PUBLIC R&D EXPENDITURE EFFICIENCY AND KNOWLEDGE CREATION IN THE CEE REGION

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ABSTRACT

In this paper we use the data envelopment analysis (DEA) to analyze the efficiency of public expenditure on R&D in Central and Eastern European countries (CEE), using knowledge creation and knowledge diffusion as key output indicators. Our results show that most CEE countries do not use public R&D resources efficiently and that the current level of expenditure should generate much better results on the Global Innovation Index scale. Thus, we believe that instead of increasing the level of public expenditure on R&D, the CEE countries need to increase efficiency first. In order to do so, these countries should continue to improve their institutional framework in terms of government effectiveness, business climate and suppression of corruption. The increase in R&D efficiency is of great importance for the CEE countries as they look for new knowledge-based growth models that are more challenging for policy makers than pre-crisis models, which were based on physical capital accumulation and adoption of technologies from abroad.

Keywords: *R&D, public sector, knowledge creation, DEA, CEE*

JEL Classification: O43, O34, O38

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1 INTRODUCTION

According to Todaro and Smith (2014), there are three fundamental sources of economic growth: (i) capital accumulation, including all new investments in land, physical equipment and human resources through improvements in health, education and job skills; (ii) growth in population and hence eventual growth in the labour force; and (iii) technological progress – new ways of accomplishing tasks. In this paper we will focus on the latter growth factor as the contribution of technological progress to economic growth is becoming even more pronounced in the new digital era.

The importance of technological progress was already recognized in a pioneer work by Solow (1956) within the neoclassical analytical framework. In these models, technological change is exogenous, it comes as *manna from heaven*, and it determines the long-run growth rate of countries through the effects on long--run productivity. Although these models were a breakthrough in the economic development and growth theory, they failed to "internalise" the technological progress.

The situation changed in 1990 after Paul Romer published his seminal paper on endogenous technological change (Romer, 1990). In this paper, Romer did not challenge Solow's main conclusions. Indeed, in his view technological change provides the incentive for continued capital accumulation and, together, capital accumulation and technological change account for much of the increase in output per hour worked. However, Romer went a step further and explained that technological change arises in large part as a result of intentional actions taken by people who respond to market incentives and invest in research and development (R&D). In this sense, technological progress in his model is endogenous rather than exogenous.

However, the level of R&D expenditure *per se* cannot ensure adequate private or social returns on investments in an economy. More precisely, if R&D resources are not used efficiently (we use the term efficient in terms of technical efficiency), they cannot generate adequate output needed for sustainable technological progress. Thus, in this paper we will analyze not just the levels of R&D expenditure but also the efficiency of this expenditure in the CEE region. Our focus is on public expenditure on R&D as we are interested in the public policy perspective of this topic.

In order to determine the efficiency of public expenditure on R&D, we use the data envelopment analysis (DEA) approach. The key input in our analysis is the total size of the government budget appropriations or outlays on R&D. The novelty of this paper lies in the chosen outputs as we do not use usual outputs such as the number of patents or the number of published scientific papers but the results of the Global Innovation Report, which in our view contains more information on knowledge-creation – the key prerequisite for technological progress in some countries. Our main hypothesis is that most CEE countries do not use public R&D resources efficiently.

The paper is structured as follows. The Introduction is the first part of the paper; in the second part we present a brief overview of the existing literature, with the focus on papers using the DEA approach. In the third part of the paper we briefly explain the methodology, i.e. the data envelopment analysis, while in the fourth part we describe and analyze the data used in the model. In the fifth part of the paper we discuss the results and the last part of the paper contains conclusions and policy recommendations.

2 LITERATURE REVIEW

Werner and Souder (1997) divided the research on R&D effectiveness and efficiency into two categories: macro and micro. Macro-level techniques focus on the impact of R&D on society as a whole. Micro-level techniques focus on the impact of a firm's R&D on its own effectiveness.

