

Yugoslav Journal of Operations Research  
29 (2019), Number 3, 415–431  
DOI: <https://doi.org/10.2298/YJOR180815013M>

## DYNAMIC ANALYSIS OF THE EFFICIENCY OF RESEARCH AND DEVELOPMENT SYSTEMS OF SOUTH-EUROPEAN COUNTRIES

Predrag MIMOVIĆ

*University of Kragujevac, Faculty of Economics, Serbia*  
*mimovicp@kg.ac.rs*

Ana KRSTIĆ

*University of Kragujevac, Faculty of Economics, Serbia*  
*anakrstic@kg.ac.rs*

Milena JAKŠIĆ

*University of Kragujevac, Faculty of Economics, Serbia*  
*milenaj@kg.ac.rs*

Received: August 2018 / Accepted: May 2019

**Abstract:** The non-parametric deterministic procedure of Data Envelopment Analysis (DEA) to measure and compare relative efficiency of research and development (R/D) activities in nine South-European countries in the period 2007-2016 is applied in this paper. To that end, we made a corresponding DEA model with nine decision-making units, two inputs and two outputs, selected by correlation analysis. The obtained results, i.e., relative R/D efficiency, were subject to correlation analysis in the context of the achieved average gross domestic product growth rate of the observed decision-making units, which showed that there was no strong correlation between those two variables at the level of the observed national economies.

**Keywords:** Research and Development, Performance, Efficiency, Economic Growth, Data Envelopment Analysis.

**MSC:** C61, D80, O32.

## 1. INTRODUCTION

National innovative capacity is the ability of the state as a political and economic entity to produce and commercialize the flow of globally new technology over the long term [15]. This concept is multidimensional and requires the definition of consistent indicators of the level of commercially usable and measurable results of innovation activities, such as research and development indicators, the number of granted international patents, the number of scientific and professional papers in reference scientific and professional journals, export of high-tech products, total number of scientists, research and development costs as a percentage of GDP, higher education costs as a percentage of GDP, etc.

Research and development (R/D) is a well-organized process of creation, production, diffusion, and application of knowledge that includes innovation in science and technology, management measures, and social and political systems. New knowledge and new technology generated from research and development activities stimulate productivity growth of companies and industry at the national level. Productivity growth, in turn, leads to higher return on investment, higher income, and greater and faster economic growth. However, although the positive role of the innovative national R/D sector is indisputable, it is difficult to access its impact clearly.

Since it is considered that every country inefficient in R/D resource allocation has fewer benefits from these activities, additional investment, as a rule, will not significantly stimulate economic growth. The issue of efficient use of R/D resources in scientific and professional literature has been given relatively little attention in relation to the analysis of the importance of new investment in generating greater economic growth. Therefore, the aim of this paper is to assess the efficiency of using R/D resources and their impact on economic growth using the appropriate analytical model. The hypothesis is that the effective use of R/D resources has a positive and strong impact on GDP growth rate. In this regard, we created a sample of nine countries of Southern Europe, which are, except Serbia, members of the European Union. The efficiency of utilizing R/D resources is monitored and measured over a period of eight years, from 2007 to 2016, by using the Data Envelopment Analysis Method (DEA), based on data taken from the World Bank database. The final part of the paper presents a correlation analysis, carried out to examine the link between the average efficiency of each individual country in the sample during observed period and its achieved average GDP growth rates, as an indicator of economic growth. DEA Frontier and StatFi for Excel software packages are used for calculation.

## 2. LITERATURE REVIEW ON R/D EFFICIENCY

R/D efficiency is a relatively recent research subject in scientific and professional literature. Generally, two types of studies dedicated to this issue can be distinguished: the first type of studies analyzes R/D efficiency determinants, while the second type measures R/D efficiency. The techniques used in the second study

