Effectiveness of Selected Knowledge-Based Determinants in Macroeconomics Development of EU 28 Economies

Viktor Prokop, Jan Stejskal and Petr Hajek

Abstract The stage of development of knowledge-based economy depends not only on the effectiveness of the innovation system but on the effectiveness of economic and institutional regime, education of population and information and communication technology. The aim of this paper is to determine which of the selected determinants of the knowledge-based economy provide the intended macroeconomic effects. The measurement of the effectiveness is performed by data envelopment analysis. In the case of inefficient determinants, DEA enables to detect how such a determinant should be regulated or modified to become more effective. We employed DEA models and analysed the effectiveness of inputs involved in the macroeconomic processes. We used data from Eurostat for EU 28 countries in the years 2011–2015. The results show that minority of EU countries were efficient and that these countries were at different levels of knowledge economy. The implications can be generalized for several types of knowledge-based economies.

Keywords Effectiveness · Knowledge-based economy · Determinant Macroeconomics development · EU 28

1 Introduction

In today's globalized world economy, national governments increasingly aspire to become knowledge-based economies. The crucial aspect is to increase the effectiveness of traditional production factors (labour force and capital) by new

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productivity determinants, such as knowledge, skills and ability to learn. These have become the key determinants of contemporary national competitive advantage. Economic entities in knowledge-based economies have to be able to acquire, transfer and apply the knowledge, as well as to create innovations. In addition to governments, the key actors in knowledge-based economies include firms, universities and non-profit organizations. Their interactions also provide support to the development of knowledge-based economy.

The stage of development of knowledge-based economy depends not only on the effectiveness of the national innovation system but also on the effectiveness of economic and institutional regime, education and skills of population and information and communication technology. Previous research has mainly focused on how to measure the determinants of knowledge-based economy. However, it is also important to make an international comparison of the effectiveness of these determinants in generating macroeconomic outputs. This could give the national governments and public policy makers the guidance for decision-making (e.g. in science, technology and innovation policies).

The structure of this paper is divided into following: Sect. 2 consists of theoretical background that clarifies the issue of innovation determinants and the influence on selected economic macroeconomic indicators. Section 3 will be dedicated to describe our methodology which utilizes own DEA model and used data. In the last section, we discuss the main results and conclusions.

2 Theoretical Background

The knowledge is the key competitive factor in every business all over the world. Government at the every level prepare the public policy (especially at the regional level—regional policy) where knowledge and so innovations have been moved to the foreground and have been considered mandatory for surviving in a dynamic market environment (Tödtling and Trippl 2005; Seidler-de Alwis and Hartmann 2008; Asheim et al. 2011). Therefore, governments try to support by this policy (and mainly by the financial schemes) engines of economic growth. We have to point out that innovations are the fundamental force for global, national and also local economic and social growth. Innovations influence industrial sector (firms' competitiveness), households and also the welfare of the society (Galia and Legros 2004; Tödtling and Trippl 2005; Hudson and Minea 2013; Stejskal et al. 2016).

The experiences from many researches and also many scholars highlighted that innovation processes are accelerated by the environment in which they are being implemented. Innovations do not take place in isolation; rather interaction is central to the process of innovation. The innovation milieu consists from many entities (firms, companies, universities, R&D organizations), also from governmental organizations. The networking, relationships or some knowledge-based or cooperative-based ties are integral part of this environment. All these assets are present in most of the developed regions. But, actual growth performance depends on how well a region (or enterprise) is able to mobilize its assets in order to fully exploit its potential for growth (Papacharalambous and McCalman 2004). The knowledge sector is the necessary part of every modern tool in regional development. The industrial clusters, research centres, centres of excellence, etc., interact with many entities in the regional and also with their external environment (Guellec and Wunsch-Vincent 2009). The cooperative links deepen the technological, creative and innovative competence of the actors (Tsai and Wang 2009). The collaboration with research organizations helps a firm broaden its technological knowledge and firms can acquire new scientific knowledge to benefit their product or process innovations by interacting formally and informally with universities and research institutes (Cowan and Zinovyeva 2013).

