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Diffusion Efficiency of Innovation among EU Member States: A Data Envelopment Analysis

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Abstract: Innovation, in contemporary times, has been established as the lynchpin of growth and national competitive advantage among countries. Supranational and national resources have jointly combined to create sound innovation strategies and diffusion policies for member states in recent times. However, there is the question of whether increased innovation translates to effective diffusion of innovation. With this in mind, the present research aims to comparatively assess and evaluate the efficiency of diffusion of innovation of European Union member states in reference to their European Innovation Survey rankings. Using the Charnes, Cooper and Rhodes (CCR) model of Data Envelopment Analysis (DEA), the present research found contrasting diffusion efficiency scores of member states with different innovation performances as most innovative member states had much lower efficiency scores compared to some supposedly weak innovating member states. We also computed the input-redundancy and output-deficiency of member states, provided recommendations for efficient input-output combinations based on findings of respective member states and innovation groups, and finally, outlined directions for future studies.

Keywords: efficiency; diffusion; innovation; European Union; DEA analysis

JEL Classification: 011, 032, 038

1. Introduction

Innovation creation has been deservedly lauded as the driver of economic growth, and has generated substantial interest in policy creation in most countries. Baden Wurttemberg in Germany, for example, recognizes innovation as the lynchpin of their regional growth, as stated on their website and actively rewards the more innovative with even more resources. The European Union (EU), having recognized regional differences in endowments used for innovation, rightly adopted the Territorial Innovation model of regional growth and innovation. This effort refutes a superimposed model of regional development and allows regions the flexibility of operating with their available resources effectively permitting variations in strategies for innovation generation. The Cohesion policy document (2014–2020) further endorsed this model to recognize geographical variations in the creation of innovation by firms and regions to the reception of many scholars (Capello 2012). Even in light of the flexibility in innovation generation of member states, there seemed to be lagging productivity issues potentially caused by input insufficiency or ineffective diffusion of innovation to recoup the capital invested. Andrews, Criscuolo and Gal (2016) revealed that over the past decade the productivity gap between frontier and laggard firms has widened. One of the main reasons being the persistently insufficient diffusion of technologies and innovations across firms and countries, both between and within sectors. Furthermore, even though innovation has driven the European Union economy in the years prior, it has been reported that EU companies reportedly spend less on innovation than their counterparts in the United States and China (European Commission 2018). Venture capital also remains underdeveloped as well, thereby driving most companies to ecosystems where with quicker growth opportunities. Even though Public funding has been set to be increased to 3% of Gross Domestic product (GDP) by 2020, this has also been impeded by the erratic foreign direct-investment (FDI) performance from 2007. In spite of this relative scarcity, we are moved to question whether the current venture capital and public spending on innovation are even efficiently used to diffuse innovation created that is desperately sought to be improved in the Union.

Comparatively little research has been conducted on the diffusion of innovation of member states within the European Union. Zanello, Fu, Mohnen and Ventresca (Zanello et al. 2016) researched on the diffusion of innovation in the private sectors (industry and services) in low-income countries (LICs). They found that innovation in LICs is about creation or adoption of new ideas and technologies; but the capacity for innovation is embodied by dynamics between socio-economic, geographical, political and legal subsystems. Carayannis, Grigoroudis, and Goletsis (Carayannis et al. 2015) came closest by applying a multi-stage DEA efficiency analysis to assess innovation generation of 23 selected European regions focusing on sub-processes and hierarchical modelling at the Nomenclature of Territorial Units for Statistics (NUTS) II level. Results showed significant differences among regions and countries used. Relying on the assertion of European Union that the high innovative countries perform well in diffusion, the territorial influences on innovation creation and having observed little research in the direction of efficiency of innovation in the European Union and the relatively low resource inputs available, the aim of our research is to comparatively assess the efficiency of diffusing innovation created in the twenty-eight (28) European Union member states with key reference to their innovation ranking according to European Commission (European Commission 2018). We are of the opinion that the more a country pursues innovation generation, the higher the tendency to innovate but efficiency of diffusing innovation can differ irrespective of the innovation ranking. Results of our research revealed efficiency of diffusing innovation was independent of national innovation scores or ranking. This was all summed up by Sweden, the most innovative EU member state, recording the lowest efficiency score among all the member states considered. Recommended input and output adjustments were analyzed and reported for all member states concerned to restructure their diffusion scope and appropriately reap their economic potential.

The remainder of the paper is as follows: Section 2 will review studies undertaken on innovation diffusion and the supportive requirements, the methodology detailing data sources, variable selection, and research areas, including the CCR (the model proposed by Charnes, Cooper, and Rhodes in 1978) will be explained in Section 3. The fourth section will discuss and present results of the research, including innovation diffusion comparison, the portion occupied by countries on the efficiency pie based on their innovation scores and the analysis of redundancy and deficiency values of member states. The final section will present the conclusions of this paper and provides related recommendations.

2. Literature Review

Territorial Innovation Systems (TIS) was revealed in the early 1980's as an effort to comprehend evolving geographies of economic growth (Crevoisier 2014). This concept merges various theories such as industrial districts, milieu innovators, new industrial spaces and local production systems. TIS as a model examines the interactions between organizations in a spatial context and their relations with other economic and social contexts with a specific focus on innovation centric activities and specificities of regions. Under this perspective, regions can develop their own mode of innovation according to the presence of local conditions effectively permitting the varying phases of the innovation process to occur and seamlessly move from one process to the other (Capello 2012). National institutional framework is argued to have a strong impact on the development of regional innovation system such that entrepreneurial regional innovation system (ERIS) and Institutional regional innovation system (IRIS) are more common in liberal and coordinated markets respectively (Asheim, Grillitsch and Trippl 2016); however, there was slight opposition from Crescenzi and

Rodriguez-Pose (Crescenzi and Rodriguez-Pose 2012) who conducted an extensive theoretical analysis and eventually concluded that there is no need to classify approaches according to National or even continental difference, but rather, key focus should be on sustainable models of local conditions that maximize potential returns of regional innovation policies.

