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RESEARCH AND DEVELOPMENT INDICATORS OF EU28 COUNTRIES FROM VIEWPOINT OF SUPER-EFFICIENCY DEA ANALYSIS

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Abstract

Research and development are important sources of economic growth and social welfare and play a key role in creating new knowledge, products and technological processes. In our paper we focused on the analysis and evaluation of research and innovation potential in the European Union countries in 2010 and 2015 using Data Envelopment Analysis. For the evaluation, seven indicators were selected, as starting point for the evaluation of research activities and the measurement of the innovation performance and of competitiveness of the individual countries. Input capital indicators were – R&D expenditure in the higher education sector and in the business enterprise sector as % of GDP. Input human labour indicators were total researchers (FTE), human resources in science and technology (HRST) as % of active population and employment in total service intensive sectors as % of total employment. Output indicators were the number of scientific publications and high-tech export as % of total export. On basis of DEA super-efficiency analyses results we can make following conclusions. The best group of five countries is characterized by efficient status in both analysed periods 2010 and 2015 (Bulgaria, Romania, Cyprus, Croatia and United Kingdom). The second group contains two countries Germany and Italy. This countries improved status from inefficient in 2010 to efficient in 2015. In the third group are five countries that worsened their status from efficient in 2010 to inefficient one in 2015: Portugal, Malta, Poland, Luxembourg and Netherlands. In last fourth group are all other EU28 countries that were inefficient in both analysed periods 2010 and 2015. In group of V4 countries situation is not optimistic. Poland worsened its status from efficient in 2010 to inefficient one in 2015 and three remaining countries – Hungary, Czech Republic and Slovakia stagnated in inefficient status in both periods. On the opposite there was not significant difference in super-efficiencies in 2010 and in 2015 and in their differences between capitalist and post-socialist EU28 countries.

Keywords: Data Envelopment Analysis, EU countries, indicators, research & development, slack based model, super-efficiency analysis

INTRODUCTION

The Europe 2020 strategy defines five intertwined objectives pertaining to employment, R&D, climate change and energy, education and poverty reduction. Research and development plays a key role in creating new knowledge, products and technological processes that are a prerequisite for a stable and sustainable economic growth for the society. The level and intensity of research, development and innovation are closely linked to the country's economic maturity, the dynamics of economic development and the structure of value added and employment creation. For the purpose of assessing the level of competitiveness of the economies, it is necessary to monitor not only the individual elements of the national innovation system, but also their interdependence and the effectiveness of these links. The level and intensity of research, development and innovations are connected with the economic level of a respective country, the dynamic of economic development and the structure of creating added value and employment (EC, 2010). For the Europe 2020 strategy in the field of R&D to be implemented, areas to focus on are better conditions for financing research, development and innovations, where financial capabilities of EU countries are an important prerequisite (Halaskova and Halaskova, 2015).

The objective of the article is to evaluate the efficiency of the research and innovation potential of European Union countries on the basis of a theoretical and empirical approach. We focus more closely on analysing and evaluating the efficiency of R&D of EU countries using Data Envelopment Analysis (DEA) in 2010 and 2015 on the basis of selected five input R&D indicators (R&D expenditure in the higher education sector and the business sector as % of GDP, total researchers (FTE), human resources in science and technology as % of active population and employment in total knowledge intensive service sectors as % of total employment) and two output indicators – number of scientific publications and high-tech exports (relative share of exports of all high technology products in total exports) with the aim of evaluating also the differences in efficiency in individual countries in 2010 and 2015.

In connection with the objectives, two research questions are verified in the article. Research question (RQ1): Do countries with higher R&D intensity have higher efficiency in R&D work? Research question (RQ2): Is the small input range of research and innovation potential due to the low efficiency of R&D?

Theoretical background and literature review

Research and development (R&D) is a central area of individual national and international policies. According Delanghe and Muldur (2009) research and development plays a key role in generating new knowledge, products and technological processes, which are a necessary condition for a stable, sustainable social growth. Over the past decades, EU initiatives and individual states have been paying increased attention to conditions for research, development and innovations. For most, this concerns the connection of R&D policies with education, innovation, employment, information and business policy. To implement the strategy Europe 2020 in the field of R&D, areas to focus on are better conditions for financing research, development and innovations, where financial capabilities of EU countries are an important prerequisite. In R&D, member states should begin investing 3% of their GDP (1% public expenditure, 2% expenditure from the private sector), (EC, 2010). Total expenditure on R&D (GERD) in % of GDP includes all investment and non-investment expenditure allocated to R&D in the area of a given country over the observed period, regardless of the source of financing (OECD, 2015; Eurostat, 2017). This financial relation is allied "research and development intensity" and belongs to the group of elementary structural indicators evaluating the progress of Strategy Evropa 2020 objective-fulfilments in individual EU countries. The total expenditure on R&D (GERD) includes expenditure in four sectors (government sector, higher-education sector, business-enterprise sector and private non-profit sector). Many authors (Conte *et al.*, 2009; Priede and Neuert; 2015; Szarowská and Žurková, 2017 or Tkač *et al.*, 2017) solves the efficiency of public spending and national policies in the area of R&D, relationship between public R&D expenditures and economic growth or other indicators of the competitiveness by Europe 2020.

Human resources in science and technology (HRST) are one of the indicators which reflects a country's degree of implication in supporting the development of the science and technology field as an important factor of the economic and social progress and their evaluations are the topics of interest of many researchers. Lelek (2014) discusses the issue of precondition for the number of researchers as an important input factor for research and development. Marinoiu (2014) propose a EU classification based on similarities in the evolution of HRST, during the period 2002–2012.

Other author e.g. Furkova (2015) monitors selected R&D indicators in European Countries as employment in knowledge-intensive activities, patent applications, total intramural R&D expenditure, and human resources in science and technology and business enterprise R&D expenditure by using the over to multi-criteria evaluation approach. Johansson, Lööf and Savin (2015 or Prokop, Stejskal and Mikušová Meričková (2017) evaluate of innovation performance and competitiveness of economies and authors solve not only the numbers and structure of patent activities but also their relationship with other indicators. Indicators of own production of new knowledge in the form of output indicators usable in practical applications include Patent application to the EPO but also scientific publications and citable publications. Larsen and von Ins (2010) evaluate the growth rate of scientific publication, citable analysis in research and of peer-reviewed scientific publications indexed in Scopus database.

R&D Efficiency and Innovation Performance

Evaluation and measurement of R&D efficiency and innovation policy are addressed in the publications of many authors in the European and international dimension. Rousseau and Rousseau (1997) assess by used DEA the R&D efficiency of various countries using constant returns to scale (CRS) formulation. Authors analyse 18 developed countries and highlighted methodological problems like the language bias in the ISI publications data and the fact that there could be problems due to taking patent data from the European Patent Office (EPO). Lee and Park (2005) have performed a CRS DEA study on 27 countries and have concluded that Asian countries in general are inefficient in R&D. While discussing areas for further research, they mention the need to take the variable returns to scale (VRS) formulation. Wang and Huang (2007) analyse R&D efficiency in 30 OECD and non-OECD countries also taking into account environmental factors such as knowledge of English language. They find that a large portion of the inefficiency can be explained by a country's English proficiency indicator. Sharma and Thomas (2008) examine the relative efficiency of the R&D process across a group of 22 developed and developing countries by using Data Envelopment Analysis (DEA). The R&D technical efficiency is examined using a model with patents granted to residents as an output and gross domestic expenditure on R&D and the number of researchers as inputs.

Ekinci and Karadayi (2017) analyses the R&D efficiencies of European Union (EU) member countries with by using DEA in order to measure the relative efficiency scores. The relative efficiency scores and hypothesis test results give valuable information for social policy makers in making decisions about planning R&D activities. Loukil (2016) dealt with his research Innovation Policy and R&D Efficiency in Emerging Countries and examined the impact of public support on R&D efficiency in 10 emerging countries over the period from 2001 to 2010. Results are different depending on the nature of the output (patents-oriented R&D efficiency or scientific publications). Ekinci and Ön (2015) attempt to analyse the R&D efficiencies of EU countries by used DEA and summarize the studies on R&D efficiencies of the 28 European Union countries.