group are the Malmquist Productivity Index [38], [20]; DEA [42], [25], [9], [16], [28], [2], [26]; Stochastic Frontier Analysis [42], [21] and Regression Analysis [26]. DEA is the most often used method to measure R/D efficiency, because it shows how to increase efficiency of inefficient decision-making units [10]. Some numerical studies measure efficiency of companies, while other studies measure efficiency of countries or regions. DEA method in assessing relative efficiency of R/D processes was firstly used by Rousseau & Rousseau [30]. They applied an input-oriented model with constant return, following the example of 18 developed countries, with two outputs, the number of publications and the number of patents granted, while GDP per capita and R/D investment were taken as inputs. The results obtained showed that, in 1993, Switzerland was the most efficient European country, immediately followed by the Netherlands. Using identical inputs and outputs, the authors expanded their work to include R/D efficiency of non-European countries, such as the USA, Canada, Australia, and Japan, with the same results as in the previous survey: Switzerland, with the Netherlands immediately behind it, had the highest R/D efficiency by Rousseau & Rousseau [29]. Wang & Huang [42] were the first to take into account external environmental factors in an attempt to measure R/D efficiency of individual countries. They proposed a three-step approach to evaluate relative technical efficiency of research and development in 30 OECD member countries. They applied an input-oriented DEA model, where patents and publications were outputs, and research and development costs and the number of researchers inputs. The results showed relative R/D efficiency in about half of the total number of countries. Lee & Park [24] measured R/D efficiency of Asian countries, by dividing them into four homogeneous subgroups; Cullman et al. [9] assessed relative efficiency of public and private research and development allocations in OECD countries, and concluded that Sweden, Germany, and the United States had the best performance. Wu and Liu [44] analyzed R/D efficiency in different parts of China, using an advanced DEA model. The results of this study show that research and development efficiency in most parts of China is low, suggesting potential improvement in these areas. Thomas et al. [39] study measured R/D efficiency of 50 US states and the District of Columbia, as the ratio of granted patents and R/D costs for scientific publications. The study ranked federal states with the highest R/D efficiency. Sharma and Thomas [33] measured relative R/D efficiency within a group of 22 developed countries, including the developing countries, using DEA method. They used granted patents as outputs, and R/D costs in GDP and the total number of researchers as the inputs. Roman [28] analyzed research efficiency at a regional level, in the case of Romania and Bulgaria, and concluded that Bulgarian regions were more efficient than Romanian ones in terms of R/D activities. Aristovnik [2] explored relative efficiency of education and R/D costs in the new member states of the European Union, and found that new members were relatively efficient in higher education, while Altıntaş & Mercan [1] analyzed the effects of R/D efficiency on economic growth.

### 3. METHODOLOGY

Data Envelopment Analysis (DEA) is a mathematical, non-parametric approach to calculate efficiency, which does not require a specific functional form. It is used to evaluate performance of decision-making units (DMUs) by reducing multiple input variables to a single “virtual” input and multiple output variables to a “virtual” output, using weight coefficients. The DEA methodology proved to be adequate especially when assessing efficiency of non-profit organizations operating outside the market, because, in their case, performance indicators such as income and profit do not measure efficiency in a satisfactory way.

Unlike typical statistical methods, data envelopment analysis is based on benchmarking, comparing each decision-making unit with only the best DMU. Data envelopment is a set of models and methods based on linear programming, which allows for calculating unit efficiency within a group of organizations. All data on input and output variables for each  $n$  decision-making unit is inserted into a particular linear program, which is actually the corresponding  $n$ -formed DEA model. In this way, efficiency of the observed decision-making units is evaluated, which, in fact, represents the ratio of weighted sum of output variables and weighted sum of input variables. Data envelopment analysis focuses on relative efficiency because decision-making units are viewed in relation to others. Efficiency ranges from 0 to 1, and each deviation from 1 is attributed to an excess output or a missing input. In other words, DEA determines the optimal amount of resources that makes the inefficient decision-making unit relatively efficient. This allows the management to implement suggestions derived from the results in order to realize potential savings, using specific changes in inefficient decision-making units. In this sense, DEA is a very useful tool for managers and organizational strategists since it enables them to optimize the decision-making process. More about practical DEA use see in Thrall [40], Dyson et al. [11], Sarkis [31], Sherman & Zhu [34] etc.

Table 1 gives an overview of advantages and disadvantages of applying DEA method.

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>- DEA relative efficiency for each DMU can be seen as an integral measure of their performance;</li> <li>- It is not necessary to determine in advance the functional form of resource transformation (input variables) into results (output variables);</li> <li>- Weight coefficients for input and output variables are formulated with a model without prior determination;</li> <li>- DEA method allows the inclusion of multiple output variables in the model;</li> <li>- Input and output variables can be expressed in different units of measure;</li> <li>- In DEA model, the user can include external factors in the form of variables from the environment;</li> <li>- DEA method assesses changes in input and output variables that are necessary for achieving efficiency frontier.</li> </ul>	<ul style="list-style-type: none"> <li>- DEA relative efficiency can be values;</li> <li>- DEA relative efficiency can be strongly influenced by the problem elements (when new objectives of the analysis are added, it is necessary to perform additional calculations);</li> <li>- A small sample and too many input and output variables can have a poor effect on efficiency results.</li> </ul>

Table 1: Advantages and disadvantages of DEA method; Source: Cooper, W.W., Seiford, L.M., Tone, K. [6]. Introduction to Data Envelopment Analysis and its use with DEA-Solver Software, Springer Science Business Media, Inc.

