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Efficiency of the R&D sector in the EU states.
Does the source of funds matter?

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ABSTRACT

The first aim of this study was to measure the efficiency of the R&D sector in the EU countries. The findings have indicated that the sector's efficiency was different in particular countries. It was more than three times higher in the most efficient states than in the least efficient ones. The results also indicate that decreasing returns to scale are characteristic in the R&D sector in the EU countries. The second aim was to examine the relationship between the efficiency of the R&D sector and the structure of its financing. The empirical results occurred to be consistent with the research hypotheses – the public sector's share in the R&D financing structure affects the efficiency of the R&D sector positively, while the private sector's share affects it negatively.

Keywords: R&D sector, R&D financing, R&D efficiency, R&D financing structure, EU countries.

1. Introduction

The neoclassical theory of economic growth presented technical progress as a major source of long-term growth (Solow, 1957). However, it treated it as an exogenous phenomenon and did not identify or analyze its determinants. A few decades later, the endogenous theory of economic growth has linked the technical progress with the research and development (R&D) activity in the economy (Lucas, 1988; Romer, 1986, 1990). Since then, the role of the R&D sector in economic theory has been growing. It has been found that R&D sector's activity, understood as innovations, diffuses to various sectors and countries increasing productivity in particular enterprises and driving the global economy (Baumol, 2002; Keller, 2002).

Most economists agree that ownership and sources of financing affect the efficiency of economic activities. However, there is no wide agreement about the nature of this relationship. Similarly, in the case of the R&D sector, there are no clear results concerning the influence of the source of funds and the sector's efficiency.

This article has two goals. The first is to estimate the efficiency of the R&D sector in the European Union states, where by the R&D sector we understand all persons and institutions working in order to create a new knowledge or to find a new application for existing knowledge. The next objective is to investigate the relationship between the R&D financing structure and its efficiency. The study is conducted for the years 2006-2015.

The DEA method was used in the study to measure the efficiency of the R&D sector in the EU countries. Expenditure on R&D was an input variable. The Hirsch index, grants awarded by the European Research Council and the share of export of high technologies in total export were used as outputs. In the next step, the correlation between the efficiency of the R&D sector and the public and private sectors' share in its financing was measured.

The structure of the article is as follows. In the second part, literature on the influence of the source of funds on the R&D sector's efficiency is discussed. In the third section, the

research method is presented. The next section shows the results of the research. The last part concludes the paper.

2. Literature review

Some authors indicate that public spending on R&D is less efficient than private spending. This statement is confirmed by a part of empirical studies conducted in recent years. Wang (2007) has measured R&D efficiency using stochastic frontier analysis. He found that the involvement of the public sector is a negative factor affecting R&D efficiency and argued that this is due to the bureaucracy, which makes the public sector less efficient than the private one. Guan and Yam (2015) examined the impact of government innovation programs on innovation activity in the private sector and found that this influence is negative. However, the authors noted that the results should be treated with caution, because this dependency was statistically significant only in part of the cases examined.

Conversely, there are findings which indicate that public sector's involvement in the R&D sector affects the R&D efficiency positively. Guellec and Van Pottelsberghe de la Pottrie (2004) examined the impact of public and private spending on R&D on the level of productivity in the economy. The authors argued that the government's R&D programs fulfil a public mission, providing basic knowledge which does not increase productivity directly but might be used as a base for further innovations. Private financing usually focuses on applied research. The authors have found that an individual firm's returns on this applied research are usually lower than social returns on the public sector's research. In a similar fashion, Lee (2017) estimated the efficiency of the R&D sector using the Tobin model and found that the public sector's share influences the R&D efficiency positively. He stated that the private sector, in contrast to the public sector, focuses on the commercial performance. Thus, the private research mostly is aimed at industry specific technology. Public research provides basic technology, which is available for use in all industries.

Other authors found that particular countries differ in the level of the R&D sector's efficiency and that this sector is generally faced with decreasing returns to scale (Wang and Huang, 2007; Sharma and Thomas, 2008). However, the results also did not allow drawing clear conclusions on the impact of the financing structure on the sector's efficiency.