Hu, Yang and Chen (2014) attention R&D efficiency and the national innovation system and applies the distance function approach for stochastic frontier analysis (SFA) to compare research and development (R&D) efficiency across 24 nations during 1998–2005. Aristovnik (2012) attempts to measure relative efficiency in utilizing R&D expenditures in the new EU member states in comparison to the selected EU (plus Croatia) and OECD countries and applies a non-parametric approach (DEA). Same author (Aristovnik, 2014) in the empirical analysis integrates across selected EU regions and available inputs (R&D expenditures, researchers and employment in high-tech sectors) and outputs (patent and high-tech patent applications) over the 2005–2010 interval. Roman (2010) investigates R&D efficiency at the regional level for Romania and Bulgaria between 2003 and 2005 by DEA analysis and highlights the common features of Romania and Bulgaria in terms of R&D activities and the existing differences in respect of knowledge based economy. Hudec and Prochadzkova (2013) evaluate to the relative efficiency of knowledge innovation processes in 19 countries of the European Union and study 19 countries of the European Union, with a particular focus on the efficiency of innovation processes in the Visegrad countries. The results of the evaluation by the DEA method shows that majority of countries reach higher relative innovation efficiency in knowledge commercialization than in knowledge

I: *Tab. I Statistic parameters of EU28 R&D indicators*

Indicator	Mean	Median	SD	Min	Country	Max	Country
GOVERD	0.20	0.18	0.095	0.02	MT10	0.41	DE15
HERD	0.41	0.38	0.225	0.05	BG15	0.99	DK15
BERD	0.93	0.74	0.675	0.08	CY10	2.59	FI10
Researchers (FTE)	61.620	31.968	89.5930	0.587	MT10	387.982	DE15
HRST	42.6	42.7	8.69	23.9	PT10	58.8	LU15
Empl. KIS sectors	38.5	35.9	7.66	19.8	RO10	55.2	LU10
High-tech exports	12.2	10.2	7.05	3.0	PT10	32.9	MT10
Sc. publications	34.347	16.397	47.0449	0.323	MT10	188.882	UK15

Source: Authors calculation according Eurostat (2017) and SJR (2017)

production and the most important slacks can be found in financing of research and development.

MATERIALS AND METHODS

EU28 countries represented by R&D indicators are our research objects. In all reports we use common abbreviations of EU28 countries with corresponding year (Austria – AT , Belgium – BE, Bulgaria – BG, Croatia – HR, Cyprus – CY, Czech Republic – CZ, Denmark–DK, Estonia–EE, Finland – FI , France – FR , Germany – DE, Greece – EL, Hungary – HU, Ireland – IE, Italy – IT, Latvia – LV, Lithuania – LT, Luxembourg – LU, Malta – MT, Netherlands – NL, Poland – PL, Portugal – PT, Romania – RO, Slovakia – SK, Slovenia – SI, Spain – ES, Sweden – SE, United Kingdom – UK) (for instance MT10 is abbreviation of Malta in the year 2010).

Data for the year 2010 and 2015, available at Eurostat (Statistic database – Research and Development) and Scopus database (Scimago Journal & Country Rank). We analysed suitable available seven indicators of R&D during two periods 2010 and 2015. From available indicators we chose following input indicators: 1) R&D expenditure by government sector – GOVERD (% of GDP), 2) R&D expenditure by higher education sector – HERD (% of GDP) , 3) R&D expenditure by business enterprise sector – BERD (% of GDP), 4) total researchers FTE – res. FTE (abbr. FTE = Full-time equivalent, it corresponds to one year's work by one person), 5) Human resources in science and technology – HRST (% of active population in the age group 25–64) and 6)Employment in high- and medium-high technology manufacturing sectors and knowledge-intensive service sectors (it is share of employment in high- and medium-high technology manufacturing sectors (C_HTC_MH) and in employment in knowledge-intensive service sectors (Empl. in KIS) of total employment. Data source is the European Labour force survey (LFS). The definition of high- and medium-high technology manufacturing sectors and of knowledge-intensive services is based on a selection of relevant items of NACE Rev. 2 on 2-digit level and is oriented on the ratio of highly qualified working in these areas), (Eurostat, 2017).

If we consider R&D production process as special type of production function (Y = f (K, L)) then three R&D relative expenditures are capital inputs and three human related indicators (Total researchers (FTE) – res. FTE, Human resources in science and technology – HRST and Employment in total knowledge-intensive service (Empl. in KIS) sectors) are human labour inputs. Two values of total researchers (FTE) were missing (France in 2015 and Greece in 2010). The values were estimated by linear regression model. Output indicators were: 1) number of scientific publications (Scimago – Sc. Public.), 2) high-tech exports as % of total export – HT-export (It is share of exports of all high technology products in total exports). High technology products are defined according to SITC Rev.4 as the sum of the following products: Aerospace, Computers-office machines, Electronics-telecommunications, Pharmacy, Scientific instruments, Electrical machinery, Chemistry, Non-electrical machinery, Armament), (Eurostat, 2017).

At first it is useful to find out basic statistic parameters of our EU28 R&D indicators. They are presented in Tab. I (Mean = arithmetic mean, SD = standard deviation, indicators Total researchers (FTE) and Number of scientific publications are in thousands). Standard deviation is relatively large in comparison with mean in case of Total researchers (FTE) and in case of scientific publications. It can

II: *Tab. II Spearman correlation coefficients among R&D inputs and R&D outputs in 2015*

Outputs / Inputs	GOVERD	HERD	BERD	Res. (FTE)	HRST	Empl. in KIS	Sc. publications	High-tech export
High-tech exports	−0.141 (0.009)	0.084 (0.110)	0.158 (0.295)	−0.045 (−0.076)	0.523** (0.437*)	0.546** (0.627**)	−0.045 (−0.004)	1.000 (1.000)
Sc. publications	0.136 (0.252)	0.460* (0.502**)	0.568** (0.419*)	0.990** (0.965**)	0.155 (0.223)	−0.231 (0.210)	1.000 (1.000)	−0.045 (−0.004)

Note1: **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)
Note2: Values in brackets belong to the year 2010
Source: Authors calculation according Eurostat (2017) and SJR (2017)

III: *Tab. III Statistic parameters of EU28 R&D indicators difference between 2015 and 2010*

Indicator	Mean	Median	SD	Min.	Country	Max.	Country	p-value
HERD	0.03	0.02	0.096	−0.13	Ireland	0.34	Slovakia	0.392
BERD	0.06	0.07	0,230	−0,66	Finland	0.42	Bulgaria	0.067
Res. FTE	8.764	3.620	14.9305	−12.213	Spain	59.984	Germany	0.008
HRST	4.5	4.3	2.59	0.0	Slovakia	10.9	Portugal	<0.001
Empl. in KIS	1.4	1.1	1.83	−3.1	Luxembourg	5.8	Malta	<0.001
HT–exports	0,0	0.7	3.71	−11.0	Luxembourg	5.1	Ireland	0.286
Sc. publications	5.687	2.789	6.4013	0.165	Bulgaria	22.460	Italy	<0.001

Note: SD – standard deviation; p -value – two sided p-value of one sample Wilcoxon test (median = 0)
Source: Authors calculation according Eurostat (2017) and SJR (2017)

indicate skewness of distributions and (or) outliers. From eight selected indicators relatively the most frequent minimum values were in case of Malta in 2010 (in three indicators). It could be expected in absolute indicators (Total researchers (FTE) and Number of scientific publications) because Malta is among the smallest countries of EU28. Maximum values are divided more equally among countries (Germany in 2015 – two indicators).

Before efficiency analyses it is reasonable to find out formal associations between group of inputs and group of outputs. There is no purpose to involve inputs that do not correlate with outputs. Associations among R&D inputs and outputs by Spearman correlation coefficients are presented in Tab. II Critical values of Spearman correlation coefficients are 0.264 ($p < 0.05$), 0.343 ($p < 0.01$) and 0.432 ($p < 0.001$), (Sachs, 1984). In the Tab. II we can see that expenditure by government sector (GOVERD) is not significantly correlated with any of two outputs. That is why we excluded R&D expenditure by government sector from further analyses.