#### 4. DEA MODEL FOR EVALUATING R/D EFFICIENCY FOR SOUTH-EUROPEAN COUNTRIES

In order to evaluate R/D performance, an input-oriented CCR DEA model is formed, based on the following assumptions:

- a) The observed time period is 2007-2016;
- b) A set of decision-making units (DMUs) is formed of South-European countries: Bulgaria, Croatia, Greece, Hungary, Portugal, Serbia, Slovenia, Spain, and Romania. The observed decision-making units differ both in size and the number of inhabitants, as well as in their annual gross domestic product and the degree of development, but in relative terms, they satisfy the condition of homogeneity of the set of decision-making units [11]. In addition, with the exception of Serbia, all observed countries are members of the European Union;
- c) Outputs identified are: O1 – Income from the use of intellectual property in dollars, O2 – Number of patents per year, O3 – Number of scientific and professional papers and publications annually;
- d) Inputs are: I1 R/D allocation as percent of GDP, I2 Export of high-tech sector products as percent of total export, I3 Payments based on the use of in-

lectual property in dollars, I4 Total number of researchers and scientists in all sectors (per million inhabitants). The choice of inputs and outputs was carried out in accordance with a number of conducted studies and surveys [24], [9], [44]. Since the number of decision-making units of the observed countries is 9, the total number of inputs and outputs should not be greater than three or four, as suggested by numerous studies [5], [7], [36]. That is why first correlation analysis is applied, by which a set of inputs and outputs is reduced to two inputs and two outputs, which is at the level of the number recommended in relation to the number of decision-making units. Data for the selected input and output indicators is collected from the Worldbank database, and is given in Table 2 for the initial model that measures efficiency in 2007.

The applied CCR model in its dual form is:

$$\min \Theta \quad (1)$$

s.t.

$$\sum_{i=1}^m \lambda_j * x_{ij} \leq \Theta * x_{i0}, \quad i = 1, m \quad (2)$$

$$\sum_{j=1}^n \lambda_j * y_{kj} \geq y_{k0}, \quad k = 1, s \quad (3)$$

$$\lambda_j \geq 0, \quad j = 1, n \quad (4)$$

where  $\Theta$  represents the technical efficiency score of unit DMUs,  $\lambda_j$  represents the dual variables that identify the benchmarks for inefficient units.

DMU	I1	I2	I3	I4	O1	O2	O3
BUL	0,43	6	77561078	1480,2	10864075	211	2372
CRO	0,79	8,2	213000000	1406,7	39706518	344	3480
GRE	0,58	7,4	600000000	1887,8	52302447	575	10838
HUN	1	23,8	1750000000	1728	920000000	689	5676
POR	1,1	8,2	480000000	2670,5	87699506	250	7351
SRB	0,4	3,6	144000000	964,5	10451909	395	2477
SLO	1,4	5	169000000	3098	18717268	331	2659
SPA	1,2	5,1	3500000000	2714,4	450000000	3267	41318
ROU	0,52	3,5	248000000	896,5	41369245	827	4783

Table 2: Values of decision-making unit inputs and outputs in 2007

DMU	Efficiency	Benchmark(Lambda)
BUL	1,00000	BUL(1,000000)
CRO	0,85038	BUL(0,516091); HUN(0,016)
GRE	1,00000	GRE(1,000000)
HUN	1,00000	HUN(1,000000)
POR	0,86316	BUL(0,256258); HUN(0,030)
SRB	0,84125	BUL(0,167145); ROU(0,434)
SLO	0,71411	BUL(0,380374); ROU(0,367)
SPA	1,00000	SPA(1,000000)
ROU	1,00000	ROU(1,000000)

