THE INNOVATION EFFICIENCY IN CENTRAL AND EASTERN EUROPE – AN INPUT-OUTPUT COMPARATIVE ANALYSIS BETWEEN CZECH REPUBLIC, HUNGARY, POLAND AND ROMANIA

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Abstract

The aim of this paper is to investigate the innovation efficiency in Central and Eastern Europe by performing an input-output approach using Data Envelopment Analysis (DEA). R&D government spending and total R&D personnel stand for inputs and patent applications and high-tech exports stand for innovation outputs. We performed a comparative analysis between Czech Republic, Hungary, Poland and Romania using a 10 year-time span (2007-2016). We demonstrated that over time the innovation efficiency has improved (both regarding technical efficiency and scale efficiency) in all the four countries under scrutiny. Moreover, our research showed that the most efficient country was Hungary which balanced properly between the efforts of supporting innovation and its benefits due to reaping its positive effects in terms of high-tech exports and patent creation.

Keywords: innovation efficiency, inputs, outputs, Data Envelopment Analysis, comparative analysis

Introduction

In the last decades, innovation has become a central point to create competitive advantage (Barney, 1991), to promote economic development, or to obtain a better performance (Dittrich and Duysters, 2007). The economic literature emphasized the importance of innovation in relation with improvements in productivity, competitiveness and overall economic growth. In a more and more competitive globalized world, the increase of research and development expenditures is a key factor of either a firm's or a country's progress and long-term success (Castano *et al.*, 2016).

Investments in the innovative capacity of a firm or a nation are a must nowadays. A firm needs to innovate not only in products and processes as proposed by Schumpeter's "creative destruction" approach, but in organizational structures and managerial behaviors. As stated in Fotia (2017), Schumpeter's growth theory

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ISBN 978-606-714-568-7 | ISSN 2393-2384 | ISSN-L 2392-8867

comprises three important thoughts regarding innovation (Schumpeter, 1934): growth is mainly generated by technological innovations, innovations are produced by entrepreneurs who seek rents and profits from them, new technologies drive out the old ones (in his view the growth model is centered on innovations whose aim is to improve the quality of the existing products considered to be obsolete). At a country level, innovation is essential because it contributes to the general well-being of the population, improves administration processes, fosters economic growth, reduces unemployment, and strengthens the national security.

Due to the fact that innovation is a continuously accumulative process, it still triggers the economists' interest, especially in terms of measuring its efficiency in order to obtain better results with the adequate effort.

Therefore, the *objective* of this paper is to investigate the innovation efficiency in Central and Eastern Europe by performing an input-output analysis. The *research hypothesis* assumes that for all the four countries included in the sample, the innovation efficiency has improved throughout time.

This paper is organized as follows. The first section reviews the current literature showing different approaches to the innovation efficiency, then it analyses the variables employed in relation to innovation (such as R&D government spending, total R&D personnel, patent applications and high-tech exports) and it ends with a discussion about the main methods used to measure it. The second section depicts the methodology of the Data Envelopment Analysis (DEA), presenting its advantages and shortcomings compared to the more traditional approach of regression analysis. The third part of the paper provides details about the data set (e.g. the countries from Central and Eastern Europe which are subject to the assessment), the variables and how the DEA method is applied. The results and their interpretation will be presented in the next section, along with the rank of the countries in terms of innovation efficiency. Lastly, in the conclusion section, the final remarks along with the policy implications, the limitations of the study and the directions for future research will be presented.

1. Literature review

1.1. Innovation efficiency and the related variables

Innovation efficiency should be always related to the notion of productivity and to the relationship between the amount of inputs and outputs (the input-output mix). An improvement in the innovation efficiency is when with the same amount of inputs, a greater amount of outputs is generated or when less inputs are necessary for the same level of outputs. However innovation cannot be treated as a linear process where all the inputs are transformed into outputs. Despite of the fact that innovation efficiency originates from production theory and implies that performance is defined as the achievements (output) in comparison to the involved costs (input), the best approach is to determine the innovation efficiency as an output-input ratio.

As stated in Guan and Chen (2012), efficient National Innovation Systems (NIS) are operating at their production possibility frontier (PPF) or "transformation curve", which indicates the maximum amount of innovation output that can be produced with a given input. The innovation efficiency of a NIS is measured by the ability to transform innovation input into output and generate profits.

When studying the innovation efficiency of the firms, Hagedoorn and Cloodt (2003) have identified two main types of performance:

- inventive performance (defined as the achievements of firms related to ideas, products, processes, systems, and new devices) - this type of performance is frequently measured using patents;

- technological performance (defined as "the accomplishment of companies with regard to the combination of their R&D input, as an indicator of their research capabilities, and their R&D output in terms of patents" (p. 1367).

In the same vein, Zheng *et al.* (2013) state that innovation performance for a company has two distinct components: on one hand, there is the innovation efficiency (measured by the number of new products released, the novelty and the success on the market of those new products, the development speed of new production) and on the other hand innovation profitability (estimated by the proportion of new product revenue, the improvement of quality, the reduction of cost).

