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ANALYSIS OF THE RESEARCH AND DEVELOPMENT EFFICIENCIES OF EUROPEAN UNION COUNTRIES

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ABSTRACT

Research and Development (R&D) activities of the countries are of crucial importance in order to compete in the emerging market. Although this importance is widely recognized, the efficiency of these activities has been rarely examined in the literature. Therefore, this study is an attempt to analyze the R&D efficiencies of European Union (EU) member countries. EU countries are selected for this study since the competition between these countries is very high and they invest a significant amount of resources in this area. Data Envelopment Analysis (DEA) is used in order to measure the relative efficiency scores. Then, the effect of political and regulatory environment on R&D efficiencies of EU countries is analyzed via hypothesis testing. The relative efficiency scores and hypothesis test results give valuable information for social policy makers in making decisions about planning R&D activities. The findings will also be useful for the countries aiming to participate the union, such as Turkey.

Keywords: *Data Envelopment Analysis; EU Countries; R&D Efficiency*

JEL Classification: *C610*

AVRUPA BİRLİĞİ ÜLKELERİNİN ARAŞTIRMA VE GELİŞTİRME ETKİNLİKLERİNİN ANALİZİ

ÖZ

Ülkelerin Araştırma ve Geliştirme (Ar-Ge) faaliyetleri gelişmekte olan pazarda rekabet edebilmek adına büyük önem taşımaktadır. Bu önem yaygın olarak kabul edilmesine rağmen, Ar-Ge faaliyetlerinin etkinliği literatürde nadir olarak incelenmiştir. Bu nedenle, bu çalışma Avrupa Birliği (AB) üyesi ülkelerin Ar-Ge verimliliğini incelemeyi amaçlamaktadır. Çalışma kapsamında, ülkeler arasındaki rekabetin çok yüksek olduğu AB ülkeleri seçilmiştir, ayrıca bu ülkeler Ar-Ge faaliyetlerine ciddi miktarda kaynak ayırmaktadırlar. Veri Zarflama Analizi (VZA) göreceli etkinlik skorlarını ölçmek için kullanılmıştır. Sonrasında, AB ülkelerinin siyasi ve düzenleyici ortamının Ar-Ge verimliliği üzerindeki etkisi hipotez testleri ile analiz edilmiştir. Göreceli etkinlik

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skorları ve hipotez testlerinin sonuçları, sosyal politika düzenleyiciler için Ar-Ge faaliyetlerinin planlanması konusunda karar vermede değerli bilgiler vermektedir. Çalışmanın sonuçları ayrıca Türkiye gibi, AB'ye katılmak isteyen ülkelere fayda sağlayacaktır.

Anahtar Kelimeler: *Veri Zarflama Analizi; AB Ülkeleri; Ar-Ge Etkinliği*

JEL Sınıflandırması: *C610*

1. INTRODUCTION

It has been well recognized in the last century that; in order to gain a competitive advantage in the world, effective utilization of intangible assets such as knowledge, skills and innovative potential is very important. This fact motivates countries to invest on Research and Development (R&D) activities more than ever. This point motivates us to perform an analysis of R&D efficiencies of countries. European Union (EU) is selected as a region since the competitiveness is relatively higher in this area compared to the other regions in the world (Güngör, 2016: 280). Another motivation for this study is to provide some useful information for the candidate countries such as Turkey. The information gathered from this study can be used by Turkey in order to be able to compete with the EU countries in terms of R&D activities. Turkey's application to accede to the European Economic Community was made on 14 April 1987, and Turkey was officially accepted as a candidate for full membership on 12 December 1999 -the Helsinki summit of the European Council-. Negotiations for full membership began on 3 October 2005, however, they have not been resulted positively for Turkey until now.

R&D efficiencies of the EU countries will be calculated by using some inputs and outputs related to R&D activities since efficiency can be described as the ratio of output to input. Absolute or optimum efficiency is obtained if the greatest possible output per unit of input is realized. In the case of optimum efficiency, it is not possible to become more efficient unless new technology or other changes in the production process are performed (Sherman & Zhu, 2006:3). If there are many inputs and outputs rather than one, the efficiency may be calculated as a weighted sum of its outputs divided by a weighted sum of its inputs. This is the most common way for evaluation of efficiency of multi-input and multi-output cases. Formulation of the preference of these weights is constructed as a Linear Program (LP) by a method, which is called DEA (Doyle & Green, 1994:567). DEA is a LP based non-parametric method of measuring the relative efficiency of a Decision Making Unit (DMU) with respect to other DMUs in the analysis. Charnes, Cooper and Rhodes (1978) first introduced DEA into the Operations Research (OR) literature. The most important property that DEA distinguishes from the other efficiency calculation methods is being able to make evaluations with multiple inputs and outputs. This makes DEA a powerful benchmarking technique, which compares different DMUs and finds the relatively "best" DMU; which also motivates us to use this method in this study (Sherman & Zhu, 2006:3). Initially DEA was only applicable for estimating relative efficiency in the public and non-profit sectors. Afterwards, it has been applied to various sectors to analyze the comparative/relative efficiency of homogeneous DMUs such as hospitals, supermarkets, banks, etc (Alp & Sözen, 2014:87).