Table 3: Efficiency of the observed DMUs in 2007

Table 3 gives an overview of relative efficiency for the formed set of decision-making units in 2007, which was selected as the starting point in the observed period. Since more than half of the decision-making units are relatively efficient (value of the objective function equals 1), the question arises as to how much the obtained results represent the actual state, when it comes to efficiency measured by ratio of weighted sum of output and weighted sum of input variables, even more as it is a relatively heterogeneous group of decision-making units by several dimensions. So, one of the basic principles in defining input and output components of the DEA model lies in minimizing their number. In this regard, studies suggest that their total number should not exceed one third of the total number of decision-making units [5]. Second, highly correlated inputs or outputs are superfluous and can be eliminated without affecting the model efficiency [37]. Inputs that do not affect any output show that the set of outputs is incomplete, i.e. that there are resources that do not produce any measured result, and such inputs must be eliminated from the model [11]. The difference between inputs and outputs relates to the interest in decreasing or increasing certain values, with positive impact on the performance of DMU (isotonicity). Insufficient comprehensibility in this context is often cited as the main disadvantage of DEA model [14]. In this sense, various approaches to the choice of inputs and outputs are known in scientific and professional literature, and the most commonly used are correlation and regression analysis. In this paper, correlation analysis is applied to the example in 2007 year. Since the isotonicity, i.e. the dependence between inputs and outputs is the fundamental assumption on which the application of the DEA model lies, from the set of inputs and outputs, groups of inputs and outputs between which there is a weak or negative correlation are eliminated. In addition, as there should be no high correlation between input and output groups, and between O2 and O3 outputs it is 96.84%, one of the two observed outputs should be eliminated [37], [31]. Since the correlation coefficient between input I3 and output O2 equals 0.9177 (calculated in StatFi for Excel), and is greater than the correlation coefficient between input I3 and output O3, which is 0.9101, this also eliminates the O3 output as less important, so that the entire set, or the corresponding DEA model, is reduced to two inputs and two outputs – I2, I3, O1, and O2, which is acceptable in relation to the number of decision-making units.

		I1	I2	I3	I4	O1	O2	O3
<b>I1</b>	<b>R</b>	<b>1,0000</b>						
	R St. dev.							
	t							
	p-value							
	H0 (5%)							
<b>I2</b>	<b>R</b>	<b>0,2293</b>	<b>1,0000</b>					
	R St. dev.	0,1353						
	t	0,6233						
	p-value	0,5529						
	H0 (5%)	<i>accepted</i>						
<b>I3</b>	<b>R</b>	<b>0,4604</b>	<b>0,2794</b>	<b>1,0000</b>				
	R St. dev.	0,1126	0,1317					
	t	1,3721	0,7699					
	p-value	0,2124	0,4665					
	H0 (5%)	<i>accepted</i>	<i>accepted</i>					
<b>I4</b>	<b>R</b>	<b>0,8922</b>	<b>0,0209</b>	<b>0,3881</b>	<b>1,0000</b>			
	R St. dev.	0,0291	0,1428	0,1213				
	t	5,2277	0,0554	1,1141				
	p-value	0,0012	0,9573	0,3020				
	H0 (5%)	<i>rejected</i>	<i>accepted</i>	<i>accepted</i>				
<b>O1</b>	<b>R</b>	<b>0,3645</b>	<b>0,8499</b>	<b>0,7039</b>	<b>0,1368</b>	<b>1,0000</b>		
	R St. dev.	0,1239	0,0397	0,0721	0,1402			
	t	1,0357	4,2665	2,6220	0,3653			
	p-value	0,3348	0,0037	0,0343	0,7256			
	H0 (5%)	<i>accepted</i>	<i>rejected</i>	<i>rejected</i>	<i>accepted</i>			
<b>O2</b>	<b>R</b>	<b>0,3391</b>	<b>-0,0996</b>	<b>0,9177</b>	<b>0,3058</b>	<b>0,4071</b>	<b>1,0000</b>	
	R St. dev.	0,1264	0,1414	0,0225	0,1295	0,1192		
	t	0,9537	-0,2648	6,1136	0,8497	1,1792		
	p-value	0,3720	0,7988	0,0005	0,4236	0,2769		
	H0 (5%)	<i>accepted</i>	<i>accepted</i>	<i>rejected</i>	<i>accepted</i>	<i>accepted</i>		
<b>O3</b>	<b>R</b>	<b>0,3812</b>	<b>-0,1110</b>	<b>0,9101</b>	<b>0,4297</b>	<b>0,3507</b>	<b>0,9684</b>	<b>1,0000</b>
	R St. dev.	0,1221	0,1411	0,0245	0,1165	0,1253	0,0089	
	t	1,0911	-0,2955	5,8116	1,2589	0,9908	10,2736	
	p-value	0,3114	0,7762	0,0007	0,2484	0,3548	0,00002	
	H0 (5%)	<i>accepted</i>	<i>accepted</i>	<i>rejected</i>	<i>accepted</i>	<i>accepted</i>	<i>rejected</i>	

Table 4: Correlation coefficients matrix of the inputs and outputs

Table 5 provides descriptive statistics for 2007, with the values of input and output variables for the formation of the appropriate DEA model.