Neither in the microeconomics nor macroeconomics related literature, is there a consensus to the measurement of the quality of the innovation process, and this lack of a homogeneous view is sometimes an impediment to the process of creating more competitive advantages of the innovative organizations (be them firms or countries). However, throughout time, a wide variety of factors were used in order to determine the efficiency of innovation.

The pioneering work of Griliches (1964) and Mansfield (1965) underlined the importance of expenditures in R&D, as a basic input of innovation. The amount of R&D expenditure of a country is a good indicator to quantify its governmental policy towards innovations and economic progress. The higher the R&D expenditures, the more developed a country is. Guellec and Pottelsberghe de la Potterie (2004) continued on the same idea, showing that three sources of knowledge (public sector, local business sector and foreign firms) are significant determinants of long-term productivity growth.

At the same time, both Romer (1986) and Lucas (1988) placed great emphasis on human capital in developing the innovative capacity of a national system, arguing that the economic growth lays on the human capital accumulation (through learning by doing and investments in education). In the same vein, Tappeiner *et al.* (2008) noted that there are three basic inputs (R&D expenditure, human and social capital) that have a significant economic impact on innovation at the regional level of a country. Furthermore, the authors of some studies regarding regional innovation used either the number of R&D employees (Fritsch, 2003), or R&D employees in relation with the level of highly qualified employees in a certain region (Broekel, 2012), or a complex set of factors including R&D employees (Chen and Guan, 2011). Even if there is a lively debate among economists, the use of R&D employees as an input factor has increased due to the fact that its utilization provides an accurate approximation (when the full data is available) of the resources invested either by firms or countries in the innovation processes.

In terms of outputs, the number of patents seems to prevail as the main indicator of innovation efficiency (see, e.g. Jaffe, 1989; Anselin *et al.,* 1997; Baptista and Swann, 1998; Bode, 2004; German-Soto and Gutierrez Flores, 2013). A patent represents the sole right or the title given by a certain government authority for a set period to exclude others from making, using, or selling an invention. Nasierowski and Arcelus (1999, p. 239) define the external patents generated by residents as "measure of a country's involvement in international business cooperation and export activities" and the patents generated by a country's residents as a "measure of the effort of the locals in the investment in solutions for one country's internal demand".

Although imperfect because it constitutes only an intermediate output of the innovation process (Acs and Audretsch, 1989), due to the fact that it is the revenues earned from the use of a patent in the production process which represent the final output, it is still viewed as one of the most reliable measures to capture the effect of innovation, usually testifying the innovative capacity of a country (Hu and Mathews, 2005).

Another chosen output that emerges in the economic literature in order to measure the innovation output is the high-tech exports (Hollanders and Celikel Esser, 2007). This measure is appropriate because the high-tech industries undertake more innovation-intensive activities.

As an intermediary conclusion, this sub-section showed that the current literature has not offered yet a wide consensus either on the meaning of innovation efficiency or on the variables which drive the innovation process. The following part concentrates on two different approaches regarding the estimation of innovation efficiency.

1.2. Measurement of innovation efficiency

In terms of methods to better illustrate the innovation performance, this causal relationships between innovation inputs and outputs are often tested through regression models, not by the Data Envelopment Analysis (DEA) - see here Bottazi and Peri, 2003; Guellec and Pottelsberghe de la Potterie, 2004; Tappeiner *et al.*, 2008, only to name a few. A graphic comparison regarding the advantages and drawbacks of the DEA compared to regression analysis will follow in the next section of this paper.

There are a few articles that use DEA in order to study the effects of the domestic R&D and international spill-overs, but the measurement used is primarily based on trade rather than the patenting activity (Kim and Lee, 2004).

Lee and Park (2005) employ the DEA approach for measuring the R&D efficiency for a set of 27 OECD countries. They used two input indicators (namely R&D expenditures and number of researchers) and three output variables (technology balance receipts, scientific and technical journal articles and triadic patent families). They built a number of six DEA models, one linking all inputs to all outputs and five linking the different inputs piecewise to all outputs (input-specialized efficiency scores) or the different outputs piecewise to all inputs (output-specialized efficiency scores). Then the countries were classified into four clusters based on the output-specialized R&D efficiency: inventors, merchandisers, academicians, and duds.

Another relevant study based on the DEA method was the one carried out by Matei and Aldea (2012). They used the DEA method in order to measure and then compare the performance of the National Innovation Systems of the EU-27 countries plus Croatia, Norway, Switzerland, Iceland and Turkey. The variables used for describing the innovation process were intended to estimate the technical efficiency within this country set.

Guan and Chen (2012) expanded the research, proposing a relational network DEA model intended to measure the efficiency of the National Innovation Systems by splitting the whole innovation process in two sections: an upstream knowledge production process (named KPP) and a downstream knowledge commercialization process (named KCP). Their analysis was performed on 22 OECD countries.