Another aim of this this study is to investigate if there is a relationship between the countries' R&D efficiency scores and their political and regulatory environments. The motivation under this aim is that; political and regulatory environments are important factors that affect the development of the countries, hence R&D efficiencies. For this aim, *government effectiveness index* and *regulatory quality index* values (Dutta & Lanwin, 2013) are used. Hypothesis tests are performed using the efficiency scores and these index values of the countries.

The rest of the paper is organized as follows. The previous studies on R&D activities of countries are given in Section 2. Section 3 gives brief explanation about DEA models. The proposed R&D efficiency evaluation framework is described in Section 4. Section 5 gives the numerical results and Section 5 finalizes the paper with conclusions and suggestions.

2. LITERATURE REVIEW ON R&D EFFICIENCY

R&D efficiency is a relatively new subject in the literature, hence there are not many studies on this subject. There two groups of studies; the first group discusses the indicators that are important on determining the R&D activities' efficiency; and the second group performs numerical analysis to measure the efficiencies. The techniques used in the second group are; Malmquist Productivity Index (Thomas et al, 2009:4; Han et al., 2014:1), DEA (Wang, 2007:345; Lee et al., 2008:250; Cullmann et al., 2009:3; Garcia-Valderrama et al, 2009:1177; Roman, 2010:33; Aristovnik, 2012:832; Lee &Yoon, 2015:250; Han et al., 2014:1), Stochastic Frontier Analysis (Wang, 2007:345; Hu et al, 2011:55), and Regression Analysis (Lee & Yoon, 2015:250). The numerical studies -which are recent studies due to above mentioned reason- show that DEA is the most widely used technique in measuring R&D efficiency. One of the reasons that researchers/practitioners use DEA widely is that, for the inefficient DMUs, it provides scenarios on how to increase their efficiencies (Doyle & Green, 1994:567). In other words DEA determines the amount and type of resource savings that can be obtained by making each inefficient unit as efficient as the most efficient - best practice – units. This allows the management to implement the suggestions derived from the results to achieve potential savings by utilizing the specific changes in the inefficient service units. Moreover, DEA finds out the amount of additional service that an inefficient unit can provide without the need of additional resources. Thus, DEA method is a very useful tool for the managers and policy makers (Sherman & Zhu, 2006:3).

Some of the numerical studies (second group) measure the efficiencies of companies, while some studies measure the efficiencies of countries or some regions. The country-based analysis provide the policy makers valuable insights, therefore our study aims to do the analysis is for comparable countries, namely EU countries. Since the DEA gives relatively efficient scores, it is very important to select comparable DMUs. As an example, the study of Lee & Park (2005: 208) is an attempt to measure the R&D productivity for Asian countries; and in order to provide homogeneous groups, the twenty-seven countries are divided into four sub-groups depending on the output-specialized R&D efficiency and then the analysis is carried out. Cullman et al (2009:25) assesses the relative efficiency of public and private research expenditures in the OECD using DEA and their results suggest that Sweden, Germany and the United States belong to the best performing countries. Wu and Liu (2007:108) analyze the R&D efficiency of different areas in China by using an improved DEA model. The results of this study show that the research and development efficency of most of the areas in China are really low and the study suggests the potential improvements for these areas.

In the study of Thomas et al (2011) where R&D efficiency of 50 US states and the District of Columbia is investigated, the R&D efficiency is estimated as the ratio of patents granted and scientific publications of R&D expenditures. The paper lists the states in the US with the highest R&D efficiency and presents benchmarks, which can be followed by policy interventions. This research highlights the significance of attending analyzes of R&D efficiency using patent and publications.

