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The Research and Development Efficiency of Institutes of the Polish Academy of Sciences and the External Factors Affecting It

Łukasz Brzezicki[1], **Artur Prędki**[2]

[1] Ustka City Hall, Wyszyńskiego 3, 76-270 Ustka, Poland, e-mail: brzezicki.lukasz@wp.pl, ORCID: https://orcid.org/0000-0002-0761-1109

[2] Krakow University of Economics, Institute of Quantitative Methods in Social Sciences, Department of Econometrics and Operations Research, Rakowicka 27, 31-510 Kraków, Poland, e-mail: predkia@uek.krakow.pl, ORCID: https://orcid.org/0000-0001-8104-1995

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ABSTRACT

Objective: The aim of the research is to assess the research and development efficiency of the institutes of the Polish Academy of Sciences (PAS) in 2019 and to identify external factors that have a significant impact on it.

Research Design & Methods: A two-stage procedure in the field of DEA methodology was used. In the first stage, the efficiency of PAS institutes was estimated using alternative BCC and SBM models. In the second stage, a Tobit model was used to isolate external factors significantly influencing efficiency. Given the data available, two types of research and development (R&D) efficiency were analysed: publishing efficiency and combined publishing and implementation efficiency.

Findings: A significant share of institutes are highly inefficient (nearly a half of the units in terms of publishing efficiency and a third in terms of combined efficiency). The fields in which a given

scientific unit conducts research which significantly affect publication efficiency differ from those that significantly affect combined efficiency. Both types of efficiency are significantly negatively affected by the increase in the scientific category of the unit.
Implications/Recommendations: The source of high research and development inefficiency among a significant number of institutes is the fact that they also generate other outputs than those considered in the work. The majority of institutes do not apply to the R&D sphere. The significant negative impact of the increase in the scientific category on R&D efficiency indicates that future focus should prioritise the quality of publications over their quantity.
Contribution: The efficiency of the research and development activities of the PAS institutes was assessed after the introduction of the last reform of Poland's system of science and higher education in 2018 (such studies have yet to be carried out). It is also important to use a two--stage approach within the DEA methodology in order to isolate external factors that significantly influence this efficiency.

Article type: original article.

Keywords: public research institutes, efficiency, R&D, DEA.

JEL Classification: C67, I23, O31, O32.

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1. Introduction

In Poland, higher education and scientific and research institutes are the main public entities responsible for scientific and research development. While there is a great deal of research dedicated to higher education, little has been done on scientific and research institutes. What has been researched shows that they are not functioning properly (Brzezicki, 2022). One reason for this is that most institutes conduct research and development (R&D) on a small scale. An indication is the audit conducted by the Supreme Audit Office (SAO) from 2020, which reported that „attention is drawn to the relatively minor share in total revenues of proceeds from the basic activity of institutes, which encompasses conducting research and development efforts aimed at their practical implementation and application. The share of revenues on this account in 2018 and 2019 was 9.5% and 11.5%, respectively" (SAO, 2020, p. 29). The same report stresses that „research institutes covered by the audit were characterised by a favourable financial situation in the period under review" (SAO, 2020, p. 11). This means that research institutes made money, but not necessarily by means of their core business.

A more complete implementation of a knowledge-based economy in Poland and reduction of technological backwardness, through regional innovation systems, influencing the national innovation system, requires a check on the performance of the main actors responsible for the creation of scientific and research activities (Łącka & Brzezicki, 2023). This, in turn, should increase regional and national innovativeness. There are three groups of institutes in Poland (Brzezicki & Prędki, 2023b): institutes of the Polish Academy of Sciences – PAS (approximately 60 units), research institutes operating within the Łukasiewicz Research Network (over 20 units), and other entities conducting mainly scientific activities on an independent and continuous basis (approximately 50 units). The first and second groups are clustered in specific networks where a central unit functions and the institutes are its sub-units. All institutes, whether scientific or research, belong to the public finance sector, which subsidises their activities. Therefore, the expenditure of public funds in relation to the products the institutes bring forth must be rationalised.

This paper is a continuation of the study presented in (Brzezicki & Prędki, 2023b), which analysed the efficiency of a wider group of research institutes in Poland in 2019. That paper described a number of difficulties, and the outcome of the search for a solution to these difficulties comprises the present study. Brzezicki and Prędki (2023b) concluded that the R&D activities of a significant share of the institutes in Poland in 2019 is inefficient. The authors attributed this to a range of causes, including the heterogeneity of the group of institutes as a whole, and the existence of subgroups of institutes that function in a different manner. This led us to conduct an in-depth analysis of efficiency in the selected subgroups. The previous study only estimated the efficiency of scientific and research institutes, leaving aside external variables that may influence efficiency levels.

The main purpose of this paper is to put to analysis the efficiency of R&D activity of institutes of the PAS by means of the DEA (Data Envelopment Analysis) methodology. In this study, using the so-called the two-stage approach, external factors significantly influencing the (in)efficiency of the analysed group of institutes of the PAS were also identified.

