

Kinga KARPİŃSKA, PhD

Faculty of Economics and Finance, University of Białystok

e-mail: k.karpinska@uwb.edu.pl

ORCID: 0000-0002-3150-8339

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EFFICIENCY OF R&D EXPENDITURE IN POLAND AND THE OTHER MEMBER COUNTRIES OF THE EUROPEAN UNION: COMPARATIVE ANALYSIS BY THE DEA METHOD¹

Summary

Purpose – Measurement and evaluation of the effectiveness of R&D expenditure in Poland and comparison of this amount to selected European countries.

Research method – The effectiveness of R&D expenditure was measured using the non-parametric DEA (Data Envelopment Analysis) method, which is result-oriented, since the goal of the R&D sector is to maximize the effects. In this paper, a model was created to determine the effectiveness of R&D expenditure in relation to the effects in the form of: the number of scientific publications, the number of patent applications submitted to the EPO and the export of high-tech products per 1 million euros of R&D expenditure.

Results – The overall efficiency index for Poland was 0.6925 and was slightly higher than the average for the countries in the study group (0.682). In the efficiency ranking Poland was ranked 12th. The only country that was fully efficient was Germany. Second place was taken by France (0.815), and third place by Italy (0.7825).

Originality / value / implications / recommendations – The paper presents a comprehensive analysis, evaluation and comparison of the effectiveness of R&D expenditure in Poland in relation to European countries using the DEA method, taking into account three effects, i.e.: the number of publications, the number of patent applications and exports of high-tech products.

Keywords: R&D sector, efficiency, spending on R&D sector, DEA method

JEL Classification: O32

1. Characteristics of the R&D sector in Poland

According to the publication of the Organization for Economic Cooperation and Development (OECD), called the Frascati Manual, the R&D sphere includes “creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to create new applications” [Podręcznik Frascati..., 2006, p. 34].

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The definition given also coincides with the definition in the Oslo Manual, which was developed in collaboration between the OECD and Eurostat, and which deals with the measurement of scientific, technical and innovative activities [*Podręcznik Oslo...*, 2006, p. 96].

All individuals and institutions undertaking activities aimed at increasing the stock of knowledge, as well as finding its practical application, form the so-called research and development sector [Piotrowska, Roszkowska, 2014, p. 154].

R&D activities include [Francik, Poczowski, 1991, pp. 12-15]:

- Basic research – finding new regularities, focused on general relationships, most often these are new theories and laws in science. This research is usually not aimed at practical value, its purpose is to expand knowledge in a given field. It can take the form of free research (no relation to its usefulness, topics are self-defined by researchers) and directed research (commissioned by various institutions on a specific topic). The research area is usually wide, covering general social problems.
- Applied research – usually the results of the work of basic research are used, therefore the scope of problems is much narrower than in the case of basic research. This research is focused on solving specific problems and regularities. Its purpose is usually to create new solutions, inventions, etc.
- Development work – application of previously acquired knowledge to the production of specific products, materials, systems, technologies or services. Usually it is a continuation of applied research. Its purpose is to verify in practice the results obtained at an earlier stage.

To qualify as research and development, an activity must be novel, creative, unpredictable, methodical, and transferable or reproducible [*Podręcznik Frascati...*, 2006, p. 47].

Referring to the methodology presented in the Frascati Manual, for the purpose of measuring R&D activity the classification of sectors is used, according to which the following are distinguished [*Podręcznik Frascati...*, 2006, p. 31]:

- corporate sector;
- government sector;
- higher education sector;
- private nonprofit sector;
- abroad.

