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Zeszyty Naukowe Uniwersytet Ekonomiczny w Krakowie

2 (1000)
2023

Zesz. Nauk. UEK, 2023, 2(1000): 33–50
ISSN 1898-6447
e-ISSN 2545-3238
https://doi.org/10.15678/ZNUEK.2023.1000.0202

An Estimation of the Efficiency of Public Research Institutes in Poland: The DEA Approach

Oszacowanie efektywności publicznych instytutów badawczych w Polsce – podejście DEA

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

ABSTRACT

Objective: The purpose of this paper is to measure and assess the efficiency of research institutes in Poland. The institutes operate on the basis of various legal frameworks, but they serve a common purpose and have a joint area of activity, research and development.

Research Design & Methods: We used the SBM model, a component of the non-parametric Data Envelopment Analysis (DEA) methodology, to analyse the efficiency of research institutes in 2019. The Metafrontier approach was also employed to verify whether the above different legal framework had an impact on the functioning of the entities under analysis.

Findings: Histograms of the efficiency measure indicate a large dispersion of its value. In particular, a significant fraction of units is characterised by extremely high values of this measure. Average MTRs, calculated using the Metafrontier approach, are mostly significantly lower than one.

Implications/Recommendations: The obtained results indicate that groups of institutes with different legal framework function differently. Moreover, a large proportion of the objects analysed is characterised by significant inefficiency within the area of R&D. The paper lists the potential reasons, which will be the object of further, in-depth research.
Contribution: The research constitutes a preliminary attempt to analyse and evaluate the efficiency of research institutes in Poland after the introduction of the last reform of the science and higher education system in 2018, as such studies have not been carried out to date. It is also essential to use the Metafrontier approach within the DEA methodology in order to model differences in the functioning of three different groups of research institutes in Poland.

Article type: original article.

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

JEL Classification: C67, I23, O31, O32.

STRESZCZENIE

Cel: Celem artykułu jest pomiar i ocena efektywności instytutów badawczych w Polsce, które funkcjonują na podstawie różnych ram prawnych, lecz mają wspólny cel i obszar aktywności, jakim jest działalność badawczo-rozwojowa.
Metodyka badań: Do analizy efektywności instytutów badawczych w 2019 r. wykorzystano model SBM, należący do nieparametrycznej metodyki *data envelopment analysis* (DEA). Zastosowano również podejście metafrontier w celu sprawdzenia, czy wspomniane odmienne ramy prawne mają wpływ na sposób funkcjonowania badanych jednostek.
Wyniki badań: Histogramy miary efektywności wskazują na duże rozproszenie jej wartości, w szczególności występuje znacząca frakcja jednostek, które charakteryzują się skrajnie wysokimi wartościami tej miary. Średnie współczynniki MTR, obliczone z wykorzystaniem podejścia metafrontier, są w przeważającej większości znacznie niższe od jedności.
Wnioski: Uzyskane wyniki wskazują, że grupy instytutów działających na podstawie różnych ram prawnych funkcjonują odmiennie. Ponadto znacząca część analizowanych jednostek charakteryzuje się stosunkowo dużą nieefektywnością w obszarze B+R. Wymieniono potencjalne przyczyny takiego stanu rzeczy, które będą przedmiotem dalszych, pogłębionych badań prowadzonych przez autorów.
Wkład w rozwój dyscypliny: Dokonanie wstępnej analizy i oceny efektywności działalności instytutów badawczych w Polsce po wprowadzeniu ostatniej reformy systemu nauki i szkolnictwa wyższego z 2018 r. – badania takie nie zostały jak dotąd przeprowadzone. Istotne jest również wykorzystanie podejścia metagranicy w ramach metodyki DEA w celu modelowania różnic w funkcjonowaniu trzech różnych grup instytutów badawczych w Polsce.

Typ artykułu: oryginalny artykuł naukowy.

Słowa kluczowe: publiczne instytuty badawcze, efektywność, R&D, DEA.