Sharma and Thomas (2008: 483) examine the relative efficiency of the R&D process across a group of 22 developed and developing countries using DEA. They use the patents granted to residents as an output and gross domestic expenditure on R&D and the number of researchers as inputs. Japan, the Republic of Korea, China, India, Slovenia and Hungary are found to be efficient. Roman (2010:33) analyzes research efficiency at the regional level for NUTS2 regions from Romania and Bulgaria, using DEA. Bulgarian regions are found more efficient in R&D activities compared to Romanian regions. Aristovnik (2012: 833) investigates the relative efficiencies of education and R&D expenditures in the new EU member countries and it has been seen that, in general, new EU member states show relatively high efficiency in tertiary education, while lag well behind in the R&D efficiency measures.

This study investigates the R&D efficiencies of EU countries using DEA analysis. There are some other studies carried out for European countries, however, to the best of our knowledge, there has been no study in the literature, which compares all of the EU countries' R&D efficiencies. Motivating from the study of Lee & Park (2005), EU can be defined as a homogeneous group and can be put in the same analysis. Another gap that this paper aims to fill is to explore the effect of the external environment, country-level conditions -i.e. the regulations that differ among countries- on R&D efficiency of the countries. This is given as future research by some of the studies but this area is still open. There is a study of Altıntaş & Mercan (2015), which analyzes the effects of R&D activities on economic growth. However, our study tries to find if there is a relationship between the internal conditions of the countries and their R&D efficiency scores. In order to achieve this goal, *The Global Innovation Index* report provides us the indices that are found effective in getting an understanding of the governmental and regulatory situation of the countries (Dutta & Lanvin, 2013) which are given below with their short definitions:

Government effectiveness index: *"An index that captures perceptions of the quality of public and civil services and the degree of their independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies".*

Regulatory quality index: *"An index that captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private-sector development".*

3. DATA ENVELOPMENT ANALYSIS (DEA)

DEA is a LP technique to measure the relative efficiency of organizational decision units with multiple inputs and outputs (Ulucan, 2002;Yıldız, 2006). It easily converts multiple inputs to multiple outputs. DEA is a non-parametric technique and there is no restriction on the functional form of inputs and outputs. It generalizes the concept of Farrell's (1957) technical efficiency measure of the single-input, single-output case to the multiple-input and multiple-output case. DEA consists of n DMUs to be evaluated, where each DMU uses varying amounts of m inputs to produce s outputs. The relative efficiency score of a target DMU is computed as a ratio of a virtual output to a virtual input. There is a set of normalizing which satisfies the condition that the output to input ratio of every DMU should be less than or equal to 1. The model is then represented as:

$$\max E_{j_0} = \frac{\sum_r u_r y_{rj_0}}{\sum_i v_i x_{ij_0}}$$

subject to (1)

$$\frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \le 1 \quad , \quad j = 1, ..., n$$

$$u_r, v_i \ge \varepsilon > 0, r = 1,\dots, s;\ i = 1, \dots, m.$$

where E_{j_0} is the efficiency value of the target DMU (j_0), u_r is the weight of output r, v_i is the weight of input i, y_{rj} represents amount of output r produced by the jth DMU, x_{ij} denotes amount of input i used by the jth DMU, and ε is an infinitesimal positive number. DEA categorizes DMUs into two categories as efficient and inefficient. A DMU is rated as fully efficient if and only if it attains a relative efficiency score of 1.

Main characteristics of the employed DEA model in this study can be summarized as follows: It is input-oriented and constant returns to scale (CRS). It means with input-oriented assumption; we aim to minimize the amount of input used to produce given amount of output for each DMU. Furthermore, the reason of assuming the CRS model for examining R&D efficiencies is to analyze the input and output correspondence in the absence of any scale effects.

4. PROPOSED FRAMEWORK TO EVALUATE THE R&D EFFICIENCIES OF EU COUNTRIES

This section outlines the proposed DEA framework to analyze R&D efficiencies of EU Countries. The detailed stepwise representation of the proposed framework that is also depicted in Figure 1 is presented below.

Step 1. Determine the important input and output variables for the efficiency model after analyzing existing literature in a detailed manner. Identify inputs and outputs for the R&D efficiency model.

Step 2. Collect data for the respective inputs and outputs of EU countries. Gather input and output variables via searching related databases and official websites.

Step 3. Construct the DEA model. Identify number of DMUs, and number of inputs and outputs for the model. Write down the objective function and the constraints in order to take a run for each DMU.