In the Tab. III are results of nonparametric one sample Wilcoxon test of R&D indicator differences (between 2015 and 2010). Test hypothesis was: median of difference is equal to zero. Parameter "mean" is mean difference of values in 2015 and of values in 2010. We can see that in all analysed indicators there is increase (growth) between the year 2015 and the year 2010. But statistically significant increase is in case of three input indicators – Total researchers (FTE) ($p = 0.008$), Human resources in science and technology – HRST ($p < 0.001$) and in Employment in KIS sector ($p < 0.001$) From two output indicators only Number of scientific publications increased significantly ($p < 0.001$) In column "median" are medians of differences of values in 2015 and of values in 2010.

We wanted to involve all R&D relevant indicators and at the same time to obtain reliable and meaningful efficiency estimates for relatively small number of EU28 countries. So besides descriptive statistics and nonparametric statistical Wilcoxon tests we used super-efficiency slack based data envelopment analysis (abbr. DEA) model (Cooper et al., 2007; Tone, 2002). Classic DEA models are either input oriented (optimization of inputs) or output oriented (optimization of outputs). In our paper we use more general model of non-oriented non-radial super-efficiency slack based DEA model. The objective of slack based DEA model is to optimize both inputs and outputs simultaneously. And concept of super-efficiency enables to rank also efficient DMUs what is not possible in classic DEA models. The super-efficiency of (x_o, y_o) under variable returns to scale is the minimum of optimal objective function δ from the following equations (Cooper, 2007):

$$\delta = \frac{1/m\sum_{i=1}^{m} x_{i/x_{i0}}}{1/s\sum_{r=1}^{s} y_{r/y_{r0}}},$$

subject to

$$x \geq \sum_{j=1}^{n} \lambda_j x_j ,$$

$$y \leq \sum_{j=1}^{n} \lambda_j y_j ,$$

$x \geq x_0$ and $y \leq y_0$,

$$\sum_{j=1}^{n} \lambda_j = 1 ,$$

$y \geq 0, \lambda \geq 0$

As we shall present later the number of indicators involved in DEA analysis was somewhat reduced due to nonsignificant associations among some indicators. We assume if there is not at least formal significant association (e.g. correlation) between some input and output then there is no reason to involve them in DEA analysis. We used both classic Pearson correlation coefficients and robust Spearman coefficients.

We have got R&D data of EU28 countries from two periods – 2010 and 2015. In DEA methodology are two basic approaches in such a case. The first approach is to pool the data and estimate one single efficient frontier. This approach assumes an unvarying best-practice technology, which may be unrealizable in long panels. Thus we obtain efficiency estimates equal to number of periods for each DMU relatively against the one efficient frontier, and trends in efficiency estimates of individual producers may be of interest (Fried et al., 2008). The second approach uses sets of single periods for efficiency estimates (window analysis and Malmquist analysis). Window analysis estimates a sequence of overlapping pooled panels, each consisting of several time periods of suitable length. This option follows efficiency trends through successive overlapping windows. In Malmquist analysis two adjacent periods of data are used. It may look like two-period window analysis, but it is different. It is used to estimate and decompose Malmquist indexes of productivity change.

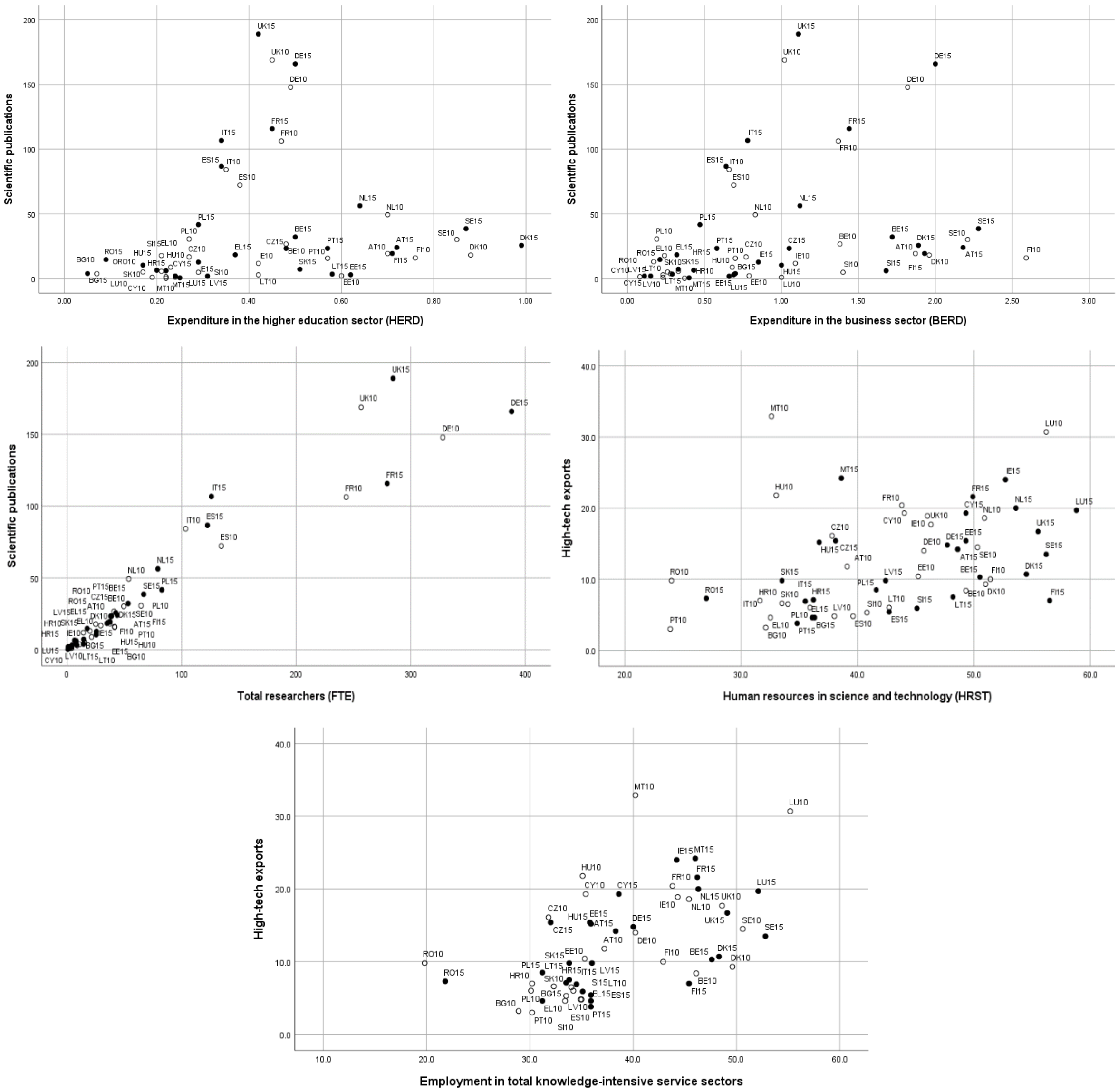
In our paper we used the first approach. Then the result of DEA analysis is one table with 56 efficiencies. It will be shown later that our efficiency problem is dependence of two R&D output indicators on five R&D input indicators. We have got 28 DMUs (abbr. Decision Making Units) in our case countries and seven corresponding R&D indicators. Minimum necessary number of DMUs is in our case 21 (3*(number of inputs + number of outputs) = (3*7). It is fulfilled (Cooper, 2007). In case of smaller number of DMUs the most of DMUs is efficient so worthwhile ranking is not possible. In our paper we use super-efficiency slack based DEA model to avoid the problem and also to avoid problems of so called slacks both in inputs and in outputs (Tone, 2002). Objective of our DEA model is to optimize both inputs and outputs simultaneously. We involve all countries from both periods at once.