1. Introduction

Many countries strive to fully develop an economy based on knowledge and innovation, and corresponding National Innovation Systems (NIS) are designed to serve this purpose. Three main groups of entities under this system have the biggest impact on NIS: enterprises, universities and public institutions. In Poland, the higher education and science sector is crucial for the NIS.

According to the Act of 20 July 2018 – Law on Higher Education and Science, the system of higher education and science comprises:

1) institutions of higher education,

2) federations of entities of the higher education system and science,

3) Polish Academy of Sciences (PAS) and scientific institutes of PAS, acting on the basis of the Act of 30 April 2010 on the Polish Academy of Sciences,

4) research institutes, acting on the basis of the Act of 30 April 2010 on Research Institutes,

5) The Łukasiewicz Centre and research institutes operating within the Łukasiewicz Research Network, operating under the Act of 21 February 2019 on the Łukasiewicz Research Network,

6) other entities conducting mainly scientific activities on an independent and continuous basis.

Prior to the implementation of the Act of 20 July 2018 – Law on Higher Education and Science in 2018, the activity of universities was very different from that of research institutes. Higher education was mainly evaluated through the prism of didactic activity, and scientific endeavors were conducted only to the extent necessary. On the other hand, implementation activity was practically neglected.

With the introduction of the higher education reform in 2011, greater attention was paid to scientific activity, which was assessed on the basis of points assigned to various types of scientific publications. On the other hand, only in recent years the Ministry of Science and Higher Education in Poland (MSHE) has shown a rising interest in seeing knowledge and technology transferred to the economy. For several years, the MSHE (currently: Ministry of Education and Science) has been setting up programmes and projects to stimulate and encourage universities and institutes to be more active in this field. A consequence of the strategy chosen to develop higher education and science was the assessment of knowledge and technology transfer announced in 2020 by the MSHE, whose first effects were used to evaluate scientific activity for 2017–2021.

For years, the Supreme Audit Office (SAO) has been revealing the problems of research institutes in Poland (Brzezicki 2022). In 2014, it performed an extensive analysis of these entities and combined its findings with previous audits. As a consequence, the SAO has concluded the existence of many years of: "Ineffective exploitation of the scientific potential of institute employees, focusing activities on the provision of services unrelated to conducting scientific research and developmental works, achieving negligible revenues from the sale of research and targeted projects, and a limited scope of R&D activities undermining the status of some entities as research institutes" (SAO 2014, p. 8).

Interesting conclusions can be found in a 2020 SAO audit, which indicated that "Attention is drawn to the relatively low share in total income, revenues from the basic activities of institutes, which is research and development work aimed at their implementation and practical application. The share of these revenues in 2018 and 2019 was 9.5% and 11.5%, respectively" (SAO 2020, p. 29). This means, in effect, that research institutes were earning, but the earnings did not come from their core business.

Before proceeding with a more detailed analysis of the activities of public research institutes (PRIs), it is necessary to define this concept. In *Oslo Manual 2018* it was found that "Although there is no formal definition of a PRI (sometimes also referred to as a public research organisation), it must meet two criteria: (i) it performs R&D as a primary economic activity (research); and (ii) it is controlled by government (formal definition of public sector). This excludes private non-profit research institutes" (OECD/Eurostat 2018, p. 140).

However, according to Polish legal regulations, the Act of 30 April 2010 on Research Institutes defines that research institutes are state entities, separated in terms of legal, organisational, economic and financial matters. They conduct scientific research and development activities focused on their implementation and application in practice.

As Mazzoleni and Nelson (2007) rightly point out, public research institutions have historically been important parts of the NIS architecture to support a country's economic "catching-up". However, recent developments in the international economic environment and the growing scientific base for modern technologies will raise the profile of these institutions even more in the future (Lim & Kim 2019).