In addition to its cognitive value and filling the research gap found (to estimate the level of efficiency of public research institutes taking into account the impact of external factors on their performance), the study is intended to provide information for the management of PAS institutes (how other external factors may affect their efficiency and how to optimise their structure), as well as the government in order to develop a more rational scientific and research policy based on the results of this performance-oriented research on PAS activities.

2. Literature Review

A systematic review of the global and Polish literature was done. Polish research has focused mainly on legal and organisational issues (Kozłowski, 2007; Barcikowska, 2016, 2021; Trzmielak & Krzymianowska-Kozłowska, 2020). A single monograph (Łącka, 2011) presented a more comprehensive and quantitative study in the field. Empirical research was carried out on the technological cooperation of 50 research and development units with enterprises. The author analysed the financing sources of their activities, the share of revenues outside the statutory activities, the number of patents, patent applications, licences sold, industry-oriented projects, organisational implementations, participation in research programmes, forms of cooperation between R&D units and enterprises, and barriers to this cooperation. The study has shown that SRI (current research institutes) of that time should become the most important link in the transfer of knowledge and technology from the science and research sector to the economy.

Another interesting study (Brzezicki, 2022) analysed three groups of scientific and research institutes in Poland, including those of the PAS, the Łukasiewicz Network and others. It took into account data from 2019 on the number of patents filed and obtained, as well as the share of funds from enterprises and funds collected from foreign sources in the total funds. The research shows that the institutes focused primarily on obtaining financing from enterprises, and then on the application for and execution of patents. The acquisition of foreign resources only came third. It is worth noting that some general institutes came out with a performance similar to that of the institutes of the Łukasiewicz Research Network (measured by the synthetic index of development). It has also been shown that some institutes of the PAS scored better than a group of general research institutes, taking into account the average development index for these units. This indicates that several PAS units are outstanding, though they exist alongside many that perform poorly.

It is more and more common for authors who study scientific and research institutions to pay attention to the field of science in which a given public institution operates. Coccia (2008) estimated the efficiency of Italian state research institutes considering the represented field of activity. The findings indicate that institutes operating in the technology, engineering and information sciences were the most efficient. Institutes of basic sciences, natural sciences, earth science and, lastly, social sciences and humanities, followed. Research evidence suggests that the results of these entities' activities depend on the field of science which they represent.

Analysing the role of knowledge specialisation in public research institutes (PRIs), de la Torre *et al.* (2021) arrived at similar conclusions. They listed three groups of units. The first group of PRIs relies on external infrastructure to exploit the results of their knowledge: spin-offs, incubators and research commercialisation companies. The second group included PRIs that obtain a significant part of their research funds competitively and rely on commercialisation in the market for both research results (through patenting) and service provision (through specialised companies). The third group included PRIs that collaborate with users through government-funded research and collaborate directly with users through research contracts, consultancy services and service provision. The latter group is managed by the PRI but, unlike the other two groups, they do not rely on external companies.

Depending on the field of science they represented, the institutes used other channels of technology transfer, as well as other resources to effectively accomplish their goals. By way of example, institutes with a “market commercialisation” transfer profile had to plan their resources in such a way as to ensure the ability to manage relations with external commercialisation companies, establish corporate spin-offs and seek financing for them.

Huian, Bisogno and Mironiuc (2023) analysed whether the technology transfer scores achieved by Romanian PRI – measured as the ability to generate patented technologies – were positively related to institutional, human, commercial and financial factors. The authors demonstrated that qualified human resources and commercial resources (including technology transfer offices and spin-offs) had a significant, positive impact on the generation of technology patents, as did institutional factors and fields of research. On the other hand, the public funds received actually reduced patent activity. Meanwhile, institutional factors showed no relation to patent activity or scientific publications.

According to Lynskey (2009, p. 161), “there is evidence that knowledge transfers from national research institutes are particularly relevant for companies in strategic industries such as biotechnology, information technology and new materials”. The research conducted for this paper demonstrates that small technology-based companies have an edge over large enterprises in using the knowledge of scientists from research institutes.

Brzezicki and Prędki (2022) present a review of variables used to study the efficiency of research institutes. However, no studies analysing the impact of external variables on the efficiency of research institutes or scientific institutes have been done. This led us to cite relevant studies in (Brzezicki & Prędki, 2023a) on universities that conduct activity similar to scientific and research institutions.

We considered two groups of external variables. The first are those that represent neither inputs nor outputs in the model used to measure the efficiency of facilities. These variables are directly related to the surveyed institution (e.g., year of establishment, employment structure, nature of conducted activity, including the scientific fields in which research or education is conducted). The second were general variables (location of the surveyed units, regional wealth, size or structure of the university’s funding sources activities). These variable types aside, the inclusion of specific variables depends primarily on the purpose of the analysis and the possibility of obtaining relevant data.