Additive slack based DEA model is designated for general evaluation of transforming inputs to outputs. It does not restrict to output oriented approach whose objective is to maximize outputs with fixed inputs. Also it does not intend only to minimize inputs with fixed outputs (input approach). Slack based model involve all three possible scenarios for improvement of decision making units: larger outputs with fixed inputs or fixed outputs with smaller inputs or larger outputs with smaller inputs. If it is possible it tries to minimize inputs and maximize outputs simultaneously. If it is not possible then excess in output or shortage in output is given to zero (Tone, 2002).

For comparison of super-efficiencies we used nonparametric Wilcoxon one sample and two sample tests. Statistical reports and graphs were made in statistic software IBM SPSS version 19. Results of data envelopment analyses were obtained by DEA Solver Pro version 10.

RESULTS

In our analysis we evaluate indicators dependence of R&D in 2010 vs. 2015 in EU(28). Corresponding significant positive monotonous dependences among inputs and outputs are depicted in Fig 1 (empty circles belong to period 2010, black circles to 2015). Output indicator of high-tech exports (HTE) correlate with relative human inputs (HRST and Employment in KIS sector) ($p < 0.001$). On the other hand scientific publications correlate with relative shares of both HERD and BERD and with total researchers – FTE ($p < 0.001$). Human resources in science and technology and Employment in KIS do not correlate with number of scientific publications. We think that reason of it is in type of analysed indicators.



1: *Scatterplot of EU28 countries according to indicators dependence of R&D in 2010 vs. 2015*

a) Number of publications on input of expenditure R&D in the high education sector and in the business sector

b) Number of publications on total researchers (FTE) c) High-tech exports on HRST

d) High-tech exports on employment in total knowledge-intensive service sectors in 2010 vs. 2015

Source: Authors

Both human input indicators are relative (in %). But number of scientific publications is absolute indicator. So it is understandable they do not mutually correlate. The other reason is that in group of EU28 countries there are relatively very small countries (e.g. Cyprus, Malta) on one side and really large and significant countries like UK, Germany and France on the other side.

It is important to find out whether R&D inputs and outputs of EU28 countries changed significantly in location parameter (mean or median) between period 2015 and 2010. It can be done either by paired t test or by nonparametric one sample Wilcoxon test. Paired t test requires normal distribution of values but it is not fulfilled in case of our R&D indicators.

Now we can step to results of super-efficiency model of EU28 countries from the viewpoint of R&D in 2010 and 2015. In Tab. IV a, b there are results of non-oriented and non-radial super-efficiency slack based (SBM) DEA model with variable returns to scale. Table shows the way for countries to optimize both inputs (possible decrease) and outputs (possible increase).

IV: *a) Results of slack based VRS DEA super-efficiency model of EU28 countries from the viewpoint of R&D*

No.	DMU	Score	Excesses					Shortages	
			HERD	BERD.	Researchers FTE	HRST	Empl. in KIS	HT export	Scientific Publications.
1	MT10	1.360	0.027	0.000	0.2	6.506	4.806	9.160	0.0
2	CY15	1.152	0.000	0.000	0.6	0.000	0.000	0.000	0.0
3	BG10	1.150	0.014	0.000	6.0	0.000	0.000	0.000	0.0
4	CY10	1.135	0.020	0.030	0.0	5.300	3.200	0.000	0.0
5	RO10	1.129	0.000	0.038	0.0	4.960	4.317	0.000	0.0
6	BG15	1.105	0.026	0.000	0.0	0.000	0.000	0.000	0.0
7	RO15	1.099	0.021	0.000	4.5	0.000	0.000	0.000	0.0
8	UK15	1.071	0.030	0.000	0.0	0.000	0.000	0.000	20.2
9	IT15	1.068	0.000	0.000	21.5	3.712	2.228	0.000	0.0
10	PL10	1.066	0.000	0.063	0.0	0.000	0.000	0.000	0.0
11	DE15	1.030	0.000	0.000	0.0	2.304	4.108	0.000	0.0
12	UK10	1.028	0.000	0.003	0.0	6.415	0.000	0.000	0.0
13	HR15	1.026	0.000	0.000	0.8	0.000	0.000	0.000	0.0
14	LU10	1.018	0.017	0.000	0.0	0.000	0.000	0.000	0.0
15	NL10	1.016	0.000	0.000	4.3	0.000	0.000	0.000	0.0
16	HR10	1.000	0.000	0.000	0.0	0.000	0.000	0.003	0.0
17	PT10	0.999	0.000	0.000	0.0	0.000	0.005	0.003	0.0
18	DE10	0.866	0.078	0.459	41.1	0.000	0.000	0.865	0.0
19	FR10	0.752	0.139	0.603	83.1	0.000	0.000	1.765	0.0
20	FR15	0.751	0.108	0.617	105.0	3.289	0.555	1.389	0.0
21	IT10	0.728	0.053	0.006	0.0	0.000	0.405	4.236	0.0
22	MT15	0.631	0.023	0.121	0.0	0.000	6.527	3.268	0.4
23	NL15	0.627	0.360	0.532	0.0	15.831	5.198	5.361	0.0
24	CZ10	0.610	0.069	0.402	0.0	7.824	0.000	3.908	6.6
25	CZ15	0.570	0.267	0.645	0.0	7.640	0.000	3.361	7.6
26	HU10	0.567	0.035	0.308	0.0	1.761	1.264	0.000	9.1
27	IE15	0.547	0.071	0.435	0.0	20.536	8.112	0.000	8.7
28	IE10	0.547	0.187	0.676	0.0	13.086	4.719	11.180	0.0

Note: all indicators are in % units beside Researchers FTE and Sc. publications (in thousands)
Source: Authors calculation

b) Results of slack based VRS DEA super-efficiency model of EU28 countries from the viewpoint of R&D

No.	DMU	Score	Excesses					Shortages	
			HERD	BERD.	Researchers FTE	HRST	Empl. in KIS	HT export	Scientific Publications.
29	LU15	0.536	0.000	0.529	0.0	10.482	13.533	0.000	1.5
30	PL15	0.526	0.091	0.068	19.8	9.273	0.000	9.377	0.0
31	HU15	0.510	0.000	0.658	0.0	6.548	5.714	1.427	10.9
32	ES15	0.488	0.061	0.003	0.0	4.787	0.000	10.009	0.0
33	EE15	0.478	0.427	0.385	0.0	16.672	0.000	10.642	0.5
34	LV15	0.462	0.100	0.052	0.0	0.000	1.822	8.308	1.7

No.	DMU	Score	Excesses					Shortages	
			HERD	BERD.	Researchers FTE	HRST	Empl. in KIS	HT export	Scientific Publications.
35	SK15	0.432	0.314	0.000	0.0	2.800	0.000	14.287	3.8
36	EL10	0.412	0.030	0.000	0.0	0.000	4.142	11.936	0.0
37	AT15	0.403	0.477	1.726	14.9	15.638	0.000	12.261	0.0
38	SE10	0.386	0.598	1.723	3.7	14.072	8.990	15.833	0.0
39	SK10	0.379	0.013	0.000	0.0	5.992	4.486	11.795	5.5
40	AT10	0.374	0.471	1.452	13.1	6.878	0.000	14.435	0.0
41	ES10	0.358	0.135	0.141	25.9	2.473	0.000	12.819	0.0
42	SE15	0.358	0.609	1.760	8.5	18.954	10.794	16.113	0.0
43	EE10	0.346	0.406	0.524	0.0	10.933	0.000	13.983	1.3
44	BE15	0.337	0.246	1.225	4.6	14.032	5.897	19.864	0.0
45	LT15	0.318	0.398	0.000	0.0	15.753	0.000	15.237	3.4
46	DK15	0.301	0.741	1.422	11.9	21.208	9.460	15.996	0.0
47	BE10	0.299	0.232	0.907	0.6	13.499	4.656	22.235	0.0
48	LT10	0.285	0.223	0.000	0.0	6.377	0.000	15.018	4.6
49	EL15	0.283	0.154	0.000	7.2	0.364	0.000	19.224	0.0
50	SI15	0.276	0.033	1.346	0.5	13.972	0.000	19.590	0.0
51	FI10	0.256	0.522	2.160	22.4	18.372	3.540	19.066	0.0
52	DK10	0.247	0.640	1.521	15.8	17.913	10.358	19.231	0.0
53	SI10	0.245	0.110	1.093	0.9	10.738	0.000	19.379	0.0
54	LV10	0.233	0.037	0.037	0.0	0.000	0.000	17.010	2.6
55	FI15	0.210	0.468	1.486	14.4	23.378	6.226	21.221	0.0
56	PT15	0.204	0.357	0.184	3.4	2.005	0.000	21.476	0.0