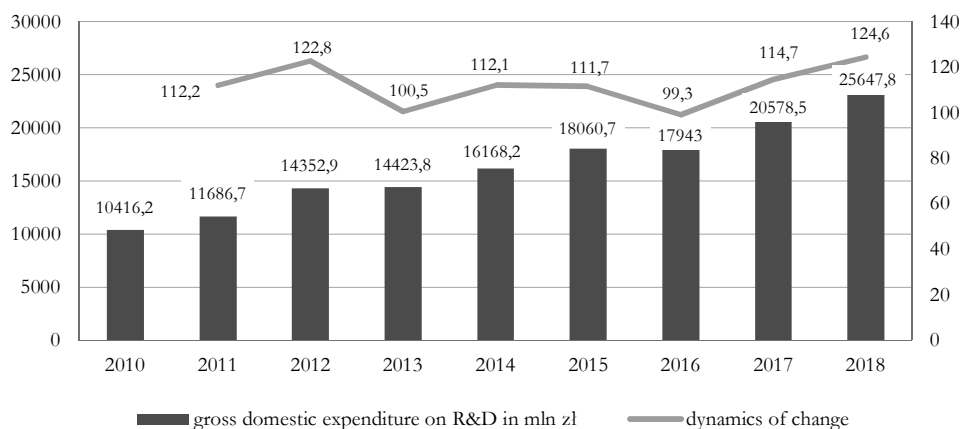
The first four are included in the analysis of R&D expenditure by the executive sector. The “foreign” sector, on the other hand, is included in the compilations conducted due to the sector financing R&D activity. The basic measure of R&D expenditure is the gross domestic expenditure on R&D (GERD) which is the amount of total gross domestic expenditure on R&D performed in the territory of a given country in a given reporting period. Gross domestic expenditure on R&D may be current or capital expenditure [*Podręcznik Frascati...*, 2006, p. 121, 416].

Interest in R&D and, more broadly, in innovative activities is motivated by their significance, which, as the results of research indicate, is expressed in many dimensions. In particular, it is noted that innovation drives economic growth, employment

and income growth, contributes to improving the quality of life and competitiveness of nations [Atkinson, Ezell, 2014, p. 130]. Innovation activities have a measurable impact on the functioning of enterprises. In this context, it has been, *inter alia*, argued that innovation has a positive impact on the survival probability of firms [Cefis, Marsili, 2006], R&D intensity significantly increases firms' profitability in the future [Grabińska, Grabiński, 2018, pp. 58-59], and firms engaged in R&D have higher productivity growth than non-innovators [Medda, Piga, 2014, pp. 428-429].

CHART 1.

Gross domestic expenditure on R&D (GERD) in millions of PLN (current prices) and its dynamics (previous year = 100) from 2010 to 2018



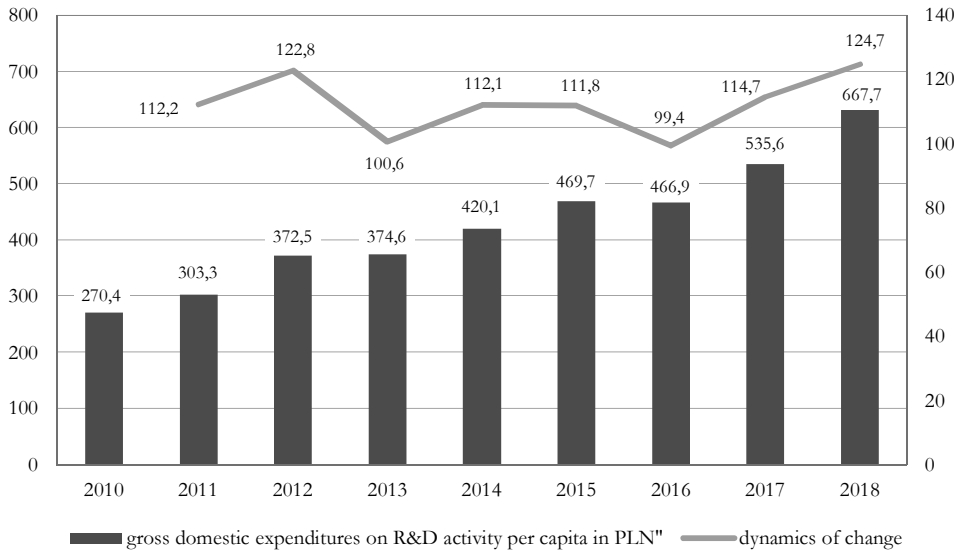
Source: own elaboration based on: [www 1].