The results of the literature analysis of both the variables adopted in DEA models and external variables indicated that human resources and their structure, the areas of activity of scientific and research units and the financial resources allocated to R&D activities are all important. We therefore decided to adopt some of these variables as data for the DEA model and others as exogenous variables influencing efficiency levels.

3. Methodology

DEA methodology is used to examine economic units whose efficiency is analysed as specific production units that obtain one or many types of outputs from specific types of inputs. Hence, the nomenclature and considerations are closely connected to the theory on the production process.

To measure efficiency and analyse the external factors which affect it, a two-stage procedure was used (see Hoff, 2007, for details). In the first stage, the efficiency measures of the units are calculated. Stage two uses a regression model to examine the extent to which the external factors affect efficiency. The measures obtained in the first stage are treated as observations concerning this dependent variable. In the first stage of the procedure calculations were done with MaxDEA software, while Gretl was used in the second stage.

For this paper, the first stage used the output-oriented BCC model (envelopment form) to measure efficiency (Cooper, Seiford & Tone, 2006). This approach was adopted because performing an analysis of the possibility of reducing the number of inputs consumed by units seemed pointless. Examining the potential for increasing outputs representing the effects of R&D activity appeared to be far more promising. In addition, due to the varying size and degree of development and involvement of institutes in R&D activity, it was assumed that there would be variable returns to scale.

If there are many outputs, the BCC model allows one to consider only the proportional growth of outputs[1]. To avoid this arbitrary assumption, for the case of two outputs, the SBM model was used in the first stage, making it possible to analyse the disproportionate increase of outputs[2]. The SBM model was also output-oriented and offered variable returns to scale (Tone, 2001). Like the previous measure, this one is not less than one and is equal to one for the efficient unit[3].

Stage two involved the use of a censored regression model to analyse the significance of the impact of external factors on efficiency, specifically the type I Tobit model with a threshold value of zero (Kostrzewska, 2011). A censored regression model is used because the efficiency measure values are not less than one – that is, it is bound on the left side. Moreover, pursuant to the design of DEA models

[1] This is a "radial" model.

[2] This is a "non-radial" model.

[3] Both types of efficiency measures were interpreted in the empirical part of the paper, using the example of extremely inefficient units.

that measure efficiency, there is usually more than one efficient unit – that is, with a measure value of one[4].

Crucially, part of the empirical work examined only the direction and significance of the impact of individual exogenous factors on the efficiency of the objects under analysis. In this case, backward stepwise regression, consisting in the gradual elimination of irrelevant factors, starting with the most irrelevant (the largest *p*-value), was used. Proceedings were discontinued when the *p*-value for all factors remaining in the model fell below 0.1.

4. Gradual Selection of Categories of Study

4.1. General Remarks

2019 was chosen as the evaluation period, for the same reasons as in (Brzezicki & Prędki, 2023b). It is the year where the largest number of reports on research and development activities is found[5] (the reports on R&D were obtained on the basis of a request for access to public information). 2019 was also the first full year following the introduction of the higher education reform in 2018.

Table 1 presents the variables used in the previous paper (Brzezicki & Prędki, 2023b).

Table 1. Categories Used to Assess the Efficiency of Research Institutes in (Brzezicki & Prędki, 2023b)

Specification	Designation	Explanation
Inputs	x_1	number of researchers and technicians involved in R&D activity
	x_2	number of other support personnel (e.g., administrative)
	x_3	internal funds for R&D activity (in thousand PLN)
	x_4	external funds for R&D activity (in thousand PLN)
Outputs	y_1	total number of patent applications and patents obtained
	y_2	total number of publications

Source: the authors.

As regards the factors representing labour (x_1, x_2), researchers and technicians were separated as two different types of employees, and the measurement unit was changed from persons to the more precise “FTE” (full-time equivalent). As defined in the *Report on Research and Development Activities*, FTE is the ratio of working

[4] Hence, it was decided to forego truncated regression (Simar & Wilson, 2007) and simple linear regression models (Banker & Natarajan, 2008), which were used in the second stage of the relevant procedure.

[5] For the sake of confidentiality, entities refused to share more recent data (though a small number of institutes also sent reports for 2020).

hours actually spent on R&D in a given reference period to the total number of hours formally worked in the same period by a person[6].

The previous paper also considered only internal staff – people who are employed in a given unit. Many institutes consider staff to comprise people not necessarily employed in a given unit, including doctoral students. Such external staff are less associated with the institute. For our purposes, these staff are treated as an external factor and it was to be determined whether they had a significant impact on the research and development efficiency of individual units.

On a similar vein, we approached factors representing capital (x_3, x_4), while internal funds (x_3) were considered as input from the institute. External funds, or those received from other units for the purpose of a given institute's internal R&D activity, were initially assumed to be an external factor influencing efficiency; that is because it partly remains beyond the control of the examined unit.

Another input expressing the unit's capital – the gross value of scientific and research equipment in thousand PLN – was adopted.