Step 4. Solve the DEA model via standard LP solver. After obtaining efficiency scores for each DMU, list down the efficient and inefficient countries in terms of R&D efficiency. The ones which get efficiency score of 1 will be identified as efficient. Similarly, the ones which get efficiency score value less than 1 will be identified as inefficient.

Step 5. Gather government effectiveness and regulatory quality index values for the EU countries from Global Innovation Index report and use this data to investigate the effects of political and regulatory environment on R&D efficiencies of EU countries via hypothesis testing using independent samples t-test using a statistical software.

Step 6. State the statistical decision whether the research hypothesis is accepted or rejected using t-test and p-values for each hypothesis, Interpret the results of hypothesis test and comment on the relationship between R&D efficiency and political and regulatory environment.

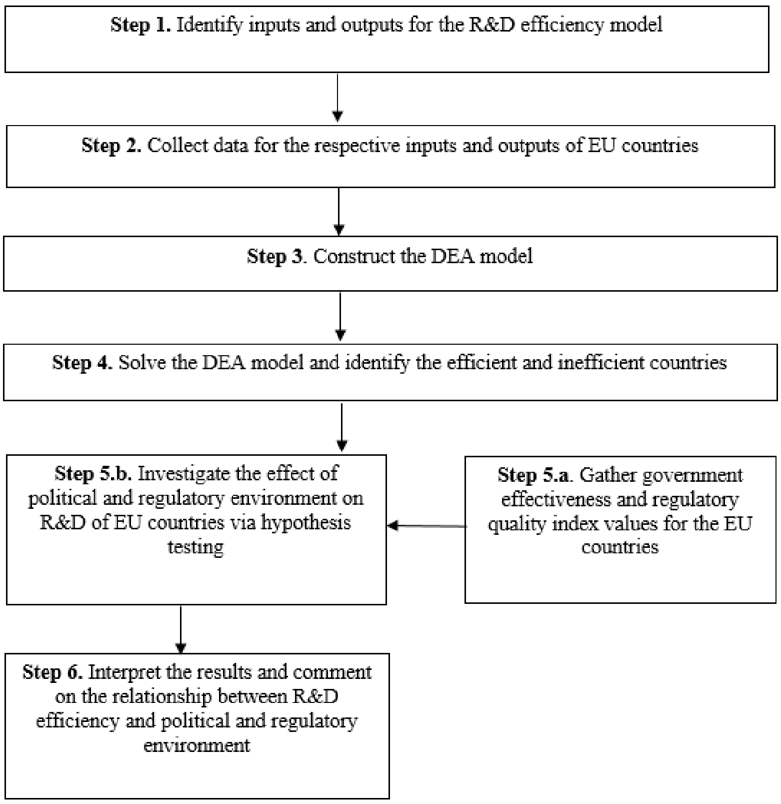

Figure 1: Representation of the proposed framework

5. NUMERICAL STUDY

Step 1. *Identify inputs and outputs for the R&D efficiency model.*

As a rule of thumb, DEA suggests that the number of DMUs (say n), should be defined as $\max\{m \times s, 3 \times (m + s)\}$, where m is the number of inputs and s is the number of outputs (Cook et al, 2001:). Since the number of DMUs (i.e. number of EU countries) is equal to 28 in our study, the number of indicators should not be greater than 9. With this derivation in mind, and considering the data availability for the most recent year that we have data of all the 28 countries for 2013 and considering the indicators commonly used in the literature, the input and outputs are selected as follows:

Outputs: number of publications including citable and non-citable documents (PUBLICATIONS), number of patents granted by European Patent Office (EPO) and number of patents granted by United States Patent and Trademark Office (USPTO);

Inputs: R&D expenditures conducted by business enterprises (BERD), government (GOVERD) and higher education sector (HERD), number of full time R&D personnel hired by all sectors (RESEARCHERS), number of people with tertiary education and employed in science and technology (POSTGRADUATE), employment in high and medium-high technology manufacturing sectors and knowledge-intensive service sectors (EMPLOYMENT).

Given the above inputs and outputs; there will be three outputs and six inputs in the DEA model. The data for these inputs and outputs will be gathered for the 28 EU countries which are; Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

Step 2.*Collect data for the respective inputs and outputs of EU countries.*

The values of the 6 inputs and 3 outputs for 28 EU countries for 2013 (since most recent data for all countries is available for 2013) are gathered from offical websites of European Statistical Office (EUROSTAT), European Patent Office and United States Patent and Trademark Office. The values are given in Appendix A .