In the light of this fact, considering the previously discussed audit results from the SAO, it is justified to examine the efficiency of scientific institutes in terms of research and development activity, the main area of their core operations. In this work we analyse to what extent funds allocated to R&D and the professional efforts of R&D personnel translate into specific effects. We are also making a preliminary attempt to analyse and evaluate the efficiency of research institutes in Poland after the introduction of the last reform of the science and higher education system in 2018, as such studies have not been carried out to date. To these ends, we use the Metafrontier approach within the DEA methodology in order to model differences in the functioning of the three different groups of research institutes in Poland.

2. Literature Review

For years, global research has addressed the role and importance of research institutes in the NIS (Suzuki, Tsukada & Goto 2015, Intarakumnerd & Goto 2018), their cooperation with universities (Wong, Hu & Shiu 2015), and comparisons of the results of their work (Park & Shin 2018). However, this research has mainly been limited to simple comparisons of data or indicators for relevant categories between institutes (Shiu, Wong & Hu 2014). Occasionally, complex analyses have been done by means of more sophisticated quantitative methods (Xiong, Yang & Guan 2018). As Suzuki, Tsukada and Goto (2015) and Kang (2021) rightly make clear, PRIs[1] are the least explored element of the NIS. Most attention in the literature has centered around universities, which are a separate component of the NIS (Wolszczak-Derlacz 2013, Łącka & Brzezicki 2020). This is especially supported by works which present a review of literature in this field (De Witte & López-Torres 2017, Rhaiem 2017, Brzezicki 2020). In any case, more publications in the subject literature are devoted to the activities of universities than those of other entities in the NIS system, including the PRI.

Analyses of research or scientific units have been conducted only sporadically in Poland, while no analysis of the efficiency of research institutes has been carried out to date. An overview of the Polish literature shows that the relevant works have concerned only the legal and organisational aspects of their functioning (Kozłowski 2007, Barcikowska 2016, 2021, Trzmielak & Krzymianowska-Kozłowska 2020), without empirical analysis of the effects of their activities. Given this, the present literature review centers around foreign research.

Interesting research results have been presented by Ko, Kim and Lee (2021), who analysed the Korean GRI (see footnote 1), representing three mission types: basic future leading, public infrastructure and industrialisation.

The research results presented by Ko, Kim and Lee (2021) indicate that the pace of development and application of technology in industry is much faster in the GRIs that deal with industrialisation than in other types thereof. According to the above study, the mission of a given GRI group affects the results of technology transfer.

Ortega, López-Romero and Fernández (2011) distinguished three classes of research institutes: humanistic, scientific and technological. The classes were defined on the basis of the distinctive research products of each institute. According to the authors, a "scientific" institution is one that mainly publishes the works of the ISI (Institute of Scientific Information); a "humanistic" institution publishes primarily books and publications that are in no way tied to the ISI; and a "tech-

[1] Also called Public Research Organisations (PROs), Government Research Institutes (GRIs), Government-Funded Research Institutes (GFRIs), National Research Institutes (NRIs) or Research Centers (RCs).

nological" institute "produces" patent applications (Ortega, López-Romero & Fernández 2011).

In this respect, an interesting study was carried out by Dusdal *et al*. (2020) who compared the scientific activity (as seen through scientific publications) of universities and research institutions in Germany. Their research shows that scientific institutes generate more articles in science, technology, engineering and mathematics, and medicine and health, and publish these articles in journals with a higher Impact Factor than universities.

The results presented in the report *Science in Poland 2019* (OPI-PIB 2019) indicate a somewhat different trend in Poland. The largest number of scientific articles from part A of the MSHE list per a single R&D employee in 2013–2018 were published by PAS institutes (4.66), followed by public universities (3.46). Other research institutes fared quite poorly on this list (1.78). On the other hand, taking into account the scientific articles from part B of the MSHE list, the remaining research institutes (2.00) take the third place in the ranking, while the PAS institutes rank only fourth (1.22).