4.2. Publication Efficiency

As only some PAS institutes generate patents or submit patent applications, it was first decided to examine only the publication efficiency of the units expressed in the number of publications[7] in 2019 (former output y_2). The data collected applied to 60 of the 68 units, thus a significant portion of the overall "population".

Data obtained from the report *Information on the Activities of a Scientific Unit of the PAS* were very significant. Comparative analysis of data sources revealed that fewer publications were available in the RAD-on system[8] (RAD-on, 2023) than in the new data source for as many as 47 PAS institutes. The opposite held for only 13 units, for which it was decided to always take the higher value of the two obtained from the sources for the number of publications of a given institute.

To deepen the analysis, an attempt was made to break down the publications by type[9]. However, this proved partially unfeasible, because, in the report *Information*

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[6] The FTE for one person must not exceed a value of 1. The FTE for a group is sum of ratios for its members.

[7] The conversion thereof into ministerial points would be too tedious and laborious, and ready--made data in this area are not available.

[8] The RAD-on system is part of the Integrated Information Network on Science and Higher Education, the largest public system in Poland in terms of the scope of data collected, which helps the Ministry of Science and Higher Education and other state agencies to shape science policy (the data are publicly available).

[9] The authors' core intention was to extract a number of monographs, which often require much more effort than creating smaller publications, such as a chapter in a monograph or an article. Obviously, the authors are aware that there can be many exceptions to this rule.

on the Activities of a Scientific Unit of the PAS, the chapters in the monograph are counted together with other monographs. It was also pointless as the number of monographs identified for many institutes turned out to be negligible compared to, for example, the number of articles they published.

We also sought to examine whether a unit's scientific category and the field(s) of research it was involved in had an impact on publishing efficiency. To this end, appropriate external factors were introduced into the model. The scientific category was expressed by a discrete variable with the values 1, 2 and 3 denoting the category[10] B, A and A+, respectively. In turn, the domains were expressed in zero-one variables. Notably, a few of them could simultaneously assume the value of one for a given institute if that institute conducted scientific activity in many fields[11].

A summary, in the form of categories adopted for the first version of empirical model, which was used to examine the publication efficiency, was presented in Table 2.

Table 2. The Set of Categories Adopted in the First Version of the Empirical Model (Publication Efficiency)

Specification	Designation	Explanation
Inputs	x_1	internal researchers involved in R&D activity (in FTE)
	x_2	internal technicians involved in R&D activity (in FTE)
	x_3	remaining internal support staff, e.g., administrative (in FTE)
	x_4	gross value of research equipment (in thousand PLN)
	x_5	internal funds for R&D activity (in thousand PLN)
Output	y	total number of publications
External factors	z_1	external researchers involved in R&D activity (in FTE)
	z_2	external technicians involved in R&D activity (in FTE)
	z_3	remaining external support staff, e.g., administrative (in FTE)
	z_4	external funds for R&D activity (in thousand PLN)
	z_5–z_{10}	fields in which the unit conducts scientific research[a]: natural sciences, engineering and technology, medical and health, agricultural and veterinary, arts and humanities, social sciences; variables 0–1
	z_{11}	scientific category of the unit – 1(B), 2(A), 3(A+)

[a] The distribution of fields in force in 2019.

Source: the authors.

[10] The analysed group contains no units characterised by the categories C and B+.

[11] Therefore, it was not required to extract the reference category to avoid linear dependence of these variables. It should also be noted that it was decided not to assign variables to disciplines, because too many of them were often assigned to a given institute.

The next step was to apply the two-stage procedure described in the methodological part. This yielded measures of publishing efficiency for 60 institutes of the PAS covered by the analysis (stage I), with the extraction of external factors significantly affecting this efficiency (stage II). The only relevant factors proved to be z_8 and z_9 (conducting scientific research in the agricultural and veterinary sciences as well as humanities and arts, respectively).

These results shall not be further analysed here. The statistical insignificance of external personnel factors (z_1–z_3) and external funds (z_4) led us to combine them with appropriate inputs (x_1–x_3 and x_5). This yielded four inputs, constituting the components of the second version of empirical model.

We would be remiss to omit external employees and funds, which in practice have too much influence on the research and development activities carried out by institutes. While external employees and funds cannot play the role of external factors, and although these employees remain, at least partially, beyond the control of the entities under analysis, they will nonetheless be treated as inputs. Unfortunately, they cannot be identified individually as separate inputs in relation to the relevant internal categories as the size of the input categories would then be too large relative to the entire research group. That would negatively affect the discriminatory power of the model. Consequently, these external factors were to be combined with the appropriate internal inputs by means of aggregation.

The wisdom of this move was confirmed by the correlation analysis performed on aggregated values, which are significantly positively related to the only output – the number of publications. This excludes the category $x_3 + z_3$ (correlation of approx. 0.21), i.e., the total number of remaining support staff. This exception was initially adopted as an external factor in the second version of the empirical model, thus indicating that such personnel do not directly participate in scientific or research and development activities.