There are many determinants what influence the innovation (or knowledge) environment. Tavassoli (2015) analyses how the influence of firm-level innovation determinants varies over the industry life cycle. Two sets of determinants are distinguished: (1) determinants of a firm’s innovation propensity, i.e. the likelihood of being innovative and (2) determinants of its innovation intensity, i.e. innovation sales. He shows in Sweden case study that the importance of the stage of life cycle of the industry where the firm belongs. Ulusoy et al. (2014) analyse the comprehensive model of innovation determinants in Turkey. This study investigates how significant is an antecedent compared to others. Such knowledge is invaluable for the decision-makers in order to manage their innovation strategies and provides a guideline for effective allocation of their limited resources to be more innovative. The analysis reveals that among all possible determinants considered, the intellectual capital has the highest impact on innovativeness followed by the organizational culture. In Spain, Fraj et al. (2015) analyse the links between proactive environmental strategies, organizational capabilities and competitiveness. According to their results, knowledge, ability to learn and innovations are conceived not only as drivers for adopting pro-environmental policies, but also as determinants of competitiveness. The determinants of innovation activities were examined also in China. Liu et al. (2014) used the panel data analysis for the high-technology industries and analysed the impact of foreign competition on innovation activities at industry level in a large emerging economy. The results indicate that the intensity of competition from foreign-invested enterprises and domestic skill intensity affects industry buy and make activities. Further, the findings show that domestic skill intensity weakens the impact of foreign competitive pressure on innovation activities. In USA, Wang et al. (2014) explored specific determinants: network of collaborations between researchers and in a knowledge network composed of linkages between knowledge elements.

There are also many other determinants of the knowledge economy in individual EU countries. These determinants are divided into four drivers (pillars) such as (i) economic incentive and institutional regime, (ii) educated and qualified workers, (iii) an effective innovation system, and (iv) information infrastructure (Dahlman and Anderson 2000; Chen and Dahlman 2005). Also, a knowledge stock seems to be a specific innovation determinant. Roper and Hewitt-Dundas (2015) analysed the role and interaction of firms’ existing knowledge stocks and current knowledge flows in shaping innovation success. Their paper contributed to understanding of the determinants of firms' innovation outputs and provides new information on the relationship between knowledge stocks, as measured by patents, and innovation output indicators. They stated that existing knowledge stocks have weak negative rather than positive impacts on firms' innovation outputs, reflecting potential core-rigidities or negative path dependencies rather than the accumulation of competitive advantages. Second, knowledge flows derived from internal investment and external search dominate the effect of existing knowledge stocks on innovation performance. Both results of this study emphasize the importance of firms' knowledge search strategies.

It is necessary to examine relevance of the innovation determinants and effectiveness and to draw implications from conclusions that will help to increase the level of knowledge economy in practice. Therefore, the aim of this paper is to determine which of the selected determinants of the knowledge-based economy provide the intended macroeconomic effects.

3 Research Methodology and Data

Data envelopment analysis (DEA) was used for our analyses. DEA is a parametric approach used as a model specialized tool for assessing the effectiveness, performance and productivity of comparable production units (homogeneous units, also decision-making units—DMUs) based on the size of inputs and outputs. DMUs convert multiple inputs into outputs, meaning a set of units that produce the same or equivalent effects that are referred as the outputs of these units (Staničkova and Melecky 2011). DEA has become the most prominent method for performance measurement.

DEA models are derived from Farrell's model for measuring the effectiveness of units with one input and one output. These DEA models use mathematical programming models to estimate best-practice frontiers without a priori underlying functional form assumption through computing multi-input/multi-output values and calculate a maximal performance measure for each DMU relative to all DMUs in the countries (EU 28) under observation (Guan et al. 2006; Stejskal and Hajek 2016). The DEA model can be built on the assumption of constant returns to scale (one unit of input generates one unit of output), when all DMUs are operating at optimal scale (CCR model). Rather unrealistic condition is solved by introducing variable returns to scale (VRS) considering all types of returns: increasing, constant or decreasing (BCC model). The efficiency can be increased either by increasing outputs under increasing returns to scale or by reduction in outputs under decreasing returns to scale (Hudec and Prochádzková 2013; Hajkova and Hajek 2014).