While in most cases the effects generated by universities can be quantified (numbers of students, graduates, publications, patents), some effects of the institutes' endeavors, due to the nature of the technology transfer channel to the economy (e.g., reports, conversations, training and consulting), are not included in the reports on these entities, so these objects cannot be fully analysed. For instance, Costa Póvoa and Rapini (2010), researching technology transfer from universities and PRI to firms in Brazil, indicated that publications and reports are the main transfer channel, followed by conversations, training, consulting, recruit grads, patents and other measures of knowledge exchange.

Moving on to the research methodology used in the source literature, it should be noted that PRI studies are conducted by means of various analytical methods and procedures. For example, Han, Gwak and Kim (2017) used a panel generalised least squares (GLS) model with fixed effects. Ko, Kim and Lee (2021) used fixed-effects and random-effects models, and Han, Park and Kwak (2021) employed multiple panel linear regression model in their analysis of Korean GFRIs (see footnote 1).

Lynskey (2010) used Poisson and Tobit regression to explore the relationship between spillovers from PRIs and innovation in Japanese firms. Yang *et al*. (2015) proposed strategy maps for Chinese NRIs, and a new method – Forecasting--Objective Achievement System (FOAS) – to set targets for key performance indicators (KPIs). Lim and Kim (2019) utilised the three-stage analytical hierarchy process (AHP) technique.

The scientific community, PRI managers and NIS politicians and decision--makers seek to know not only what factors affect the results achieved in the field of patent activity and technology transfer (Cheah & Yu 2016), but also what efficiency characterises a given PRI compared to other similar entities. Therefore, primary sources also include a few studies conducted using the non-parametric DEA method (Brzezicki & Prędki 2022), which makes it possible to measure the efficiency of the PRI in a manner independent of the researcher's subjective approach. The authors of the PRI study used both classic DEA models (e.g., CCR or BCC) as well as more complex (e.g., two-stage network DEA) or dynamic (e.g., DSBM) models.

Lee *et al*. (2012) estimated the efficiency of cooperation of 23 Korean PRIs using the Window DEA. The research indicates that PRIs with higher efficiency apply a coherent network strategy, maintaining close relationships with their existing partners. Conversely, overly coherent alliances can lead to lock-in relationships that hamper new innovation opportunities.

Xiong, Yang and Guan (2018) used a two-stage dynamic DEA model to estimate the efficiency of 17 research institutes in the Chinese Academy of Sciences. The results showed a significant increase in the institutes efficiency, mainly due to an improved technology transfer to the economy. The authors commented that there is still much room for improvement in the flow of scientific and technological achievements. Additionally, it was stressed that the scale of resources played a major role in influencing basic research conducted by the institutes.

Another interesting study was conducted by Park and Shin (2018). Unlike other authors, they focused on analysing government-sponsored R+D Subdisciplines--Biotechnology projects, presenting results for various NIS entities, including PRI. The data used for the analysis included: total amount of funds allocated to an R&D project, its duration, number of researchers involved in the project, number of SCI and non-SCI papers, and the number of granted and applied patents. As the only researchers doing work in this area, the pair used the Metafrontier, calculated on the basis of the classic BCC model. Their approach imposed a certain restriction, as only a radial measurement of efficiency was performed.

The literature review implies that PRI research conducted by means of the DEA method is performed almost exclusively in Asian countries (Brzezicki & Prędki 2022), with rare exceptions (Italy, Brazil). Unfortunately, no such analysis has been carried out in Poland, even though the relevant research units have already been reformed twice. Recent changes were implemented in 2018. Given this research gap, we chose to analyse the efficiency of Polish PRIs after the recent reforms.