The ambiguity of the previous findings is an incentive to further research in this field. The presented statements allow conjecturing that public research also affects the private sector's research positively. It is confirmed by Ali-Yrkkö (2004), who found that public spending on R&D drives the private research. Similarly, David, Hall and Toll (2000) implied that knowledge provided by government research is available for private firms. Government agencies, public institutes and national laboratories also increase research capabilities in the whole economy. These considerations allow formulating the following research hypotheses:
- (H1) The amount of the public sector's shares in the R&D financing structure influences the R&D sector efficiency positively.
- (H2) The amount of the private sector's share in the R&D financing structure influences the R&D sector's efficiency negatively.

3. Research method

The first step of the empirical analysis was to measure the efficiency of the R&D sector using the DEA method. DEA is a method of measuring technical efficiency, defined as a quotient of weighted sum of the outputs by weighted sum of inputs. This method is based on the formulation of the decision-making mechanism with weights as decision variables. The advantage of that method is that it allows measuring efficiency using a variety of variable inputs and outputs. DEA measures relative efficiency. It means that the most efficient object is understood as being 100% efficient and efficiency of others is defined in relation to it (Domagała, 2007).

A mathematical formulation of the basic DEA model is presented by the equation:

$$\theta_O = \sum_{r=1}^{S} u_{ro} y_{ro} \Big/ \sum_{i=1}^{M} v_{io} x_{io}, \qquad (1)$$

where: θ_O – efficiency of the O-th object, u_{ro} – weight of the r-th output variable in the O-th object, y_{ro} – value of the r-th output variable in the O-th object, v_{io} – weight of the i-th input variable in the O-th object, x_{io} – value of the i-th input variable in the O-th object.

Two DEA models have been used in the study. The first one was the basic model that assumes constant returns scale. This model is based on the transformation of the equation (1) into a linear form in the following way (Domagała, 2009):

$$t \sum_{i=1}^{M} v_{io} x_{io} = 1, \tag{2}$$

where: t > 0. Multiplying the numerator and the denominator of the equation (1) by t, we can use the following transformation:

$$\begin{aligned} \mu_{ro,} &= t u_{ro}, r = 1, \dots, s \\ V_{io,} &= t v_{io}, i = 1, \dots, m \end{aligned} \tag{3}$$

This allows us to formulate the following decision-making task:

$$max\theta_O = \sum_{r=1}^{S} \mu_{ro} y_{ro}, \tag{4}$$

with limitations:

$$\begin{aligned} \sum_{i=1}^{M} V_{io} x_{io} &= 1, \\ \sum_{r=1}^{S} \mu_{ro} y_{ro} - \sum_{i=1}^{M} V_{io} x_{io} &\leq 0, \\ v_{io}, \mu_{ro} &> 0. \end{aligned} \tag{5}$$

In addition, an extended version of the model which allows analysing the returns to scale was used. The additional decision variable λ, the so-called intensity weight is included in this model. The decision-making task is to find the minimum efficiency of the O-th $min\theta_{BCC,O}$ object with the following limitations:

$$\begin{aligned} \theta_{BCC,O} x_{io} &\geq \sum_{j=1}^{n} x_{ij} \lambda_{jo}, \\ y_{ro} &\leq \sum_{i=1}^{M} y_{rj} \lambda_{jo}, \\ \sum_{i=1}^{M} \lambda_{jo} &= 1, \\ \lambda_{jo} &> 0. \end{aligned} \tag{6}$$

This formulation transforms a simple linear model into a nonlinear form. Therefore, it relaxes the assumption of constant returns to scale and allows also variable returns to scale to occur in the model.

However, if we are analysing research and development expenditures, the assumption of variable returns to scale seems to be more intuitive. Previous studies on the efficiency of the R&D sector using the DEA method also confirm this assumption (Wang and Huang, 2007; Sharma and Thomas, 2008).

The European Union is an interesting region to undertake such research. Most of the discussed findings indicate that the R&D sector's ef-ficiency depends mostly of the public sector's involvement. An average public sector's share in R&D financing in the EU states in the analysed period was relatively high – it was 33.2%. However, an average private sector's share in the R&D financing was even higher – 54.9%. Secondly, the R&D financing structures in the EU states are different. In 16 states, private sector's expenditure is predominant, and in 12 states public sector's share is prevailing. Thus, the analysis of the R&D efficiency in the European Union states should provide reliable conclusions.