Under the next version of the model, it was decided to continue to analyse the impact of the unit's scientific category and the field(s) in which it conducts research on its publishing efficiency. Table 3 presents the categories of the model's second version.

After once again carrying out the two-stage procedure described in the methodological part, it appears that major external factors identified in the first version of the model retain their significant impact on publication efficiency. We believe that this validates the results obtained in the second version of the model. Finally, the scientific category of the institute is yet another important factor.

Because the remaining support staff is not an external factor significantly affecting publication efficiency, the empirical model needs to be slightly revised. The authors believe that it should have its place in the model – in practice, administrative employees assist in the formal implementation of research and development tasks (documentation, accounting, etc.). In addition, this variable has a weak but positive correlation with the number of publications.

Table 3. The Set of Categories Adopted in the Second Version of the Empirical Model (Publication Efficiency)

Specification	Designation	Explanation
Inputs	x_1	researchers involved in R&D activity (in FTE)
	x_2	technicians involved in R&D activity (in FTE)
	x_3	gross value of research equipment (in thousand PLN)
	x_4	funds for R&D activity (in thousand PLN)
Output	y	total number of publications
External factors	z_1	other support personnel, e.g., administrative (in FTE)
	z_2–z_7	fields in which the unit conducts scientific research: natural sciences, engineering and technology, medical and health, agricultural and veterinary, arts and humanities, social sciences; variables 0–1
	z_8	scientific category of the unit – 1(B), 2(A), 3(A+)

Source: the authors.

In view of the above, Table 4 presents the final form of the model used to measure the publishing efficiency of the PAS institutes and to isolate external factors that influence it.

Table 4. The Set of Categories Adopted in the Final Version of the Empirical Model (Publication Efficiency)

Specification	Designation	Explanation
Inputs	x_1	researchers involved in R&D activity (in FTE)
	x_2	technicians involved in R&D activity (in FTE)
	x_3	other support staff, e.g., administrative (in FTE)
	x_4	gross value of research equipment (in thousand PLN)
	x_5	funds for R&D activity (in thousand PLN)
Output	y	total number of publications
External factors	z_1–z_6	fields in which the unit conducts scientific research: natural sciences, engineering and technology, medical and health, agricultural and veterinary, arts and humanities, social sciences; variables 0–1
	z_7	scientific category of the unit – 1(B), 2(A), 3(A+)

Source: the authors.

4.3. Combined Publishing and Implementation Efficiency

The review of the literature and websites of the institutes shows that their R&D activities also include expert opinions, reports and analyses, which, unfortunately, are only available to a small extent. The collection of such data turned out to be unfeasible, at least for the moment.

This is important as the high publishing inefficiency of some units may result from the fact that the observed inputs are used for purposes other than publishing.

Therefore, in the frame of a separate empirical model, institutes with a positive value of patents or patent applications (y_2) were also analysed – together with a positive output y_1 value (number of publications). Data on this second output was obtained from reports on research and development activities sent by the institutes.

Unfortunately, this group comprises only 28 PAS institutes. With the total number of seven inputs and outputs, this gives the model too little discriminatory power – as many as 20 units are then fully efficient. The analysis, then, brings little information to the considerations regarding joint publication and implementation efficiency.

Table 5. The Set of Categories Adopted in the Empirical Model (Publication and Implementation Efficiency)

Specification	Designation	Explanation
Inputs	x_1	researchers and technicians involved in R&D activity (in FTE)
	x_2	other support personnel, e.g., administrative (in FTE)
	x_3	gross value of research equipment (in thousand PLN)
	x_4	funds for R&D activity (in thousand PLN)
Outputs	y_1	total number of publications
	y_2	total number of patents and patent applications
External factors	z_1–z_6	fields in which the unit conducts scientific research: natural sciences, engineering and technology, medical and health, agricultural and veterinary, arts and humanities, social sciences; variables 0–1
	z_7	the unit's scientific category – 1(B), 2(A), 3(A+)

Source: the authors.

It was therefore decided to aggregate two similar categories related to the labour factor – researchers and technicians involved in R&D. At the same time, it was once again studied whether the remaining support staff could act as an external factor. Once more, it appeared that remaining support staff does not have a significant impact on the total efficiency, but at the same time, for practical reasons, it cannot be ignored[12]. Therefore, it plays the role of input – similarly as in the final version of the model used to measure publication efficiency.

Table 5 presents the final form of the empirical model used to measure publication and implementation efficiency and to determine external factors significantly influencing it.

5. Description of the Results

5.1. Publication Efficiency

Figure 1 shows a histogram of the publication efficiency measure, obtained in the first step of the appropriate two-stage procedure and performed for the final version of the empirical model.