2007	Mean	St. Dev.	Min	Max
I2	5,533	6,871	1,6767 (BUL)	23,3 (HUN)
I3	857962417	1388552284	86570027 (BUL)	3876595351 (SPA)
O1	350054287	543880494	59578881 (BUL)	1706117940 (HUN)
O2	842,778	1072,702	249 (BUL)	3632 (SPA)

Table 5: Descriptive statistics for 2007

Since there is a large dispersion in data, it is necessary to solve the problem data imbalance. One of the best ways of making sure there is not much imbalance in the data sets is to have them at the same or similar magnitude. A way of making sure the data is of the same or similar magnitude across and within data sets is to mean normalize the data as proposed by Dyson et al [11] and Sarkis [32]. The column means from Table 6 are given in the first column of Table 6. The mean is determined by the simple mean equation (1) that sums up the value of each DMU's input or output in that column and then divides the summation by the number of DMUs.

$$V_{imean} = \frac{\sum_{n=1}^N V_{ni}}{N} \tag{5}$$

Where  $V_{imean}$  is the mean value for column i (an input or output), N is the number of DMUs and  $V_{ni}$  is the value of DMU n for a given input or output i.



In Table 5,  $V_{1mean} = 5,533$ ,  $V_{2mean} = 857962417,116$ ,  $V_{3mean} = 350054287,182$ ,  $V_{4mean} = 842,778$ . The second step is to divide all of the values of a given column by this final row of mean values. The general equation for each cell of Table 5 is:

$$V_{Normni} = \frac{V_{ni}}{V_{imean}} \tag{6}$$

Where  $V_{Normni}$  is the normalized value for the value associated with DMU  $n$  and input or output in column  $i$ . Table 6 shows the mean normalized data set. Efficiency scores for the data set in Table 7 are the exact same efficiency score results as for the data set in Table 6.

DMU	I2	I3	O1	O2	CRS eff.	Benchmark (Lambda)
BUL	0,762389	0,0972	0,059986	0,275658	0,82266	HUN(0,000349) ROU(0,254848)
CRO	1,041931	0,266934	0,219238	0,449415	0,66747	HUN(0,025407) ROU(0,394795)
GRE	0,94028	0,751926	0,288787	0,751202	0,38541	HUN(0,023731) ROU(0,640710) SPA(0,008810)
HUN	3,024142	2,193116	5,079755	0,900136	1,00000	HUN(1,000000)
POR	1,041931	0,601541	0,48423	0,32661	0,43003	HUN(0,084913) ROU(0,231554)
SRB	0,457433	0,180462	0,05771	0,516043	0,82461	ROU(0,477630)
SLO	0,635324	0,211792	0,103347	0,432431	0,61026	HUN(0,002439) ROU(0,398210)
SPA	0,64803	4,386233	2,484663	4,268133	1,00000	SPA(1,000000)
ROU	0,444727	0,310796	0,228419	1,080424	1,00000	ROU(1,000000)
Col. mean	1	1	1	1	-	

Table 6: Mean Normalized Data Set for the Table 5

### 5. THE RESULTS OF THE REDUCED DEA MODEL

DMU	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BUL	0,8227	0,9095	0,7193	0,6849	0,6332	0,5872	0,6759	0,4660	0,7637	0,5861
CRO	0,6675	0,4437	0,4099	0,3681	0,2968	0,3126	0,3948	0,3043	0,3876	0,3396
GRE	0,3854	0,4040	0,4993	0,5105	0,5074	0,7497	1,0000	0,7394	0,8197	1,0000
HUN	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
POR	0,4300	0,3017	0,8403	0,6646	0,7520	0,8066	0,9975	1,0000	1,0000	0,9481
SRB	0,8246	0,7579	0,9426	0,8405	0,6453	0,4856	0,7554	0,7192	0,7661	0,8071
SLO	0,6103	0,4109	0,4827	0,5537	0,5398	0,6348	1,0000	1,0000	1,0000	1,0000
SPA	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
ROU	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	0,8427	1,0000

Table 7: Comparative overview of R/D efficiency in the period 2007-2016

Table 7 gives an overview of the relative efficiency in the observed South-European countries in a given period. It is noticeable that Hungary, Spain, and Romania throughout the period relatively efficiently used their R/D potential. Descriptive statistics by years shows, among other things, that Bulgaria (U2) and Serbia (U3) had the smallest investment in the observed period, while the largest investment was made by Hungary (U2) and Spain (U3). On the other hand, the worst results were again recorded in Bulgaria, Serbia, and Croatia (O1), while the best results in that period were achieved by Hungary (O1) and Spain (O2). This logically resulted in the most favorable relationship between the invested and the

achieved, which was manifested as an average relative efficiency equal to 1 in the formed DEA model. A similar favorable relationship and efficient use of available R/D resources were also found in Romania.