3. Research Methodology

We use non-parametric DEA to calculate the efficiency of object o (θ_o) by means of an output-oriented SBM (Slack Based Model) model with variable returns to scale, following (Tone 2001):

$$\theta_o = \max\left[\frac{1}{R}\sum_{r=1}^{R}\left(1+\frac{s_{ro}^{+}}{y_{ro}}\right)\right] \tag{1}$$

$$x_{io} = \sum_{j=1}^{J} \lambda_{jo} x_{ij} + s_{io}^{-}, \quad i = 1, \ldots, I \tag{2}$$

$$y_{ro} = \sum_{j=1}^{J} \lambda_{jo} y_{rj} - s_{ro}^{+}, \quad r = 1, \ldots, R \tag{3}$$

$$\sum_{j=1}^{J} \lambda_{jo} = 1 \tag{4}$$

$$\lambda_{jo}, s_{io}^{-}, s_{ro}^{+} \geq 0 \quad (\forall j, i, r) \text{ – decision variables,} \tag{5}$$

where:

x_{ij} – amount of the *i*-th input of the *j*-th object[2],
y_{ro} – amount of the *r*-th output of the *j*-th object,
λ_{jo} – intensity variables,
s_{io}^{-}, s_{ro}^{+} – slacks,
I, *R*, *J* – number of inputs, outputs and objects, respectively.

We adopted the output orientation because the authors believe the aim of the institutes should be to maximise the number of outputs, with the current volume of inputs. In addition, the assumptions in the model include variable returns to scale, not wanting to presume that all tested objects are effective in terms of the scale of activity (the so-called constant returns to scale).

The measure of efficiency θ_o is not less than 1. Efficient objects are characterised by a value equal to one. Consequently, the more the measure value exceeds unity, the more inefficient the object.

We also used the Metafrontier approach, which serves to analyse technological similarities between *k* groups of objects (O'Donnell, Rao & Battese 2008). In the first instance, we used model (1–5) to calculate an efficiency measure θ_o for each object $o = 1, \ldots, J$, with the understanding that technology for all groups is common.

Next, after the division of *J* objects into *K* groups, here too model (1–5) was used to calculate the efficiency measure θ_o^k for object *o* forming part of the *k*-th group. In the mentioned model, the number of objects was assumed to be the numerousness of the *k*-th group.

The last step involved calculating the metatechnology ratio $\frac{\theta_o^k}{\theta_o}$ for object *o* from the *k*-th group. Its value is not greater than 1, and the closer it is to unity, the closer the technology of the *k*-th group is to the theoretical, common technology of all groups (so-called metatechnology) in the data point corresponding to object *o*. To check whether, in general, the technology of the *k*-th group is close to metatechnology, we calculated the geometric mean[3] metatechnology ratios (MTR) for objects in this group. If this mean value is close to unity, it can be assumed that on average, the technology of the *k*-th group is similar to metatechnology.

[2] In particular, *j* can be equal to *o*.

[3] Geometric mean was selected for the multiplicative nature of the metatechnology ratio.

This approach is used to verify whether a given group of objects is technologically homogeneous[4], which it is if all group means are close to unity. In the opposite case, the technology of at least one group is fundamentally different from a common technology (metatechnology) that can be assumed when the assumption of homogeneity is satisfied.

The literature review and available data made it possible to select the variables (inputs and outputs) used to analyse the efficiency of research institutes. Table 1 presents the empirical models adopted to estimate the efficiency of the objects under study.

Table 1. Empirical Models for Estimating the Efficiency of Research Institutes

Specification	Designation	Explanation	Model 1	Model 2	Model 3
Inputs	x_1	number of researchers and technicians involved in R&D activities	×	×	×
	x_2	other support personnel (e.g., administrative staff)	×	×	×
	x_3	internal funds for R&D activities (in thousand PLN)	×	×	×
	x_4	external funds for R&D activities (in thousand PLN)	×	×	×
Outputs	y_1	total number of patent applications and patents granted	×	×	
	y_2	total number of publications	×		×

Source: the authors.

The data collected include a number of zero values, which influenced the method of analysis. In the first instance, the efficiency of R&D activities conducted by the research units characterised by non-zero value of both products (model 1, 63 entities) was examined. Next, to take maximum advantage of the data, we analysed the efficiency of two subsequent groups of institutes. They are characterised by a non-zero value of products y_1 (model 2, 70 entities) and y_2 (model 3, 121 entities), respectively. Naturally, both these groups contain the institutes considered in model 1. Therefore, the efficiency of R&D activities in place at scientific units was also examined for each individual output.