In this paper we focus on the macro-level approach, cross-country comparisons and papers based on the DEA analysis. This literature is relatively scarce. Although Teitel (1994) did not use DEA, this paper is worth mentioning as it represents one of the benchmark papers in this field. The author showed that investment in R&D can result in an increase of patents and improve scientific results in various countries. This finding motivated future research on R&D expenditure efficiency. Rousseau and Rousseau (1997) and Rousseau and Rousseau (1998) used DEA in the analysis of R&D expenditure efficiency in developed countries. They showed that there is a huge difference in efficiency across countries, meaning that even highly developed countries can position below the technological frontier. Based on the DEA approach, Lee and Park (2005) analyzed R&D efficiency in twenty--seven mostly developed countries, and based on the results divided the countries into four categories: inventors (Finland, France, Germany, Japan and the United States), merchandisers (Austria, Ireland, Norway and Singapore), academics (Australia, Canada, Hungary, Italy, New Zealand, Spain and the United Kingdom) and duds (China, the Czech Republic, Korea, Mexico, Poland, Portugal, Romania, the Russian Federation, Slovakia, Slovenia and Taiwan). Wang and Huang (2007) analyzed R&D efficiency in thirty OECD and non-OECD countries also taking into account environmental factors such as knowledge of the English language. They found that a large portion of the inefficiency can be explained by a country's English proficiency indicator. Sharma and Thomas (2008) used DEA to examine the relative efficiency of the R&D process across a group of twenty-two developed and developing countries and documented a relatively high level of inefficiency in the R&D resource usage in both groups. Thomas, Jain and Sharma (2009) analyzed R&D expenditure efficiency in twenty OECD countries, China and the Russian Federation. The authors concluded that Asian countries have shown remarkable progress in R&D efficiency which seems to be at the cost of the leading nations like the USA and the UK. As for the Asian countries, authors show that China exhibits a rapid increase in the number of scientific publications, while the Republic of Korea shows exemplary performance in patenting among residents. Cincera, Czarnitzki and Thorwarth (2011) analyzed the efficiency of R&D in OECD and EU countries. The results show that the most efficient countries in terms of R&D public support are Australia, Canada, Finland, Germany, Japan, the Netherlands, New Zealand, Singapore, Switzerland and the USA.

The research that is the closest to ours is Aristovnik (2012). Based on the DEA methodology, the author measured the relative efficiency in utilising public education and R&D expenditure in the new EU member states in comparison to the selected EU and OECD countries. Results showed that Cyprus and Hungary dominated in the field of R&D. The empirical results also showed that, in general, the new EU member states show relatively high efficiency in tertiary education, while lagging well behind in R&D efficiency measures.

3 METHODOLOGY

As mentioned in the Introduction, in this paper we will use data envelopment analysis to determine the technical efficiency of public R&D expenditure.

In order to better explain why we use this type of efficiency measure, we have to remind that there are two main measures of efficiency in economics – allocative and technical efficiency. Allocative efficiency refers to how the different resource inputs are combined to produce a mix of different outputs. Technical efficiency, on the other hand, is concerned with achieving maximum outputs with the least cost. The focus of this paper is on the latter type as we are interested in a rational use of public resources.

The data envelopment analysis (DEA) is a deterministic, non-parametric, linear programming technique for the determination of so-called efficiency scores. DEA scores reflect the distance between the respective data point, in this paper a country, and the best practice point which lies at the frontier. The countries (data points) on the frontier are given a score of 1, while those inside the frontier are given a score between 0 and 1. DEA provides a measure of relative efficiency, meaning that it indicates that a country is the more efficient relative to the other countries in the sample.

DEA can be input-oriented or output-oriented. The input-oriented method shows by how much input quantities can be proportionally reduced without changing the output quantities produced. On the other hand, output-oriented methods are focused on the question by how much output quantities can be proportionally expanded without altering the quantities of inputs used (for details see Coelli, 1996). At the same time, DEA can be based on the assumption of constant returns to scale (CRS) or variable returns to scale (VRS). In this paper we use the output-oriented VRS approach as the objective of R&D policies lies in increasing the outputs rather than decreasing the inputs (Lee and Park, 2005). DEA linear program is defined as:

$$min \sum_{i=1}^{m} v_i x_{ik} \tag{1}$$

$$s.\ t. \ \sum_{r=1}^{s} u_r y_{rk} = 1 \tag{2}$$

$$\sum_{r=1}^{s} u_r y_{rk} - \sum_{i=1}^{m} y_{rj} x_{ij} \leq 0, j = 1,\ldots, n \tag{3}$$

$$u_r \geq \varepsilon,\ r = 1,\ldots, s$$
$$v_i \geq \varepsilon,\ i = 1,\ldots, m$$

x_{ij} is the amount of the *i-th* input, y_{rj} is the amount of the *r-th* output, v_i is the weight given to the *i-th* input, u_r is the weight given to the *r-th* output, and k is the decision-making unit, in our case a country, measured. The constraints avoid any inputs or outputs being weighted at 0.