One year later, Kotsemir (2013) provided a broad analysis of 11 empirical studies of the efficiency of the National Innovation Systems in multiple countries using the DEA method. This article is relevant to the literature for the description and analysis of the DEA models used, the country sets under scrutiny, and for the input and output variables in determining the most efficient states in terms of innovation.

In their research, Kou *et al.* (2016) measured the innovation efficiency of the OECD countries using R&D expenditure and R&D personnel as inputs and products exports in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery (on one hand) and the ratio of GDP to total employment in the economy (on the other hand) as outputs.

Even though in the last decades the measurement of the relationship between output and input variables used to be performed mainly by stochastic parametric methodologies such as regression analysis, lately the data envelopment analysis has expanded its scope, being regarded as a very useful tool in assessing efficiency issues.

2. Methodology

The research method used in order to reach the objective of this article (namely to investigate the innovation efficiency in Central and Eastern Europe by performing an input-output analysis) is Data Envelopment Analysis (DEA).

DEA is a non-parametric method which was developed by Charnes *et al.* (1978) to evaluate the relative performance of a collection of similar public sector units which provide multiple services that are not all priced on markets. The main purpose of DEA is to evaluate the performance of Decision Making Units (named DMU) performing a transformation process of several inputs into several outputs.

As stated by Sherman and Zhu (2006) DEA is a very powerful benchmarking technique. Although DEA was originally intended for use in microeconomic environments, it is ideally suited for the macroeconomic performance analysis. DEA is an appropriate analytical technique for evaluating the relative efficiency of national innovation system.

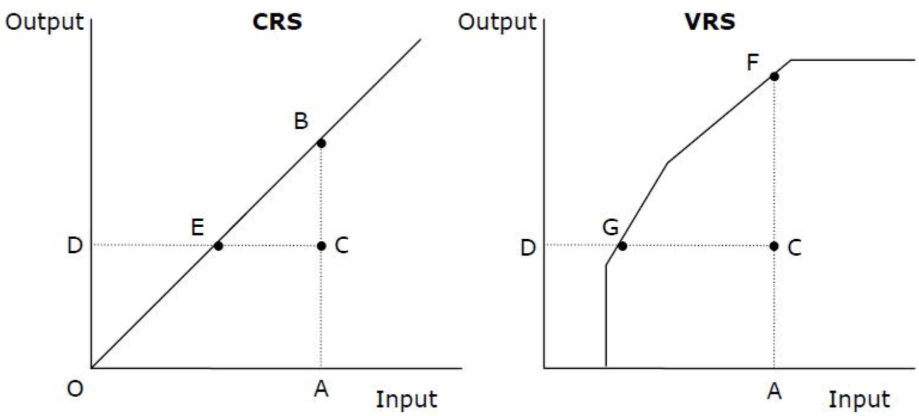
This methodology is built on the information regarding inputs and outputs of individual entities in order to construct an efficiency frontier enveloping the data. The DEA model selects a benchmark entity, which lies on the frontier, and measures the efficiency of the other entities related to the selected benchmark. There are two alternatives of this method: either input-oriented or output-oriented. The former minimizes the effect of inputs, the outputs being kept at their current level, whereas the latter maximizes the outputs and keeps the inputs at their current level.

Another approach to DEA is either a constant returns to scale (CRS) technology or a variable returns to scale (VRS) technology. The difference between CRS and VRS is shown in Figure 1. With CRS there is a linear relation between inputs and outputs: outputs increase with the same ratio as inputs. In the VRS model, outputs can increase with a higher ratio, the same ratio, or a lower ratio depending on the respective section of the efficiency frontier. Hollanders and Celikel Esser (2007) gave an easy-to-follow graphical explanation on the difference between CRS and VRS, therefore we will use it in order to depict these two methods.

The diagonal line in the left-hand Figure 1 gives the CRS efficiency frontier, point C reflecting an inefficient country combining below optimal levels of both inputs and outputs.

Following the input-oriented view, one can find out that country C could produce the same amount of inputs OD by using only DE inputs (instead of DC used previously). In this case, the degree of input-oriented innovation efficiency equals DE/DC which is the ratio of used inputs over the minimum inputs that are needed in order to produce the same amount of outputs.

Figure 1. CRS and VRS models



Source: Hollanders and Celikel Esser (2007, p. 7)

On the other hand, following the output-oriented view, country C could produce as much as AB outputs given its level of inputs OA. Consequently, the degree of output-oriented innovation efficiency equals AC/AB, which is the ratio of produced outputs over the maximum amount of outputs that could be produced using the same amount of inputs).

Under CRS, input-oriented and output-oriented innovation efficiency will be identical (DE/DC = AC/AB). Under VRS both measures will differ as depicted in the right-hand Figure 1. In the same logic as previously shown, the degree of input-oriented innovation efficiency is equal to DG/DC, whereas the degree of output-oriented innovation efficiency is equal to AC/AF.