The EU official document titled "Regional Policy Contributing to Smart Growth in Europe" (European Commission 2010) was the first official move in this direction which called for the need to identify sectors and technological domains where regional policies should be tailored to promote local innovation processes in their specialization fields. This policy direction supported the policy report presented by "knowledge for Growth" expert team (Camagni and Capello 2013). Following the TIS concept, Cooke, Uranga and Exteberria (Cooke et al. 1998) attempted to link new regional work to evolutionary economics arguing for the development of evolutionary regional science. Developing an analytical framework, they assessed the financial mechanisms, knowledge infrastructure and even cultural dispositions concluding that most regions do not yet have the necessary institutional and organizational characteristics to fully justify the status of Regional Systems of Innovation (RSI), but by means of evolutionary processes many may already possess key elements for that status. Camagni and Capello (Camagni and Capello 2013), following up on Europe 2020 report, extensively discussed and proposed the adoption of a smart innovation policy that goes a step further, taking into consideration the research and development (R&D) element whilst also adapting the two concepts of "embeddedness" and connectedness (Camagni and Capello 2013). They furthered on to conclude there is the need to adopt a modern version of the smart specialization to develop single innovation policy for each region according to their specialization is also critical. The specificities of single regions are fundamental for the implementation of projects and also enables identification of common approaches for similar types of regions in order to eschew misallocation of public resources and unlikely local strategies. Ponsiglione, Quinto and Zollo (Ponsiglione et al. 2018) also found that the exploration capacity, the propensity to cooperation, and the embedded competencies of actors in a region could also be key as key aspects in affecting the regional innovation performance. In spite of this essence of role of actors, Alkemade, Kleinschmidt, Hekkert (Alkemade 2007) recommended asserted that, in energy creation, policymakers should formulate energy policies on system level and not on specific actors or groups of actors alone as concurred by Foxon and Pearson (Foxon and Pearson 2008). Doloreux (Doloreux 2002) also reviewed literature on regional System of Innovation (RSI) and concurred a typology that blocks Regional System of Innovation. He outlined the "organizational thinness of RSI", i.e., the result of a region presenting a lack of relevant actors to enable collective learning, "fragmented RSI", i.e., a region exhibiting a lack of regional cooperation and mutual trust among actors and "Lock-in RSI", i.e., the result of an old industrial region characterized by industry in outdated technologies—as key factors that blocks the realization of Regional System of Innovation (RSI). Further research has also shown that the exploration capacity, the propensity to cooperation, and the endowed competencies of regional actors could be considered as key aspects in affecting the regional innovation performance hence policy-makers should make efforts to incentivize investments in research and development activities both at the public and private levels, support public-private partnerships, enhance national and regional university systems and also increase the number of researchers employed both in the public and private sectors (Ponsiglione et al. 2018). They could also strategically position intermediaries in the innovation process to seamlessly facilitate knowledge transfer to adequately generate innovation (Rippa, Quinto, Lazzarotti and Pellegrini 2016) to also assist with efficient dissemination. In effect, these innovation policies in Europe should be even more centred on Small and Medium Scale enterprises as it form due to the sensitivity of firm level innovation determinants (Sternberg and Arndt 2001).

European Commission's Cohesion policy (2014–2020), played a pivotal role in re-channeling the focus of tendencies of innovation of regions from a National-centric perspective to a region-centric one effectively admonishing regions to innovate from bottom-up unlike the traditional top-down approach previously adopted (Crescenzi and Rodriguez-Pose 2012). According to Crescenzi and Rodriguez-Pose (Crescenzi and Rodriguez-Pose 2012), the local resources are hinged on and recognized as the engine of regional economic performance such that quantitatively, they operate as inputs in the Knowledge Production Function for idea generation even as qualitatively, such innovation activities are handled in various contexts with roles played by private firms, research centers and universities. In their opinion, impact of innovative activities is dependent on two main factors: systems of innovation and social filter conditions and geography. Deeper insight into Rogers (Rogers 2003) model of innovation diffusion reveals four prime factors that determine diffusion of innovations. He perceived that innovation has to be viewed as new by the adopter or user, and must occur in the presence of effective communication channels, recognition of time constraint and the social system that adopts it. He conceptualized the process into five steps in this process: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation as visually shown in Figure 1 below.

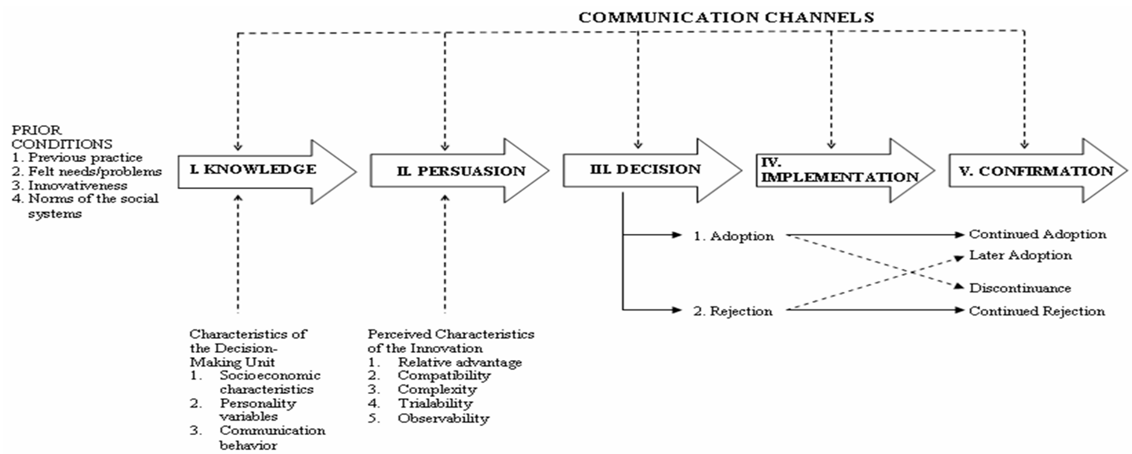


Figure 1. A model of the five-stage of diffusion process by (Rogers 2003).

Tidd (Tidd 2010) opined that, practically, the adoption of innovation is strongly determined by supply-side factors, e.g., the availability of information, relative advantage of the innovation, barriers to adoption and feedback between suppliers and consumers—and demand-side factors—adopters with different perceptions, imitation of early adopters. Hence, the absorptive capacity of regions essentially determined the diffusion model opted for. Briglauer (Briglauer 2014) also found that even in broadband service provision, substantial networks effects deeply underly the success of adoption. Aside the factor of absorptive capacity and market significance (Caiazza 2016), several researchers also pointed out various dimensions of factors that could facilitate or derail the rails of efficient innovation diffusion in countries. Technological, social and learning conditions were also found to be an impeding factor (MacVaugh and Schiavone (MacVaugh and Schiavone 2010). Entrepreneurship policies were also pointed out as variables that expedited or receded innovation. Hall, Matos and Sheehan (Hall et al. 2012) assessed the participation of personnel as entrepreneurs in a research. They found that weak institutions rather assisted undesirable outcomes even more when entrepreneurial policies were solely based on economic indicators. Allard, Martinez and Williams (Allard et al. 2012) also added that pro-business market reforms had a lasting effect that superseded political instability effects in developing countries with declining science and technology performance. Cultural and linguistic barriers are also thought to affect the effective flow of innovation such that as well as physical and technological proximity, sharing a common language does facilitate the ease of information flow and even creation of trust (Caiazza 2016). Cultural barriers are usually tied to poorly organize inter-firm relationships, business climate, entrepreneurial behavior and risk-taking attitude.