Note: all indicators are in % units beside Researchers FTE and Sc. publications (in thousands).
Source: Authors calculation

Seventeen countries are efficient from overall 56 cases (28 countries in two time periods). In the table IV beside super-efficiency score values there are also values of possible improvements of all countries from the viewpoint of efficiency. In case of inputs they should be subtracted from original data values (excesses). On the opposite so called shortages should be added to outputs to improve efficiency. But we present excesses and shortages not for real subtraction or addition. They serve as peers for not efficient countries to become efficient. For example if there is an excess in some input then country has got excess in that input in comparison with corresponding efficient countries. For corresponding efficient countries there is needed less amount of input than in case of not efficient country to obtain the same outputs. On the other side if there is a shortage in some output then country has got shortage in that output in comparison with corresponding efficient countries. In this case larger amount of output is produced in corresponding efficient countries than in case of not efficient country with the same inputs.

It should be noted that zero values in potential improvements are either identical zeros or negligible values close to zero. Meaning of improvement is „The projection of a super-efficient DMU designates the nearest point on the production possibility set excluding the DMU“ (DEA Solver Pro Users Guide). In 2010 the last efficient country was Portugal but in 2015 Portugal fell down to the position of least efficient country of all EU28 countries. In 2010 for Portugal there was no opportunity to relative improvement. But in 2015 its position worsened a lot. There was surplus input of R&D expenditure in higher education sector by 0.357% and of R&D expenditure in business sector by 0.184%. Also HRST employment was excessive by 2%. It means productivity of these inputs was worse than it was in 2010. On the other side there is also shortage in outputs in case of high-tech export. It should be increased by 21.476% to become efficient.

The development of relative positions of V4 countries is not very positive. Three of them – Poland, Hungary and Czech Republic worsened more or less their positions. The largest decrease was in case of Poland from efficient position (rank 10) to score 0.526 (rank 30). Only Slovakia improved slightly its efficiency from 0.379 to 0.432 but still remained inefficient. Slovakia in 2010 had got following excesses in inputs: R&D expenditure in higher education sector – 0.013%, HRST – 5.992%, Empl. KIS – 4.486%. In 2015 position of Slovakia somewhat improved (smaller excess in HRST – 2.8% and zero excess in Empl. KIS), but larger excess was in R&D expenditure in higher education sector (–0.314%). Situation in the field of outputs was contradictory: shortage in high tech export increased (from 11.795% to 14.287%), but shortage in scientific publications decreased (from 5,500 to 3,800 scientific publications).

Czech Republic rather stagnates. Excesses in R&D expenditure in higher education sector (from 0.069% to 0.267%) and of R&D expenditure in business sector increased (from 0.402% to 0.645%) while shortages in outputs are almost the same. In Hungary was development similar – slight decrease in efficiency (from 0.567 to 0.510). Small excess in R&D expenditure in higher education sector (0.035%) vanished in 2015 but R&D expenditure in business sector excess increased from 0.308 to 0.658. Also shortages in other inputs increased: HRST (from 1.761% to 6.548%) and employment in KIS (from 1.264% to 5.714%). There was increase also in output shortages – high tech export from zero to 1.427% and scientific publications from 9.100 to 10.900. The fall of Poland from V4 countries was the most dramatic. In 2010 Poland belonged to relatively the best EU28 countries but it went down to rank 30 in 2015. Well excesses in total researchers (FTE) and HRST increased from zero to 19.800 researchers (FTE) and to 9.273% (HRST) what is large increase. In field of outputs was large increase in case of high tech export (from zero to 9.377%).

Tab. V shows ranking of EU28 countries by their status (efficient vs. inefficient). From the viewpoint of super-efficiency values relatively the best five cases were: Malta in 2010, Cyprus in 2015, Bulgaria in 2010, Cyprus in 2010 and Romania in 2010. On the other side there is group of the worst five cases: Portugal in 2015, Finland in 2015, Latvia in 2010, Slovenia in 2010 and Denmark in 2010.

We can see that the best group of five countries with efficient status in both analysed periods 2010 and 2015 includes: Bulgaria, Romania, Cyprus, Croatia and United Kingdom. Difference of efficiency scores (2015 – 2010) is negligible so we can conclude that they stagnated in efficient status. It can be surprising that two less developed countries – Bulgaria and Romania are among the best ones. The purpose of efficiency analyses is to evaluate input utilisation of inputs for production of outputs. Both Bulgaria and Romania have got relatively small available R&D inputs but were able to produce relatively large R&D outputs. The size of country is not disadvantage as can be seen in case of Cyprus. For possible comparisons of larger countries with smaller ones we used DEA model with variable returns to scale. But we must keep in mind that results depend heavily on used indicators. In second group are five countries that worsened their status from efficient in 2010 to inefficient one in 2015: Portugal (on edge of efficiency), Malta, Poland, Luxembourg and Netherlands. Difference of efficiency scores is negative and notable. The third group contains opposite group of two countries – Germany and Italy. They improved status from inefficient to efficient. Difference of their efficiency scores is positive and notable. In last fourth group are all other EU28 countries that were inefficient in both analysed periods 2010 and 2015. Some of them stagnated in inefficient status (Hungary, Finland, Czech Republic, Sweden, France, Ireland, Austria, Slovenia, Lithuania, Belgium, Slovakia and Denmark) with difference around zero. The other improved their efficiency but still stayed inefficient – Spain, Estonia and Latvia. Difference of their efficiency scores is positive and notable. Relatively the worst group involves only Greece that worsened their inefficient status to even more inefficient one. Difference is negative and notable.

Relative positions of EU28 countries according to their super-efficiency scores of R&D indicators in 2010 and in 2015 are depicted in the Fig.2. Identity line is also depicted for classification of efficient status (super-efficiency ≥ 1.000 means efficient status vs. super-efficiency < 1.000 (inefficient status)).

If we focus on V4 countries then situation is not optimistic. Poland worsened its status from efficient in 2010 to inefficient one in 2015. And three remaining countries – Hungary, Czech Republic and Slovakia stagnated in inefficient

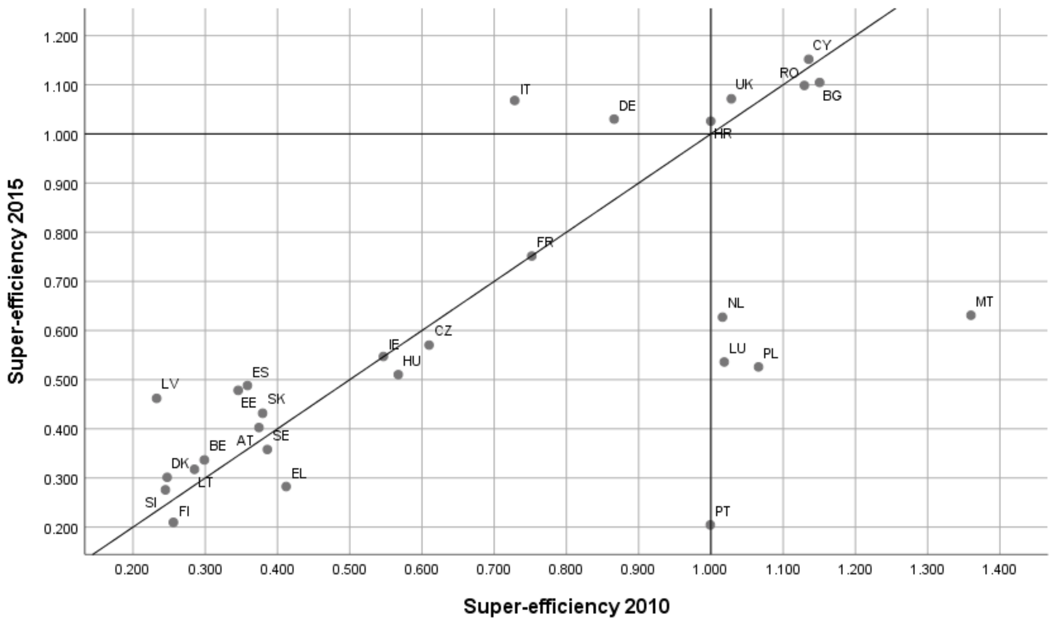
V: *Super-efficiencies of EU28 R&D indicators in the year 2010 and 2015*