The models used in this thematic paper are both input-oriented and output-oriented. Furthermore, we tested the both scenarios: constant return to scale (CRS) and variable return to scale (VRS). Given its assumptions, the CRS scenario may be too restrictive in real life, therefore we followed the VRS approach given its significant amount of information on technical efficiency and allocative efficiency of the selected countries.

The concept of total cost efficiency comprises both technical efficiency and allocative efficiency. Technical efficiency is measured on a scale from 0 to 1 (the larger the value, the higher the efficiency of the input-output combination). When the technical efficiency is 1 one can assume that a specific combination of input and output lies on the efficient isoquant.

The allocative efficiency can be assessed only if the input prices are known, this concept showing the cost-minimizing input mix. The values of the allocative efficiency are bounded by zero and one, as well.

Therefore the total cost efficiency is computed by multiplying technical by allocative efficiency.

The software used to compute data used in this paper was DEAP.

Despite of the multiple advantages of the DEA already depicted in this section, in order to maintain a balanced approach, we must also present the drawbacks of this method (for an in-depth analysis refer to Stolp, 1990). In order to pursue this objective, we designed a comparative analysis (see Table 1 below).

Table 1. Comparison of DEA to regression analysis

Advantages of DEA over regression analysis	Drawbacks of DEA compared to regression analysis
DEA is a non-parametric method, not requiring the user to define *a priori* a mathematical form of the frontier efficiency	DEA ignores the effect of exogenous variables on the operation
DEA measures performance against efficient rather than average performance	DEA ignores statistical errors
DEA can simultaneously analyze multiple outputs and inputs	DEA does not show ways to improve efficiency
DEA can identify the sources of inefficiency in terms of excessive use of particular resources or low levels on certain outputs	DEA Difficult to perform statistical tests with the results

Source: Thanassoulis (1993) and Jordá *et al.* (2012)

In spite of the shortcomings of DEA, we acknowledge that its advantages best suit our paper's objective, namely the assessment of the innovation efficiency in Central and Eastern European countries under scrutiny, therefore we will confidently use this method for serving the purpose of our analysis.

3. Data and variables

Even though there are more variables used in the literature to measure the efficiency of innovation, we chose to stick to the most common measures following the R&D orientation and human capital approaches (as described in the literature review above). Therefore the variables used in this paper are described in Table 2.

Table 2. Description of the variables used in the DEA model

Outputs	Inputs	Input prices
- patent applications to the European Patent Office (per millions inhabitants) - high-tech exports (measured as exports of high technology products as a share of total exports)	- R&D government spending (as percentage of GDP) - total R&D personnel (namely, FTE - full time employees; measured in tens of thousands)	- total government spending (as percentage of GDP) / R&D spending (as percentage of GDP) - tertiary education (as percentage of GDP) / total R&D personnel (tens of thousands)

Source: own representation

The data was collected from Eurostat and covers a time span of ten years (between 2007 and 2016). Our analysis was performed on four countries: Czech Republic, Hungary, Poland and Romania. Our choice of these four countries lays in their similarities in terms of geographical position and therefore cultural influences (all of them are part of the Central and Eastern Europe), and recent history (we are referring here especially to the communist era and their recent accession to European Union: Czech Republic, Hungary and Poland in 2004; Romania in 2007). The descriptive statistics of the variables used in our model are presented in Table 3.

Table 3. Descriptive statistics of the variables used

	High-tech exports (as share of total exports)	Patent applications (per million inhabitants)	R&D government spending (as share of GDP)	Total R&D personnel (FTE in tens of thousands)	Input price 1	Input price 2
Mean	11.75	14.36	1.02	5.29	76.81	0.22
Median	11.95	16.71	0.98	4.37	74.42	0.20
Minimum	3.00	1.52	0.38	2.60	29.79	0.11
Maximum	22.20	30.19	1.97	11.35	200.00	0.43
Standard Deviation	5.73	8.37	0.46	2.57	32.24	0.08
Observations	40	40	40	40	40	40

Source: own calculations based on Eurostat data

The minimum value registered for the high-tech exports belongs to Poland in 2007, whereas the maximum value is attributable to Hungary in 2009. In terms of patent applications, the minimum value belongs to Romania in 2009, while the maximum is reached by Czech Republic in 2016. Regarding the R&D government spending, Romania invested in 2014 only 0.38% of the GDP in innovation-related activities, while the maximum share of GDP was spent by Czech Republic in 2014. In 2007 Hungary had only 26,000 persons employed in the R&D sector, while in 2016 in Poland worked 113,491 people in this field.

4. Results and interpretation

The database which resulted by pooling together data from 4 countries and across 10 years is a panel-type one. Therefore we can either estimate the frontier efficiency for all the countries during the entire analyzed period (2007-2016) or we can estimate the efficiency frontier on each year. Bauer *et al.* (1993) claim that a higher flexibility is given by building one frontier for each year instead of creating one multi-year frontier. Additionally, building separate efficiency frontiers is important due to the fact that the degree of efficiency can be more easily assessed at every point in time.

As stated previously, we tested the input-oriented and output-oriented approaches for both models (CRS and VRS) in order to compare them.