Initially, six variables were used in the research. The R&D expenditure (measured as a percentage of GDP) and the R&D sector personnel (measured as a percentage of the total employed in the country) were used as input variables. The following variables were used as outputs: high-tech export as a percentage of total export, the Hirsch index estimated for a particular state (excluding publications in the humanities and social sciences, because their influence on the innovations is controversial), grants in science and technical studies funded by the European Research Council (ERC) – as a percentage of the accepted submissions, and the amount of patents registered per GDP.

However, a limitation of the DEA method is that when too many variables relative to the number of examined objects are used, it causes the method to lose its discriminatory power. This leads to redundancy of the effective objects, especially if these variables are strongly correlated (Domagała, 2014). That effect was also found in this research which forced us to reject a part of the variables. Thus, the R&D personnel and registered patents have been rejected because they were most strongly correlated with other variables. Therefore, the following variables were finally used in the study: expenditure on R&D (including all sources of funds), high-tech export, the Hirsch index and ERC grants. The empirical analysis was conducted for the years 2006-2015 (with the exception of the ERC grants, where it was possible to collect the data only for the period of 2007-2013). The average values of the variables during the analysed period were used in the estimations.

As the last step, the correlation between the estimated R&D efficiency and the public and private sectors' share in the R&D financing, measured as a percentage of the total expenditure, was estimated. Although the correlation analysis does not allow revealing the underlying cause and effect relationship, it allows identifying common cross-country tendencies, which can be the subject of a more detailed future research.

4. Results and discussion

The results for both types of DEA models (with and without constant returns to scale) are presented in Table 1. The model that assumes constant returns to scale indicates that in six countries the R&D sector can be considered as efficient: Cyprus, Italy, Latvia, Malta, the Netherlands and Spain. The average efficiency of the R&D sector in the EU countries was 66.98%. The least efficient was Estonia, Finland and Slovenia, with efficiency below 30%. When the assumption concerning the variable returns to scale was taken into account, it has occurred that the average R&D efficiency equals 72.51%. It is higher than with constant returns to scale, which indicates that returns to scale in the R&D sector in the European Union are decreasing. This is consistent with the results of the previous studies. What is more, besides the countries that were found efficient in the previous model (Cyprus, Italy, Latvia, Malta, the Netherlands and Spain), four more countries (France, Greece, Romania and the United Kingdom) occurred to be 100% efficient in the new estimates. Similar to the previous model, the least efficient are once more Estonia, Finland and Slovenia.

Table 1: Estimated efficiency of the R&D sector in the EU states in the years 2006-2015

Country	Efficiency – constant returns to scale	Efficiency – variable returns to scale
Austria	44.30%	44.66%
Belgium	61.54%	62.36%
Bulgaria	57.42%	79.27%
Croatia	49.03%	59.42%
Cyprus	100.00%	100.00%
Czech Republic	43.93%	45.35%
Denmark	46.75%	47.08%
Estonia	27.63%	29.86%
Finland	25.47%	25.54%
France	90.97%	100.00%
Germany	72.12%	81.84%
Greece	95.18%	100.00%
Hungary	83.17%	95.41%
Ireland	61.59%	72.85%
Italy	100.00%	100.0%
Latvia	100.00%	100.00%
Lithuania	35.68%	50.34%
Luxembourg	43.58%	45.53%
Malta	100.00%	100.00%
Netherlands	100.00%	100.00%
Poland	90.54%	97.54%
Portugal	52.39%	56.61%
Romania	81.97%	100.00%
Slovakia	58.58%	69.72%
Slovenia	21.26%	25.49%
Spain	100.00%	100.00%
Sweden	41.29%	41.35%
United Kingdom	91.08%	100.00%

Source: Own elaboration based on (ERC, 2018; Eurostat, 2018; Scimago, 2018).