For our analyses, we used two input-oriented VRS models (Model 1 and Model 2) operating with variable returns to scale and data from Eurostat databases (2017). These models measured efficiency of DMUs, (i) provide implications on how to

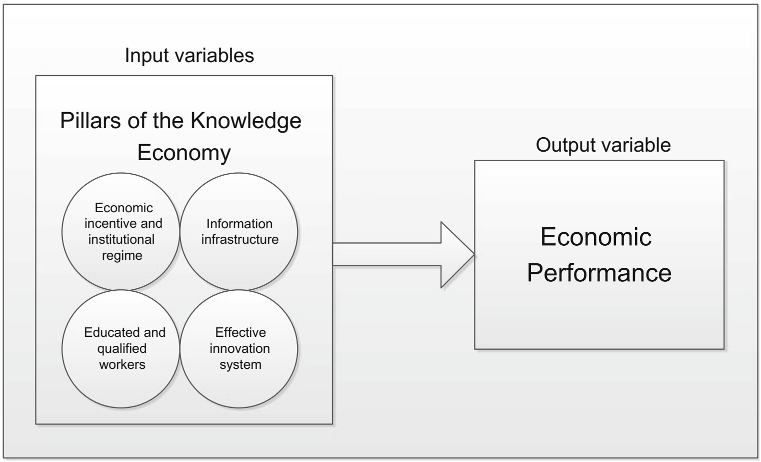

Fig. 1 Relation between input and output variables in Model 1. *Source* Own

change inputs within inefficient DMUs to become (more) efficient and (ii) show the importance of knowledge (and accumulated knowledge stock) within the process of economic development.

In Model 1 (see Fig. 1), we analyse and evaluate countries' efficiency of using determinants of knowledge economy within the process of increasing their economic performance (represented by value added). These determinants are divided into four drivers (pillars, see Table 1) such as (Parcero and Ryan 2016; de la Paz-Marín et al. 2015; Hajek et al. 2014): (i) economic incentive and institutional regime, (ii) educated and qualified workers, (iii) an effective innovation system and (iv) information infrastructure. The optimal time delay between input and output variables was analysed by number of researchers (e.g. Hollanders and Celikel-Esser 2007; Wang and Huang 2007). Following previous studies (Guan and Chen 2012; Hudec and Procházková 2013), we chose four years' time delay.

In Model 2 (see Fig. 2), the same variables were used (see Table 1). However, following previous literature (e.g. Wu and Shanley 2009; Villar et al. 2014) we add other input variable expressing the country's knowledge stock that represents the accumulated know-how from practicing research and development activities and should support the share of knowledge, learning processes and country's development (Biemans et al. 2007). Wu and Shanley (2009) argued linkage between exploration–exploitation and innovative performance and, therefore, we assume the importance of accumulated knowledge stock allowing share of knowledge, learning and gaining higher rate of countries' efficiency.

Knowledge stock represents accumulated knowledge within the country in last years. To express accumulated knowledge stock, there are number of ways—e.g. by patents, scientific citations or products in development (DeCarolis and Deeds 1999). Firms' and countries' patent portfolio is one possible means to describe and capture the characteristics of a firms' (countries') knowledge stock because a patent,

Table 1 Variables involved in the model

Input variables		
Pillar	Variable	Description of the selection of variable
Economic incentive and institutional regime	Government R&D expenditures (in Euros)	Effective use of public funds, particularly in research and development may lead to creation of positive effects and promote economic growth in the long term (Gemmell et al. 2015)
Educated and qualified workers	The number of people with tertiary education (15–74 years)	The number of people with tertiary education allows the creation of new knowledge, as well as strengthening the absorption capacity of individual countries and companies (Barro 2013)
Information infrastructure	Employees in ICT (total)	ICT sector affects corporate growth and innovation capability (Taruté and Gatautis 2014), while the number and quality (skills) of its employees are one of the main determinants
Effective innovation system	The number of employees working in the field of science and technology (15–74 years)	Employees in the field of science and technology (S&T) represent one of the fundamental elements, and their effective use can lead to greater dissemination of knowledge and the creation of synergies, as well as to the emergence of more innovative outputs, and thus influence the continuous economic growth (Yanadori and Cui 2013; Gelec and Wagner 2014)