Between 2010 and 2018, gross domestic expenditure on R&D in Poland increased almost 2.5 times – from PLN 10.4 billion to PLN 25.6 billion (current prices), as shown in chart 1. With the exception of 2016, when a decrease in gross domestic expenditure on R&D was recorded in relation to the previous year (-0.7%), in all analyzed years its value increased year-on-year. The year 2018 turned out to be record-breaking in this respect, bringing an increase in the expenditure in question by approx. $\frac{1}{4}$ compared to the previous year, which was dictated primarily by a significant increase in gross domestic expenditure on R&D in the business enterprise sector (BERD) – an increase by PLN 3.7 billion; or by 27.7%. At the same time, the expenditure on R&D of the higher education sector increased by 20.1%, of the government sector – by 6%, and of the private non-commercial institutions – by 7.4%.

As a consequence of the increase in gross domestic expenditure on R&D activity, its value per capita also increased – from 270.4 PLN in 2010 to 667.7 PLN in 2018. Due to the low dynamics of changes in the number of inhabitants in Poland, the dynamics of gross domestic expenditure on R&D activity per capita was similar to the value of gross domestic expenditure on R&D activity (chart 2).

CHART 2.

**Gross domestic expenditure on R&D activity per capita in PLN
and their dynamics (previous year = 100) in 2010-2018**



Source: own elaboration based on: [www 1].

As a starting point for comparative analyses of EU countries in terms of their R&D activity, the absolute level of R&D expenditure was taken. Although this level is undoubtedly an insufficient measure to formulate final conclusions of the study, it seems that this approach should not be completely depreciated. It is noted that the analysis of the absolute level of R&D expenditure is important because it allows for assessment of the contribution of a given country to the scientific and technological progress in the world [*Science, technology...*, 2000, p. 28].

The analysis of the structure of R&D expenditure in the EU across countries shows significant disparities in the shares recorded by them. According to the data for 2018, more than half of the total R&D expenditure incurred by EU countries were the shares of three of them – Germany, France and the UK, with Germany alone generating more than 30% of this amount. In the case of half of the Member States, the considered share did not exceed 1%. For Poland it amounted to 1.8%, ranking 12th in terms of the contribution of total R&D expenditure at the EU level [www 2].

The sensitivity of R&D expenditure to the size of the economy makes the R&D intensity indicator a commonly used measure in comparative analyses. Analysis of data from 2010-2018 clearly exposes the differences between EU Member States in their R&D activity measured by the R&D intensity ratio. The average value of the indicator in the period under consideration ranged from 0.47% for Romania to 3.24% for Sweden. High variation is also indicated by the value of the coefficient of

variation, exceeding in all analysed years the level of 50%. The analysis of the distribution of the R&D intensity index also shows that in the whole period under consideration, most countries scored below the average. This was also the case for Poland [www 2].

Comparing Member States in terms of R&D intensity, one can see differences between the countries of the so-called old (EU-15) and new Union (EU-13) – the highest positions in the ranking belong to the countries forming the EU before the accession of new members in 2004, while the ranking is closed by the countries joining the Union since 2004. The comparison of the average values of the R&D intensity indicator in these groups for 2018 shows that the EU-15 countries allocated on average twice as much funds in relation to GDP to R&D activities as the EU-13 countries (2.12% against 1.05%). In addition, taking into account the level of GDP per capita in the analysis, for 2018 data, we can see a clear positive relationship between the wealth of a country and R&D intensity [www 2].

2. DEA method

An important element of R&D activity is the measurement of effectiveness. In literature, effectiveness is defined in various and multiple ways. From the point of view of economics, this concept is related to the problem of limitation of resources and unlimited needs. Nordhaus and Samuelson defined efficiency as “one of the main objects, and perhaps even the main object of interest in economics” [Nordhaus, Samuelson, 1995, p. 60].

Efficiency was researched by, among others, Farrell, who defined efficiency as the ratio of effect to input and determined the so-called border efficiency curve, which indicates those objects in a given set that are characterized by the highest effect-input ratio [Farrell, 1957, pp. 253-261].

In this article, the concept presented is a point for defining efficiency. That is, the concept is understood as the relationship between the effects obtained and the expenses incurred. Efficiency defined in this way can be increased in three ways [Ziolo, 2012, p. 140]:

1. by minimizing inputs with fixed outputs;
2. by maximizing effects with fixed inputs;
3. by changing both variables, but in favor of the ratio of effects to inputs.

Performance testing methods are divided into three groups: indicative, parametric and non-parametric [Kosmaczewska, 2011, p. 132].

