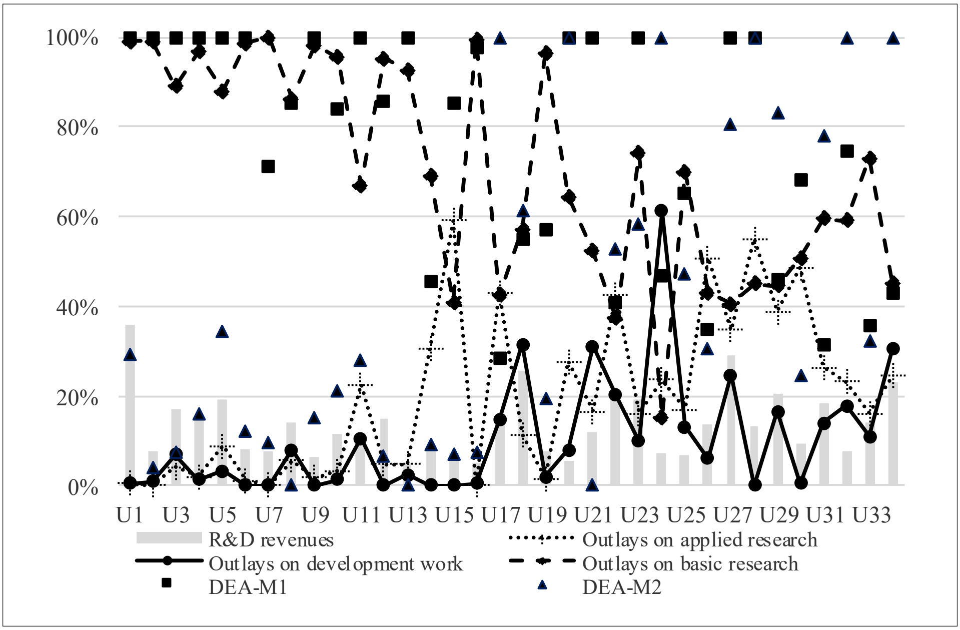

Figure 2. Efficiency in the M1 and M2 model and the allocation of resources to different types of research

Note: U1–U16: Universities, U17–U34: Technical Universities.

Source: own elaboration.

Most universities spend almost all their R&D expenditure on basic research. As a result, they achieved high efficiency in the M1 model. Bentley *et al.* (2015) showed that researchers who specialise in basic research tend to receive less external funding and rely on the university's own resources. They work in environments where there is less emphasis on applied research. As a result, they have fewer professional obligations to apply their knowledge to solving social

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problems. However, the results of Cao *et al.* (2023) indicate that there is a U-shaped relationship between basic university research and company innovation. Technical universities incurred spending on applied research and development work. That has allowed them to obtain high and relatively high efficiency in the M2 model. Some universities, such as the University of Zielona Góra (U14) and Kazimierz Wielki University in Bydgoszcz (U15), invested heavily in applied research. Thus, they achieved relatively high efficiency in the M1 model. In the case of the Kielce University of Technology (U24), the expenditure on basic and applied research was relatively small, and the spending on development work accounted for nearly 60%; consequently, this university achieved maximum efficiency in the M2 model. The reason for the differences between the two groups of universities can be traced to what Li and Yang (2023) noted, among others, which indicates that faculty members at research universities spend more time on research-oriented teaching than on curriculum-based teaching. Time spent on curriculum-based teaching has a significant negative relationship with research performance. Another reason for such differences may be the different approaches to knowledge creation and ways of using it in the two groups of HEIs. The literature (Urbanek, 2020) indicates that universities are "sanctuaries of knowledge", much more difficult to adapt to the changing reality and therefore closer to the approach known as the Bohr quadrant (basic research to acquire knowledge regardless of its application) and the Socrates quadrant (research oriented to education). In contrast, technical universities are quicker to respond to the needs of the external environment, and are therefore closer to the approach known as the Pasteur quadrant (basic research also aimed at solving specific problems) and the Edison quadrant (applied research aimed at creating a specific product). This, in turn, affects the different organisational cultures (Shah et al., 2019) of two different types of universities.