The first model which was run is the input-oriented approach under the CRS method. The results of this model are shown in Table 4. This model is identical to the output-oriented CRS model, therefore we analyzed only this one, the conclusions being valid for both.

Table 4. DEA results under Constant Return to Scale (CRS) method - input-oriented

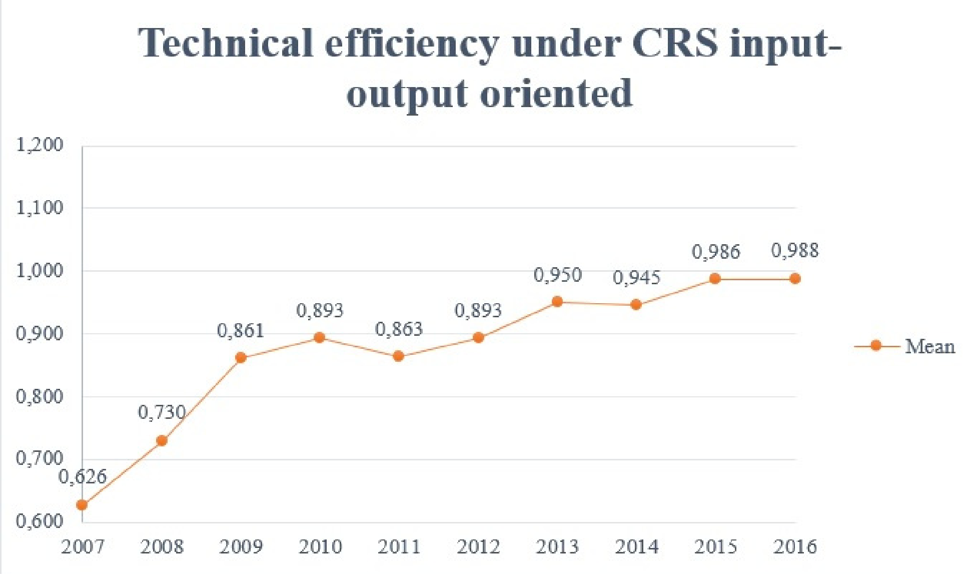
		Czech Republic	Hungary	Poland	Romania	**Mean**
Technical efficiency (TE)	2007	0.718	1.000	0.478	0.309	**0.626**
	2008	0.888	1.000	0.555	0.476	**0.730**
	2009	0.805	1.000	0.713	0.928	**0.861**
	2010	0.802	1.000	0.771	1.000	**0.893**
	2011	0.731	1.000	0.723	1.000	**0.863**
	2012	0.747	1.000	0.869	0.956	**0.893**
	2013	0.798	1.000	1.000	1.000	**0.950**
	2014	0.781	1.000	1.000	1.000	**0.945**
	2015	0.949	1.000	0.994	1.000	**0.986**
	2016	1.000	1.000	0.950	1.000	**0.988**
	Mean	**0.822**	**1.000**	**0.805**	**0.867**	**0.874**

Source: own calculations based on the DEA model with two inputs and two outputs

The only country which is considered to the most efficient under this approach is Hungary - for all the 10 years which are under scrutiny, the technical efficiency equals 1. On average, Romania is placed second (with an average of 0.867) for 2007-2016 period. Czech Republic and Poland are placed last (in this order) with averages of 0.822 and 0.805. These levels of technical efficiency can be explained as follows: for example, Romania is efficient at the level of 86.7% and it could have produced the same level of outputs by engaging 13.3% less quantity of inputs.

However, one important intermediate conclusion is that most of the times during this ten years period, the mean of technical efficiency constantly increased (with only one exception: 2011 compared to 2010) as shown in Figure 2. One possible explanation for this slight decrease can be that short after the start of economic crisis in 2008, during the recovery period which has begun in 2010, the countries did not put such a big emphasis on innovation, but concentrated on other significant measures deemed as appropriate to re-start the economy (e.g. quantitative easing and inflation promoting policies).

Figure 2. Technical efficiency under CRS input-output oriented



Source: own representation based on the DEA model

The second and third models which were developed are following the input-orientation under variable return to scale (VRS). For this approach we used the regular multi-stage DEA model in order to estimate the scale efficiency. The measure of scale efficiency provides the ability of the policy-makers to choose the optimum size of resources, i.e. R&D expenditures, or in other words, to choose the scale of output which will attain the expected production level. Choosing an inappropriate amount of the R&D expenditures (too little or too much) may sometimes be a cause of an inefficiency (this inefficiency can either take the form of Decreasing Returns to Scale - DRS or Increasing Returns to Scale - IRS).

After computing the scale efficiency, we modelled the cost-DEA in order to estimate the technical, the allocative and then the total cost efficiency for our country set. The results for second and third models are shown in Table 5.