In the ratio approach, financial ratios become the methods of measuring organizational performance. Most often, organizations analyze indicators of profitability, liquidity, turnover, or debt. The calculated indicators become the basis for comparisons over time (values achieved in subsequent reporting periods) and comparisons between organizations, e.g. with organizations operating in the same industry or with benchmark values. The main limitation of this type of analysis, apart from the fact that it is a static study (i.e. the data presented concern a selected, given period,

e.g. the end of the reporting year), is that it does not allow one-time consideration of many dimensions of the organization's activities [Mielnik, Szambelańczyk, 2006, pp. 5-6].

In addition to simple financial indicators, there are also statistical methods based on an identified functional relationship, these are called parametric methods. They are applied to models with a well-defined structure that needs to be identified. The parametric methods require making assumptions about the form of the production function. This function defines the relationship between inputs and outputs. It gives an answer to the question what maximum output can be obtained with given inputs [Ćwiakala-Malys, Nowak, 2009, p. 6].

In addition to parametric methods, so-called non-parametric methods are also used in organizations. Efficiency in non-parametric methods is defined as the ratio of actual productivity to the highest possible productivity [Helta, 2009, p. 108; Kao et al., 2011, p. 310].

One of the most important nonparametric methods is the Data Envelopment Analysis method. This method was first presented by Charnes, Cooper and Rhodes in 1978. Using linear programming, they developed the first CCR model (an abbreviation of the first letters of the authors' surnames), in which they assumed fixed effects of the scale. Other models were developed over time, but all were modifications of the CCR model. The second most widely used model is the BCC (an abbreviation of the first letters of the names of its creators: Banker, Charnes and Cooper (1984). The difference between CCR and BCC models concerns scale effects: the former assumes fixed scale effects, while the latter allows for the determination of scale efficiency. Basic DEA models can occur as input-oriented – the assumption of minimization of inputs with a lower bound on the size of results, or as output-oriented – the assumption of maximization of results with an upper bound on the size of inputs [Guzik, 2009, pp. 55-65].

The main assumption of this method is therefore based on Farrell's definition of productivity. In this model, efficiency is defined as [Baran et al., 2015, p. 173]:

$$efficiency\ index = \frac{\sum_j^J \mu_j y_j}{\sum_i^I v_i x_i}$$

where:

J – number of results;

I – number of inputs;

μ_j – weight of the j -th result;

v_i – weights of the j -th inputs;

y_j – the size of the j -th result;

x_i – the size of the j -th inputs.

The DEA method allows the study of the relationship between the level of multiple inputs and multiple effects. In the DEA model, I inputs and J different effects are reduced to single quantities of “synthetic” input and “synthetic” effect, which

are then used in the calculation of a facility performance index [Roll, Hayuth, 1993, pp. 154-156]. In linear programming, this indicator is a function of the objective. In the DEA method, two variants of the objective function can be distinguished: maximization of effects for given inputs or minimization of inputs for given effects [Cooper et al., 2007, p. 70].

The optimized variables are the coefficients, which are the weights of the effect and input quantities, and the effect and input quantities are empirical data [Cooper et al., 2007, pp. 72-75]. The constraint assumes that the quotient of the synthetic effect and the synthetic input is to be less than or equal to unity; without this constraint the task would have infinitely many solutions. The weights of the inputs and effects are set to maximize the above ratio of effects to inputs, and their magnitudes can be equal to or greater than zero. The solution of the objective function by means of linear programming allows to determine the efficiency curve, on which all the most efficient units of the studied community are located.

In the DEA method, the so-called Decision Making Units (DMUs) are taken as the objects of analysis. The relative productivity of a decision making unit in the DEA method is defined on the basis of performance, determined by the relationships between input and output variables in the analyzed units. The efficient units form a benchmark level of efficiency [Cooper et al., 2000, p. 67].

The DEA method is based on the concept of best practice frontier efficiency, which assumes that all units should be able to operate at a given level of productivity, as determined by the efficient units operating in the sector [Nazarko, Chrabolowska, 2005, pp. 38-47]. Units performing below the borderline level of productivity operate inefficiently. The extent of improvement in their efficiency is determined by relating their performance to that of efficient units [Nazarko et al., 2008, pp. 34-43].

The DEA method, as a non-parametric method, does not also require knowledge of the functional relationship between inputs and outputs. The efficiency curve is estimated on the basis of empirical data on the amount of inputs and effects [Thanassoulis, 2003, p. 12].