Rank	DMU	Score10	Status10	Rank	DMU	Score15	Status15	DiffScore
3	BG10	1.150	Efficient	6	BG15	1.105	Efficient	−0.046
5	RO10	1.129	Efficient	7	RO15	1.099	Efficient	−0.031
4	CY10	1.135	Efficient	2	CY15	1.152	Efficient	0.017
16	HR10	1.000	Efficient	13	HR15	1.026	Efficient	0.026
12	UK10	1.028	Efficient	8	UK15	1.071	Efficient	0.043
1	MT10	1.360	Efficient	22	MT15	0.631	Inefficient	−0.729
10	PL10	1.066	Efficient	30	PL15	0.526	Inefficient	−0.540
14	LU10	1.018	Efficient	29	LU15	0.536	Inefficient	−0.482
15	NL10	1.016	Efficient	23	NL15	0.627	Inefficient	−0.389
18	DE10	0.866	Inefficient	11	DE15	1.030	Efficient	0.164
21	IT10	0.728	Inefficient	9	IT15	1.068	Efficient	0.340
17	PT10	0.999	Inefficient	56	PT15	0.204	Inefficient	−0.795
36	EL10	0.412	Inefficient	49	EL15	0.283	Inefficient	−0.129
26	HU10	0.567	Inefficient	31	HU15	0.510	Inefficient	−0.057
51	FI10	0.256	Inefficient	55	FI15	0.210	Inefficient	−0.046
24	CZ10	0.610	Inefficient	25	CZ15	0.570	Inefficient	−0.040
38	SE10	0.386	Inefficient	42	SE15	0.358	Inefficient	−0.028
19	FR10	0.752	Inefficient	20	FR15	0.751	Inefficient	0.000
28	IE10	0.547	Inefficient	27	IE15	0.547	Inefficient	0.001
40	AT10	0.374	Inefficient	37	AT15	0.403	Inefficient	0.028
53	SI10	0.245	Inefficient	50	SI15	0.276	Inefficient	0.031
48	LT10	0.285	Inefficient	45	LT15	0.318	Inefficient	0.033
47	BE10	0.299	Inefficient	44	BE15	0.337	Inefficient	0.038
39	SK10	0.379	Inefficient	35	SK15	0.432	Inefficient	0.052
52	DK10	0.247	Inefficient	46	DK15	0.301	Inefficient	0.054
41	ES10	0.358	Inefficient	32	ES15	0.488	Inefficient	0.130
43	EE10	0.346	Inefficient	33	EE15	0.478	Inefficient	0.133
54	LV10	0.233	Inefficient	34	LV15	0.462	Inefficient	0.229

Note1: Rank – overall rank of country in two analysed years; Score – super-efficiency score by SBM DEA model; DiffScore = Score2015 – Score2010; Note 2: PT (10) evaluated as Efficient.
Source: Authors calculation according Eurostat (2017) and SJR (2017)

status in both periods. In the figure 1 there is scatterplot of super-efficiency scores with identity line and lines with super-efficiency scores equal to one for both periods. Countries above (below) identity line improved (worsened) their super-efficiency scores from 2010 to 2015. Beside already mentioned classification of EU28 countries we can see clusters of EU28 countries with similar super-efficiency scores (e.g. one cluster of Netherlands (NL), Luxembourg (LU) and Poland (PL) just above Portugal (PT) or second cluster of Cyprus (CY), Romania (RO) and Bulgaria (BG) in right part of identity line). Solitary outlying EU28 countries are Malta (MT), Portugal (PT), France (FR), Germany (DE) and Italy (IT).

Now let us look again at Fig. 1. Now it is clear why countries like – Bulgaria, Romania, Cyprus, Croatia and United Kingdom belong among the best EU28 countries from the viewpoint of R&D indicators development. They were on efficient production frontiers in most of their production sets in 2010 and in 2015. But such visualisation is simplifying since it is viewpoint of one input and one output in R&D production process. Some other countries were near to efficient production frontiers (Germany, Italy, Malta, Poland, Luxembourg



2: *Scatterplot of EU28 countries according to R&D super-efficiencies 2010 vs. 2015*
Source: Authors

VI: *Parameters of super-efficiencies of EU28 R&D indicators in the year 2010 and 2015*

Group	Parameter	Score2010	Score2015	DiffScore
Cap.	Mean	0.693	0.588	-0.105
	Median	0.728	0.536	0.001
	SD	0.3575	0.3200	0.3108
Postsoc.	Mean	0.637	0.618	-0.019
	Median	0.567	0.510	0.026
	SD	0.3768	0.3070	0.1926
p-value		0.677	0.853	0.746

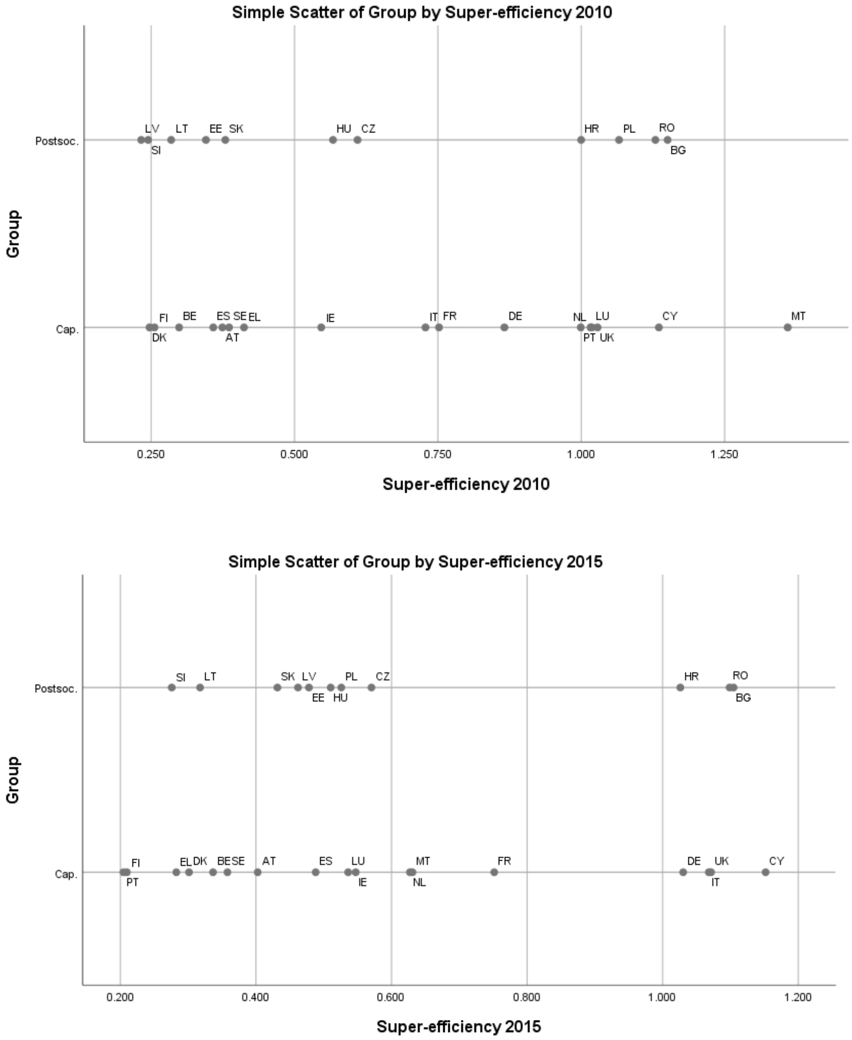
Note: *p*-value – two sided p value of two sample Wilcoxon test
Source: Authors calculation according Eurostat (2017) and SJR (2017)

and Netherlands). They were efficient in one of analysed periods. Countries placed in lower right part of scatterplots belong to less-successful ones.