Output variable		
Pillar	Variable	Description of the selection of variable
Economic performance	Value added (in Euros)	The value added is another possible determinant of economic growth and identifier of the growth of commercial gain (Guan and Chen 2012; Hudec and Procházková 2013)

Source Own

by definition, represents a unique and novel element of knowledge (Ahuja and Katila 2001; Wu and Shanley 2009). A set of patents then represents a collection of discrete, distinct units of knowledge. Identifying a set of patents that have been used in the firm can be the basis for identifying the revealed knowledge base of a firm. Therefore, accumulated patents represent the knowledge that the firm (country) is acknowledged as having created (Jaffe et al. 1993). For our study, following

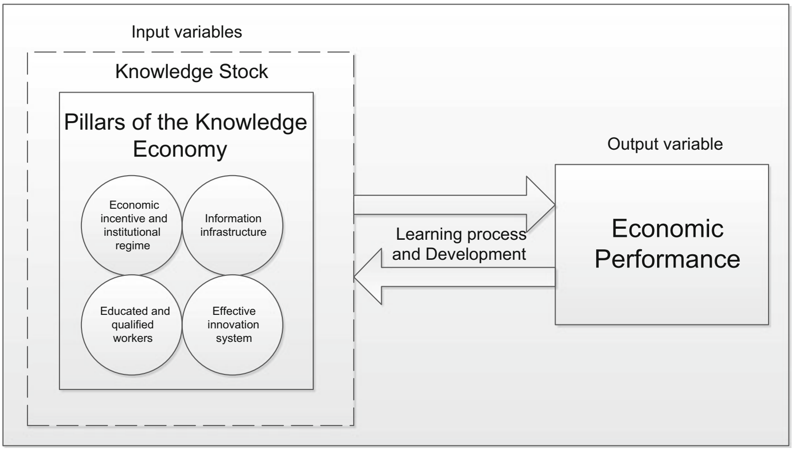

Fig. 2 Relation between input and output variables in Model 2 extended by Knowledge Stock. *Source* Own

arguments above and previous studies (e.g. Guan and Chen 2012; Hudec and Procházková 2013) we express knowledge stock by number of patents granted by USPTO between 2006 and 2010.

4 Results

Results of input-oriented VRS Model 1 and Model 2 are shown in Tables 2 and 3. DMUs (countries of EU 28) that efficiently used selected determinants of knowledge economy reached the rate of effectiveness 1000. Countries that did not reach the rate of effectiveness 1000 were not considered as effective (less rate of effectiveness means less efficiency of the country).

Results of Model 1 show that only eight countries of EU 28 (32%) were effective. These countries were Germany, Ireland, France, Italy, Luxembourg, Malta, Austria and UK (on the same rank, efficiency is 1.00000). On the other hand, Bulgaria was the least effective country within EU 28 (the last rank, efficiency 0.24918). The advantage of the DEA models is that they provide practical implications (for each country) on how to improve and how to change inputs and outputs to become (more) efficient. Input-oriented models propose changes focusing primarily on input variables (or even minor changes on the output side). Table 2 therefore shows both original values (obtained from the Eurostat databases) and adjusted values (provided by DEA) that show how the input (output) variables should be reduced/increased. We can see that the selected determinants were inefficiently used in most countries of EU 28.