Step 3.*Construct the DEA model.*

Eq. (1) given in Section III is employed in order to construct the DEA model. In the given equations, j takes values as $j=1,2,\ldots 28$ since we have 28 DMUs (countries). In addition, index i can take values as $i=1,2,3,4,5,6$ and index r can take values as $r=1,2,3$ since we have 6 inputs and 3 outputs, respectively.

Step 4. *Solve the DEA model and identify the efficient and inefficient countries.*

The model is solved using the given input-output values for 28 EU countries. The proposed model can be solved by a standard LP solver. The resulting relative efficiency scores are given in Table 1. The results reveal that there are 11 countries 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 eleven efficient countries are Austria, Croatia, Cyprus, Germany, Italy, Luxembourg, Netherlands, Poland, Romania, Sweden and United Kingdom. The lowest three efficiency scores belong to Lithuania (0.352) Latvia (0.427) and Hungary (0.466). Moreover Bulgaria (0.543), Estonia (0.656), Malta (0.792) and Slovakia (0.611) have low efficiency scores when we compare 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 (0.848), Czech Republic (0.806), Finland (0.912), France (0.941), Greece (0.804), Ireland (0.920), Portugal (0.973) and Slovenia (0.904). Denmark and Spain seem almost fully efficient since their efficiency scores are very close to 1; they have 0.997 and 0.995 efficiency scores, respectively.

Table 1: R&D Efficiency Scores

Country	*Technical Efficiency Score*	*Country*	*Technical Efficiency Score*
Austria	1.000	*Italy*	1.000
Belgium	0.848	*Latvia*	0.427
Bulgaria	0.543	*Lithuania*	0.352
Croatia	1.000	*Luxembourg*	1.000
Cyprus	1.000	*Malta*	0.792
Czech Republic	0.806	*Netherlands*	1.000
Denmark	0.997	*Poland*	1.000
Estonia	0.656	*Portugal*	0.973
Finland	0.912	*Romania*	1.000
France	0.941	*Slovakia*	0.611
Germany	1.000	*Slovenia*	0.904
Greece	0.804	*Spain*	0.995
Hungary	0.466	*Sweden*	1.000
Ireland	0.920	*United Kingdom*	1.000

After determining inefficient EU countries in terms of R&D, potential improvement percentage of each input are calculated. Potential improvement percentage (PI (%) - column 3 in Table 2) corresponds to the decrease in the *Actual* (column 1 in Table 2) input values. Hence, *Target* (column 2 in Table 2) input values are found. If the DMU i.e. the country used the *Target* amount of input values, it would have been an efficient country by producing the same amount of output. One of the findings that can be derived from Table 2 is that the countries which have the lowest efficiency scores have higher PI (%) values than other countries.

The information in Table 2 can be a pathway for countries in order to increase their efficiencies or make plans about their R&D activities. This feature of DEA is one of the reasons that DEA is used in this study.