In studies that attempted to compare the efficiency at the international level, two methods were most often used: parametric SFA (Stochastic Frontier Analysis) and non-parametric DEA (Data Envelopment Analysis). However, the DEA method was more often used to compare the effectiveness of R&D expenditure between countries. Therefore, the measurement and evaluation of the effectiveness of R&D expenditure have been carried out using this method.

One of the first applications of this method for studying the effectiveness of R&D expenditures was a study conducted by Rousseau and Rousseau. In their study, they attempted to examine the relative efficiency of three inputs (GDP value, expenditure on R&D, and the number of economically active people) and two outputs (number of scientific publications and the number of patents) [Rousseau, Rousseau, 1997, pp. 45-53]. On the other hand, Kocher, Luptacik and Sutter [2006, pp. 314-321] used R&D expenditures, number of universities with economics departments and population size as input variables, while they included as outputs:

the number of publications in ten economics journals with the highest impact factor. Other authors, Lee and Park [2005, pp. 210-217] used two variables as inputs: R&D personnel and R&D expenditures, in turn, the effects were the number of scientific publications, the number of patents, and the balance of payments revenues in technology. In the next presented models (Wang and Huang; Sharma and Thomas; Fu and Yang; Thomas, Jain and Sharma; Usai, Dettori and Gagliardini) usually the number of scientific publications and the number of patents were taken into account as outcome variables, while they differed in the variables used as inputs. In the case of Wang and Huang [2007, pp. 265-270] R&D personnel and accumulated R&D capital were used as variables, while Sharma and Thomas [2008, pp. 483-490] used as many as four variables: R&D personnel, R&D expenditure, population size, and GDP; Fu and Yang [2009, pp. 1207-1213] used as variables: R&D personnel, R&D expenditure and education expenditure, while Thomas, Jain and Sharma [2009, pp. 3-4] used the variables: R&D personnel and R&D expenditure, and the last mentioned authors only R&D expenditure [Usai et al., 2013, pp. 3-10].

Findings indicate that there is no universal set of variables included in inputs and outputs. Their selection is often limited by the availability of data and results from the experience of previous studies. Among inputs, R&D expenditures are the most frequently used. On the other hand, the measures included in the results include: the number of scientific publications and the number of patents.

In this article, effectiveness was examined by comparing expenditure with the direct effects of R&D activity (the number of scientific publications and the number of patents) and the broader effects of R&D investment on the economy (the export of high-tech products). This approach allowed both to identify direct links between R&D expenditures and their effects, and at the same time to take into account the importance of the ability to transform the results of R&D into practical activities, which are so important for the innovation of countries.

Testing the effectiveness of R&D spending using the DEA method requires making the following decisions:

- a) selection of study objects;
- b) selecting the number of models and measures representing inputs and outputs;
- c) determination of the time scope of the study;
- d) selection of the orientation of the models and determination of the approach to scale effects.

The study used a maximization-focused DEA model because the key objective of the R&D sector is to achieve the best possible results rather than to minimize inputs. Consequently, the effects-focused model fits better the specifics of the R&D sector. The model also assumes fixed scale effects because the selected sample of 29 European countries is characterized by not a large number of facilities, compared to that which could be used with variable scale effects.

In this paper, a model of the effectiveness of total expenditure on R&D was created, in which expenditure is treated as an input, and the number of scientific publications, the number of patent applications to the EPO (European Patent

Office) and exports of high technology products (technology transfer from research to production) as output. The model refers both to scientific results of R&D activity (scientific publications), inventive results (patents) and effectiveness of converting direct results of R&D activity into broader economic effects. Focusing only on one result, e.g. patents, leads to the narrowing of the field of research, as other objectives of individual R&D activities are not taken into consideration.

It is known that there is a debate in the world literature on the representativeness of the variables adopted. On one hand, the way to measure the scientific result on the basis of publications is a part of a wide debate, in addition, the citability of publications is often criticized by the scientific community. The second issue also concerns patenting. On one hand, it is emphasized that the number of patents perfectly reflects the practical outcome of R&D activity, but some entities use completely different business patents to secure knowledge, apart from patents. The same is true for the third variable, exports of high technology products, which is characterized by low variability over time. Awareness of these drawbacks is important, but the author feels that they are not sufficient to abandon the adopted variables.