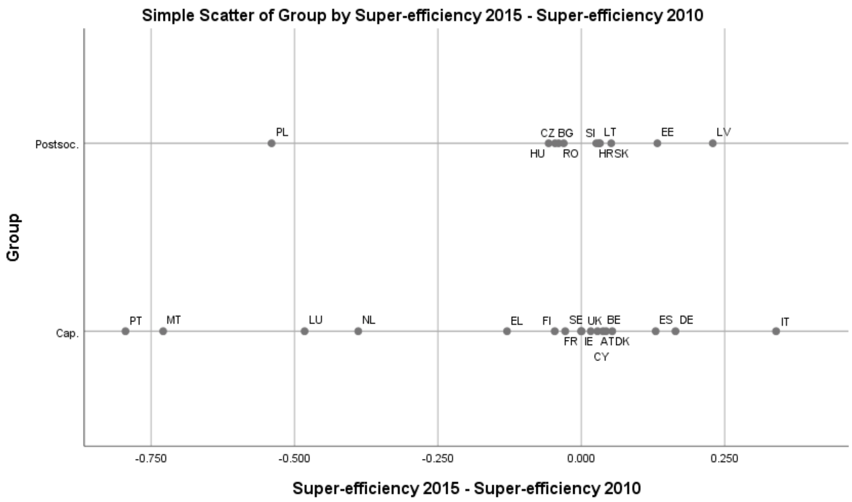
It is possible to compare EU28 countries on basis of their classification to two basic economic groups – capitalist and post-socialist countries. But we must keep in mind that comparison of original R&D input and output indicators has not any sense since two of used R&D indicators are absolute (total researchers – FTE, publications) and such large countries like United Kingdom, France and Germany would distort results. But it is possible to compare super-efficiencies of capitalist vs. post-socialist countries. In Tab. VI are presented results of two sample Wilcoxon test of differences of efficiency scores (2010, 2015 and their difference) between group of capitalist and post-socialist countries. There is not significant difference in super-efficiencies in 2010 and in 2015 and in their differences between capitalist and post-socialist EU28 countries.

In Figs. 3, 4 are depicted corresponding super-efficiencies and their differences in both capitalist and post-socialist EU28 countries.

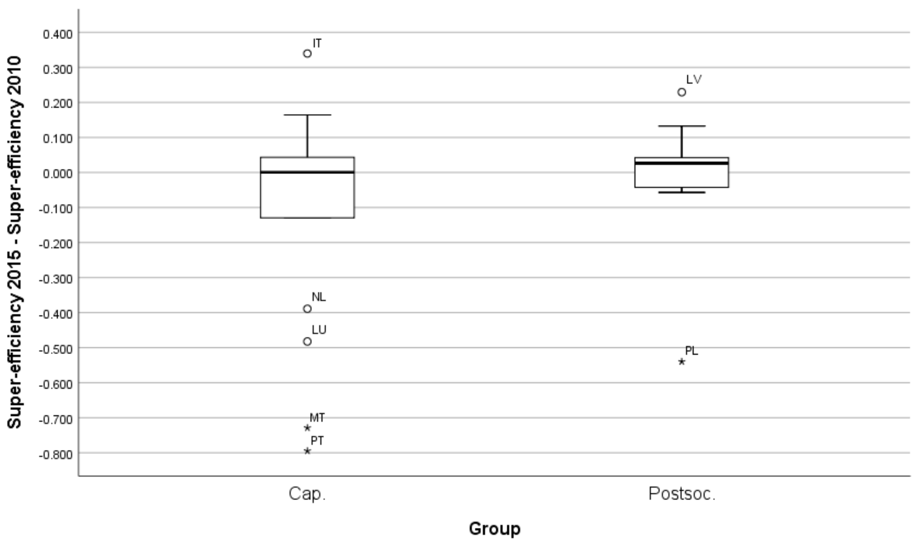
Also it is useful to examine homogeneity of data. In case of separate super-efficiencies there is not any outlier country. But in case of their difference there are three outliers depicted in boxplot (Fig. 5). In group of capitalist countries are two outliers – Malta and Portugal. From post-socialist countries it is Poland. It means that their super-efficiencies worsened significantly more in comparison with other countries in corresponding group.



3: *Dotplot of R&D super-efficiency values comparison between capitalist countries and post-socialist countries in 2010 and 2015*
Source: Authors



4: *Dotplot of R&D super-efficiency values difference (2015-2010) comparison between capitalist countries and post-socialist countries*
Source: Authors



5: *Boxplot of R&D super-efficiency values difference (2015-2010) comparison between capitalist countries and post-socialist countries*
Source: Authors

DISCUSSION

The evaluation and measurement of R&D efficiency, innovation policy and selected indicators by used of DEA in both EU and international dimensions are solved a by number of older and more recent research such as Aristovnik (2012, 2014); Ekinci and Karadayi (2017); Ekinci and Ön (2015); Hudec and Prochadzková (2013); Lee and Park (2005); Roman (2010); Rousseau and Rousseau (1997); Sharma and Thomas (2008). Various approaches to evaluating R&D and innovation performance (different sample size, number and structure of the input and output indicators monitored, objectives, methods used) can be found in the literature. In our paper we used super-efficient non-oriented non-radial slack based data envelopment analysis model of available R&D indicators (five input indicators and two output indicators) of EU28 countries. During our analyses latest available patent data were from 2014 and most of them were only estimations. That is why we did not involve patent indicator to our paper. Disadvantage of patent indicator is its late availability in comparison with other R&D indicators.

In our R&D analysis by used DEA super-efficiency in 28 countries, showed that ten countries was efficient in 2010 and seven countries in 2015. From our results we can conclude that the first research question (RQ1) was not confirmed. For some advanced countries, with high R&D intensity, high R&D efficiency has not been identified, which does not mean that they are inefficient. It should be kept in mind that R&D efficiency is influenced not only by the priorities of national R&D policies, but also by economic and political factors, by national state bases and by the use of input potential. In particular R&D efficiency expenditure and the quality of outputs play an important role.

Results of (Conte et al. (2009) indicate large cross-country differences in terms of measured efficiency, which is an indication that in many Member States remains a significant potential for further improvement. Currently, there is appears to be a division in efficiency levels between old and new Member States. Research innovation policy and R&D efficiency are different depending on the nature of the output. From our results also follows that R&D efficiency is not influenced by R&D and input innovation potential in most of EU28 countries. It means that also the second research question RQ2 was not confirmed. In case of Bulgaria, Cyprus, Malta, Romania (states entering the EU after 2004 with minimum financial input and human resources), there is a more progressive trend in research and development and efforts to achieve maximum outputs in scientific research activities (e.g. in publications on However, the quality of the outputs should be taken into account, e.g. citations of publications, which would not be correct in our case because of near period 2015 (Hirsch, 2005).

When evaluating the efficiency, a number of authors used a different time period as well as different sample sets, i.e. EU 28 countries respectively. EU countries (27), other surveys target only selected countries (e.g. 19, 22 or 24 countries) on so-called new EU countries, V4 countries, OECD countries or selected developing countries, so it is very difficult to evaluate our achieved results with other research (Hu, Yang and Chen (2014); Hudec and Prochadzkova, 2013; Lee and Park, 2005; Sharma and Thomas, 2008; Wang and Huang, 2007). Some existing studies on R&D efficiency have either failed to use the concept of time lags between inputs and outputs Rousseau and Rousseau 1997) or have compared relative R&D efficiency of countries using CRS (Constant Returns to Scale) or VRS (Variable Returns to Scale) formulations (Lee and Park, 2005; Wang and Huang, 2007; Sharma and Thomas, 2008). Also other authors (e.g. Aristovnik, 2012; Hu, Yang and Chen, 2014; Hudec and Prochadzkova, 2013) used expenditure on R&D and the number of full-time researchers per million population as input indicators when assessing the efficiency of R&D by DEA method, just like us, and the number of scientific publications indexed in the Science Citation Index as output indicators.