Having known the territorial influence on innovation generation and limitations to innovation diffusion in mind, some researchers have attempted to comparatively compute the innovation performance of countries and regions to reveal the innovation differences. Most notable of them is (Carayannis et al. 2015) who used a multi-stage and multi-level DEA to compute and compare innovation performance of 23 selected countries from around the world. Afzal (Afzal 2014) also selected 20 countries around the world to assess their national innovation system using DEA bootstrap and a Tobit regression model. Based on his findings, he further classified countries that were efficient at both constant and variable returns to scale as innovation leaders. We observed that despite the territorial differences in innovation generation, little theoretical and practical focus has been given to the efficiency of diffusion of this generated innovation, even in the wake of these geographical variations in innovation generation and the astronomical funding program, 'Horizon 2020', set up for European Union firms. Hence, the novelty of the present research will be to reveal information regarding the member states that are efficiently utilizing funding and framework structures set up for diffusion of innovation and to fill in the literature on efficiency of diffusion of innovation of EU member states. Based on the aforementioned assumption, the literature affirming that proper structures and adequate finance results in higher innovation (Franco and De Oliveira 2017; Akcali and Sismanoglu 2015), the territorial impact on regions' innovation sources (Crescenzi and Rodriguez-Pose 2012), we set two research questions:

- Is the diffusion efficiency of innovation determined by the innovation excellence or innovation deficiency of member states? If not, which member state reported highest and/or lowest efficiency?
- To what degree were inputs (outputs) inefficiently used? Which inputs were most inefficiently utilized? And how should inputs (and outputs) be juggled to produce an efficiency in innovation diffusion in member states?

3. Data and Methodology

3.1. Data Resources and Research Area

Data was extracted from the European Innovation Scoreboard (EIS) collated in 2018 via the website of the European Commission. This is a repository of information for the innovative capacities and rankings of all European Union member states. The present research is exploratory and quantitative in nature and also employs purposive sampling technique. Following this sampling technique, we selected the twenty-eight member states in the European Union as the unit of analysis because of the intent to comparatively assess the efficiency of diffusion of innovation of all European Union member states. We exclusively focused on EU member states due to their growing public investment and relatively poor private investment, venture capital investments compared with United States and China. However, even though United Kingdom are currently negotiating to leave the Union, we still decided to include them as part of the analysis since the process had not formally been concluded yet.

In Table 1 below, the member states are ranked and grouped according to their relative score with the EU average. The first group of Innovation Leaders includes Member States whose performance is more than 20% above the EU average namely: Denmark, Finland, Luxembourg, the Netherlands, Sweden, and the United Kingdom. The second group of strong innovators are those that performed close to or higher above the EU average but not more than 20% of the average. The third group of Moderate Innovators includes Member States whose performance is between 50% and 90% of the EU average and the fourth, the Modest Innovators, includes Member States that show a performance level below 50% of the EU average.

Table 1. Innovation rankings of member states according to European Commission (2018).

Innovation Leaders	Strong Innovators	Moderate Innovators		Modest Innovators
Denmark (DK)	Austria (AT)	Croatia (HR)	Italy (IT)	Bulgaria (BG)
Finland (FI)	Belgium (BE)	Cyprus (CY)	Latvia (LV)	Romania (RO)
Luxembourg (LU)	France (FR)	Czech Republic (CZ)	Lithuania (LT)	
Netherlands (NL)	Germany (DE)	Estonia (EE)	Malta (MT)	
Sweden (SE)	Ireland (IE)	Greece (GR)	Poland (PO)	

United Kingdom (UK)	Slovenia (SI)	Hungary (HU)	Portugal (PT)
			Slovakia (SK) Spain (SE)

Source: European Commission (2018).

In Table 2, the input and output variables selected for the present research are presented. These variables selected encompass the category of finance, human resource, creativity and non-financial innovation structures as used by (Rickne 2001; Moon and Lee 2005; Afzal 2014; Carayannis et al. 2015) and also published by European Commission (2018) in the latest European Innovation Scoreboard. Below is a list of inputs and output variables used for computation.

Table 2. Input and Output variables selected for analysis.

Abbrev.	Category	Input Variables	Abbrev.	Output Variables
NDG	Human Resource	New doctorate graduates (NDG)/1000 pop. (25–34) (European Commission 2018)	**EMP**	Employment (EMP) in knowledge-intensive activities—Number of employees in high-growth enterprises per total employment for enterprises with 10 or more employees
LL		Lifelong learning (LL)—Population aged 25–64 involved in education and training per total population of the same age group (European Commission 2018)	**SLS**	Sales (SLS) of new-to-market and new-to-firm innovations—sum of total turnover of new or significantly improved products for all enterprises per total turnover for all enterprises.
OE	Creativity	Opportunity-driven entrepreneurship (OE)—degree to which individuals pursue entrepreneurial activities as they see new opportunities (European Commission 2018)		
PSE	Finance	Public sector R&D expenditure (PSE) and the higher education sector per Gross Domestic Product (GDP) (European Commission 2018)		
VCI		Venture capital investments (VCI)—private funds raised investment in companies per GDP (European Commission 2018)		
PRE		Private sector R&D expenditure (PRE) per GDP (European Commission 2018)		

NIE	Non-financial structures	Non-R&D Innovation expenditure (NIE)—total innovation expenditure for enterprises per total turnover for all enterprises. (European Commission 2018)	

Source: European Commission (2018).

To assess the potential inflation of the variance in the event of multicollinearity, variance inflation factor (VIF) was employed to test the multicollinearity. According to Hair, Sarstedt, Ringle and Mena (Hair et al. 2012) the variance inflation factor (VIF) exhibits a high collinearity when the collinearity rate exceeds 5.0. Mathematically, it can be shown that the variance of the estimated coefficient *bk* is:

$$\mathrm{Var}(bk)\mathrm{min} = \frac{a^2}{\sum \mathrm{ni} = 1\left(x\mathrm{ik} - x\overline{\mathrm{k}}\right)2} \quad (1)$$

Results of the Variance inflation factors (VIF's) in Table 3 below showed that the inputs and the output variables had no strong multicollinearity issues according to (Hair et al. 2012).

Table 3. Results of correlation test among input and output variables.