4 DATA AND ANALYSIS

As noted above, we are interested in the efficiency of public expenditure on R&D, which represents the input in our DEA analysis. Although many research studies use data on the share of public sector R&D expenditure in GDP, we see this indicator as deficient as it strongly depends on the level of development of each country. Thus, in this paper we use an alternative indicator, namely the total size of government budget appropriations or outlays on R&D as a share of total government expenditure, obtained from the Eurostat database. The indicator defined in this way partially annuls the effects of the differences in the level of development among countries.

As for the outputs, in this paper we use data from the Global Innovation Index (GII) report as in our view complex indicators from this report provide a better insight into the quality of knowledge and technology outputs than the commonly used indicators such as the number of patents or published scientific papers across countries. Also, most of the indicators in this report are PPP-adjusted, which makes a cross-country analysis more robust. As main outputs we use two sub-categories of the GII pillar VI "Knowledge and Technology Outputs" – *Knowledge Creation and Knowledge Diffusion*" (for details see Dutta et al., 2017).

The *Knowledge Creation* indicator combines data on the number of resident patent applications filed at a given national or regional patent office (per billion PPP$ GDP); the number of international patent applications filed by residents at the Patent Cooperation Treaty (per billion PPP$ GDP); the number of utility model applications filed by residents at the national patent office (per billion PPP$ GDP); the number of scientific and technical journal articles (per billion PPP$ GDP).

The *Knowledge Diffusion* indicator includes data on charges for use of intellectual property n.i.e. receipts (%, total trade); high-tech net exports (% of total trade); telecommunications, computers and information services exports (% of total trade); foreign direct investment (FDI), net outflows (% of GDP, three-year average).

Our sample includes eleven EU countries from Central and Eastern Europe (CEE): Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. The input is defined as the 2011–2016 average, while outputs represent GII scores in 2017. The use of "lagged" values of inputs is a standard approach in the DEA analysis as it takes time for inputs, in our case public expenditures on R&D, to provide results in terms of outputs. For detailed discussion on the use of average data see Graves and Langowitz (1996).

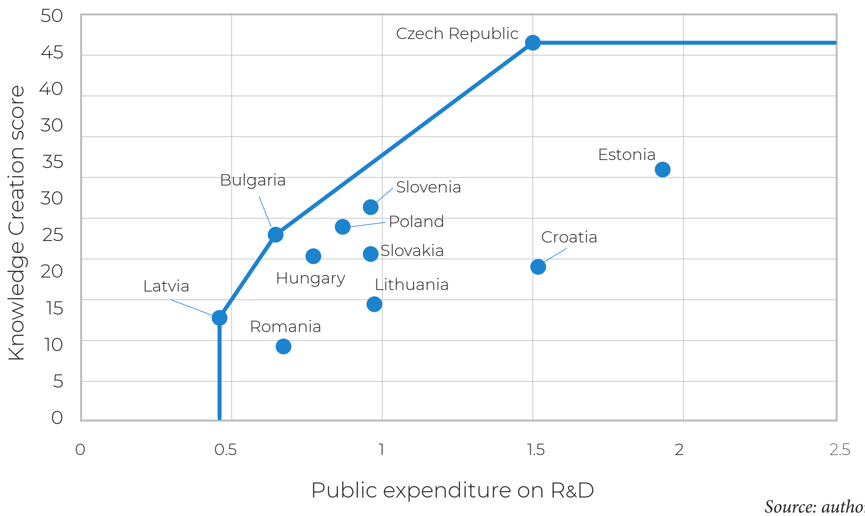
Tab. 1 » Inputs and outputs in the DEA model

	Definition	Source
Input	Government budget appropriations or outlays on R&D as % of total government expenditure	Eurostat
Outputs	Knowledge Creation score Knowledge Diffusion score	Global Innovation Index

Source: authors

The scatter diagrams in Figure 1 and Figure 2 present data in a way that allows for easy understanding of the DEA analysis background. X-axis contains data on the input and y-axis contains data on the output. The solid line "envelops" the sample by connecting countries that produce the maximum output at the given level of input.

