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An Attempt to Estimate the Efficiency of Public Research Institutes in Poland – DEA Approach[3]

Próba oszacowania efektywności publicznych instytutów badawczych w Polsce – podejście DEA

Introduction

Many countries strive for an increasingly complete implementation of an economy based on knowledge and innovation, and corresponding National Innovation Systems (NIS) are designed to serve this purpose. There are three main groups of entities under this system, specifically enterprises, universities and public institutions with the biggest impact on NIS. In Poland, the higher education and science sector is crucial for NIS.

According to the Act on higher education and science (2018), the system of higher education and science is composed of:

1) higher education institutions;
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) 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 on higher education and science in 2018, the activity of universities was very different from that of research institutes. Higher

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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 judged on the basis of points assigned to various types of scientific publications. On the other hand, only recent years have seen an intensified interest of the Ministry of Science and Higher Education in Poland (MSHE) in the transfer of knowledge and technology to the economy. For several years, the MSHE (currently: Ministry of Education and Science) has been setting up various programs and projects to stimulate and encourage universities and institutes to be more active in this field. The natural consequence of the chosen strategy for the development of higher education and science was the assessment of knowledge and technology transfer announced in 2020 by the MSHE, whose first effects were used in the evaluation of scientific activity for 2017-2021.

For years, the Supreme Audit Office (SAO) has been revealing the problems of research institutes in Poland. 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 more recent SAO audit from 2020. It was 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 these 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 (Act of 30 April 2010 on Research Institutes) defines that research institutes are state entities, separated in terms of legal, organizational, economic and financial matters, which conduct scientific research and development activities focused on their implementation and application in practice.

As Mazzoleni and Nelson (2007) rightly points 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, which is the main area of their core operations. In this work we have made an attempt to analyze to what extent the funds allocated to R&D and the professional efforts of R&D personnel translate into specific effects.

The added value of the work is the preliminary attempt to analyze 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.

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). As yet, however, this research was mainly limited to simple comparisons of data or indicators for relevant categories between institutes (Shiu, Wong & Hu 2014). Occasionally, complex analyses were made by means of more sophisticated quantitative methods (Xiong, Yang & Guan 2018). As Suzuki, Tsukada and Goto (2015) and Kang (2021) rightly make clear, PRIs[4] are the least explored element of

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

the NIS. Most attention in the literature has centered around universities, which are a separate component of the NIS e.g. (Wolszczak-Derlacz 2013, Łącka & Brzezicki 2020). This is especially supported by works which present a review of literature in this field (Rhaiem 2017, De Witte & López-Torres 2017, Brzezicki 2020) – definitely more publications in the subject literature are devoted to the activities of universities than that of other entities of the NIS system, including the PRI.

Poland has seen only sporadic analyses of research or scientific units, and even more so, no analysis of the efficiency of research institutes has been carried out to date. The overview of Polish literature shows that the relevant works concerned only the legal and organizational aspects of their functioning (Barcikowska 2016, 2021, Kozłowski 2007, Trzmielak & Krzymianowska-Kozłowska 2020), without empirical analysis of the effects of activities of those entities. In this connection, this literature review centers around foreign research.

Interesting research results were presented by Ko, Kim and Lee (2021) who analyzed the Korean GRI (see footnote 4), representing three types of missions: basic future leading, public infrastructure and industrialization.

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 industrialization than in other types thereof. According to the above study, the mission of a given GRI group affects the results of technology transfer.

In turn, 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” institute is one that publishes mainly the works of the ISI (Institute of Scientific Information), a “humanistic” one publishes primarily books and publications that are in no way tied to the ISI, and a “technological” institute “produces” patent applications (Ortega, López-Romero and Fernández 2011).

In this respect, an interesting study was carried out by Dusdal et al. (2020) who made a comparative analysis of the scientific activity (in terms of scientific publications) of universities and research institutions in Germany. Their research shows that scientific institutes generate more articles in the fields of science, technology, engineering and mathematics, and in of 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" (NIPI-NRI 2019) indicate a somewhat different trend in Poland, as 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), but 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, and the PAS institutes rank merely fourth (1.22).