Variables	EMP	LL	NDG	NIE	PSE	PRE	SLS	VCI
VIF	1.016	2.790	2.049	1.240	2.222	3.722	1.016	1.332

3.2. DEA Model: CCR

Created by Charnes in 1978, CCR model is regarded as the most commonly used DEA model. This model analyses a DMU's efficiency on the premise of a constant or variable return to scale (CRS) using the input or output orientation. When using the CCR model at constant returns to scale, a DMU is regarded as inefficient if the technical efficiency value is less than 1, which means that the production value is below the production–possibility frontier; on the other hand, the operation of a DMU is efficient if the technical efficiency value is equal to 1. This will enable further analyses of the inefficient units to propose improvement and suggestions by circulating the redundancy and the deficiency value. The objective function as used by (Li et al. 2019) is stated as follows:

$$hj = \frac{\sum_{r=1}^{\mathrm{s}} u_{\mathrm{r}}\, y_{\mathrm{rj}}}{\sum_{i=1}^{\mathrm{mn}} v_{\mathrm{r}}\, x_{\mathrm{ij}}} \text{ , j} = 1, \ldots., \mathrm{n}\,. \quad (2)$$

where *hj* denotes the technical efficiency of DMU *j*; *xij* and *yrj* represent the values of input *i* and output *r* for DMU *j*, respectively; and *vi* and *u*r are weight coefficients that measure input *i* and output *r*, respectively. For the CCR model, the goal is to maximize the efficiency value *hj* of the above DMU. Taking the efficiency value of DMU *j* as the target, we use the efficiency value of all DMUs as constraints. As stated by Charnes Cooper and Rhodes (1978) the CCR (C2R) model is constructed as follows:

$$\mathrm{max}h_{j0} = \sum_{r=1}^{s} u_r\, y_{rj_0} \Big/ \sum_{r=1}^{m} v_i\, x_{ij} \quad (3)$$

$$hj = \frac{\sum_{r=1}^{s} u_r\, y_{rj}}{\sum_{i=1}^{m} v_i\, x_{ij}} \leq 1 \quad (4)$$

$$u \geq 0, v \geq 0; j = 1, \ldots, n; r = 1, \ldots, s; i = 1, \ldots, m \quad (5)$$

Slack variable, S^+, and the residual variable, S^-, are further introduced into the model, which change the inequality constraints into the equality constraints. In 1952, Charnes, Cooper, and Mellon successfully proposed a small "non-Archimedean" quantity, making calculations faster and more convenient, which is why DEA can be widely used in various fields. Similarly, Charnes established a CCR model with the non-Archimedean quantity, shown below

$$\begin{cases} \min[\theta - \varepsilon(\sum_{j=1}^{m} S^- + \sum_{j=1}^{m} S^+\} = v_d(\in) \\ \sum_{j=1}^{m} x_j \lambda_j + S^- = \theta x_0 \\ \sum_{j=1}^{m} y_j \lambda_j + S^- = y_0 \end{cases} \quad (6)$$

$$\lambda_j \geq 0, S^+ \geq 0, S^- \geq 0, j = 1, \ldots\ldots, n \quad (7)$$

where θ denotes the radial value or distance from the production–possibility frontier in this equation, and S^+, S^- represent the redundancy value and the deficiency value, respectively. The classification criteria are such that (θ represents the optimal solution):

(1) The DMU *j* is DEA-inefficient when $\theta < 1$;
(2) The DMU *j* is DEA-efficient when $\theta = 1$ and $S^+ + S^- = 0$;
(3) The DMU *j* is weakly DEA-inefficient when $\theta = 1$ and $S^+ + S^- > 0$.

4. Results and Discussion

To compute the efficiency of diffusion of innovation, we opted for employment of knowledge intensive service and sales of developed or newly produced products as the output variables. The input variables of new doctorate graduates, lifelong learning, opportunity-driven entrepreneurship, R&D expenditure in the public sector, venture capital investments, R&D expenditure in the business sector and non-R&D innovation expenditure were also selected.

From Table 4, the existence of a wide gap in resource availability for the considered member states can easily be observed. The degree of deviation of new doctorate graduates per thousands of the population was reported as 63.25 persons per thousand population and lifelong learning figure of 79 persons from the mean. None of the figures for standard deviation reported was less than one third of the reported arithmetic mean among all inputs and outputs. This could be inferred as a large gap in availability of resources of innovation with respect to the measures of diffusion. However, Netherland, an innovation leader and Slovenia, a strong innovator, both recorded inputs below the arithmetic mean but was still relatively efficient compared to other member states hence, resource availability could not conveniently be held as a reason for lower efficiency.

Table 4. Descriptive statistics of data used for all member states.

Statistical Dispersion	NDG	LL	OE	PSE	NIE	VCI	PRE	Emp	Sales
Mean	119.1	104.2	95.20	80.31	93.83	80.64	80.31	82.64	67.45
Std. Deviation	63.25	76.01	48.09	43.89	65.11	61.19	56.89	43.68	44.28
Minimum	33.33	1.000	1.000	5.640	4.900	0.8900	5.640	1.000	9.700
Maximum	235.9	284.4	210.7	193.5	280.8	205.5	193.5	159.4	157.8
Number of observations	28								

Source: Authors' computation.

From Figure 2 below, it can be observed that almost half (50%) of all member states considered were relatively efficient and vice-versa. We named member states were named according to their official two-letter international abbreviations as used by the European Commission. Amongst these countries that were found to be significant, two (2) were innovation leaders, one (1) strong innovator, eight moderate innovators and two modest innovators. This result reveals a mix of countries with variations in results in spite of the level of innovation scores and ranking on the European Innovation Scoreboard published by European Commission (2018).This effectively implies that firms' efficiency of diffusing innovation generated has no bearing with the innovation generation status of the member state or even the economic status of countries concerned but purely connected with efficient combinations of input resources. These findings answer the first research question and support the hypothesis that firm's efficiency of innovation diffusion does not depend on excellence or deficiency of innovation performance of member states and largely corroborates findings of (Carayannis et al. 2015) at their first level analysis. At the first level, they employed human capital, financial support to knowledge processes and non- financial research and development support whilst mapping it to product or process innovation, marketing or organizational innovation, employment and sales of new to market or new to firm products. They found 19 out of 23 countries assessed to be efficient including Netherland, Czech Republic, Hungary and Bulgaria. Having found this, it is worthy to note that, in regional innovation assessment, certain complexities, ambiguities in regional innovation analysis may be lessened by bringing to the fore analytical fields that portrays insights of regional science (Cooke et al. 1998). Hence, to capture the regional drivers of regional differences in efficiency and performance and arrest the trends, is essential to build targeted normative strategies, well beyond what is proposed by the smart specialization model that has recently been adopted (Capello 2012). This is because geography of innovation is much more complex than a simple core-periphery model; the capacity to pass progress from knowledge to innovation as well as the specific innovation patterns is different among regions, (Camagni and Capello 2013).