The results of the correlation analysis are presented in Table 2. The findings indicate that there is a statistically significant correlation between the efficiency measured by the model with variable returns to scale and the public and private sectors' share in R&D financing. What is more, the correlation with the government share is positive and the correlation with business shares is negative, which is consistent with the analysed hypotheses.

The signs of the relationship with the private and public shares are also consistent with the hypotheses for the constant returns to scale, but this correlation is weaker than with the assumption of variable returns to scale. However, we can suppose that this result is contaminated because of decreasing returns in R&D. Thus, the results obtained with the model with variable returns to scale can be considered as more convincing.

The negative correlation between the efficiency and the size of the expenditures on R&D is surprising. In the case of the model with constant returns to scale it could be explained by decreasing returns to scale, but in reference to the model with variable returns to scale it is more unexpected. A possible explanation of that are the R&D externalities. The knowledge produced in the state with higher expenditures on R&D is available in the countries with lower expenditures, especially in the EU which is an open economy.

Table 2: Correlation coefficients between the R&D efficiency and public and private sectors' share in the R&D financing and total expenditure on R&D

Variable	Efficiency – constant returns to scale	Efficiency – variable returns to scale
	Correlation coefficient	Correlation coefficient
Public sector's share	0.322*	0.377**
Private sector's share	-0.328*	-0.397**
Total expenditure on R&D	-0.432**	-0.510***

Note: The Pearson's correlation coefficient for all 28 EU countries was calculated in all estimates. Asterisks denote the significance level: *** - 0.01, ** - 0.05, * - 0,1.
Source: Own elaboration based on (Eurostat, 2018).

Figures 1a and 1b graphically show the relationship between the public and private sectors' share in R&D financing and the sector's efficiency. The results indicate that the public and private sectors' share in the R&D financing determine 14.2% and 15.7% variability of the sector's efficiency, conversely. However, it is clear that there are also other factors that affect the sector's efficiency. The goal of further research should be to find these factors.

There is an interesting lack of noticeable geographical relationships that determine the efficiency of the R&D sector. The results indicate that there is no clear division between old and new EU countries. Another surprising finding is the very low efficiency of the R&D sector in the developed Scandinavian countries. The proposed explanations in this case are also the external effects of the R&D sector, which cause the reduction in relative efficiency in the countries with higher R&D expenditures.

The results obtained are consistent with the established research hypotheses. They allow concluding that the higher the public sector's share in the R&D financing is, the higher the efficiency of this sector is. This is also consistent with the theoretical considerations that the public research increases the efficiency of the whole sector. Conversely, the higher the private sector's share in the R&D financing is, the lower the efficiency of this sector is.
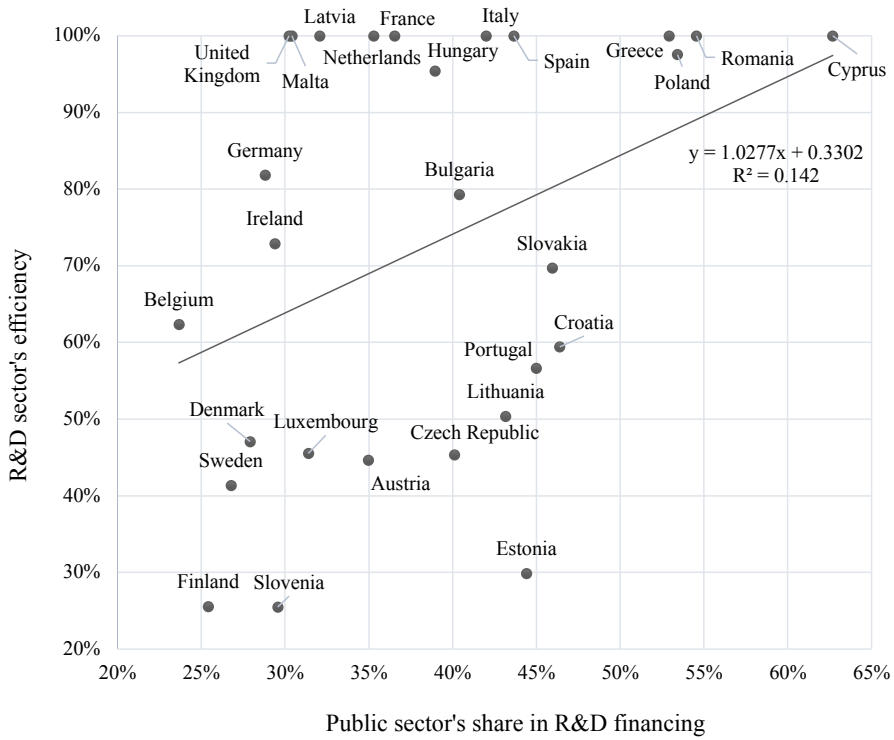
Figure 1a. Public sector's share in R&D financing and R&D efficiency measured with variable returns to scale