One can find another reason for such negligible interest in broadly understood science, knowledge and technology transfer to the economy by HEIs. Brzezicki (2022) indicates that higher education was evaluated primarily in the context of teaching activity, and scientific activity was carried out only to the extent necessary, indicating that it was less important for evaluating the efficiency of HEIs. Implementation activities, however, were practically ignored in the evaluation of university performance. It was only after the higher education reform introduced in 2011 that more attention was paid to scientific activity by evaluating it on the basis of points assigned to various types of scientific publications. On the other hand, it is only in the last few years that one can notice an increased interest in Poland by the Ministry of Science and Higher Education in the transfer of knowledge and technology to the economy. The Ministry of Science and Higher Education has for several years organised various programs and projects to encourage universities and institutes to become more active in this area. However, it was only the evaluation of knowledge and technology transfer that was used in the evaluation of the scientific activity of higher education institutions for 2017–2021. As a result,

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the focus of public policymakers and the mass media on the higher education and science sector only in the context of didactics, as well as the negligible interest in matters of science and the transfer of knowledge and technology to the economy, resulted in the fact that higher education institutions, which should be obtaining significant results in this regard, functioned inefficiently, obtaining unsatisfactory results of activity. However, according to Cao *et al.* (2023), neither the supportive nor intervening role of the government can moderate the U-shaped relationship between HEIs and businesses.

The authors' research on the effectiveness of scientific activity and HEI technology transfer in Poland and the research of the team led by Tomasz Geodecki and Jerzy Hausner on the cooperation of Polish universities with businesses (Geodecki, Hausner (eds.), 2023) have shown that these two worlds do not overlap, they do not know each other and rarely communicate with each other. Despite many years of support under the innovation policy for this cooperation in the field of research and development, technology transfer and their commercialisation by scientists, the progress is still relatively small.

As a result, scientists and entrepreneurs "can't work together well and systematically. The reason is the different expectations of these worlds as to the goals and forms of cooperation, the resources they possess, and the quality of the results they strive for and that matter to them. The expectations and criteria for measuring success as well as motivation systems are also different" (Geodecki, Hausner (eds.), 2023, p. 87). For this reason, Polish universities still represent a relatively small research potential, and stimulate the competitiveness and innovativeness of the Polish economy to a relatively small extent. Entrepreneurs are willing to establish cooperation with selected scientists and rent some laboratories, but they do not create lasting and strong links with Polish HEIs.

Conclusions

The authors' research shows that higher education reforms (more evolutionary than revolutionary) undertaken in 2011 focused too little on scientific research (and more on didactic) activities and thus did not bring about appropriate changes in the functioning of its entities in this regard. Only in the last few years can one see a shift in Polish higher education and science policy towards research that can translate into the economic sphere. However, higher education institutions are expected to play a significant role therein. The next reform of higher education and science, introduced in 2018, directly marks the direction of the development of this sector in Poland. However, it should be remembered that reorienting universities' activities and changing the priority of their goals is a complex and protracted process. Therefore, the first significant changes will only be noticeable in a few years.

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The result of the changes introduced in 2011, on the other hand, is that universities focused most on basic research, while applied (industrial) research and development work received less attention from researchers. In the latter case, technical universities were more effective than universities. The following reasons can explain the situation:
- little practical usefulness of the conducted research,
- too weak relations between universities and enterprises and too little participation of research teams in projects implemented in cooperation with enterprises (domestic and foreign),
- inappropriate system of incentives to establish collaboration between the university and business,
- the applicable rules for evaluating scientists – relating primarily to achievements in scientific activity and underestimating technology transfer (implementations, patent applications, patents).

The following conclusions can be drawn from the conducted research. A comparison of the average efficiency values of the two models, M1 and M2, for all HEIs, indicates that the studied HEIs obtained higher levels of efficiency in scientific activities (M1) than technology transfer (M2). However, a comparison of efficiency scores between the two groups of HEIs indicates that the two groups differ significantly. The group of universities was more efficient in scientific activities (M1) and technical universities in technology transfer (M2). It was also noticed that the difference in the efficiency of universities between M1 and M2 is very significant, while technical universities obtained similar efficiency values in both models. However, it should be remembered that this study analysed the relationship of achieved outputs to committed inputs by individual universities in relation to other units in 2016. Therefore, the efficiency results of universities should only be assessed in this context.

Universities and technical universities pursued strategies considered rational, which had a factual basis in the period under study. They were also related to the specificity and different nature of the two types of universities. There are many units in the humanities and arts or social sciences in the university structure which cannot provide innovative business solutions for obvious reasons. Technical universities are characterised by a different domain structure, most of which are units in engineering and technology. Whereas universities are better at scientific activities (M1), they mainly specialise in this area of R&D. Conversely, technical universities obtain higher results in technology transfer (M2). Thus, they specialise in this area of R&D. Based on the study, H1 and H2 were confirmed.