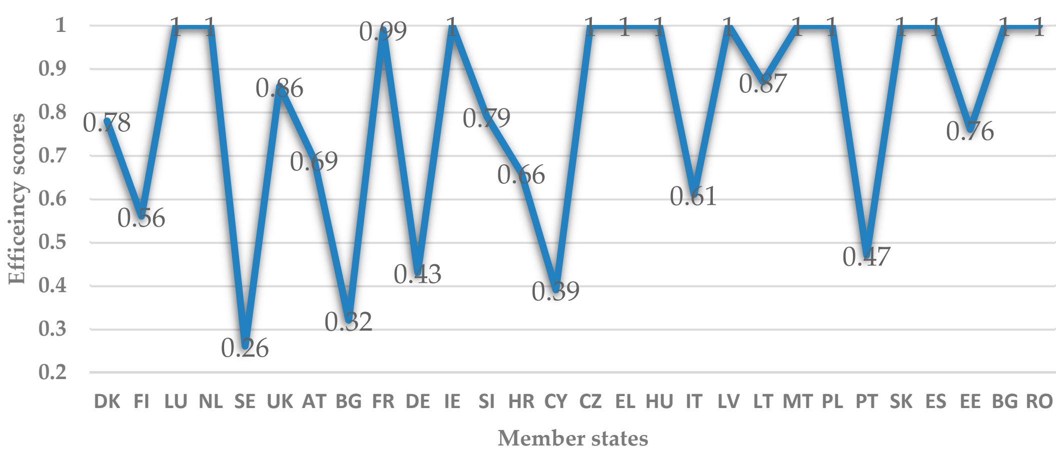


Figure 2. DEA efficiency scores of EU member states.

As part of the first research question, efficient and inefficient member states and their proposed input (output) combination can be found in Table A1 and Table A2. To further interpret, it could be seen that among the innovation leaders, only Luxembourg and Netherlands were found to be relatively efficient in their usage of inputs, i.e., human resources, finance, creativity and innovation structures. Luxembourg has made great strides in research and development policies lately which could be alluded as a significant contributor to this efficiency score. According to the European Commission (2018), since 2000, there has been a five-fold increase in public sector research and development intensity from 0.12% to 0.59% in 2014 indicating a strong resolve to achieve innovation targets. They also backed this up with solid and newly structured research and investment strategy by concentrating on their most important research and investment actors. However, United Kingdom, Denmark, Finland and Sweden, in descending order, were found to be rather relatively inefficient. Sweden was, in relative terms, was revealed as the least efficient member state among all the 28-member states considered even as it is currently the most innovative European Union member state. These findings were largely in line with the findings of (Guan and Zuo 2014). To assess the innovative performance they used knowledge generated, general expenditure on research and development and patents as inputs and scientific output as the output of their innovation of 37 countries around the world. Although their results did not adequately measure the dissemination efficiency of innovation, results revealed at the constant returns to scale (CRS) showed all above-mentioned innovation leaders to be inefficient in innovation creation; even though results of variable returns to scale was largely the same. These contrasting results could be a reason of different innovation measurement variables used in the analysis as this could portray some countries as stronger and more efficient than others if it is based on their innovative strength. It must also be noted that territorial nature of innovation structures within the European Union largely put some member states at a disadvantage especially when assessing their inputs used. Since DEA analysis also computes efficiency based on relative efficiency scores, the results could also be affected by several other countries like Turkey, Australia, Canada, Argentina and the like that were also analysed by the author aside the EU member states assessed. However, to improve its sales and employment efficiency, the model shows that Sweden, the most innovative member state in the European Union operated with much more inputs than it would conveniently need and recommends that a reduction of human resource, financial and non-financial inputs already expended towards innovation diffusion to generate efficient employment and sales output. Creativity exploited from human capital should be adequately educated and supported in their quest for entrepreneurship to reduce set-up failures, increase their success rate whilst assigning them selectively defined and controlled roles in the diffusion process. Even as the public incentives may be imperative for cooperation, The CARIS model, from agent-based modelling can be lent from the work of (Ponsiglione et al. 2018) to expertly create sound policies to manage the actors in play, their cooperation and trust levels to even reap more results in terms of creativity via learning and communication.

Regarding the strong innovators, only Ireland was found to be the relatively efficient member state in this rank. Over time, Ireland has gradually strengthened the performance of innovators and employment variables. The provisional 2016 data has also shown a drastic improvement in sales of new products France recorded a nearly efficient score of 0.99. Lately in Ireland, range of policy responses have been implemented to accommodate SME's inability to absorb innovations to raise the number of local SME's involved in research and development activities whilst actively eliminating duplicate funding for research. Even though Slovenia and Germany were relatively inefficient, ranking 17th and 25th respectively, Belgium's efficiency was substantially lower, only next to Sweden. These results also corroborate the research of (Wang and Huang 2007; Guan and Zuo 2014; Carayannis et al. 2015). According the model, input redundancy is in excess, and needs to be largely downsized in line with results from Table 5, to reach relative maximum efficiency.

Table 5. Input redundant and Output deficient analysis (in %).

Member States	NDG %	LL %	OE %	VCI %	PRE %	NIE %	PSE %	EMP %	SLS %
Innovation Leaders									
Denmark	66.2	63.5	73.7	22.4	72.2	22.4	66.3	-	-
Finland	55.9	81.7	79.7	44.4	81.8	44.4	71.9	-	-
Sweden	73.6	78.2	92.9	89.8	85.6	73.6	89.1	-	-
United Kingdom	14.1	66.0	45.8	75.8	55.5	14.1	14.1	−28.6	-
Strong Innovators									
Austria	30.8	88.8	72.2	79.2	90.1	30.8	80.3	−219.8	-
Belgium	67.8	89.4	73.4	93.9	92.7	67.8	88.8	−8.0	-
France	1.0	87.9	69.9	90.7	75.8	1.0	72.1	−63.2	-
Germany	56.6	57.4	56.6	56.9	76.1	56.6	73.2	−14.3	-
Slovenia	65.0	74.4	52.7	21.0	79.3	35.7	21.0	-	-
Moderate Innovators									
Estonia	23.5	79.7	52.3	73.1	23.5	32.7	52.2	−6.1	-
Croatia	34.3	34.3	46.3	34.3	34.3	73.0	82.1	-	−53.5
Cyprus	60.8	96.4	93.7	98.2	75.4	60.8	82.3	-	-
Italy	38.9	73.6	63.8	61.3	59.1	38.9	70.6	−53.6	-
Lithuania	13.3	65.2	64.4	85.2	13.3	82.2	59.2	-	-

Portugal	53.0	53.0	76.4	84.3	53.6	53.0	79.3	-	−71.0

Source: Author's calculation.