An analysis of (output-oriented) efficiency measures according Aristovnik (2012) shows that the new EU member states (Cyprus and Hungary) dominate in the field of R&D sector, even if for different reasons. The empirical results suggest that, in general, new EU member states show relatively high efficiency in tertiary education, while lag well behind in the R&D efficiency measures. The results of other studies have shown that R&D efficiency and innovation policy in EU countries differs in relation to the indicators used. Study authors Ekinci and Karadayi (2017) comparing all of the EU countries' R&D efficiencies and by exploring the effect of the country-level conditions on R&D efficiency of the countries. This research used as outputs (number of publications including citable, number of patents) and as inputs (R&D expenditures BERD, GOVERD and HERD, the number of full time R&D personnel hired in all sectors, the number of people with tertiary education and employed in science and technology, employment in high and medium-high technology manufacturing sectors and knowledge-intensive service sectors). The results reveal that there are 11 countries (Austria, Croatia, Cyprus, Germany, Italy, Luxembourg, Netherlands, Poland, Romania, Sweden and United Kingdom) which are fully efficient in terms of R&D, and 17 countries which are relatively inefficient. Hence, it can be argued that a majority of countries are inefficient in terms of R&D. The lowest three efficiency scores belong to Lithuania, Latvia and Hungary. Moreover Bulgaria, Estonia, Malta and Slovakia have low efficiency scores when we compare them with other EU countries, and they are also far from the average efficiency score, which is 0.855. The countries which have almost average efficiency scores are Belgium, Czech Republic, Finland, France, Greece, Ireland, Portugal and Slovenia. Denmark and Spain seem almost fully efficient since their efficiency scores are very close to 1.

In the study by Tarnawska and Mavroeidis (2015), efficiency of R&D policy was evaluated in 25 EU member states in year 2012. These authors used three inputs (Research and development personnel, by sectors of performance, Intersectoral mobility of researchers, Expenditure on public and private educational institutions per student PPP) and three outputs (High-technology exports% exports, Scientific and technical publications, SME introducing marketing/organisational innovations (% of SMEs). Results show that under DEA output-oriented VRS model, 16 countries are technically efficient, variation among the efficiency scores is small (coefficient of variation amounts to 25%). A more detailed analysis of output efficiency indices reveals that there are countries: Bulgaria, Greece, Lithuania, Spain and Slovakia, which have a large potential for improvement. Bulgaria has 62% potential improvement on average, Slovakia 40%, Spain 37%, Greece 36% and Lithuania 33%. In three countries (Bulgaria, Greece and Lithuania), the values of EKTEI index are the lowest which suggests that in these countries, a problem of a relatively low level of high-tech exports should be addressed in the first place as actual knowledge triangle policy mix does not give good results concerning their ability to export innovative goods. In the article Hudec and Prochadzkova (2013), the innovation efficiency of knowledge innovation process and its two sub-processes is measured by DEA modelling in the period of 2004–2010. Authors evaluated 19 countries of the European Union, with a particular focus on the efficiency of innovation processes in the Visegrad countries. In this research was used as Inputs the number of scientists and researchers employed full time, R&D expenditures of private and public sector, The labour force out of the R&D, Accumulated "knowledge stock" in the process of commercialization and as outputs (International scientific papers, the number of patents, Added value of industries (VAD), The export of new products in high-tech industries). Findings suggest that although the efficiency of innovation processes would have been expected higher in the old EU member countries, their efficiency is lower than in some of the Visegrad countries. Similarly to our research, the Scandinavian countries, Austria and France were evaluated as inefficient. Authors show that the reason may be the ability of the Visegrad countries to generate relatively satisfactory outputs from low inputs compared with other countries. Surprisingly, they are also in a group of high performers in bringing innovations to market, although they show substantial deficiencies in generating patents and papers.

Also results of our analysis are rather surprising since some post-socialist developing countries (Bulgaria, Romania and Croatia) and two small countries (Cyprus and Malta) are among the best ones while on the other side some developed countries (like e.g. Ireland, Finland) are not efficient. We must keep in mind that our viewpoint is only research and development production. It does not concern standard of living, social system support, wages, healthcare quality, high education system quality etc. Why we used in our research and efficiency R&D slack based DEA model? Slack based model involve all three possible scenarios for improvement of decision making units: larger outputs with fixed inputs or fixed outputs with smaller inputs or larger outputs with smaller inputs. Slack based DEA model is able to solve problem of so called weak efficiency or pseudo-efficiency when some units are efficient because of slacks in basic DEA input or output oriented models. Slacks can be easily identified in case of two or three indicators but we have efficiency problem in seven dimensional space of indicators. Another reason is in type of used available R&D indicators. We used output indicator – number of scientific publications. It is just overall aggregate number of research documents from SCOPUS database (articles, proceedings etc.) and does not tell about the quality of publications. Publications from other databases (Web of Science) were not available for our research.

CONCLUSION

The objective of the article was to evaluate the efficiency of the research and innovation potential of European Union countries in two periods – 2010 and 2015. We used super-efficient non-oriented non-radial slack-based data envelopment analysis model of available R&D indicators (five input indicators and two output indicators) of EU28 countries. Statistically significant increase between 2010 and 2015 was in case of three input indicators – Total researchers (FTE) ($p = 0.008$), Human resources in science and technology ($p < 0.001$) and in Employment in KIS sector ($p < 0.001$) and one output indicator – Number of scientific publications increased significantly ($p < 0.001$). In our R&D analysis by used DEA super-efficiency, showed that ten countries were efficient in 2010 and seven countries in 2015. In the best group there are five countries with efficient status in both analysed periods (Bulgaria, Romania, Cyprus, Croatia and United Kingdom). Germany and Italy improved their status from inefficient in 2010 to efficient in 2015. Five countries worsened their status from efficient in 2010 to inefficient one in 2015 (Portugal, Malta, Poland, Luxembourg and Netherlands). In last fourth group are all other EU28 countries that were inefficient in both analysed periods 2010 and 2015. From the viewpoint of super-efficiency values relatively the best five cases were Malta in 2010, Cyprus in 2015, Bulgaria in 2010, Cyprus in 2010 and Romania in 2010. On the other side there is a group of the worst five cases Portugal in 2015, Finland in 2015, Latvia in 2010, Slovenia in 2010 and Denmark in 2010.

The most significant reduction in R&D efficiency in EU countries (from overall 56 cases) in 2015, compared to 2010, was found in Malta (from the 1st to 22nd place), Poland (from 10th to 30th place), Luxembourg (from 14th to 29th place), and the Netherlands, from 15th place in 2010 to 23rd place in 2015. In contrast, the most significant increase in R&D efficiency in 2015, in comparison to 2010, was proved in Germany (from 18th to 11th place) and Italy (from 21st to 9th place). Out of the 16 inefficient countries in 2015, compared to 2010, decrease in R&D efficiency was found in five countries, by contrast, a mild increase in R&D efficiency was found in nine countries, and in case of two countries, R&D efficiency remained unchanged. Recommendations leading to increased R&D efficiency vary across EU countries. In the majority of inefficient countries, emphasis is put on the increase and production of outputs, namely in the present case high-tech exports as % of total export under current inputs. The next recommendations are directed to R&D efficiency and an efficient use of input indicators, namely human resources in science and technology and researchers, who bear the outputs.

Based on the results obtained on the basis of the selected indicators (input and output), it has not been confirmed that the volume of input R&D potential affects R&D efficiency in the observed EU countries. The results also failed to confirm that countries with a high R&D intensity attain a high R&D efficiency. By contrast, there is no significant difference in super-efficiencies in 2010 and in 2015 and in their differences between capitalist and post-socialist EU28 countries.

New methodological approaches to evaluation and measuring of efficiency R&D appear in the scientific world, applying not only direct but also indirect descriptors or indicators. Finally, the limitations of the study should be mentioned. The first major limitation results from the quality of data inputs. Data quality and the significance of the data are relative. The DEA analysis has also some limitations. Our viewpoint was only research and development production and does not concern standard of living, social system support, wages, healthcare quality, high education system quality etc. This can be seen as a stimulus for further on-going research in the future.

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