[4] This is one of the basic assumptions in DEA methodology.

The data also includes zero input values x_2 and x_3 for some entities, which had little impact on the analysis due to the adopted output orientation of the model (Tone 2001, subsec. 6.1).

Data regarding the number of scientific publications was extracted from the RAD-on system (OPI-PIB 2022). The RAD-on database contains information from numerous previous databases, including POL-on, PBN or "Polish Science" ("Nauka Polska"). The remaining data, on the other hand, was derived from reports on research and development (R&D) efforts obtained on the basis of an application for access to public information. Some institutes sent relevant data (the most valid and sufficiently numerous figures related to 2019)[5]. Hence, the analysis was carried out for that year.

129 entities shared relevant information for 2019. To put this in context, the total number of entities registered in the RAD-on database as research institutes is currently[6] 203. This means that only some institutes from the entire group of those operating in Poland were analysed. The study excluded institutes for which it was impossible to obtain complete data or which limited themselves only to teaching or scientific activity, without research and development undertakings.

The statutory scheme of the system of higher education and science presented in the introduction demonstrates that research institutes in Poland can be divided into three separate groups, each of which operates under a different set of standards:

1) scientific institutes of the Polish Academy of Sciences (designation PAS, 59 entities),

2) research institutes operating within the Łukasiewicz Research Network (designation Network, 24 entities),

3) other research institutes (designation Other, 46 entities).

One of this paper's objectives is to use the Metafrontier approach to verify whether these groups of institutes actually function in a different manner in terms of the technology they deploy to transform their specific inputs into their characteristic products[7].

The efficiency of research institutes was calculated by means of the free version of MaxDEA (http://maxdea.com/MaxDEA.htm, accessed: 20.09.2022) and MS Excel software, including the Solver optimisation plug-in.

[5] Mindful of confidentiality, entities were reluctant to provide more actualised figures. However, a small number of institutes also sent their reports for 2020.

[6] This is subject to minor changes in the following years as a result of various types of restructuring these entities underwent (merger, division, liquidation).

[7] DEA methodology treats the objects being analysed as specific production entities.

4. Empirical Results

Table 2 presents histograms of the efficiency measure for all three models. Entities with a measure of efficiency greater than eight were arbitrarily considered extremely inefficient and identified in a separate group. These entities account for a major percentage of the total size of each group – 12.70% (model 1), 25.71% (model 2), and 16.53% (model 3). Of the eight extremely inefficient entities under the combined model 1 (both outputs), six are extremely inefficient under models concerning single products as well. The other two are extremely inefficient under models 1 (combined) and 3 (publications), but not under model 2 (patents).

Table 2. Histograms of Measures of Efficiency for Models 1–3

Efficiency	Size_Model 1	Size_Model 2	Size_Model 3
1	19	13	18
2	12	10	25
3	7	7	24
4	5	5	15
5	4	4	6
6	3	5	5
7	3	5	5
8	2	3	3
> 8	8	18	20
Total	63	70	121

Source: the authors.

The percentage of fully efficient entities is also significant and amounts to 30.16% (model 1), 18.57% (model 2), and 14.88% (model 3). Of the 19 entities that are fully efficient under model 1, only five are also efficient under models 2 and 3, and another five are efficient for only 1 model. The remaining nine entities are inefficient under both single-output models; two cases concern extreme inefficiency.

It is the opinion of the authors that values of measure no greater than two are useful. This means that, according to the interpretation of the measure, the relative potential growth of both outputs (model 1) or one of them (models 2 and 3) by no more than 100% is allowed. The possibility of obtaining a greater, relative increase in output(s) from the current number of inputs (personnel and expenditure on R&D) makes the obtained results unreliable from a practical point of view. The percentage of such inefficient entities under each model is also significant – 19.05% (model 1), 14.29% (model 2), and 20.66% (model 3).