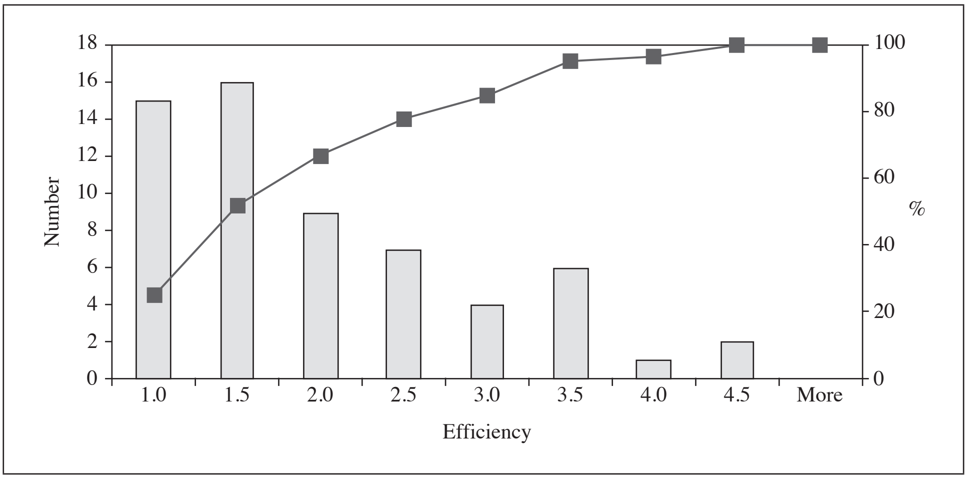

Fig. 1. Histogram of Efficiency Scores for the Final Version of Empirical Model

Notes: polyline – cumulative frequency in percent.

Source: the authors.

The research results indicate that 15 PAS institutes, or 25% of the entire group, operate efficiently[13] in terms of the number of publications in relation to the input of labour (x_1–x_3) and capital (x_4–x_5). The fraction of units characterised by low inefficiency in the range (1; 1.5] – 26.67% (16 institutes) is equally relevant. On the other

[12] Yet another vital element is that this factor is weakly but positively correlated with both outputs. In general, the situation is similar to that of empirical model of publishing efficiency.

[13] Notably, the measure of efficiency is relative here, i.e., institutes are compared with one another, and not with respect to some external benchmark.

hand, the efficiency measure of almost half of the institutes (48.33%, 29 institutes) exceeds 1.5. This means that these units could potentially publish over 50% more scientific papers than they currently do. However, this inefficiency for most units is still much lower than in (Brzezicki & Prędki, 2023b), which used an appropriate empirical model[14].

In the second stage of the procedure, factors other than inputs or outputs were also identified, significantly affecting the efficiency of the PAS institutes in 2019. The publication efficiency was negatively affected by research conducted by a given unit within agricultural and veterinary sciences, while research conducted in humanities boosted the efficiency.

The results indicated that the higher (better) the scientific category of an institute, the lower (weaker) its level of publication efficiency. That is, units with higher categories focus on higher quality, rather than the number of publications they put out. They also attempt to operate in more comfortable conditions, involving more employees and different types of capital. Other external factors, listed in Table 4, did not have a statistically significant impact on publication efficiency.

5.2. Combined Publishing and Implementation Efficiency

As there is more than one output in the model, in the first stage of the procedure the publication and implementation efficiency measure were calculated by means of two models, BCC and SBM. This made it possible to analyse both radial and non-radial efficiency. In other words, it became possible to make proportional and non-proportional modifications in output amounts, respectively. Nevertheless, the same facilities under both models were considered efficient, and at all times the measure of efficiency for a given unit obtained in the SBM model was not lower than that measured with the BCC model.

Figure 2 presents the total histograms of efficiency measures obtained from the BCC and SBM models.

Half of the institutes (14) are efficient. This may partially be the result of the model still having too weak discriminatory power. The number of slightly inefficient institutes is similar for both models – 5 and 4 for the BCC and SBM models, respectively.

Assuming that only proportional changes in outputs can be made, the maximum value of the measure for the BCC model does not exceed 3.5. This is qualitatively similar to the maximum for measures of publication efficiency generated using the

[14] However, the 2023 paper considered a much larger group of 121 Polish institutes, characterised by a positive number of publications and a set of inputs which, as described earlier, was substantially modified in this paper.

third empirical model. The SBM model involves three extremely inefficient units, with inefficiency exceeding 3.5.

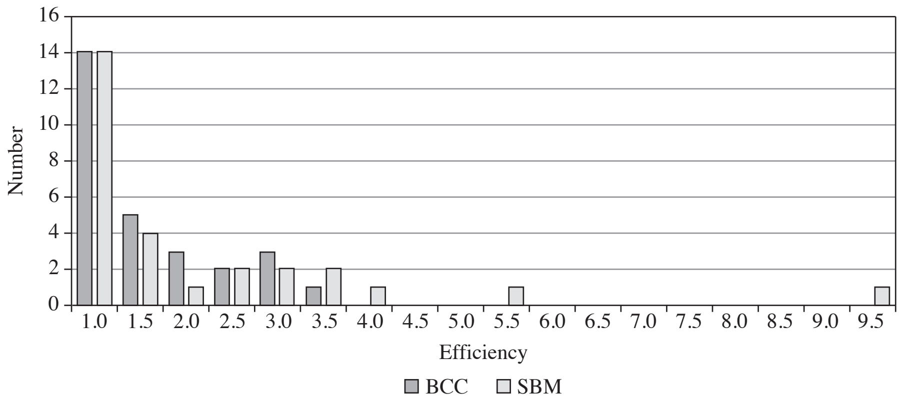

Fig. 2. Histogram of Efficiency Scores for the BCC and SBM Models
Source: the authors.