Table 5. DEA results under Variable Return to Scale (VRS) method - input-oriented (SE, TE, AE, CE)

		Czech Rep.	Hungary	Poland	Romania	**Mean**
Scale efficiency (SE)	2007	0.988	1.000	0.478	0.309	**0.694**
	2008	0.888	1.000	0.555	0.476	**0.730**
	2009	0.975	1.000	0.713	0.928	**0.904**
	2010	0.983	1.000	0.771	1.000	**0.938**
	2011	0.986	1.000	0.723	1.000	**0.927**
	2012	0.747	1.000	0.869	0.956	**0.893**

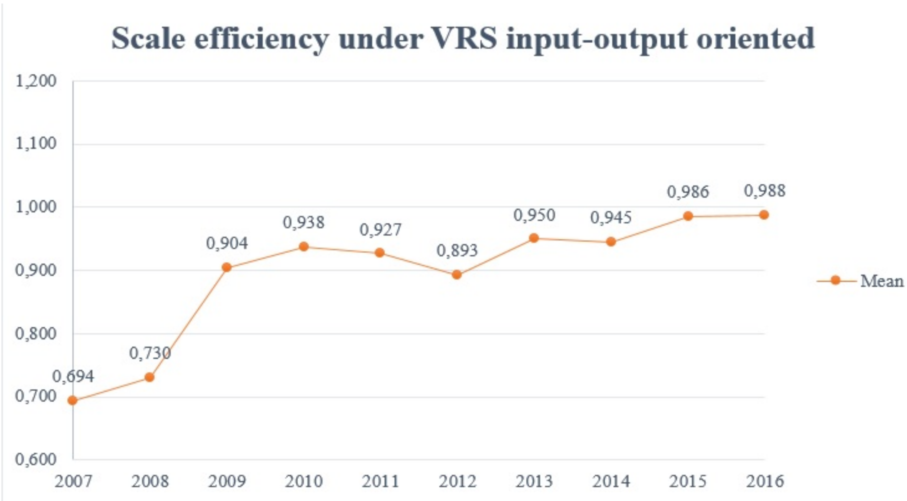
		Czech Rep.	Hungary	Poland	Romania	**Mean**
	2013	0.798	1.000	1.000	1.000	**0.950**
	2014	0.781	1.000	1.000	1.000	**0.945**
	2015	0.949	1.000	0.994	1.000	**0.986**
	2016	1.000	1.000	0.950	1.000	**0.988**
	Mean	**0.910**	**1.000**	**0.805**	**0.867**	**0.896**
Technical efficiency (TE)	2007	0.724	1.000	1.000	1.000	**0.932**
	2008	1.000	1.000	1.000	1.000	**1.000**
	2009	0.825	1.000	1.000	1.000	**0.956**
	2010	0.816	1.000	1.000	1.000	**0.954**
	2011	0.741	1.000	1.000	1.000	**0.935**
	2012	1.000	1.000	1.000	1.000	**1.000**
	2013	1.000	1.000	1.000	1.000	**1.000**
	2014	1.000	1.000	1.000	1.000	**1.000**
	2015	1.000	1.000	1.000	1.000	**1.000**
	2016	1.000	1.000	1.000	1.000	**1.000**
	Mean	**0.911**	**1.000**	**1.000**	**1.000**	**0.978**
Allocative efficiency (AE)	2007	0.997	1.000	1.000	1.000	**0.999**
	2008	1.000	1.000	1.000	1.000	**1.000**
	2009	0.998	1.000	1.000	1.000	**0.999**
	2010	0.998	1.000	1.000	1.000	**1.000**
	2011	0.998	1.000	0.993	1.000	**0.998**
	2012	1.000	1.000	0.999	1.000	**1.000**
	2013	1.000	1.000	1.000	1.000	**1.000**
	2014	1.000	1.000	1.000	1.000	**1.000**
	2015	1.000	1.000	1.000	1.000	**1.000**
	2016	1.000	1.000	1.000	1.000	**1.000**
	Mean	**0.999**	**1.000**	**0.999**	**1.000**	**1.000**
Cost efficiency (CE)	2007	0.724	1.000	1.000	1.000	**0.931**
	2008	1.000	1.000	1.000	1.000	**1.000**
	2009	0.824	1.000	1.000	1.000	**0.956**
	2010	0.815	1.000	1.000	1.000	**0.954**
	2011	0.739	1.000	0.993	1.000	**0.933**
	2012	1.000	1.000	0.999	1.000	**1.000**
	2013	1.000	1.000	1.000	1.000	**1.000**
	2014	1.000	1.000	1.000	1.000	**1.000**
	2015	1.000	1.000	1.000	1.000	**1.000**
	2016	1.000	1.000	1.000	1.000	**1.000**
	Mean	**0.910**	**1.000**	**0.999**	**1.000**	**0.977**

Source: own calculations based on the DEA model with two inputs and two outputs

Hungary ranks first again on all the four types of efficiencies analyzed (SE = TE = AE = CE = 1). Czech Republic places second in terms of scale efficiency, but only last when calculating the technical efficiency. Romania has gained the third place for the scale efficiency (the value being the same as the technical efficiency in the input-oriented CRS model). Poland ranks last in terms of scale efficiency (0.805), but it is fully efficient regarding the technical efficiency.