Table 2 Results of input-oriented VRS Model 1

Country	Efficiency	Input variables (2011)								Output variable (2015)	
		Government R&D expenditures		Tertiary educated		Employees in ICT		Employees in S&T		Value added	
		Original	Adjusted	Orig.	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
BE	0.90464	658,600	483,387.3	2368	1371.6	138	124.8	1632	1476.4	410.351	367.354
BG	0.24918	78,711	19,613.1	1124	180.9	67.5	15.7	697	121.8	45,286.5	39,138.1
CZ	0.40923	504,383	206,410.0	1269	519.3	145.1	50.2	1553	635.5	166,964.1	150,119.6
DK	0.94535	148,052	139,961.6	1086	1026.7	110.1	76.1	1119	609.3	271,786.1	235,907.7
DE	**1.00000**	10,974,300	10,974,300.0	14,245	14,245.0	1235.9	1235.9	14,600	14,600.0	3,032,820	2,729,662
EE	0.50524	31,097	15,711.4	315	80.4	16.7	8.4	196	68.7	20,251.7	17,496.7
IE	**1.00000**	131,900	131,900.0	1041	1041.0	76.3	76.3	592	592.0	25,5815.1	236,813.5
GR	0.62549	331,727	207,492.7	1703	565.8	75.5	47.2	1034	519.2	175,697.4	155,098.3
ES	0.83609	2,762,385	1,055,361.5	9567	5571.1	532.6	431.5	5022	4198.8	1,075,639	975,795
FR	**1.00000**	6,248,990	6,248,990.0	11,378	11,378.0	760.6	760.6	9430	9430.0	2,181,064	1,949,825
HR	0.33250	92,105	30,624.8	498	161.4	42.3	14.1	410	113.9	43,846.9	36,823.9
IT	**1.00000**	2,653,600	2,653,600.0	5512	5512.0	544.3	544.3	6944	6944.0	1,642,443.8	1,475,046.8
CY	0.80392	14,731	11,842.6	202	73.9	10	8.0	119	64.5	17,637.2	15,520.7
LV	0.39738	32,846	13,052.2	360	101.8	25.3	10.1	252	79.3	24,348.5	215,46.6
LT	0.51357	55,346	28,424.2	617	147.6	25.5	13.1	422	106.3	37,330.5	33,576.5
LU	**1.00000**	147,788	147,788.0	117	117.0	8.5	8.5	115	115.0	51,216.2	46,230.2
HU	0.34432	189,839	65,365.8	1339	398.8	89.2	30.7	1128	244.5	10,9674.2	91977.7
MT	**1.00000**	1999	1999.0	46	46.0	6.2	6.2	48	48.0	9250.3	8129.3
NL	0.77451	1,319,387	860,757.5	3315	2466.5	284.1	220.0	3211	2486.9	67,6531	607,860
AT	**1.00000**	425,222	425,222.0	1017	1017.0	99.7	99.7	1329	1329.0	339,896	302,652.9
PL	0.43771	979,421	428,699.9	5569	1558.3	299	130.9	4354	1339.6	429,794.2	381,271

(continued)

Table 2 (continued)

Country	Efficiency	Input variables (2011)								Output variable (2015)	
		Government R&D expenditures		Tertiary educated		Employees in ICT		Employees in S&T		Value added	
		Original	Adjusted	Orig.	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
PT	0.61626	189,330	116,675.7	1149	668.9	80.2	49.4	1083	395.4	179,539.9	15,6612.2
RO	0.37429	267,643	100,175.1	1860	604.7	120.4	45.1	1751	358.7	159,963.7	140,569.1
SI	0.38729	127,831	49,507.4	334	129.4	29.9	11.6	313	106.3	38,570	33,311.4
SK	0.44311	129,575	57,415.5	675	299.1	56.5	25.0	704	223.2	78,685.6	70,993.6
FI	0.56609	633,712	180,012.7	1275	717.4	99.3	56.2	943	533.8	209,149	180,358
SE	0.80509	566,901	456,407.2	2002	1611.8	191.4	136.3	1908	1409.4	447,009.5	39,5501.1
UK	**1.00000**	2,706,303	2,706,303.0	13,670	13,670.0	1066.6	1066.6	10,647	10,647.0	2,577,280.1	2,296,927.7

Note Government R&D expenditures, tertiary educated, employees in ICT, employees in S&T are in thousands Euros, value added is in million Euros; EU 28 countries are marked according to international country codes
Source Own