It is noteworthy that, while in most cases the effects generated by universities can be expressed in terms of value in the form of, for example, students, graduates, publications, patents, etc., 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 of these entities, and therefore these objects cannot be fully analyzed. 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 generalized least squares (GLS) model with fixed effects, Ko, Kim and Lee (2021) – fixed-effects and random-effects models, and Han, Park and Kwak (2021) – multiple panel linear regression model to analyses Korean GFRIs (see footnote 4).

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

The scientific community, PRI managers, as well as NIS politicians and decision-makers, not only want to know what factors affect the results achieved in the field of patent activity and technology transfer (Cheah & Yu 2016), but also what efficiency characterizes a given PRI compared to other similar entities. Therefore, primary sources also include a few studies conducted using the non-parametric DEA method (Appendix 2022), which delivers the opportunities 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 intense relationships with their existing partners. Conversely, too coherent alliances can lead to lock-in relationships that hinder the exploitation of 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 efficiency in the institutes, 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.

An interesting study was conducted by Park and Shin (2018). Unlike other authors, they focused on analyzing 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, duration of an R&D project, number of researchers involved in an R&D project, number of SCI and non-SCI papers, number of granted and applied patents. As the only ones in this area of research, the authors used the metafrontier, calculated on the basis of the classic BCC model, which represents 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 (Appendix 2022), with rare exceptions (Italy, Brazil). Unfortunately, no such analysis has been carried out in Poland to date, although the relevant research units have already been reformed twice. Recent changes were implemented in 2018. Because of it was decided to bridge this research gap by analyzing the efficiency of Polish PRIs after the recent reforms.

Research Methodology

In this paper we decided to 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, in the form of (Tone 2001):

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

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

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

$$\sum_{j=1}^{J}\lambda_{jo} = 1 \quad (4)$$

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

where:

x_{ij} – amount of the i-th input of the j-th object[5],

y_{ro} – amount of the r-th output of the j-th object,

$\lambda_{jo}^{(1)}$, $\lambda_{jo}^{(2)}$ – 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 maximize 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 characterized by a value equal to one. Consequently, the more the measure value is greater than unity, the more inefficient the object.

We also used the metafrontier approach, which serves to analyze technological similarities between k groups of objects (O'Donnell, Rao & Battese 2008). In the first instance, we used the 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. Whereby 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-

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

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[6] 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.

In fact, this approach is used to verify whether a given group of objects is technologically homogeneous[7]. If all group means are close to unity, then this assumption can be considered to be met. 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 review of literature and available data allowed to select the variables (inputs and outputs) used to analyze the efficiency of research institutes. Table 1 presents the empirical models adopted to estimate the efficiency of the studied objects.

Table 1. Empirical models for estimating the efficiency of research institutes

	Designation	**Explanation**	**Entity**	**Model 1**	**Model 2**	**Model 3**
Inputs	x_1	number of researchers and technicians involved in R&D activities	Person	x	x	x
	x_2	other support personnel (e.g., administrative staff)	Person	x	x	x
	x_3	internal funds for R&D activities	Value in PLN (thousand PLN)	x	x	x
	x_4	external funds for R&D activities	Value in PLN (thousand PLN)	x	x	x

[6] Geometric mean was selected due to the multiplicative nature of the metatechnology ratio.
[7] This is one of the basic assumptions in DEA methodology.

Outputs	y_1	total number of patent applications and patents granted	Number	x	x	
	y_2	total number of publications	Number	x		x

Source: own elaboration.

The collected data include a number of zero values, which influenced the method of analysis. In the first instance, the efficiency of R&D activities of research units characterized by non-zero value of both products (Model 1, 63 entities) was examined. Next, to take maximum advantage of the collected data, we analyzed the efficiency of two subsequent groups of institutes, which are characterized 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.

It needs to be stressed that the data also includes zero input values x_2 and x_3 for some entities, which nevertheless have little impact on the analysis due to the adopted output orientation of the model, except for the fact that the optimal value of the appropriate slack for zero input is also zero (Tone 2001, subsec. 6.1).

Data regarding the number of scientific publications was extracted from the RAD-on system (NIPI-NRI 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 have sent relevant data, whereby the most valid and at the same time sufficiently numerous figures related to 2019[8]. Hence, just this year became the period during which the analysis was carried out.