Most member states fell within the range of moderate innovators according to European Commission (2018). Among the fourteen member states recognized as such, a total of seven nations, namely, Czech Republic, Greece, Hungary, Latvia, Malta, Poland, Slovakia and Spain, were relatively efficient in the analysis. Comparatively, Croatia, Cyprus, Italy, Estonia, Lithuania and Portugal were singled out as inefficient in descending order. This research corroborates the findings of (Sharma and Thomas 2008) when they assessed the research and development efficiency of 22 nations including Russia, Japan and even Australia using variable returns to scale (VRS). According to the model, Croatia is recommended to possibly reduce human resources, financial, creative and innovation framework inputs to attain an efficient employment and even higher sales of new or developed goods. This implies an over-allocation of inputs which could have been employed in other productive ventures to genuinely utilize their output potential. An equally viable recommendation was also proposed by the model for Cyprus, Portugal, Estonia and Italy. This seems to conclude that in most cases member states with lower efficiencies have too much input allocated for outputs and could achieve such efficiency with even lower inputs to free up the unused potential to be diverted to other output orientations in the economy. Bulgaria and Romania were the only modest innovators and were 24th and 27th respectively on the ranking of efficiencies as also found by (Carayannis et al. 2015). Contrary to their performance on the EU innovation ranking, which ranks them the lowest on the EIS ratings, their diffusion efficiency relative to other member states was efficient. Although EU reports confirms that innovative capacity of firms is a significant factor in the diffusion capacity and performance of member states, this finding reveals the possibility of occurrence of "too much input for too little output" compared with highly innovative member states in light of their input invested and output accrued. This finding further reveals viable potential for new venture creation and resource investments amongst some innovative leaders and strong innovators.

Looking at the efficiency performance scores of the moderate and modest innovators, a leaf could be taken from the research of Ponsiglione, Ivana, and Giuseppe (Ponisiglione et al. 2018) in arresting this canker. Assessing leading and lagging European regions, they inferred that lagging regions lacked solid interactions, network coordination, competences and skills as well. However, it is imperative to note that cooperation cannot be imposed from the top, but rather emerges from the interactions between the actors in the eco-system. An approach which has been sensitively outlined by Morieux and Tollmann (Morieux and Tollmann 2014). Furthermore, lagging regions would also do well adopting the proposed CARIS structure by Ponsiglione et al. (2018), as it enables the fine-tuning of parameters that regulate the local behaviors of the actors and the creation of partnerships among them, in order to evaluate ex-ante the impact of policies on the emergence of extended forms of cooperation. Intermediaries of the innovation process, with consideration to the firm size, should be strategically positioned to expedite innovation processes and to close the gap in inefficiencies of innovation dissemination as concurred by Rippa et al. (2016). This is adjudged to enable development of effective innovation policies able to foster the growth and innovativeness of all European regions, especially the lagging ones.

Table A3 shows changes in efficiency of innovation diffusion scores and rankings of member states in 2017 relative to 2010. This comparison revealed a vast improvement in the ranking of some countries like Netherland when compared with diffusion efficiency scores of 2010. It is also worth mentioning that despite the differences in efficiency among member states, much blame cannot be put at their doorstep. This is because even though inputs selected for the analysis were predominantly fundamental inputs that every member state needed in their quest for creation and efficiently diffusing innovation, the Regional System of Innovation of the European Union allows differentiated strategies by firms to create their own innovation according to their regional resources thereby creating different styles, different strengths and weaknesses for these regions. Hence, the variables used may be considered as strengths for some but weaknesses for others. Furthermore, according to the European Commission (2018), venture capital has remained sorely under-developed in the Union such that the Union still lags behind in the venture capital queue compared with other continents, This has contributed to the valuation of entire start-up firms in the Union as $1billion compared with $109 billion dollars in the United States and $59 in China. Business research and development expenditure is also at 1.3% compared with 2% in the United States and 3.3% in China. Even in 2006, a European Commission report captioned '*How is the internal market integration performing*?' revealed a poor inward foreign direct investment (FDI) flow into the service sector particularly even as it formed the most part of EU's. It was tipped to improve however the results have not been quite stable as can be seen from Figure 3. This can be interpreted as a poor acceptance of mergers and acquisitions, or even as unattractive for such undertakings, and could really be useful especially in light of the consistently low venture capital figures.

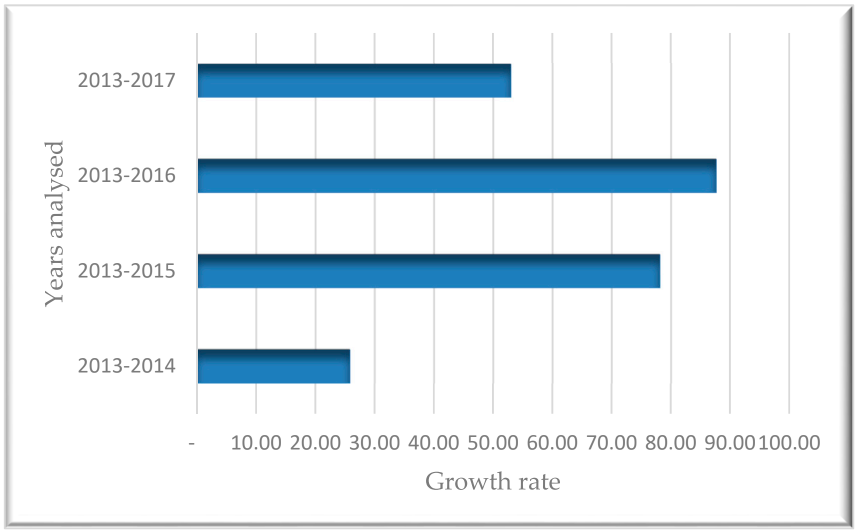
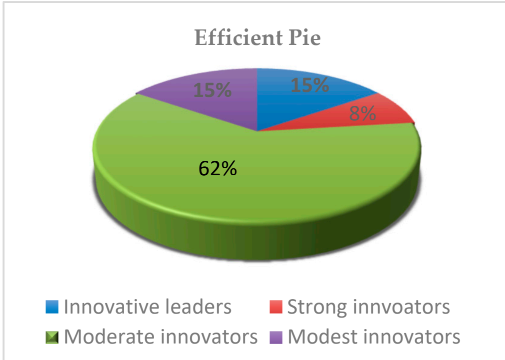
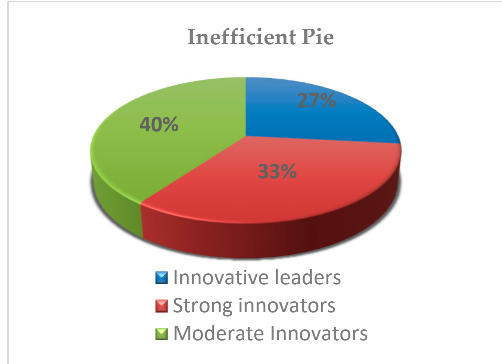


Figure 3. Inward Foreign-direct investment flow into the EU as a percentage of GDP.