In order to determine the performance and monitor the performance trends of the decision-making units over a specific time period, it is possible to use an extended DEA. In the literature, this analysis is known as the Window DEA method and represents a variant of the traditional DEA approach. That can be described as a moving-moving technique that establishes efficiency measures by observing the DMU at different time periods as a separate unit [43]. At the beginning of the analysis, the length and number of windows in which the time periods overlap. Each unit is treated as a different DMU in a different time period, while the performance of the observed DMU is compared with its performances over other periods of time and with the performance of all other units encompassed by a single window [45]. According to Kutlar et al. [23], in this analysis, a smaller window size can lead to a smaller number of DMUs, which in combination with a large number of variables reduces the discriminatory power of analysis. But on the other hand, the larger size of the window can cause erroneous results, because important changes that happen at a certain point can be ignored since the oversized window. In this extended DEA model,  $n$  DMU ( $j = 1, \dots, n$ ) in time intervals ( $t = 1, \dots, P$ ) are observed and all are used from the input to obtain the  $m$  output. The observed set consists of  $n \times P$  entities and one entity in the period  $t$ . A window that starts at the moment  $l$ ,  $1 \leq l \leq P$ , and has length  $w$ ,  $1 \leq w \leq P-1$ , is denoted by  $/w$ , and consists of  $n \times w$  observations [22].

Adequate input-oriented CCR DEA Window model [3], [18] is:

$$\Theta_k = \min_{\Theta, \lambda}(\Theta) \quad (7)$$

s.t.

$$-x_{kw}x\lambda + \Theta x_t \geq 0, \quad t = 1, T \quad (8)$$

$$y_{kw}x\lambda - y_t \geq 0, \quad t = 1, T \quad (9)$$

$$\lambda_n \geq 0, \quad n = 1, Nxw, Model1 \quad (10)$$

where  $1 \leq k \leq T$  and  $1 \leq w \leq t-k$ .

Using the DEA Window analysis with five windows, each length  $w = 6$ , average efficiency was calculated in the observed period, for each country. The R/D efficiency of the first DEA Window for Bulgaria, length  $w = 6$ , had started in 2007 and lasted until 2012, was calculated using the appropriate input-oriented CCR model (model 1):

$$\min \Theta_1 \quad (11)$$

Subject to:

$$-6*\lambda_1 - 6, 6*\lambda_2 - 8, 2*\lambda_3 - 7, 9*\lambda_4 - 7, 9*\lambda_5 - 7, 7*\lambda_6 + 6*\Theta \geq 0 \quad (12)$$

$$-77561078*\lambda_1 - 95185419*\lambda_2 - 117000000*\lambda_3 - 114000000*\lambda_4 - 140000000*\lambda_5 - 185000000*\lambda_6 + 77561078*\Theta \geq 0 \tag{13}$$

$$10864075*\lambda_1 + 11411533*\lambda_2 + 10027644*\lambda_3 + 18320000*\lambda_4 + 11950000*\lambda_5 + 22800000*\lambda_6 \geq 10864075 \tag{14}$$

$$211*\lambda_1 + 249*\lambda_2 + 242*\lambda_3 + 243*\lambda_4 + 262*\lambda_5 + 245*\lambda_6 \geq 211 \tag{15}$$

where  $\lambda_j \geq 0, j=1,6$ .

Efficiency for other windows as well as other countries from the observed set are calculated in the same way, and their values are shown in Table 8.

<b>Bulgaria</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	0,962	0,7603	1	0,6879	0,8122				
Window2		1	0,7907	1	0,8791	0,9083	1			
Window3			0,8819	0,9185	0,9740	0,9058	1	1		
Window4				1	1	0,8691	0,9568	0,858	1	
Window5					1	0,8691	0,9568	0,858	1	1
Average	1	0,981	0,8109	0,9837	0,9082	0,8729	0,9807	0,905	1	1
<b>Croatia</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	1	0,8136	0,7506	0,7214	0,5749				
Window2		1	0,9212	0,8965	0,7703	0,5749	0,6424			
Window3			1	1	1	0,6387	0,7872	0,909		
Window4				1	1	0,8103	0,8103	0,787	1	
Window5					1	0,8596	0,8596	0,936	1	1
Average	1	1	0,912	0,912	0,898	0,6917	0,7743	0,877	1	1
<b>Greece</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	0,885	0,8849	0,9678	1	1				
Window2		0,734	0,7076	0,8554	0,8804	1	1			
Window3			0,7076	0,8399	0,8632	1	1	1		
Window4				0,8399	0,8632	1	1	1	0,965	
Window5					0,8632	0,9808	1	1	0,805	1
Average	1	0,809	0,767	0,876	0,894	0,996	1	1	0,885	1