Overall, differences in scale efficiency scores are quite modest. This means that the countries included in the study operate close to the point that allows them to benefit from scale economies. In the long run, on average, the scale efficiency had an increasing tendency (however, there was a small drop in 2012 compared to 2011) as depicted in Figure 3 below.

Figure 3. Scale efficiency under VRS input-output oriented



Source: own representation based on the DEA model

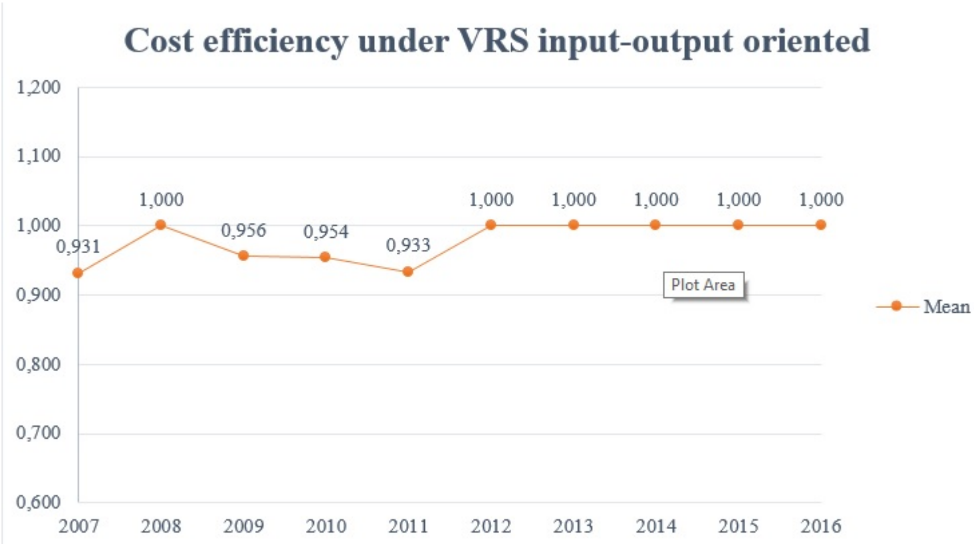
With respect to technical efficiency scores, the majority of countries (the exception is Czech Republic) is found to be operating close to the frontier. In the same vein, just a significant difference is observed when expressing the allocative efficiency scores; these scores were compared taking into account the inputs prices. The main conclusion which be extracted from these results is that the differences in input prices (namely the ratio of R&D government spending in total government spending, on one hand, and the ratio of tertiary education spending on total R&D employees, on the other hand) are being similar in all the four countries during time.

As mentioned earlier in this study, the product of technical efficiency and allocation efficiency scores generated the cost efficiency score. Hungary and Romania are operating on the efficient isoquant, whereas Poland is slightly below. Czech Republic scores on average 0.910, which roughly means that it overemployed inputs, namely it used more inputs than required to get the same level of output.

Moreover, when it comes to cost efficiency, we can split the ten years period analyzed into 3 sections: before economic crisis (2007-2008), during crisis (2009-

2011), and after crisis (2012-2016). The cost efficiency scores increased before the crisis (even reaching their peak in 2008), then strongly decreased during the economic turmoil because the policy-makers changed their focus from the innovation policy to other more pressing economic measures, then reached their peak again starting with 2012 once the economic recovery has started, as shown in Figure 4.

Figure 4. Cost efficiency under VRS input-output oriented



Source: own representation based on the DEA model

The fourth model developed is based on the output-oriented model under variables returns to scale (VRS). This model places a greater importance on maximizing the outputs while keeping the inputs at their current level. For this particular model we computed only the scale efficiency due to the fact that the output-orientation model under VRS is not applicable in cost-DEA. The results obtained are presented in Table 6.

Table 6. DEA results under Variable Return to Scale (VRS) method - output-oriented

		Czech Republic	Hungary	Poland	Romania	**Mean**
Scale efficiency	2007	0.738	1.000	0.478	0.309	**0.631**
	2008	0.888	1.000	0.555	0.476	**0.730**
	2009	0.876	1.000	0.713	0.928	**0.879**
	2010	0.851	1.000	0.771	1.000	**0.905**
	2011	0.763	1.000	0.723	1.000	**0.871**
	2012	0.747	1.000	0.869	0.956	**0.893**

	2013	0.798	1.000	1.000	1.000	**0.950**
	2014	0.781	1.000	1.000	1.000	**0.945**
	2015	0.949	1.000	0.994	1.000	**0.986**
	2016	1.000	1.000	0.950	1.000	**0.988**
	Mean	**0.839**	**1.000**	**0.805**	**0.867**	**0.878**

Source: own calculations based on the DEA model with two inputs and two outputs

The hierarchy of scale efficiency scores is as follows: Hungary (on the efficient isoquant), Romania, Czech Republic and Poland (the lowest score of 0.805).