The article also takes into account the time shifts that occur between expenditure on R&D and the achieved results. Therefore, it was assumed (based on the literature analysis) that the optimal time of this shift was 2 years and the time range of the study covered the years 2005-2016 (2005-2007; 2008-2010; 2011-2013; 2014-2016) for inputs and 2007-2018 for outputs (2007-2009; 2010-2012; 2013-2015; 2016-2018).

The Efficiency Measurement System (EMS) program was used to process the research material and to calculate the efficiency indicators. In order to verify the results obtained, the calculation procedure was also carried out in the DEA Solver Pro program, in which similar results were obtained.

3. Test results

Table 1 presents the results of applying the DEA method to examine the efficiency of R&D spending in the adopted model. Countries are ranked in descending order of overall efficiency index.

In each of the four analyzed periods, only one country in the study group proved to be fully effective: Germany. This country is characterised by a relatively high level of R&D expenditure in GDP (higher than the EU average), but also stands out in terms of the number of patent applications to the EPO per 1 million euro of R&D expenditure, and a relatively good level of exports of high-tech products. It should also be noted that Germany achieved average results in terms of the number of scientific publications per 1 million euro of R&D expenditure in the years covered by the study.

TABLE 1

Performance indicators of the studied countries

Country	Efficiency index				Overall efficiency index	Ranking
	Period I	Period II	Period III	Period IV		
Germany	1.00	1.00	1.00	1.00	1.00	1
France	0.81	0.79	0.8	0.86	0.815	2
Italy	0.81	0.81	0.75	0.76	0.7825	3
United Kingdom	0.79	0.71	0.79	0.79	0.77	4
Netherlands	0.75	0.78	0.71	0.8	0.76	5
Cyprus	0.66	0.7	0.8	0.75	0.7275	6
Denmark	0.7	0.6	0.8	0.8	0.725	7
Norway	0.69	0.69	0.74	0.75	0.7175	8
Sweden	0.65	0.72	0.72	0.77	0.715	9
Austria	0.69	0.7	0.7	0.76	0.7125	10
Malta	0.7	0.68	0.7	0.75	0.7075	11
Spain	0.69	0.66	0.75	0.73	0.7075	11
Romania	0.69	0.66	0.75	0.73	0.7075	11
Belgium	0.69	0.75	0.66	0.73	0.7075	11
Poland	0.76	0.65	0.66	0.7	0.6925	15
Hungary	0.67	0.69	0.7	0.7	0.69	16
Finland	0.7	0.65	0.65	0.72	0.68	17
Czech Republic	0.7	0.65	0.65	0.72	0.68	17
Bulgaria	0.65	0.65	0.72	0.7	0.68	17
Portugal	0.65	0.65	0.69	0.7	0.6725	20
Greece	0.63	0.67	0.7	0.7	0.675	21
Ireland	0.63	0.67	0.7	0.7	0.675	21
Slovakia	0.66	0.65	0.67	0.7	0.67	23
Latvia	0.7	0.62	0.6	0.72	0.66	24
Slovenia	0.65	0.62	0.67	0.7	0.66	24
Croatia	0.62	0.65	0.67	0.7	0.66	24
Lithuania	0.5	0.42	0.6	0.5	0.505	27
Estonia	0.5	0.44	0.5	0.52	0.49	28
Luxembourg	0.5	0.4	0.44	0.46	0.45	29

Source: own elaboration based on: [www 2].

France was ranked second. Its high score is mainly due to intensive patenting activity, despite the moderate level (compared to the surveyed group) of R&D expenditure. The same is the case with Italy, which ranked third.

Countries with relatively high efficiency (overall efficiency index above 0.75) also include Great Britain and the Netherlands. In the case of these two countries, we can observe a moderate level (in comparison with the surveyed group) of R&D expenditure, but at the same time relatively better results in the number of patents in the case of Great Britain, and exports of high-tech products in the case of the Netherlands.

An interesting case in the group of countries with high efficiency is Cyprus, which is characterised by a low level of expenditure on R&D, but at the same time has the highest number of scientific publications per 1 million euro of expenditure on R&D in the EU in all four analysed periods.