Table 2: PI Percentage of Each Input For Inefficient EU Countries

DMU	Inputs	Actual	Target	PI(%)	DMU	Inputs	Actual	Target	PI(%)
Belgium	RESEARCHERS	46355	39301	-15.22	Ireland	RESEARCHERS	16844	15496	-8.00
	POSTGRADUATES	1242	1053	-15.22		POSTGRADUATES	491	452	-8.00
	EMPLOYMENT	4.7	1.9	-58.92		EMPLOYMENT	5.2	1.1	-79.13
	GOVERD	69.5	27.3	-60.68		GOVERD	28.1	20.1	-28.42
	BERD	604.4	185.6	-69.30		BERD	440.4	67.2	-84.73
	HERD	178.4	88.4	-50.46		HERD	131.8	59.2	-55.12
Bulgaria	RESEARCHERS	12275	5198	-57.65	Latvia	RESEARCHERS	36.25	1548	-57.30
	POSTGRADUATES	528	287	-45.68		POSTGRADUATES	190	67	-64.54
	EMPLOYMENT	3.9	1.1	-71.02		EMPLOYMENT	1.8	0.59	-67.02
	GOVERD	10.9	3.3	-69.47		GOVERD	20	5.1	-74.50
	BERD	22.4	3.1	-86.22		BERD	19.5	8.3	-57.30
	HERD	3.2	1.7	-45.68		HERD	29.6	12.6	-57.30
Czech Republic	RESEARCHERS	34271	24917	-27.30	Lithuania	RESEARCHERS	8557	3010	-64.83
	POSTGRADUATES	807	651	-19.36		POSTGRADUATES	347	110	-68.23
	EMPLOYMENT	10.5	1.7	-83.91		EMPLOYMENT	1.8	0.5	-72.04
	GOVERD	52.2	14.3	-72.60		GOVERD	22.2	6.2	-71.97
	BERD	154.2	124.4	-19.36		BERD	28.5	10	-64.83
	HERD	77.6	48.6	-37.42		HERD	61.2	21.5	-64.83
Denmark	RESEARCHERS	40316	36152	-10.33	Malta	RESEARCHERS	857	679	-20.78
	POSTGRADUATES	740	738	-0.33		POSTGRADUATES	30	24	-20.78
	EMPLOYMENT	5.0	3.3	-33.12		EMPLOYMENT	4.1	0.12	-97.08
	GOVERD	32.3	32.2	-0.33		GOVERD	13.4	10.6	-20.78
	BERD	891.7	493.1	-44.70		BERD	84.8	19	-77.57
	HERD	463	182.3	-60.63		HERD	54.3	10.3	-81.02
Estonia	RESEARCHERS	4407	2891	-34.39	Portugal	RESEARCHERS	37813	26249	-30.58
	POSTGRADUATES	141	93	-34.39		POSTGRADUATES	730	710	-2.73
	EMPLOYMENT	4.1	0.3	-93.06		EMPLOYMENT	2.7	1.6	-40.16
	GOVERD	22.1	3.2	-85.44		GOVERD	14	13.6	-2.73
	BERD	117.9	6.8	-94.24		BERD	102.3	98.9	-3.36
	HERD	104.5	10.2	-90.23		HERD	96.1	40.6	-57.72
Finland	RESEARCHERS	39196	35591	-9.2	Slovakia	RESEARCHERS	14727	8061	-45.27
	POSTGRADUATES	738	673	-8.85		POSTGRADUATES	355	217	-38.90
	EMPLOYMENT	5.1	3.3	-36.02		EMPLOYMENT	9.8	0.5	-94.86
	GOVERD	109.9	31	-71.76		GOVERD	23.1	4.3	-81.60
	BERD	848.1	421.1	-50.35		BERD	52.2	31.9	-38.90
	HERD	265	142.4	-46.28		HERD	37.4	12.98	-65.30
France	RESEARCHERS	266222	207903	-21.91	Slovenia	RESEARCHERS	8884	8031	-9.6
	POSTGRADUATES	5990	5324	-11.11		POSTGRADUATES	199	180	-9.6
	EMPLOYMENT	4.6	4.3	-5.92		EMPLOYMENT	8.3	0.74	-91.04
	GOVERD	94.3	60.2	-36.22		GOVERD	59.1	6.37	-89.22
	BERD	468.4	326.8	-30.23		BERD	347.5	79.1	-77.23
	HERD	150.8	105.5	-30.03		HERD	47.3	28.5	-39.86
Greece	RESEARCHERS	29228	22126	-24.3	Spain	RESEARCHERS	123225	122616	-0.49
	POSTGRADUATES	782	629	-19.62		POSTGRADUATES	4090	3678	-10.07
	EMPLOYMENT	1.2	0.96	-19.62		EMPLOYMENT	3.9	3.88	-0.49
	GOVERD	37.3	8.2	-77.96		GOVERD	52.1	24.55	-52.88
	BERD	44.5	35	-21.42		BERD	147.8	147.07	-0.49
	HERD	49.9	17.5	-64.88		HERD	78.1	62.05	-20.56
Hungary	RESEARCHERS	25038	11674	-53.38					
	POSTGRADUATES	777	357	-54.02					
	EMPLOYMENT	8.5	0.7	-91.31					
	GOVERD	21.3	5.2	-75.75					
	BERD	99.2	18.5	-81.37					
	HERD	20.6	9.6	-53.38					

Step 5. *Gather government effectiveness and regulatory quality index values for the EU countries and use this data to investigate the effects of political and regulatory environment on R&D efficiencies of EU countries via hypothesis testing.*

We determine average government effectiveness and average regulatory quality score of 28 EU countries. If a selected EU Country's government effectiveness score or regulatory quality score is less than obtained average score then it takes value of 1. Otherwise, the country takes value of 0. In this manner, we obtained two different groups of contries for each hypothesis. The average score for government effectiveness of 28 EU Countries was calculated as 69.60 and the average score for regulatory quality was calculated as 80.71 over score of 100. The government effectiveness and regulatory quality index values for the 28 EU countries are given in Appendix B.