Table 3 Results of input-oriented VRS Model 2 extended by knowledge stock

Country		Input variable (2006-2010)		Input variables (2011)								Output variable (2015)	
	Efficiency	Knowledge stock		Government R&D expenditures		Tertiary educated		Employees in ICT		Employees in S&T		Value added	
		Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
BE	0.90468	3536.4	3199.3	658,600	482,832.0	2368	1372.5	138	124.8	1632	1475.0	410,351	367,354
BG	0.50934	121.2	61.7	78,711	40,090.6	1124	271.8	67.5	21.4	697	257.3	45,286.5	39,138.1
CZ	0.71255	530.6	378.1	504,383	232,378.8	1269	904.2	145.1	66.9	1553	894.3	166,964.1	150,119.6
DK	0.94535	3025.9	1496.9	148,052	139,961.6	1086	1026.7	110.1	76.1	1119	609.3	271,786.1	235,907.7
DE	**1.00000**	55,838.9	55,838.9	10,974,300	10,974,300.0	14,245	14,245.0	1235.9	1235.9	14,600	14,600.0	3,032,820	2,729,662
EE	0.52997	127.4	67.5	31,097	16,480.4	315	86.7	16.7	8.9	196	77.7	202,51.7	17,496.7
IE	**1.00000**	1441.6	1441.6	131,900	131,900.0	1041	1041.0	76.3	76.3	592	592.0	255,815.1	236,813.5
GR	0.99233	269.8	267.8	331,727	210,310.4	1703	1047.6	75.5	74.9	1034	1007.3	175,697.4	155,098.3
ES	**1.00000**	2671	2671.0	2,762,385	2,762,385.0	9567	9567.0	532.6	532.6	5022	5022.0	1,075,639	975,795
FR	**1.00000**	22,313.6	22,313.6	6,248,990	6,248,990.0	11,378	11,378.0	760.6	760.6	9430	9430.0	2,181,064	1,949,825
HR	0.62594	79.3	49.6	92,105	39,708.4	498	303.9	42.3	20.6	410	256.6	43,846.9	36,823.9
IT	**1.00000**	8823.1	8823.1	2,653,600	2,653,600.0	5512	5512.0	544.3	544.3	6944	6944.0	1,642,443.8	1,475,046.8
CY	**1.00000**	26.1	26.1	14,731	14731.0	202	202.0	10	10.0	119	119.0	17,637.2	15,520.7
LV	**1.00000**	26.5	26.5	32,846	32,846.0	360	360.0	25.3	25.3	252	252.0	24,348.5	21,546.6
LT	**1.00000**	33.3	33.3	55,346	55,346.0	617	617.0	25.5	25.5	422	422.0	37,330.5	33,576.5
LU	**1.00000**	195.5	195.5	147,788	147,788.0	117	117.0	8.5	8.5	115	115.0	51,216.2	46,230.2
HU	0.49128	443.9	218.1	189,839	93,263.6	1339	602.2	89.2	43.8	1128	533.4	109,674.2	91,977.7
MT	**1.00000**	23.6	23.6	1999	1999.0	46	46.0	6.2	6.2	48	48.0	9250.3	8129.3
NL	0.77451	8055.1	3749.9	1,319,387	860,757.5	3315	2466.5	284.1	220.0	3211	2486.9	676,531	607,860
AT	**1.00000**	3667.3	3667.3	425,222	425,222.0	1017	1017.0	99.7	99.7	1329	1329.0	339,896	302,652.9
PL	**1.00000**	413.9	413.9	979,421	979,421.0	5569	5569.0	299	299.0	4354	4354.0	429,794.2	381,271
PT	**1.00000**	169.2	169.2	189,330	189,330.0	1149	1149.0	80.2	80.2	1083	1083.0	179,539.9	156,612.2

(continued)

Table 3 (continued)

Country		Input variable (2006-2010)		Input variables (2011)								Output variable (2015)	
	Efficiency	Knowledge stock		Government R&D expenditures		Tertiary educated		Employees in ICT		Employees in S&T		Value added	
		Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
RO	0.75530	199.8	150.9	267,643	202,151.6	1860	1180.6	120.4	81.7	1751	1098.3	159,963.7	140,569.1
SI	0.54240	156.1	84.7	127,831	60,224.3	334	175.7	29.9	14.2	313	169.8	38,570	33,311.4
SK	**1.00000**	73.2	73.2	129,575	129,575.0	675	675.0	56.5	56.5	704	704.0	78,685.6	70,993.6
FI	0.56609	4039.9	1333.3	633,712	180,012.7	1275	717.4	99.3	56.2	943	533.8	209,149	180,358
SE	0.80509	8233.5	2402.9	566,901	456,407.2	2002	1611.8	191.4	136.3	1908	1409.4	447,009.5	39,5501.1
UK	**1.00000**	19,556.9	19,556.9	2,706,303	2,706,303.0	13,670	13,670.0	1066.6	1066.6	10,647	10,647.0	2,577,280.1	2,296,927.7