Again, the value of the measure is interpreted differently for the two models. This difference shall be discussed through an example of the two most inefficient institutes, for which the value of the measure is 3.19 (BCC) and 9.34 (SBM), respectively. For BCC this means that a given institute, with the current volume of inputs, would be able to obtain more than three times as many publications, patents, and patent applications. For SBM, the corresponding value means that the unit could potentially obtain more than nine times the average relative increase in outputs[15].

Finally, the least efficient units under the BCC and SBM models are two different institutes. In general, the rankings of inefficient units imposed by the BCC and SBM are practically independent – the rank correlation coefficient is approximately 0.033. On the other hand, four units occupy identical places in both rankings.

Returning to the analysis of external factors, there is the same set of categories that significantly affect efficiency, regardless of which method of measuring it is used in the first stage (BCC or SBM model). This lends credence to the results obtained in this area.

As in the case of publication efficiency, the increase in the scientific category of a unit has a negative impact on the total efficiency (publishing and implemen-

[15] It is the average of the relative increments of individual outputs, which do not have to be identical, i.e., proportional, as in the radial BCC model.

tation). Confirmation of this fact for two outputs makes this relationship believable (the reasons for which have already been given in our discussion of the appropriate single-output empirical model).

However, there is also a new, important factor negatively affecting the combined efficiency of publishing and implementation – the scientific activity carried out by a given unit in the field of medical and health sciences. For this factor, conducting research in agricultural and veterinary sciences as well as humanities did not significantly impact the institutes' combined efficiency[16].

6. Conclusions and Directions for Further Research

The study shows that changing the category in the empirical model improved the credibility of the results, compared to the previous analysis in (Brzezicki & Prędki, 2023b). However, due to the limited data available, it was necessary to limit the study to the group of PAS institutes.

A significant share of institutes – almost half and one-third of the units for publishing and total efficiency (publication and implementation), respectively – were highly inefficient (exceeding the value of 1.5).

This is primarily because many institutes conduct activities unrelated to research and development, a fact confirmed by the results of the SAO inspection mentioned in the introduction to the paper. Secondly, the analysis did not include all the effects of research and development activities (e.g. expert opinions, reports and analyses) due to the lack of access to relevant data. This may also have had a negative impact on the efficiency of institutes that generate such outputs.

The institutes' publishing efficiency was negatively affected by the research conducted by a given unit in the field of agricultural and veterinary sciences, and positively by the implementation of scientific research in the humanities.

This is because the institutes conducting research in agricultural and veterinary sciences tend to conduct experimental research, which may lead to reports, analyses and reports on these studies, but not necessarily publications, being generated. On the other hand, it seems natural that units conducting research in the humanities would generate numerous publications.

At the same time, these factors did not have a significant impact on the combined efficiency, which is negatively affected by the scientific activity carried out by a given unit in the field of medical and health sciences. This too seems natural: it is an area where both publications describing the results of medical research and experiments, as well as patents related to new drugs and medical devices, play a significant role. However, why this impact is negative remains a pressing question.

[16] These factors were significant for the results obtained for publication efficiency.

The results of the present study indicated that the higher (better) the scientific category of an institute, the lower (weaker) its level of efficiency in the two aspects analysed. This is probably because a higher scientific category is awarded for the higher quality of publications rather than their number. Hence, it would be advisable in the future to obtain data on the total number of points for publications obtained by institutes in a given period.

Finally, this study has limitations that suggest certain prospects for further research. Firstly, the study analysed only one group of research institutes from among three that currently operate in Poland (Brzezicki, 2022; Brzezicki & Prędki, 2023b). Secondly, a dynamic analysis has not been performed for more than a year. This made it impossible to analyse changes in efficiency (and more broadly, productivity) which may have grown out of changes in the science and higher education system and legal and organisational changes in individual institutes[17].

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Authors' Contribution

The authors' individual contribution is as follows: Each contributed 50%.

Conflict of Interest

The authors declare no conflict of interest.

References

Banker, R. D., & Natarajan, R. (2008). Evaluating Contextual Variables Affecting Productivity Using Data Envelopment Analysis. *Operations Research*, *56*(1), 48–58. https://doi.org/10.1287/opre.1070.0460

Barcikowska, R. (2016). Instytuty badawcze w Polsce – próba syntetycznej oceny ich miejsca i roli w polityce innowacyjnej polski. *MINIB*, *21*(3), 141–154.