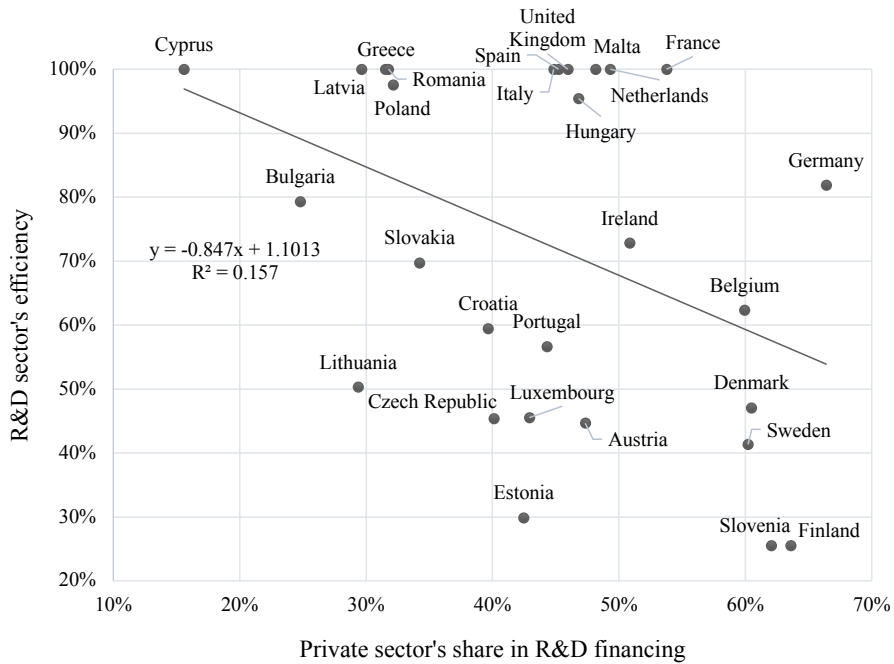Source: Own elaboration based on Eurostat (2018)

Figure 1b. Private sector's share in R&D financing and R&D efficiency measured with variable returns to scale

Source: Own elaboration based on Eurostat (2018)

5. Conclusions

The first objective of this study was to measure the efficiency of the R&D sector in the EU countries. The findings have indicated that the sector's efficiency was different in particular countries. It was more than three times higher in the most efficient states than in the least efficient ones. The results also indicate that decreasing returns to scale are characteristic in the R&D sector in the EU countries.

The second purpose was to examine the relationship between the efficiency of the R&D sector and the structure of its financing. The empirical results occurred to be consistent with the research hypotheses – the public sector's share in the R&D financing structure affects the efficiency of the R&D sector positively, while the private sector's share affects it negatively.

The study has the following limitations. First of all, there are the characteristics of the DEA method which lead to the multitude of efficient objects. It causes the findings in the next steps of the research to be contaminated, and thus they must be treated as not clear. We also have to note that the correlation analysis does not allow formulating strong conclusions. It is therefore necessary to use more advanced methods in further studies.

Further research should also focus on the following issues. Inclusion of a greater number of states will allow using more variables in the research. The results indicate that besides the source of funds there are other factors affecting the R&D sector's efficiency. It may be, for instance, conjectured that the legal regulations play a role in determining the R&D sector's efficiency. Moreover, the negative correlation between the amount of expenditure on R&D and the R&D efficiency is worth investigation.

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