Unfortunately, in each model, the value of the measure of efficiency for over 50% of research units exceeds two. Moreover, there is a significant fraction of objects, described previously, for which the values of the efficiency measure indicate that these entities should be treated as extremely unusual, unfit observations (outliers).

One source of the overly dispersed efficiency measure may be the technological heterogeneity of objects. In this case we understand that there may be groups of institutes that function differently in terms of how patents (y_1) and publications (y_2) derived from personnel work (x_1 and x_2) and R&D expenditure (x_3 and x_4) are generated.

As mentioned before, it is quite natural to distinguish three such groups: institutes of the Polish Academy of Sciences (PAS), institutes of the Łukasiewicz Research Network (Network) and other scientific institutes (Other).

Table 3 lists the average MTR coefficients for each model. They are intended to help verify the hypothesis of the technological homogeneity of the functioning of individual groups of institutes.

Table 3. Average MTRs for Models 1–3

Specification	PAS	Network	Other
Model 1	0.647	0.314	0.656
Model 2	0.635	0.743	0.530
Model 3	0.994	0.149	0.592

Source: the authors.

All the relevant means except for one are far from unity, so the overwhelming majority of the hypotheses are rejected. This means that individual groups of institutes operate on different principles in the sense described earlier in this section. Only the mode of action of a group of institutes of the Polish Academy of Sciences in model 3 (patents) is similar to the theoretical, common technology for all institutes (i.e., the metatechnology). However, there seems little to be gained from this in practice, since the other two groups function differently, also under model 3.

In light of the above, efficiency measures were calculated independently, within separate groups of institutes, thus the number of empirical models used increased to nine[8]. Unfortunately, in each case the fraction of objects with a measure of efficiency greater than two is still substantial. However, the inefficiency for most objects

[8] Within each of the existing models, three "submodels", corresponding to individual groups of institutes, were distinguished.

has decreased[9], which proves that despite everything, the tested heterogeneity of functioning may represent some source of unreliable results, but it is certainly not the only one[10].

5. Discussion and Directions for Further Research

Given the large dispersion and incredibly high measures obtained, the topic of the efficiency of research institutes requires further, in-depth research in order to obtain practically useful results. There can be a number of potential reasons for this state of affairs, and the authors intend to analyse these reasons thoroughly in the future. Here we put them in general terms.

One reason could be that most institutes conduct research and development works aimed at their implementation and practical application on a small scale. This is indicated by the SAO audit from 2020 described in the introduction. It points to a small share of income in this respect in 2018–2019 in the total revenues of institutes. As a result, expenditures in the form of personnel and financial resources translate into effects in the area of R&D to only a small extent.

This represents one of the sources of differentiation in the value of individual inputs and outputs occurring in the group of analysed entities, which is the second, more general reason for the incredibly high measures of efficiency obtained across a number of institutes. Those measures are demonstrated through the selected descriptive statistics (Table 4) calculated within model 1.

Table 4. Selected Descriptive Statistics of Inputs and Outputs for the Entities Analysed in Model 1

Specification	x_1	x_2	x_3	x_4	y_1	y_2
Average	160.71	32.79	4,584.28	28,046.18	10.00	86.51
Standard deviation	149.18	41.31	7,946.77	25,403.05	10.92	83.81
Minimum	27	0	0	456.7	1	1
Maximum	1,019	205	37,611.8	125,738.4	49	443

Source: the authors.

The standard deviation is comparable to, and in some cases even greater than, the mean value. There is also a noticeable differentiation of values for individual

[9] The theoretical properties of the models used imply that the inefficiency of a given object obtained under the "submodel" must not be greater than that obtained under the appropriate model. However, what is important here is that for most entities, their inefficiency is smaller within the "submodel", not just "not less than".