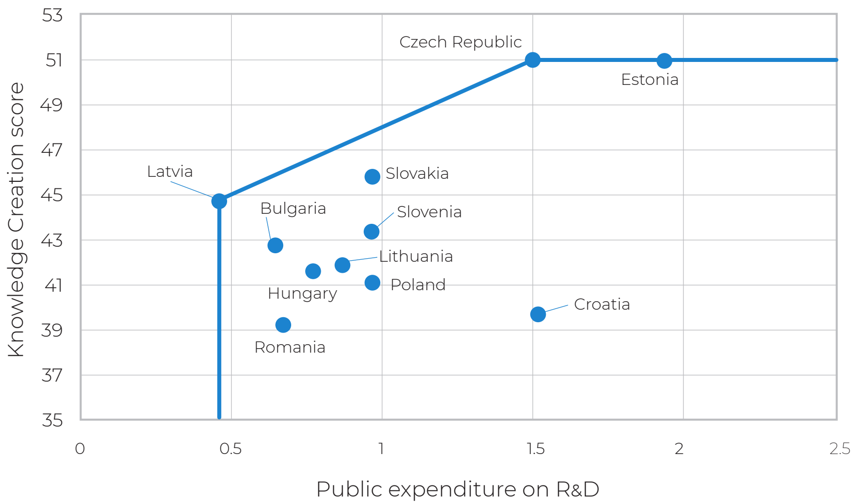
Fig. 1 » Government expenditure on R&D and the Knowledge Creation score



Source: authors

Figure 1 shows that Latvia, Bulgaria and the Czech Republic can be seen as the efficient units in this model as they lie on the efficiency frontier. Countries relatively close to the efficiency frontier include Hungary, Poland and Slovenia. Croatia is the worst performer in this sample as it is positioned deep inside the efficiency set.

Fig. 2 » Government expenditure on R&D and the Knowledge Diffusion score



Source: authors

Figure 2 leads to similar conclusions. The figure suggests that the Czech Republic and Latvia are efficient benchmarks also in the case of the Knowledge Creation score, while Bulgaria is now below, but close, to the efficiency frontier. Estonia takes the place of efficient benchmark from Bulgaria in this model. Apart from Bulgaria, Slovakia is also close to the efficiency frontier (since we are using the input method, the distance to the frontier can be read by measuring the distance between the country's position and the efficiency frontier to the left). Croatia is positioned well inside the efficiency set again, which implies that Croatia is the least efficient country.

These figures indicate that there is a high level of dispersion among the CEE countries in terms of R&D expenditure efficiency. In addition, these figures suggest that the Czech Republic and Latvia could be the regional leaders in this sense. It is also interesting to notice that the positions of countries are relatively stable regardless of which indicator we observe. In the next section, we will add more analytical rigour to this discussion by using the DEA model on the presented data.

5 RESULTS AND DISCUSSION

The tables presented below contain data on the DEA efficiency scores θ and so--called "target" outputs, which show by how much the output should increase to obtain efficiency if the input stays unaltered. The score for efficient countries takes the value of 1 and the countries which are below the "efficiency frontier" record scores in the interval of $0 < \theta < 1$.

Tab. 2 » DEA results for Knowledge Creation

	Efficiency score	Target output	Required increase of output
Bulgaria	**1**	**23.1**	**0**
Croatia	0.41	46.8	27.5
Czech Republic	**1**	**46.8**	**0**
Estonia	0.66	46.8	15.5
Hungary	0.72	28.3	8.0
Latvia	1	13.0	0
Lithuania	**0.43**	**33.6**	**19.0**
Poland	0.78	31.0	6.8
Romania	0.37	25.7	16.2
Slovenia	0.79	33.6	7.1
Slovakia	0.62	33.6	12.9