Note Knowledge stock represent number of patents accumulated between 2006 and 2010; Government R&D expenditures, tertiary educated, employees in ICT, employees in S&T are in thousands Euros, value added is in million Euros; EU 28 countries are marked according to international country codes
Source Own

These countries should focus on input variables, such as providing government R&D subsidies, as well as on human resources within universities and ICT sectors.

For example, we show proposed reductions for the less effective country—Bulgaria: government R&D expenditures: from 78,711 thousands Euros to 19,613.1 thousands Euros; tertiary educated: from 1124 thousands to 180.9 thousands; ICT employees: from 67.5 thousands to 15.7 thousands; employees in S&T: from 697 thousands to 121.8 thousands.

Results in Table 3 show how the knowledge stock influences countries' efficiency, and plays the important role in the process of development. In Model 2, 15 countries were considered as effective. These countries are Germany, Ireland, Estonia, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Austria, Poland, Portugal, Slovakia and UK. In this Model 2, Hungary was the least effective country within EU 28.

The used DEA method showed which countries are able to apply selected determinants and generate outputs with the highest efficiency rate. Given the high number of countries with high efficiency, it is possible to say that DEA method is only primary. The method makes it possible to divide countries according to their effectiveness and explore these clusters using other methods. Many studies in their investigations end just by stating that some countries are more efficient. The scholars are not already thinking about why (by what cause) they are able to be the most efficient country. Finding the cause is important for the future and for portability to other countries and their public policies.

5 Discussion and Conclusion

In this study, we show the importance of the knowledge and accumulated knowledge stock in gaining (improving) countries' efficiency. It is important to know that the level of efficiency of the inputs' use (resources) is, among other things, the competitive advantage of a country or of its enterprises (and other entities). The ability to use the resources to the maximum, or to get more than 100% of them (synergistic effect), will also differentiate individual economies and countries in the future. It is necessary to know the variables that affect and create the knowledge base and public policies which can support (support their emergence) them effectively, apply and draw on the resulting benefits. It should be remembered that synergistic and spillover effects provide benefits even around standing entities (third parties).

We conducted two DEA models to show how the proper creation and use of accumulated knowledge within countries could affect their efficiency in the process of value added creation. It is clear from the previous results that if a country has a good knowledge infrastructure and a knowledge base in individual economic entities, this country appears to be effective in any comparison and model (Germany is the typical example). This confirms the previous assertion that a knowledge base is an essential prerequisite for developing the knowledge economy and creating positive effects in it. From our results, it is possible to determine which input must be improved by the national or regional government and by benchmarking, it is possible to find out what and how to do in order to improve its effectiveness.

Our results allow us to recommend some practical implications for policy makers within countries. We recommend qualitative modifications in strategies for public funding (specifically system of science and technology funding), to improve the position of economies in the ranking of competitiveness in international comparison. This could lead to encourage more companies to invest in their research and development (e.g. through tax benefits). It is also necessary to change government's policies on tertiary education (promotion of science, technology, language skills, higher mathematical literacy and natural sciences). It should influence the innovation potential of companies, scientific and research potential of R&D institutions and universities in the future). Next, we propose supporting relationship with practice, as done in Germany through vocational education and training system which is aimed at promoting cooperation between firms, universities and public research centres. Finally, we recommend creating high-quality concept of support of knowledge-intensive industries (including the creation of a modern communication infrastructure) and creation of knowledge stocks. For the future research, we plan to follow our results and analyse microeconomic conditions (firm level) within EU 28 countries in the concept of knowledge economy.

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