[10] Alternative approaches to the problem of technological heterogeneity can be found in (Cook *et al*. 2013, Kao 2017, Podinovski 2021).

categories when comparing the lowest and the highest figures. It has to be acknowledged that the dispersion of values in models 2 and 3 is even greater, as indicated by the fact that model 1 analyses research units that are part of common groups of objects studied within other models.

This results in the presence of numerous observations that are atypical in terms of the value of inputs and outputs, which later translates into outliers of the measure of efficiency of relevant scientific institutes. A rather natural question thus arises: Is it possible to somehow limit the dispersion of the values of individual categories without compromising the substantive sense of the analysis?

This has already been done partially by eliminating zero output entities from the analysis. Should the same approach be applied to zero values of the second and third inputs, which can also be found in the set of observations under analysis? Or would it be better to aggregate category x_1 with x_2 and x_3 with x_4, creating, respectively, the total staff and financial outlays used in R&D activities[11]?

The third cause for obtaining results with little use may be that not all inputs or outputs related to the operation of scientific institutes have been addressed. This is indicated by the aforementioned zero values of outputs. For instance, one of the institutes has zero value for both outputs in 2019[12]. This raises the question of what its' activities have resulted in. The same could be asked about other institutes with a small or even zero number of patents (y_1) or publications (y_2).

It follows from the conducted literature review that the "product" of the institutes' activities includes, for example, expert evaluations, reports and analyses, which are formally published only to a small extent. Unfortunately, collecting this type of data may not be feasible, and it will certainly be a lengthy process given the limited access to such information.

Here, the number of research projects carried out by research institutes in 2019 may prove to be a "substitute"; it is available in the RAD-on database. The question nonetheless arises as to whether the mere acquisition of a scientific project can already be considered the result of an entity's R&D activity. The authors believe that only the implementation of a scientific project may give rise to the effects of R&D efforts such as an invention, publication or other (the expert evaluations, reports and analyses mentioned above).

Perhaps the source of subsequent financial categories could be financial statements of entities. Parts of these statements are available on the websites of relevant research units, ministries to which these entities are subordinate, or in the *Court and Commercial Review* (*Monitor Sądowy i Gospodarczy*). However, most are not available to the public.

[11] The values of these aggregated outlays would then be positive for all analysed entities.

[12] Therefore, it was not incorporated into the analysis undertaken as part of models 1–3.

Another reason unreliable results are obtained may be that the categories used are incorrectly defined or insufficiently detailed. For example, this study used two inputs representing the labour component, calculated in persons. It seems a much better idea to express these factors in a number of full-time equivalents, since a significant proportion of the employees of research institutes do not work full--time. In this case, the relevant data is available in the aforementioned reports on R&D activities, which represent one of the sources of data in this study.

On the other hand, the number of publications could serve as an example of insufficient detail in a category (y_2). It is possible to break them down into the number of scientific articles, monographs and chapters in a monograph[13].

The fifth reason for obtaining results that are of little use is quite universal – and beyond the control of the authors: errors and, above all, data gaps. Recall that we obtained 129 R&D reports for 203 scientific institutes catalogued in the RAD-on database in 2019. Moreover, it remains unclear whether the newly created RAD-on database contains a complete set of information, for example, regarding publications, whose number accounts for one of the model products. The fact that the study takes into account only a part of PRIs that operate in Poland means that it should be extended to include more in the future.

Due to these shortcomings in the acquired data, the analysis of the efficiency of research institutes was based only on one year. Therefore, in the future efficiency will be estimated and its changes tracked over a longer time interval. The use of data from several years in future research will enable the measurement of both efficiency, using DEA dynamic models, and changes in productivity and efficiency by means of appropriate indices (e.g., Färe-Primont or Hicks-Moorsteen index).

Financial Disclosure

The article presents the results of research project financed with a subsidy granted to the Krakow University of Economics – project no 080/EIE/2022/POT.

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[13] Corresponding data can be found in the RAD-on database.

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