The following hypotheses are tested against the null hypothesis that there is no difference between countries as follows:

H1: There is a difference between countries with low government effectiveness and high government effectiveness in terms of R&D efficiency.

H2**:** There is a difference between countries with low regulatory quality and high regulatory quality in terms of R&D efficiency.

We applied independent-samples t-test using SPSS-23. The hypothesis test results for significance level; α=0.05 are given below in Table 3. The low and high efficiency score values for each hypothesis are determined by taking average of efficiency scores for each group of countries.

Table 3: Results of Statistical Analysis

	Technical Efficiency		*t*-test		Decision
Hypothesis	Low	High	*t*	*p*	
H1	0.777	0.933	-2.190	0.038	Accept
H2	0.734	0.924	-1.879	0.071	Reject

Step 6*. Interpret the results and comment on the relationship between R&D efficiency and political and regulatory environment.*

Research hypotheses results given in Table 3 reveal that there is a significant effect of government effectiveness on R&D efficiency. However, since H2 is rejected; it can be revealed that there is no difference between countries with low regulatory quality and high regulatory quality in terms of R&D efficiency.

These findings show that countries with high government effectiveness have high R&D efficiency scores and with low government effectiveness have low R&D efficiency scores. Therefore the countries which aim to have high R&D efficiency should also focus on the quality of policy development and implementation, and the credibility of the government's commitment to these policies.

6. CONCLUSION AND FUTURE RESEARCH

This study analyzes the R&D efficiencies of EU countries motivating from the fact that R&D efficiency is a relatively new subject in the literature, hence there is a gap in this research area. DEA is used in this study in order to find the efficiency scores, since DEA is the most widely used technique in the efficiency literature. The advantages of the utilization of DEA model in efficiency calculation is that, it is capable of making evaluations with multiple inputs and outputs. Another reason for using DEA is that, for the inefficient DMUs, it provides scenarios on how to increase their efficiencies and become as efficient as the most efficient - best practice – units. Decision and policy makers are usually interested in this property of DEA since they can make plans using this valuable information.

The DEA model is run for the EU countries (28 DMUs) and the relative efficiencies are compared using three outputs and six inputs. The outputs can be summarized as the publications and patents produced by that country and the inputs can be summarized as the employment and education rates and expenditures spent for the R&D activities. Afterwards, hypothesis tests are conducted in order to understand the effect of political and regulatory environment on R&D efficiencies of EU countries. *Government effectiveness index* and *regulatory quality index* values (Dutta & Lanwin, 2013) are used in hypothesis construction.

The DEA results show that a majority of countries are inefficient in terms of R&D; since there are eleven fully efficient countries (i.e. efficiency score=1.00). Using the advantage of DEA model, potential improvement percentage of each input (the decrease in the actual input value such that the country becomes fully efficient by producing the same amount of output) for each inefficient country is calculated. This valuable information provides a pathway for countries in order to increase their efficiencies or make plans about their R&D activities. Moreover, the countries which plan to participate the union such as Turkey will be able to take actions using this information in order to be able to compete with the member countries.

Table 2 summarizes the potential improvement percentages for the inefficient countries. An overall result that can be derived from this table is that; employment in high and medium-high technology manufacturing sectors and knowledge-intensive service sectors is high (in inefficient countries), however these people perform worse than the employees in the efficient countries in producing high number of patents and publications. Hence, the inefficient countries should develop some policies which will trigger setting some performance criteria for the employees in these sectors in order to reach the efficient frontier.

After getting the efficiency scores of the countries, the hypotheses test are conducted, which aim to understand the effect of political and regulatory environment on R&D efficiencies of the countries. The test results reveal that there is a significant effect of government effectiveness on R&D efficiency. However, there is not a significant effect of regulatory quality on R&D efficiency.

This study contributes to the current literature by 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. The findings imply that countries with high government effectiveness have high R&D efficiency scores and with low government effectiveness have low R&D efficiency scores. Government effectiveness index captures perceptions of the quality of public and civil services and the degree of their independence from political pressures. The policy implication derived from this definition and the result of the hypothesis testing is that; if the people/companies in a country perceive that the public/civil services are independent from political pressures, they perform high efficiency in terms of research and development. The result of the hypothesis test also imply that the countries which aim to have high R&D efficiency should focus on the quality of policy development and implementation. Another implication that can be derived from this study is that; increasing the credibility of the government's commitment to the developed policies is highly important in increasing R&D efficiency. The relative efficiency scores and hypothesis test results found in this study give valuable information for social policy makers in making decisions about planning R&D activities. The findings will also be useful for the countries aiming to participate the union, such as Turkey.