The obtained results also confirm the views of scientists and experts dealing with the cooperation of science institutions with enterprises in Poland on the weakness of connections within the helix model, the occurrence of many barriers and difficulties in creating lasting and multilateral relations between science and business. This, of course, limits the transfer of knowledge and technology to the

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economy. The authors' research also indicates the occurrence of a situation in Poland in which considerable public funds allocated to the functioning of higher education, support for R&D and innovative activities, and the development of innovation systems do not bring the expected effects.

This forces changes in the policy of supporting cooperation between science and business and technology transfer from HEIs to the economy. Among the numerous recommendations in this regard proposed by experts (e.g., Geodecki, Hausner (eds.), 2023; Matusiak, Guliński (eds.), 2013; Borowy, Sawicka, 2016), the authors point to a rapid change in the rules for evaluating the work of scientists who are currently focused on preparing and publishing high-scoring scientific articles and filling "slots"[4] (author's contribution to a publication). Their periodic evaluation of the employee and their position at the university depends to the greatest extent on this. This causes, apart from the lack of funds for research, that many scientists do not conduct studies and scientific research of an applied nature.

The state should also continue to support the development of academic entrepreneurship and the establishment of spin-off and spin-out companies. This promotes the transfer of knowledge and technology into the economy. It is also necessary to improve the effectiveness of mechanisms facilitating public-private cooperation, which would lead to actual implementations on a larger scale in the creation of scientific-industrial consortia (especially in terms of financing high-risk ventures). The majority of scientists from public universities conducting R&D work face difficulties in financing basic and applied research. Budgetary resources are too small, and the possibility of obtaining research grants is significantly limited. This points to the need for increased funding of R&D activities from both public and private sources.

Entrepreneurs in the SME sector also point to a lack of financial resources as the main problem in undertaking innovative activities. This problem is not mitigated by the possibility of applying for grants and subsidies. Introduced corporate tax credits for innovation activities are ineffective for a number of reasons (Łącka, 2021) and are not popular. "The gap related to the implementation phase is attempted to be managed by non-university seed funds and Venture Capital funds with significant public funds for financing innovation projects" (Borowy, Sawicka, 2016, p. 51). These funds are available to a small number of business entities – technology

[4] A publication slot, or unit share, is a measure of an author's contribution to a publication. A publication with a single author will fill 1 whole slot, while for multi-author publications, such a share must be calculated. For each person included in the "N number" (research staff), there are a maximum of 4 publication slots that will be reported. In the course of the evaluation, all publications can be submitted by the author, and the slots will be filled in the most favourable way. Note that 4 slots will only accrue to an employee who has worked full-time for the entire period covered by the evaluation and has reported only one scientific discipline. In other cases, the number of slots per employee will have to be adjusted by the product of the employee's time and contribution to the discipline and will be 4 times the averaged product of time and contribution in each year.

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start-ups with high growth potential. The establishment of spin-off and spin-out companies by scientists provides an opportunity for the effective transfer of knowledge and technology to the economy, as through them, the level of readiness for implementation of research results is raised. As a result, it will be possible to implement new solutions in mature enterprises operating on a large scale.

According to the authors, systematic technological audits and analysis of current business needs should be conducted at universities. This type of research should include applied sciences, basic sciences with a technical and engineering profile, economic sciences and humanities. This will make it possible to reduce the asymmetry of information between the worlds of business and science and create the basis for cooperation in innovative ventures. It is noteworthy that the literature (Łącka, Brzezicki, 2022) increasingly emphasises the need to create ecological innovations, which are, on the one hand, expected by decision-makers of European countries, and, on the other hand, respond to the decisions of companies to implement corporate social responsibility and sustainable and ecological development of the business sector. Therefore, it is important for HEIs to play a significant role in this process.

This article only refers to two groups of higher education institutions (a fundamental limitation), which are among the main entities forming the NIS in Poland. Therefore, future research should focus on analysing the second large group of the research sector, namely public research institutes (PRI), developing and undertaking research in this area (Brzezicki, 2022; Brzezicki, Prędki, 2023) and comparing the two groups with each other. Research on their technology transfer efficiency can be carried out by considering different aspects, e.g., affiliation to networks, scientific consortia, nature of activities in scientific disciplines and other possible categories of analysis.