Source: authors

The results presented in Table 2 show that three countries determine the "efficiency frontier" for this sample – Bulgaria, the Czech Republic and Latvia. The efficiency scores for these countries equal 1. As these countries operate on the efficiency frontier, the size of their target output corresponds to the size of their real output, i.e. the required increase of output is 0. The least efficient countries include Romania, Croatia and Lithuania. Target outputs for these countries suggest that, given the level of expenditures on R&D, Romania should increase its GII score by 16.2 points, Croatia by 27.5 points and Lithuania by 19 points. It should be noted that Croatia has a higher efficiency score than Romania but requires a stronger increase in output to become efficient. This is because these countries do not have the same peers. Peers for Romania are Latvia and Bulgaria, while for Croatia it is the Czech Republic.

Tab. 3 » DEA results for Knowledge Diffusion

	Efficiency score	Target output	Required increase of output
Bulgaria	0.94	45.72	2.92
Croatia	0.78	51.00	11.20
Czech Republic	**1.00**	**51.00**	**0**
Estonia	**1.00**	**51.00**	**0.10**
Hungary	0.90	46.53	4.83
Latvia	1.00	44.60	0
Lithuania	**0.86**	**47.76**	**6.56**
Poland	0.89	47.12	5.12
Romania	0.85	45.92	6.72
Slovenia	0.91	47.68	4.28
Slovakia	0.96	47.69	1.89

Source: authors

As for the results concerning *Knowledge Diffusion*, our model also recognizes three benchmarks, but in this case they are the Czech Republic, Latvia and Estonia. We see that the Czech Republic and Latvia are benchmark countries again. The interpretation follows the lines from Table 2, meaning that now the Czech Republic, Latvia and Estonia recorded efficiency scores of 1 and required increase of outputs of 0. The least efficient countries again include Croatia, Romania and Lithuania, but in this case Croatia is positioned last. The required output increase results show that Croatia would have to increase its GII score by 11.2 points, Romania by 6.7 points and Lithuania by 6.6 points. The peer for Croatia is now

Estonia and for the other two weak performers they are Latvia and the Czech Republic.

6 CONCLUSION

There is no doubt that public investment in R&D is an important part of a broader economic policy, especially in modern economies where technological progress, often expressed through the concept of total factor productivity (TFP), is becoming more important in the growth creation process. However, the size of the investment alone cannot ensure adequate social returns. It is important that public R&D expenditure should be used efficiently, meaning that for a given level of input it provides a maximum output. The efficiency of public expenditure is of great importance in the CEE region as a lot of countries have a history of fiscal unsustainability and were compelled to cut their budget spending during the period following the 2008 financial crisis.

The results presented in this paper confirm our working hypothesis that most CEE countries do not use public R&D resources efficiently, especially within the knowledge creation process. Such inefficiency can partially explain the relatively low ranking of CEE countries on the Global Innovation Index scale, where these countries are among the weakest performers in the European Union. This is alarming as literature on economic growth shows that as an economy's income rises, productivity growth fails to keep up, with countries finding it difficult to switch from a growth model based on investment and the adoption of technology to one involving innovation and the development of new technology. Most CEE countries are in the category of high income countries (based on the World Bank definition) and thus require a new, knowledge-based growth model. Therefore, we believe that instead of increasing the level of public expenditure on R&D, these countries need to increase efficiency first. In order to do so, the CEE countries should continue to improve their institutional framework in terms of government effectiveness, business climate and suppression of corruption (it is interesting to point out that the CEE countries are still ranked relatively low on the Corruption Perception Index scale and that Romania and Croatia, which were marked as the least efficient in this paper, have some of the lowest scores in CEE).

The main contribution of this paper is the use of inputs and outputs that have not been used in the existing literature so far. As explained in the main body of the text, in our view these variables are more appropriate for the analysis than those which are most commonly used. In addition, this is the first paper that investigates the efficiency of R&D in terms of knowledge-creation and knowledge-diffusion in Central and Eastern Europe. In future research, the efficiency scores obtained from the DEA analysis in this paper can be used in a broader econometric analysis in which efficiency of public R&D expenditure could be regressed directly on the GDP growth rates in order to show that R&D efficiency is more important for long-term growth than the levels of expenditure per se.

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