As a future research, different DEA models could be employed in order to see the differences between constant returns to scale and variable returns to scale. Moreover, if data is available, an analysis could be carried out by including the member countries.

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Appendix A. Data Used In the Study

NO	DMU	RESEARCHERS	POSTGRADUATES	EMPLOYMENT	GOVERD	BERD	HERD	PUBLICATIONS	EPO	USPTO
1	*Austria*	40426	597	5.8	50.3	802	275.4	22094	837	1136
2	*Belgium*	46355	1242	4.7	69.5	604.4	178.4	29998	736	1148
3	*Bulgaria*	12275	528	3.9	10.9	22.4	3.2	3981	5	30
4	*Croatia*	6529	291	3.6	21.2	41.7	20.3	6298	7	18
5	*Cyprus*	881	92	1.0	14.2	15.4	54.4	1939	17	8
6	*Czech Republic*	34271	807	10.5	52.2	154.2	77.6	19628	67	176
7	*Denmark*	40316	740	5.0	32.3	891.7	463	22672	609	1109
8	*Estonia*	4407	141	4.1	22.1	117.9	104.5	2607	9	43
9	*Finland*	39196	738	5.1	109.9	848.1	265.0	17860	664	1297
10	*France*	266222	5990	4.6	94.3	468.4	150.8	115038	4910	6555
11	*Germany*	354463	8527	9.6	144.6	653.1	174.4	158096	13425	16605
12	*Greece*	29228	782	1.2	37.3	44.5	49.9	17901	30	70
13	*Hungary*	25038	777	8.5	21.3	99.2	20.6	9788	49	141
14	*Ireland*	16844	491	5.2	28.1	440.4	131.8	12322	187	460
15	*Italy*	116163	3330	5.9	49.2	192.3	99.5	97800	2352	2930
16	*Latvia*	3625	190	1.8	20.0	19.5	29.6	1605	5	4
17	*Lithuania*	8557	347	1.8	22.2	28.5	61.2	2959	5	6
18	*Luxembourg*	2503	96	0.9	326.7	591.9	209.3	1588	177	62
19	*Malta*	857	30	4.1	13.4	84.8	54.3	538	22	8
20	*Netherlands*	76670	2002	2.7	92.9	422.8	243.7	53809	1886	2571
21	*Poland*	71472	3248	5.0	24.2	39.4	26.4	36630	95	113
22	*Portugal*	37813	730	2.7	14.0	102.3	96.1	21199	26	71
23	*Romania*	18576	1129	4.8	13.7	8.5	5.5	14573	2	60
24	*Slovakia*	14727	355	9.8	23.1	52.2	37.4	6485	5	14
25	*Slovenia*	8884	199	8.3	59.1	347.5	47.3	5692	52	43
26	*Spain*	123225	4090	3.9	52.1	147.8	78.1	83054	395	772
27	*Sweden*	64194	1294	4.4	55.5	1039.4	409.2	35132	1790	2431

28	*United Kingdom*	267699	7320	3.7	42.0	339.9	140.5	180190	2062	6551

Appendix B. The Government Effectiveness And Regulatory Index Values For The EU Countries

DMU	*Government Effectiveness*	*Regulatory Quality*	*DMU*	*Government Effectiveness*	*Regulatory Quality*	*DMU*	*Government Effectiveness*	*Regulatory Quality*	*DMU*	*Government Effectiveness*	*Regulatory Quality*
Austria	83.9	86.5	*Finland*	100	95.9	*Lithuania*	57.1	74.2	*Slovenia*	65.4	66.1
Belgium	84.1	82.3	*France*	75.8	78.5	*Luxembourg*	86	98.3	*Spain*	66.4	78.1
Bulgaria	38.7	64.2	*Germany*	80.4	89	*Malta*	70.3	83.7	*Sweden*	92.2	97.5
Croatia	53.6	64.1	*Greece*	51.5	62.9	*Netherlands*	87.5	97.7	*United Kingdom*	80.8	91.9
Cyprus	80.3	81.4	*Hungary*	57.7	76.9	*Poland*	56.9	74.7			
Czech Republic	66.3	82.2	*Ireland*	77.4	92.6	*Portugal*	65.1	66.7			
Denmark	97.9	100	*Italy*	50.7	69.2	*Romania*	32.4	68.4			
Estonia	71.4	86	*Latvia*	57.2	74.5	*Slovakia*	61.9	76.5			