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APPENDIX

Table A1. Empirical studies using the DEA method to measure the efficiency of Higher Education and Sciences

Author	Inputs (I)/Outputs (O)	Methodology
Leitner *et al.* (2007)	I: number of staff and room space O: financial funds provided by third parties, finished projects, monographs, original papers, project reports, patents, presentations, other publications, number of finished, supervised PhD-theses	CCR, BCC
Foltz *et al.* (2012)	I: number of faculty, post-doctoral researchers, graduate students O: number of journal articles, patents, trained undergraduate students, and trained PhD graduate students	Two-stage analysis, DDF
Wolszczak--Derlacz (2013)	I: number of academic staff, total revenue O: patent applications, patent registrations, publications, citations, grants	Two-stage analysis with bootstrap, Malmquist
Yaisawarng and Ng (2014)	I: research staff, research expenditure, ranking of the previous year O: number of publications, international articles, domestic articles, grants	Meta-frontier DEA, Malmquist
Chuanyi *et al.* (2016)	I: faculties, annual educational expenditure, area of classrooms, area of laboratories O: bachelor, master and doctor degree, publication, patents	BCC, SBM
Visbal-Cadavid *et al.* (2017)	I: FTE academics, admin staff expenditure, total revenue (without the income of research), fixed assets O: articles, number of indexed journals, faculty mobility, number of undergraduate and postgraduate students	CCR, BCC, SBM, CE model, Malmquist
Yang *et al.* (2018)	I: R&D funds, teaching and research staff and government block funds O: number of publications, the total number of students, the total number of patents (including patent applications and authorised patents), the number of other intellectual property forms (e.g., software copyrights).	Two-stage network DDF, Network Luenberger
Hou *et al.* (2019)	I: FTE of universities' R&D personnel, universities' science funds entrusted by enterprises and institutions per teacher, O: number of scientific and technological achievements and technology transfer contracts, patents for co-application between universities and enterprises.	Two-stage analysis with bootstrap, Malmquist

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Author	Inputs (I)/Outputs (O)	Methodology
Shamohammadi and Oh (2019)	I: number of full-time academic staff, number of full-time non-academic staff, amount of annual research funds, number of undergraduate and postgraduate students, fixed assets O: number of publications and citations, international patents, degree-awarded students: undergraduate and postgraduate Intermediate I/O: number of degrees awarded to undergraduate students in an academic year	A variant of the two-stage network DEA
Gralka *et al.* (2019)	I: sum of annual personnel and other current expenditures, wages O: research grants, publications, the total number of graduates by science and non-science subject categories.	DEA (BCC), SFA
Łącka and Brzezicki (2020)	I: R&D personnel O: patent applications, patent registrations Carry-over links: expenditure R&D	Dynamic SBM
Xiong *et al.* (2020)	I: R&D personnel, internal expenditures for scientific and technological innovation activities O: number of citations, domestically applied patents, domestically granted patents Carry-over links: accumulated R&D expenditure	Dynamic SBM
Chen and Shu (2021)	I: number of full-time personnel, the internal expenditure on research funds, the number of S&T subjects O: number of papers, citations, patent authorisations, the national award for S&T achievements, income from technology transfer, patent sale and school-run industries	Superefficient BCC, Malmquist
Xiong *et al.* (2022)	I: R&D personnel, government funding, number of postgraduates O: number of high-quality papers, number of granted patents, knowledge transfer and transformation	Parallel DEA
Barra *et al.* (2023)	I: academic staff, number of enrolled students, non-academic staff, ratio between enrolled students and teachers O: books, scientific events, teaching activities, position of the university in SCIMAGO Institutions rankings, publications, invention patents	BCC, Malmquist

Note: Publications ranked by year of publication.

Source: own elaboration based on literature.

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Table A2. The efficiency of higher education institutions in model M1 and M2 in 2016