<b>Hungary</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	0,941	0,9392	1	1	1				
Window2		0,763	0,9392	1	0,978	1	1			
Window3			0,9392	1	0,942	1	0,9926	1		
Window4				1	0,942	1	0,9912	1	1	
Window5					0,8405	0,9214	0,9289	1	0,958	1
Average	1	0,823	0,9392	1	0,940	0,984	0,978	1	0,979	1
<b>Portugal</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	0,680	0,644	1	0,9238	1	1				
Window2		0,644	1	0,9238	1	1	1			
Window3			1	0,8689	0,9405	1	1	1		
Window4				0,7619	0,9250	0,9305	0,9451	1	1	
Window5					0,9250	0,9305	0,9451	1	1	0,909
Average	0,680	0,644	1	0,869	0,958	0,972	0,973	1	1	0,909
<b>Slovenia</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	1	0,8801	0,8371	1	1				
Window2		0,78	0,6816	0,8203	0,9969	0,9808	1			
Window3			0,6697	0,8059	0,9457	0,9637	1	1		
Window4				0,8059	0,9457	0,9637	0,9912	1	1	
Window5					0,9457	0,9637	0,9872	1	0,99	1
Average	1	0,89	0,744	0,817	0,967	0,974	0,995	1	0,995	1
<b>Serbia</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	0,992	1	1	1	0,6399				
Window2		0,996	1	1	1	0,6399	0,883			
Window3			1	1	1	0,6399	0,883	0,779		
Window4				1	1	0,7404	0,922	0,822	0,847	
Window5					1	1	1	0,948	0,968	0,999
Average	1	0,994	1	1	1	0,732	0,922	0,849	0,908	0,999
<b>Spain</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	0,997	1	0,9708	0,8798	1	1				
Window2		1	0,9612	0,7798	0,9683	0,9407	1			
Window3				0,9607	0,9798	0,9205	0,9587	1		
Window4				1	1	1	0,99	0,995	1	
Window5					1	1	0,99	0,995	1	1
Average	0,997	1	0,966	0,905	0,989	0,972	0,985	0,997	1	1
<b>Romania</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
Window1	1	0,954	0,8909	1	0,886	1				
Window2		1	0,9248	1	0,9993	1	1			
Window3			0,9248	1	1	1	1	0,877		
Window4				1	1	1	1	0,877	0,782	
Window5					1	1	1	0,877	0,782	0,721
Average	1	0,977	0,914	1	0,977	1	1	0,877	0,782	0,721

Table 8: Average R/D efficiency: variation through windows

Figure 1 shows the variation of the R/D efficiency through the windows. It is noticeable that in most of the observed countries, the average efficiency was achieved at least in 2008. This coincides with the onset of the global financial crisis. It is in the countries with the most developed financial system that the decline is the largest, with the exception of Spain. At the same time, these countries were the fastest to recover from the effects of the crisis, and their average R/D efficiency has been in relatively stable growth after 2008. The relatively high average R/D efficiency of some less developed countries, such as Serbia, in the observed period could be explained by the delayed impact of the consequences of the global economic crisis. The average R/D efficiency in the observed period varied from country to country and was the lowest in the case of Portugal (90 percents of its reference efficiency in 2014., and 2015.), and the largest in the case of Hungary, Spain, and Slovenia for the entire time period. If the possible correlation with the average gross domestic product growth rate in the period 2007-2016 was observed, our correlation analysis shows that it is not so since  $p = 0.5846$ , which is much more than the allowed 0.05 (Table 10). This means that the zero hypothesis is accepted, i.e. there is no connection between these two values. Input and output variables identified for measuring relative R/D efficiency were