Negatively, three countries in particular stand out from the group (overall efficiency indicator at the level of 0.5 or less): Lithuania, Estonia and Luxembourg. In the case of Lithuania and Estonia one can observe a low level of R&D expenditure and the achieved effects (the number of publications, the number of patent applications and exports of high-tech products) are far below the average of the examined group. On the other hand, in Luxembourg high R&D expenditure can be observed, but very low effects in all three analysed areas.

Poland can be characterized as average in comparison to the other countries in the group. The overall efficiency index in Poland amounted to 0.6925, and was slightly higher than the average for the countries in the surveyed group (0.682). In the efficiency ranking, Poland was ranked 15th. In the analyzed period, Poland was characterized by a relatively low level of R&D expenditure in each analyzed period in comparison with the average of the examined group of countries, as well as in the case of all analyzed effects. Compared to the average of the group, Poland achieves the worst result in the number of patent applications filed (on average of only 30% of applications compared to the average of the group of the examined countries). Undoubtedly, this is one of the key factors that definitely lowers Poland's effectiveness in the European context.

Table 2 shows the characteristics of the performance indicators.

TABLE 2

Synthetic characteristics of efficiency indicators

Characteristics	Period I	Period II	Period III	Period IV	Overall efficiency index
mean	0.684138	0.666552	0.699655	0.721379	0.681964
standard deviation	0.098544	0.114807	0.099408	0.100702	0.080601
coefficient of variation (%)	14%	17%	14%	14%	12%

Source: own elaboration based on data from table 1.

The overall efficiency index was 0.682, which means that most of the analyzed countries (16 out of 29) scored better than the average. The average of efficiency

ratios in the studied group of countries was 0.684 in the 1st period, 0.667 in the 2nd period, 0.7 in the 3rd period and 0.721 in the last period. On the other hand, observing the values of the coefficient of variation, it can be concluded that the studied group of countries in terms of efficiency of R&D expenditures is not strongly differentiated, as the values of this variable are within 12-17%.

4. Conclusions

The analysis of the results obtained for Poland indicates a significant progress in R&D activity in Poland in the period in question, expressed in a significant increase in gross domestic expenditure on this activity. However, a comparison of Poland's results with those of other EU countries clearly shows the distance between Poland and R&D leaders in the EU. It is worth noting that in the entire analysed period, Poland recorded a value of the R&D intensity indicator below the EU average. Also in terms of expenditure on R&D activity, Poland occupied distant positions among the EU countries

The analysis shows a high variation in the effectiveness of R&D spending in European countries.

The application of the DEA method allowed to determine the effectiveness of R&D expenditure in Poland in comparison with European countries. On the basis of the obtained results, it can be unequivocally stated that only one country in the analysed period is fully effective: Germany. However, there are also several countries with relatively high efficiency, i.e. Great Britain, the Netherlands or France. The countries of Central and Eastern Europe generally obtained worse results, including Poland. In the efficiency ranking Poland was ranked 12th. This is primarily due to the low level of R&D expenditure in each analyzed period, as compared to the average of the studied group of countries. Moreover, in comparison with the group average, Poland achieves the worst result in the number of patent applications filed. Undoubtedly, this is one of the key factors that definitely lowers Poland's effectiveness in the European context.

However, it should be emphasized that Poland achieved an average level of efficiency. During the examined period, many European countries showed much worse results (overall efficiency index of 0.5 or less), e.g. Lithuania, Estonia and Luxembourg.

It should be emphasized that in the presented study there are some limitations associated with the use of the DEA method. Namely, the mentioned method allows taking into account many variables, while in the study a rather modest range of empirical material was taken into account in terms of the number of variables considered. As a result, the main advantage of the DEA method, which is the study of efficiency taking into account many inputs and many outputs, was used to a limited extent. One should also remember about the limitations of the DEA method, such as: high sensitivity of results to erroneous or untypical data in objects considered as efficient, a relative character of object efficiency, sensitivity to the

number of inputs and effects taken into account (the higher the number of variables, the higher the possibility of finding oneself on the borderline of inefficient unit in reality). Thus, it is advisable to continue research on the effectiveness of R&D expenditures, e.g., using other methods, although it is not easy, as there are no universally recognized measures/variables that allow to unambiguously determine such effectiveness.

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