Conclusions

The concept of innovation and innovation efficiency in particular which has attracted a series of debates and different views, it is a subject that has become more and more important as a significant contributor of the economic growth of a country.

Despite of the fact that innovation efficiency is not a simple process of employing inputs in order to create a certain amount of outputs using a linear function of production, in this paper we tried to measure the innovation performance using the most common variables selected by the economic literature as being related to this process. Consequently, we used the R&D government spending and total R&D personnel as inputs for innovation, whereas the high-tech exports and the patent applications were regarded as outputs.

The *objective* of this paper (namely to investigate the innovation efficiency in Central and Eastern Europe) was reached by performing an input-output analysis with Data Envelopment Analysis on a set of four countries from the Central and Eastern Europe (Czech Republic, Hungary, Poland and Romania) and a 10 year-time span (during 2007 and 2016). Moreover, the *research hypothesis* was met as well, due to the fact that we demonstrated that with a few exceptions (especially caused by external factors such as the economic crisis), all the four countries included in the sample improved their innovation efficiency throughout time. On top of that, our research showed that the most efficient country (determined by all the four models which we ran) was Hungary which balanced properly between the efforts of supporting innovation and its benefits due to reaping its positive effects in terms of high tech exports and patent creation.

One limitation of the study is the fact that the analysis was performed for four countries with a very similar economic and historic background (all the countries placed geographically in the Central and Eastern Europe, facing the long years of the communist period), therefore no other country with a better performance in terms of innovation efficiency (e.g. Sweden which ranked first in the European Union Scoreboard - see European Commission, 2018) was included in the study. Due to particularities of the DEA method itself, the first step in performing the analysis is searching for the most efficient entity and benchmarking all the others with that particular entity in order to obtain the full picture of the data set under scrutiny. In our case, Hungary was determined to be the most efficient under all the models run, therefore it became the benchmark entity. However, we have to acknowledge that the Hungary's case is a special one: both the level of inputs and outputs are quite low, this fact generating a higher than normal efficiency score. A particular conclusion which can be drawn from here is that in order to remain an efficient innovator, Hungary has to increase its innovation inputs (namely R&D expenditures and the number of persons who are working in the R&D sectors) and thus experiment a higher economy of scale exporting a greater amount of knowledge (such as a greater share of high-tech exports and more patent applications).

Although there are studies which concluded that Czech Republic is a moderate innovator, whereas Hungary, Poland and Romania are called the "catching-up countries" (see, e.g. Hollanders and Celikel Esser, 2007), our findings show that in terms of efficiency Hungary ranks first, followed then by Czech Republic and Romania both on the second place and then Poland. There are some reasons for this rather surprising top. Firstly, as mentioned earlier, the quite small level of inputs employed by Hungary succeeded to generate a very high output. In fact, on average for the 10 years under scrutiny, the high-tech exports (as a share of total exports) is 18.6% and they are obtained only by hiring 33.200 persons in the R&D field and spending a share of 1.2% of GDP for R&D government spending. At the other end of the spectrum, the high-tech exports of Poland are on average 6.16% of the total exports and they are the result of the work of 90.200 R&D employee (three times more than Hungary) and a share of 0.8% of GDP for R&D related activities. Secondly, even though Romania has on average the lowest levels of inputs compared to the other 3 countries (i.e. 0.47% of GDP devoted for R&D government spending and only 30.200 employees in the innovation sector), it manages to optimize its outputs in order to be more efficient than Poland which has inputs two or three times higher, but the outputs are smaller. Romania and Poland are lagging behind the other two countries in terms of producing patents. A possible cause, as it is detailed in Hollanders and Celikel Esser (2007), is that the countries may still be in a process of replacing national patent applications by EPO patent applications which may explain their low efficiencies regarding the intellectual property. As a direction for future research, it would be interesting to see if this top will maintain the same when assessing the innovation efficiency through parametric methods such as regression analysis, given the fact that the comparison is made against the average performance, not the most efficient country.

In terms of policy-making advice, it can be extracted from our paper that for the countries with high efficiencies it may be more effective to focus on policies intended to increase investments in the innovation inputs. With respect to R&D funding, along with increases in the government funding for this sector, governs should promote fiscal benefits for the companies which invest in basic and applied research and development. These reduction of taxes will incentivize the companies to be more prone to orientate their capital to such activities. On the other hand, the R&D personnel should benefit from tax deductions on their wages, therefore both companies and governmental agencies hiring scientific researchers are advantaged to sustain more R&D activities. One relevant aspect related to the R&D personnel is that the more skills they acquire (through courses, workshops or international mobility programs), the more efficient their work is. As an intermediate conclusion, if an efficient country wants to increase its output (and its overall performance) it needs to invest in expanding its inputs.

On the other hand, for the countries which are modest in terms of innovation efficiency, the increases in the level of inputs will not necessarily result in better innovation performances. For these countries a more effective approach will be a focused look on the policies aimed at improving their efficiency in transforming inputs into outputs. In this category one may include policies intended to stimulate the demand for innovation in general and processes for supporting innovation in companies.

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