Barcikowska, R. (2021). New Organizational Model for Functioning of Research Institutes in Poland – Comparative Analysis of Łukasiewicz and Poltrin Networks. *Marketing of Scientific and Research Organizations*, *39*(1), 25–46.

Brzezicki, Ł. (2022). Działalność publicznych instytutów badawczych w Polsce. *Nauki Ekonomiczne*, *36*, 35–83. https://doi.org/10.19251/ne/2022.36(2)

Brzezicki, Ł., & Prędki, A. (2022). *Appendix 2022 PRI. Empirical Studies Using DEA Method and Malmquist Index to Measure the Efficiency and Productivity of PRI*. https://doi.org/10.13140/RG.2.2.32913.30564

[17] Potential field of application for Mälmquist or Färe-Primont indices.

Brzezicki, Ł., & Prędki, A. (2023a). *Appendix Table A1. A Review of Studies on the Impact of External Variables on the Level of Efficiency/Productivity in Academic, Research, Implementation and Innovation Activities in Higher Education*. https://doi.org/10.13140/RG.2.2.36094.97602

Brzezicki, Ł., & Prędki, A. (2023b). An Estimation of the Efficiency of Public Research Institutes in Poland – DEA Approach. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie*, 2(1000), 33–50. https://doi.org/10.15678/ZNUEK.2023.1000.0202

Coccia, M. (2008). Measuring Scientific Performance of Public Research Units for Strategic Change. *Journal of Informetrics*, *2*(3), 183–194. https://doi.org/10.1016/j.joi.2008.04.001

Cooper, W., Seiford, L., & Tone, K. (2006). *Introduction to Data Envelopment Analysis and Its Uses*. Springer.

de la Torre, E. M., Ghorbankhani, M., Rossi, F., & Sagarra, M. (2021). Knowledge Transfer Profiles of Public Research Organisations: The Role of Fields of Knowledge Specialization. *Science and Public Policy*, *48*(6), 860–876. https://doi.org/10.1093/scipol/scab061

Hoff, A. (2007). Second Stage DEA: Comparison of Approaches for Modelling the DEA Score. *European Journal of Operational Research*, *181*(1), 425–435. https://doi.org/10.1016/j.ejor.2006.05.019

Huian, M. C., Bisogno, M., & Mironiuc, M. (2023). Technology Transfer Performance of Public Research Institutes: The Case of Romania. *Journal of Public Budgeting, Accounting & Financial Management*, *35*(1), 41–64. https://doi.org/10.1108/JPBAFM-01-2022-0023

Kostrzewska, J. (2011). Interpretacja w modelach tobitowych. *Przegląd Statystyczny*, *58*(3–4), 256–280.

Kozłowski, J. (2007). Jednostki badawczo-rozwojowe w Polsce – między zależnością od ścieżek rozwojowych a tworzeniem nowych. *Nauka i Szkolnictwo Wyższe*, 1(29), 113–140.

Lynskey, M. J. (2009). Knowledge Spillovers from Public Research Institutions to the Private Sector: Evidence from Japanese New Technology-based Firms. *International Journal of Technology Transfer and Commercialisation*, *8*(2–3), 159–184. https://doi.org/10.1504/IJTTC.2009.024384

Łącka, I. (2011). *Współpraca technologiczna polskich instytucji naukowych i badawczych z przedsiębiorstwami jako czynnik wzrostu innowacyjności polskiej gospodarki*. Wydawnictwo Uczelniane Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie.

Łącka, I., & Brzezicki, Ł. (2023). The Efficiency of Scientific Activities and Technology Transfer in Higher Education in Poland. *Social Inequalities and Economic Growth*, 75, 62–89. https://doi.org/10.15584/nsawg.2023.3.4

RAD-on. (2023). Retrieved from: https://radon.nauka.gov.pl/ (accessed: 21.06.2023).

SAO. (2020). *Gospodarka finansowa instytutów badawczych*. Najwyższa Izba Kontroli. Retrieved from: https://www.nik.gov.pl/plik/id,23423,vp,26148.pdf (accessed: 7.09.2022).

Simar, L., & Wilson, P. W. (2007). Estimation and Inference in Two-stage, Semi-parametric Models of Productive Efficiency. *Journal of Econometrics*, *136*(1), 31–64. https://doi.org/10.1016/j.jeconom.2005.07.009

Tone, K. (2001). A Slacks-based Measure of Efficiency in Data Envelopment Analysis. *European Journal of Operational Research*, *130*(3), 498–509. https://doi.org/10.1016/s0377-2217(99)00407-5

Trzmielak, D., & Krzymianowska-Kozłowska, J. (2020). Organizacja badawcza z perspektywy rozwoju sieci. Stymulanty i bariery rozwoju nowych technologii w Sieci Badawczej Łukasiewicz. In: L. Bohdanowicz, P. Dziurski (Eds), *Innowacje i marketing we współczesnych organizacjach*. *Wybrane zagadnienia* (pp. 163–178). Oficyna Wydawnicza SGH – Szkoła Główna Handlowa w Warszawie.