The number of objects that have shared relevant information for 2019 was 129. By comparison, the total number of entities registered in the RAD-on database as research institutes is currently[9] 203. This means that only some institutes from the entire group of those operating in Poland were analyzed. The study excluded institutes for which it was

[8] For reasons of confidentiality, entities were reluctant to provide more actualized figures. However, a small number of institutes also sent their reports for 2020.

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

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 that operate under a different set of standards:

1) scientific institutes of 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).

In this context, one of the objectives of this paper will be to use the metafrontier approach to verify whether these groups of institutes actually function in a different manner in terms of the technology of transforming their specific inputs into their characteristic products[10].

The efficiency of research institutes was measured by means of the free version of MaxDEA[11] and MS Excel software, including the Solver optimization plug-in.

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 were 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

[10] DEA methodology treats the objects under review as specific production entities.
[11] http://maxdea.com/MaxDEA.htm.

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: own elaboration.

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 5 are also efficient under models 2 and 3, and another 5 are efficient for only 1 model. The remaining 9 entities are inefficient under both single-output models; 2 cases concern extreme inefficiency.

It is the opinion of the authors that values of measure no greater than two are useful. It conveys, according to the interpretation of the measure, that 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 (Others).

Table 3 lists the average MTR coefficients for each model in order to verify the hypothesis of the technological homogeneity of the functioning of individual groups of institutes.

Table 3. Average MTRs for models 1-3

	PAN	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: own elaboration.

All the relevant means but one is far from unity, indicating that the overwhelming majority of the hypotheses are rejected. This means that individual groups of institutes operate on different principles in the sense described earlier. 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 so-called metatechnology). However, there seems little to be gained from this in practice, since the other two groups function differently, also under model 3.

In the light of the above, efficiency measures were calculated independently, within separate groups of institutes, thus the number of empirical models used increased to nine[12]. 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 has decreased[13], which proves that despite everything, the tested heterogeneity of functioning may represent some source of unreliable results, but certainly not the only one.

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 analyze these reasons thoroughly in the future. At this point it is worth merely mentioning some of them in general.

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, which points to a small share of income in this respect in 2018-2019 in the total revenues of institutes. As a result,

[12] Within each of the existing models, three "sub-models" were distinguished corresponding to individual groups of institutes.

[13] 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".

expenditures in the form of personnel and financial resources translate into effects in the area of R&D only to a small extent.

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

Table 4. Selected descriptive statistics of inputs and outputs for the entities analyzed in model 1

	x_1	x_2	x_3	x_4	y_1	y_2
Average	160.71	32.79	4584.28	28046.18	10.00	86.51
Standard Deviation	149.18	41.31	7946.77	25403.05	10.92	83.81
Minimum	27	0	0	456.7	1	1
Maximum	1019	205	37611.8	125738.4	49	443

Source: own elaboration.

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 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 that model 1 analyzes research units that are part of common groups of objects studied within other models.

This results in the presence of numerous observations 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 arises: Is it possible to somehow limit the dispersion of the values of individual categories without compromising the substantive sense of the analysis?

It should be made clear that 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 analyzed set of observations? 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[14]?

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

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[15]. This raises the question of what is the result of its activities and possibly 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 due to 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 as the result of the R&D activity of a given entity. 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, e.g., those mentioned in the previous paragraph.

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 Gazette (*Monitor Sądowy i Gospodarczy*). However, most are not available to the public.

Another reason for obtaining unreliable results may be an incorrect definition or insufficient detail of the categories used. For example, this study used two inputs representing the labor 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 can 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[16].

[15] Therefore, it was not incorporated into the analysis undertaken as part of models 1-3.
[16] Corresponding data can be found in the RAD-on database.

The fifth reason for obtaining results that are of little use is quite universal and at the same time beyond the control of the authors. This refers to errors and, above all, data gaps. We should recall that the authors managed to obtain 129 R&D reports for 203 scientific institutes cataloged in the RAD-on database in 2019. Moreover, it is uncertain 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 account of merely a part of PRIs that operate in Poland means that it should be extended to include more in the future.

Due to the aforementioned shortcomings in the acquired data, the analysis of the efficiency of research institutes was based only on one year. Therefore, in the future it is planned to estimate efficiency and its changes 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).

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