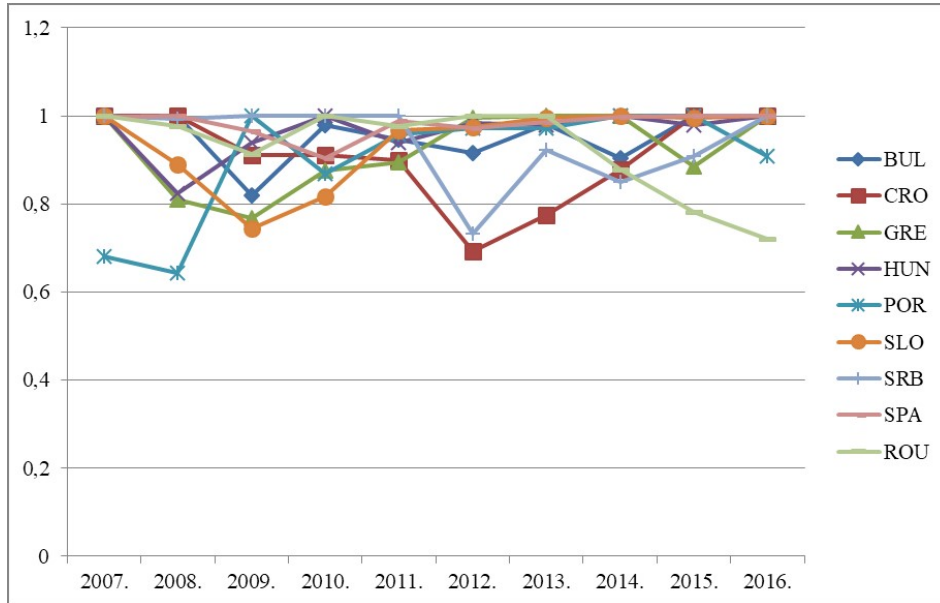


Figure 1: Variation of the R /D efficiency - DEA Window analysis

selected based on the review and analysis of several relevant studies that dealt with this issue [9], [8], [17], [2], etc. Following the example of 2007, correlation analysis was applied, which confirmed the connection between independent, in this case, selected input variables and dependent, i.e., output variables, in the proposed, reduced DEA model. Similar can be shown for other years.

DMU	Average eff. in 2007-2016	Average GDP growth rate in 2007-2016
BUL	0,944	1,629
CRO	0,906	-0,725
GRE	0,923	-3,35
HUN	0,964	0,2
POR	0,9	-0,55
SLO	0,938	1,125
SRB	0,94	0,438
SPA	0,981	-0,363
ROU	0,925	1,975

Table 9: Average R/D efficiency in the period 2007-2016

Missing values removal	Pairwise deletion		
		Average eff. in 2007-2016	Average GDP growth rate in 2007-2016 (%)
Average efficiency in the period 2007-2016	R	1,0000	
	R St. Err.		
	t		
	p-value		
	$H_0(5\%)$		
Average GDP growth rate in the period 2007-2016	R	0,2117	1,0000
	R St. Err.	0,1365	
	t	0,5730	
	p-value	0,5846	
	$H_0(5\%)$	accepted	
Variable vs. Variable	R	Number of valid cases	
Average GDP growth rate in the period 2007-2016 vs. Average efficiency in the period 2007-2016	0,2117	9	

Table 10: Correlation coefficients matrix of the average R/D efficiency of the observed countries and their average realized gross domestic product growth rates

## 6. CONCLUSIONS

In this paper, a non-parametric deterministic procedure of Data Envelopment Analysis (DEA) was used to measure and compare relative efficiency in the field of research and development (R/D) of nine countries of Southern Europe in the period 2007-2016. The observed set of decision-making units was not formed according to the pre-selected key or criterion. It is the result of an attempt to compare research and development performance of the Republic of Serbia, i.e. the way in which available research and development resources are used, with those in the countries of Southern Europe, which are members of the European Union. The obtained results, given the selected components of the DEA model formed to assess R/D efficiency (two inputs and two outputs, selected by correlation analysis), in a certain sense, are a surprise. They show that membership in the European Union is not necessarily a prerequisite for efficient use of research and development resources and capacities at the national level. The obtained results, i.e. relative R/D efficiency, were subject to correlation analysis in the context of the achieved average gross domestic product growth rate of the observed decision-making units. They confirmed the findings of earlier studies [4], [12], [13], that there is no strong connection between these two variables. The obtained results should be accepted with a certain reserve as a more realistic picture asks for more complex analysis, which would include: sensitivity analysis of the target and realized values of input and output variables, multiple factors, different approaches, comparison with the countries in the region, which are approximately at identical level of economic development, as well as a comparison with the projected strategic goals of the scientific, technological, and educational development of the Republic of Serbia in the following period.

**Acknowledgment:** This study is the result of a research project 41010, funded by the Ministry of Science and Technological Development of the Republic of Serbia.

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