Figure 4 gives us a visual view of the member states' innovative classifications and their input-modified efficiency performance relative to one another. Results revealed in Table 6 of the CCR DEA analysis showed the redundant inputs and deficient outputs of member states considered. This was calculated by computing the difference between the actual and recommended outputs revealed by the DEA results. From the variable of NDG, Sweden, an innovation leader, had the worst redundancy rate of approximately 74% implying that 74% of their new doctoral graduates incorporated in the diffusion process did not efficiently contribute to the innovation diffusion process and could be of more efficient use in other ventures and sections of the country. Croatia, a moderate innovator however, recorded the lowest redundant input of NDG for innovation diffusion. Innovation leaders recorded the highest average redundancy rate of 52% revealing that New Doctoral Graduates were least used in the diffusion of innovation. These excess doctoral graduates could preferably have been relieved to be utilized in other ventures, since their input is not statistically relevant.



(**a**)



(**b**)

Figure 4. This figure above (**a**,**b**) shows the portion of efficiency occupied the EU member states according to their taxonomy used by European Commission (2018). It could be inferred that the resources for innovation creation were not efficiently for effective diffusion of innovation. Innovation adoption is both complex and contingent on different factors that affects various types of innovation (Walker 2006), therefore, member states, in this case, could develop exclusively new structures to employ excess inputs or strategically and consciously assign them to their exclusive roles in the diffusion process.

Regarding lifelong learning, Cyprus, a moderate innovator, recorded the highest redundant input of 96% of persons incorporated in the diffusion process. Croatia, a moderate innovator reported the lowest excess of 34% of persons involved. However, the strong innovators recorded the highest average redundancy in this variable compared with the other ranked groups. This implies that strong innovators least utilise learned persons in the diffusion process contrary to other inputs. Even as other inputs are essentially required it is imperative that persons recognized as having knowledge and education be utilized within the diffusion process to instill confidence in patronage and usage of products and to minimize overdependence on other inputs and framework variables for diffusion.

Regarding public expenditure expended to public institutions for diffusing of innovations, data reported revealed Sweden had the highest redundant public expenditure of 89% of funds oriented towards innovation diffusion. This is quickly followed up by 88% of Belgium, a strong innovator. United Kingdom recorded the lowest redundancy rate of 14% of public expenditure invested affirming a more relevant and effective use of public funds apportioned for diffusion of innovation. However, moderate innovators recorded the highest redundancy average of approximately 70% of public funds invested. This reveals serious and substantial probable fund misappropriation or improper control of public research expenditure. This also reveals a marvelous opportunity for growth of moderate innovator member states if 30% of funds can generate desirable efficiency leaving behind excess funds digressive venture investment in the economy or external or complementary innovatory projects to be run as well.

Data recorded for Opportunity development entrepreneurship showed Cyprus recorded the highest redundant input of 93% followed closely by 92% of Sweden. However, the innovation leaders recorded the highest average redundancy figure of approximately 73% compared to all other ranks. This finding reveals the availability of entrepreneurial opportunities created but possibly these ventures have a shorter duration or is not actively involved in diffusion process of innovation. This could also be interpreted as persons that engaged in necessity-driven entrepreneurship does not possibly have their objectives properly aligned with innovation orientation or such firm activities are not actively engaged in innovation ventures possibly or even failure to achieve it.

Data on venture capital invested shows Cyprus also recorded the highest redundancy of venture capital invested; 98% of amount invested did not efficiently contribute to innovation diffusion and consequently, moderate innovators were found to also have the highest redundant venture capital invested. Even though data on venture capital have been extensively theorized to have a significant effect on innovation in Europe, as found by Bertoni and Tykvová (Bertoni and Tykvová 2015). Even though EU's venture capital lowest compared with United States and China, from the results, it could be interpreted that there is sufficient venture capital investment in firms but are not efficiently engaged in innovation diffusion process owing to probably low performance, non-participation or even an increased investment in non-innovation oriented ventures. Lastly, strong innovators also reported the highest average redundancy of private expenditure invested. Moderate innovators reported the lowest redundancy for non- research and development expenditure; however, member states utilized this input most efficiently as the redundancy rate was low amongst all member states ranked when compared to other inputs assessed.

5. Conclusions

The present research sought to analyze and compare the innovation diffusion efficiencies of member states based on the number of their doctoral graduates, lifelong learning, public and private funding, venture capital and opportunity development entrepreneurship in generating employment in knowledge-intensive activities and sales of new-to-market and new-to-firm innovations. The CCR DEA model was used to analyze the efficiency of innovation diffusion of member states due to its capacity to hypothesize the interrelations between input and output and provides trade off ratios for further comparative improvement.

In answering the first research question, it was revealed that innovation excellence, to a certain extent, did not depend on the innovation excellence or deficiency of member states as evidenced by Sweden, the most innovative EU member state, ranking lowest on the efficiency scale, even as Bulgaria and Romania, the two modest innovators, were relatively efficient. Several other member states on different innovation scales were both efficient and inefficient. However, aside Sweden, it is worth noting that the next lowest ranking member states were within the strong and moderate innovation ranks. No modest innovator was inefficient in the diffusion analysis, even as the literature endorses that a higher innovation performance corresponds to better efficiency of diffusion of innovation.

Regarding the second research question posed, after analysis of member' states redundancies and deficiencies, we eventually found that the highest input redundancy recorded was for lifelong learning, opportunity-driven entrepreneurship, venture capital and public expenditure chronologically. It is recommended that persons be tactfully engaged at required areas of the diffusion tree to expertly take advantage of their knowledge and expertise to make even more efficient the diffusion process. Adequate entrepreneurial guidance set up support and motivation be provided to persons engaged in opportunity driven entrepreneurship as well as start-ups receiving venture capital support. We also recommend a much open environment with less barriers to entry to facilitate higher and consistently-growing foreign direct investment. A further look at the analysis reveals that structural and financial capacity alone does not connote a higher efficiency of innovation of diffusion even as it is desperately needed as a necessity for diffusion of innovation. Member states like Romania, for example, recorded all inputs below the EU average yet had an efficient score contrary to many other Innovation leaders like United Kingdom.

Theoretically, this should elicit a stronger interest in investigating the success factors of member states underperforming in innovation but with a relatively efficient diffusion performance for comparative improvement of member states concerned. This research also adds up to the collection of literature on the innovation status of regions and how that affects their diffusion performance. It further reveals a disregard for economic status or size of a firm in efficiently diffusing innovation given the resources at hand. Previous researches have rather focused on innovation performance and levels of countries, this research penetrates the bowels of fundamental drivers and deficiencies spreading this innovation created amongst EU member states in light of their ambitious quest to stay ahead of the competition. This research theoretically draws key attention to the funding combinations and gaps faced and presses the need to closely monitor and study the intervention of cooperation, networks and trust in closing and minimizing inefficiencies in innovation dissemination. Practically, this research reveals the usage of input resources in efficiently disseminating innovation created and calls for questions about transparency, accountability and questionable priorities, which should be addressed both internally by firms and externally by concerned stakeholders owing the inefficient public and private expenditures. Even though our data did not afford us the luxury of undertaking a thorough regional analysis, the results alerts the member states to the gaps in dissemination of their innovation. They could, in turn, assess their key resource diversion areas, the sectors taking in the most or the least inputs and actively instigate further studies in these areas to begin with. Lastly, even though this study used only the CCR model, it revealed that the most innovative member state of the Union, Sweden, came up as the least efficient member state in efficiently diffusing innovation. With the revelation, policymakers should not be quick in hailing innovation generators as the generation of innovation is not key to competitive advantage but rather the usage, assimilation and improvement in the quality of life is what further generates subsequent innovation whether from a linear or open perspective.