G*	U*	Names	M1	M2	Mean
Universities	U1	University of Warsaw	1.000	0.294	0.647
	U2	University of Białystok	1.000	0.040	0.520
	U3	University of Gdańsk	1.000	0.075	0.538
	U4	Adam Mickiewicz University in Poznań	1.000	0.162	0.581
	U5	Jagiellonian University in Kraków	1.000	0.343	0.672
	U6	University of Łódź	1.000	0.120	0.560
	U7	Maria Curie-Skłodowska University in Lublin	0.711	0.095	0.403
	U8	Nicolaus Copernicus University	0.854	0.001	0.428
	U9	Opole University	1.000	0.153	0.577
	U10	University of Silesia	0.839	0.212	0.526
	U11	University of Warmia and Mazury	1.000	0.279	0.640
	U12	University of Wrocław	0.859	0.068	0.464
	U13	Cardinal Stefan Wyszyński University	1.000	0.001	0.501
	U14	University of Zielona Góra	0.455	0.092	0.274
	U15	Kazimierz Wielki University in Bydgoszcz	0.852	0.072	0.462
	U16	Jan Kochanowski University in Kielce	0.976	0.076	0.526
Technical Universities	U17	The West Pomeranian University of Technology in Szczecin	0.284	1.000	0.642
	U18	Warsaw University of Technology	0.550	0.614	0.582
	U19	Białystok University of Technology	0.571	0.193	0.382
	U20	University of Technology and Humanities in Bielsko-Biała	1.000	1.000	1.000
	U21	Częstochowa University of Technology	1.000	0.003	0.502
	U22	Gdańsk University of Technology	0.407	0.526	0.467
	U23	Silesian University of Technology	1.000	0.583	0.792
	U24	Kielce University of Technology	0.467	1.000	0.734
	U25	Koszalin University of Technology	0.650	0.473	0.562
	U26	Cracow University of Technology	0.347	0.305	0.326
	U27	AGH University of Science and Technology	1.000	0.807	0.904
	U28	Lublin University of Technology	1.000	1.000	1.000
	U29	Łódź University of Technology	0.461	0.830	0.646
	U30	Opole University of Technology	0.683	0.245	0.464
	U31	Poznań University of Technology	0.313	0.781	0.547
	U32	Kazimierz Pulaski University of Technology and Humanities in Radom	0.745	1.000	0.873
	U33	Rzeszów University of Technology	0.358	0.322	0.340
	U34	Wrocław University of Technology	0.428	1.000	0.714

Note: G* – Group, U* – Number of units.

Source: own elaboration based on literature.

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Summary

The objective of the article is to measure and evaluate the efficiency of scientific activity and technology transfer to the economy by public higher education institutions (HEIs) in Poland and to formulate recommendations for state policy to increase the effectiveness of the technology transfer process by them. The study measured scientific activity and technology transfer separately in two groups of higher education institutions (i.e., universities and technical universities). Two non-radial models, SBM and BP-SBM, which belong to the non-parametric Data Envelopment Analysis (DEA) method, were used for the study.

All examined higher education institutions are more efficient in basic research than in transferring technology to the economy. However, technical universities are more efficient in technology transfer and universities in basic research. In most cases, technical universities are more accomplished in scientific activity than universities in technology transfer. Research shows that universities have been almost entirely focused on basic research, and technical universities have engaged in basic research and technology transfer to the economy in various ways. The research results confirmed the existence of very weak links between science and business in terms of knowledge and technology transfer to the economy. This is due to many factors. The authors presented recommendations for necessary actions that will enable the increase of technology transfer by public universities in Poland.

An interesting direction of future research is the measurement and evaluation of the effectiveness of technology transfer of the second group of NIS entities in Poland, i.e. research institutes.

Keywords: higher education, technology transfer, efficiency, DEA.

Efektywność działalności naukowej i transferu technologii w szkolnictwie wyższym w Polsce

Streszczenie

Celem artykułu jest pomiar i ocena efektywności działalności naukowej i transferu technologii do gospodarki przez publiczne szkoły wyższe w Polsce oraz sformułowanie rekomendacji dla polityki państwa na rzecz zwiększenia efektywności procesu transferu technologii przez nie. W badaniu dokonano pomiaru aktywności naukowej i transferu technologii oddzielnie w dwóch grupach szkół wyższych (tj. uniwersytetach i politechnikach). Do badania wykorzystano dwa modele nieradialne SBM i BP-SBM, należące do nieparametrycznej metody Data Envelopment Analysis (DEA).

Wszystkie badane szkoły wyższe są bardziej efektywne w zakresie badań podstawowych niż transferu technologii do gospodarki. Uczelnie techniczne są bardziej efektywne w transferze technologii, a uniwersytety w badaniach podstawowych. W większości przypadków uczelnie techniczne są bardziej efektywne w działalności naukowej niż uniwersytety w transferze technologii. Badania pokazują, że uniwersytety niemal w całości koncentrowały się na badaniach podstawowych, a uczelnie techniczne w różny sposób angażowały się w badania podstawowe i transfer technologii do gospodarki. Wyniki badań potwierdziły występowanie bardzo słabych powiązań nauki i biznesu w zakresie transferu wiedzy i technologii do gospodarki. Wynika to z wielu czynników. Autorzy przedstawili rekomendacje niezbędnych działań, które umożliwią zwiększenie transferu technologii przez publiczne uniwersytety w Polsce. Interesującym kierunkiem przyszłych badań jest pomiar i ocena efektywności transferu technologii drugiej grupy podmiotów NSI w Polsce, tzn. instytutów badawczych.

Słowa kluczowe: szkolnictwo wyższe, transfer technologii, efektywność, DEA.

JEL: I21, I22, I23.

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