However, the downside of this research could be the years used with respect to the input and output variables; even though they were sourced from the latest European Innovation Scoreboard of European Commission (2018), they were borrowed from the latest Eurostat's' Community Innovation Survey data making it difficult to know how long the inputs may need to operate to produce a more efficient diffusion of innovation. Secondly, DEA tool only reveals the efficiency of a member state to another and hence the efficiency is affected by the sample size considered. Nevertheless, these findings should (re)shape and direct policy structures not just for the innovation performance of regions, but also for the adoption process utilized, the patronage and the usage by the social system, whilst also actively creating an attractive focus on not just innovation performance but diffusion structures and processes of member states. Policy makers should also properly channel resources to non-redundant areas geared towards diffusion of innovation of member states, whilst also instilling adequate pre and post control measures to mitigate embezzlement and ensure actual usage of funds as intended.

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Appendix A

Table A1. DEA results of EU member states.

Innovation Leaders	Rank	NDG	Pr (NDG)	LL	Pr (LL)	OE	Pr (ODE)	VCI	Pr (VCI)
Denmark	18th	231	78	268	98	211	55	67	52
Finland	23rd	206	91	274	50	181	37	100	55
Luxembourg	1st	83	83	168	168	141	141	206	206
Netherlands	1st	168	168	188	188	162	162	158	158
Sweden	28th	193	51	284	62	195	14	87	9
United Kingdom	16th	222	190	138	47	111	60	182	44
Strong Innovators									
Austria	20th	130	90	153	17	99	28	63	13
Belgium	27th	133	43	77	8	57	15	112	7
France	14th	115	114	183	22	137	41	206	19
Germany	25th	198	86	76	32	122	53	72	31
Ireland	1st	188	188	81	81	87	87	142	142
Slovenia	17th	236	83	114	29	81	39	6	5
Moderate Innovators									
Croatia	21st	76	50	13	8	41	22	23	15
Cyprus	26	34	13	60	2	64	4	79	1
Czech Republic	1st	114	114	91	91	90	90	6	6
Greece	1st	71	71	35	35	53	53	1	1
Hungary	1st	62	62	53	53	82	82	83	83
Italy	22nd	102	62	71	19	89	32	57	22
Latvia	1st	39	39	67	67	100	100	206	206
Lithuania	15th	51	44	50	17	78	28	56	8

Malta	1st	38	38	94	94	-	-	-	-
Poland	1st	33	33	30	30	117	117	38	38
Portugal	24th	131	62	91	43	73	17	50	8
Slovakia	1st	158	158	24	24	47	47	15	15
Spain	1st	184	184	92	92	64	64	108	108
Estonia	19th	68	52	168	34	109	52	117	32
Modest Innovators									
Bulgaria	1st	101	101	13	13	34	34	39	39
Romania	1st	50	50	1	1	42	42	39	39

Table A2. DEA results of EU member states.

Innovation Leaders	PRE	Pr PRE	NIE	Pr NIE	PSE	Pr PSE	EMP	Pr (EMP)	SLS	Pr SLS
Denmark	161	45	31	24	144	49	86	86	38	38
Finland	154	28	36	20	134	37	47	47	61	61
Luxembourg	52	52	5	5	79	79	88	88	34	34
Netherlands	97	97	10	10	127	127	93	93	76	76
Sweden	194	28	170	45	146	16	108	108	37	37
United Kingdom	95	42	95	82	65	55	130	167	175	175
Strong Innovators										
Austria	188	19	62	43	127	25	27	86	87	87
Belgium	147	11	75	24	104	12	43	47	44	44
France	121	29	66	66	111	31	77	126	117	117
Germany	171	41	193	83	139	37	89	101	101	101
Ireland	69	69	62	62	35	35	146	146	148	148
Slovenia	128	27	119	76	59	47	56	56	92	92
Moderate Innovators										
Croatia	29	19	183	49	54	10	64	64	17	27
Cyprus	11	3	17	7	20	4	0	13	13	13
Czech Republic	86	86	140	140	86	86	132	132	113	113
Greece	34	34	109	109	73	73	0	0	95	95
Hungary	74	74	107	107	24	24	159	159	92	92
Italy	62	25	77	47	61	18	54	83	68	68
Latvia	6	6	80	80	31	31	102	102	21	21
Lithuania	22	19	281	50	70	29	31	31	54	54
Malta	30	30	42	42	13	13	123	123	10	10
Poland	51	51	189	189	29	29	116	116	33	33
Portugal	49	23	90	42	86	18	97	97	31	53
Slovakia	31	31	79	79	42	42	159	159	158	158
Spain	52	52	43	43	70	70	92	92	127	127
Estonia	54	41	125	84	81	38	56	60	73	73
Modest Innovators										
Bulgaria	46	46	107	107	10	10	135	135	16	16
Romania	20	20	21	21	10	10	41	41	33	33

Source: Author's calculation. Code "Pr" connotes the recommended change by the DEA model.

Table A3. Table of Efficiency ranking comparison of Member states for the years 2010 and 2017.

Member States	2010 Efficiency Score	2010 Ranking	2017 Ranking
Innovation Leaders			
Denmark	0.448	23rd	18th
Finland	0.482	21st	23rd
Netherlands	0.538	20th	1st
Lithuania	1	1st	15th
Sweden	0.365	25th	28th
United Kingdom	0.634	17th	16th

Strong Innovators			
Austria	1	1st	20th
Belgium	0.647	15th	27th
France	0.699	14th	14th
Germany	0.634	16th	25th
Slovenia	1	1st	17th
Ireland	1	1st	1st
Moderate Innovators			
Czech Republic	0.431	24th	1st
Cyprus	1	1st	26.00
Croatia	0.574	19th	21st
Greece	1	1st	1st
Hungary	0.627	18th	1st
Estonia	0.195	28th	19th
Italy	1	1st	22nd
Latvia	0.304	27th	1st
Lithuania	1	1st	15th
Malta	1	1st	1st
Poland	0.469	22nd	1st
Portugal	0.321	26th	24th
Slovakia	1	1st	1st
Spain	1	1st	1st
Modest Innovators			
Bulgaria	1	1st	1st
Romania	1	1st	1st

Source: Authors' own computation.

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