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The Efficiency and Productivity Evaluation of National Innovation Systems in Europe

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Abstract:

Purpose: *An efficient innovation system currently plays a crucial role in creating competitive prevalence, contributing to the economic growth of individual states. The innovation system is influenced by many socioeconomic factors, including in international rankings of innovativeness of economies. These classifications have some limitations. Primarily, they do not examine the efficiency, which means they do not analyze the relationship between the involved inputs and the relevant outputs generated in the innovation system. The study aims to measure the efficiency and productivity of the European state's innovation system based on the data from the international ranking of economies' innovation.*
Design/Methodology/Approach: *In this study, the changes in the efficiency and productivity of the innovation system coming from European states were measured using the DEA and Malmquist index methods, based on data from the European Innovation Scoreboard international ranking innovation in economies. The maximizing of economic benefits was assumed in its impact on employment and sales in a given state. The non-radial SBM model, Super SBM, and Malmquist index based on SBM were used for the research. 27 European states were subjected to the analysis in the period from 2012 to 2019.*
Findings: *The research results indicate that the average level of efficiency in the surveyed period fluctuated around 70%. Higher results of efficiency were achieved more frequently by states that joined the EU after 2004. The increase in the productivity of individual states was caused most frequently by an increase in their efficiency (catch-up effect) and less frequently by shifting the efficiency frontier (frontier effect).*
Practical Implications: *The following research hypothesis was decided to be laid down: developing states and those newly admitted to the European Union after 2004 have been gaining relatively more economic benefits from smaller national innovation systems (NIS) resources than developed states and the so-called states of the "old Union."*
Originality/Value: *The added value of the article is, first of all, a comprehensive measurement of the efficiency and productivity of European states NIS in three aspects - efficiency status, efficiency ranking, and productivity changes assessment.*

Keywords: *National innovation systems, efficiency, productivity, DEA, Malmquist index.*

JEL classification: *O19, O31, O32, O52.*

Paper Type: *Research study.*

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1. Introduction

European states are currently facing many development challenges. As early as 2017, the European Commission identified the following issues: demography, migration, decarbonization, and innovations (among other things, the digital transformation of the European economy). In the following years, such issues were emphasized: the need to improve competitiveness against the BRICS states, to support democracy along with economic and social stabilizing in the Member States, to open the European Union to the world, and to implement the principles of the Green Deal. It is supposed not only to respond to climate hazards facing the world (emission-free economy, sustainable energy) but also to offer the group a new development impulse in the 21st century. From the beginning of 2020, the necessity to overcome the Covid-19 pandemic was the first plan issue as it has had a significant impact on society, economy, natural environment, and technology (Abodunrin, Oloye, and Adesola, 2020; Reinhart and Reinhart, 2020). This was manifested in such phenomena as recession, the decline in GDP, consumption, projects, unemployment increase (Gern and Hauber, 2020), and poverty. At the same time, some advantageous phenomena have been noticed at that period, which appeared as a result of knowledge societies mobilizing to overcome this hazard. They are related to a great extent to the use of the innovative potential of various states that are trying to combat health, social and economic hazards with the help of new solutions - product, service, process, organizational and marketing innovations (George, Lakhami, and Puranam, 2020).

However, before the pandemic, societies of many more or less developed states had noticed a strong influence of current and future limitations for development. Even after the Covid-19 pandemic, they will affect the potential for growth and socio-economic development of all states and their competitiveness in the long run. They occur in the ecological, socio-demographic, economic, technological, political, and legal arenas, and even in military sectors (Carayannis and Campbell, 2014). They are related to human responsibility for creating conditions for long-term social and individual well-being and harmonious relations between humans and nature (United Nations, 2015; European Commission, 2019). These challenges set out the need to introduce the concept of sustainable development that will ensure that the needs of the present generations are satisfied while the needs of future generations continue to have a chance to be met (Bak, Cheba, and Lacka, 2020).

The growth and economic development understood in such a way in the macro-, meso- and micro-scale set out the capability of economic entities to create, introduce, and diffuse innovation in the knowledge economy and to use the resources included both in the Regional Innovation Systems (RIS) and the National Innovation System (NIS) while cooperating within the framework of innovation processes. This was reflected in the works of such authors as Carayannis and Campbell (2010), Carayannis, Barth and Campbell (2012), and the United Nations Development Programme entitled Spark, Scale, Sustain, Innovation for the Sustainable Goals (UNDP, 2017). In this context, it becomes more and more essential to assess the efficiency and productivity of innovative systems in various states, whose organization and operation absorb more and more outlays from public and private funds.

The study aims to measure with the use of the DEA and Malmquist index methods the changes in the efficiency and productivity of the European state's innovation system based on the data from the international ranking of economies'' innovation. The following research hypothesis was decided to be laid down: developing states and those newly admitted to the European Union after 2004 have gained relatively more economic benefits from smaller NIS resources than developed states and the so-called states of the"old Unio."

The added value of the article is, first of all, a comprehensive measurement of the efficiency and productivity of European states NIS in three aspects - efficiency status, efficiency ranking, and productivity changes assessment. The European Innovation Scoreboard research is extended and supplemented by this approach. It also fills in the research gaps found out while reviewing the literature. It is also worth emphasizing that the Malmquist Index calculated using the non-radial SBM model, which was never applied in the discussed subject, was used to assess the changes in NIS productivity.

2. Literature Review

The transformation of the economy according to the sustainable and inclusive development paradigm requires innovative systems where research institutions, universities, enterprises, government, and local government authorities cooperate, along with non-governmental organizations, entrepreneurship support institutions together with innovation, transfer, and technology commercialization centers. The interactions created between them set out the innovativeness of enterprises in a given state (Nelson and Rosenberg, 1993). These institutions create, commercialize and make possible the diffusion of a new product, process and service solutions. Thus, they contribute to technological change (Patel and Pavitt, 1994). As laid down by Lundvall *et al.* (2009), this comprehensive system is characterized by openness and evolution. NIS is under the impact of institutional, regulatory, and structural links that make possible the development and use of new knowledge in manufacturing processes. This favors entrepreneurship as well as economic growth and development.

This confirms the continued usefulness of Lundvall's (1985) innovation system concept, Freeman's (1987) NIS idea from the second half of the 1980s, and its subsequent modifications set out in the works of Lundvall (1988, 2007). Those edited thereby (Lundvall, 1992) or derived from the quadruple and quintuple helix concept from the 21st century (Carayannis and Campbell, 2009; Leydesdorff, 2012) for the consideration of the importance of innovation and RIS in the development of the modern economy. This problem has always been in the field of interest of many authors. A review of the achievements in this field can be found in the works of

Watkins, Papaioannou, Mugwagwa, and Kale (2015), Kim, Bae, and Byun (2020), and Kim, Park, and Kwon (2020).

With the development of the NIS concept, tools for evaluating and measuring such systems began to be developed in different states. Economists used individual indices of innovation, which differ by weight, and set out the innovation process in another way. They were used to draw up complex innovation indices that express an innovation status of a given state with a single number. Based thereon, they can compare the performance of innovation systems, assess whether economies gain good or bad results in this regard, and set out the reasons for the success or failure of a given innovation system (Carvalho, Carvalho, and Nunes, 2015).

This approach has been used to develop various complex innovation indices that such international economic organizations use as the World Bank, the European Bank for Reconstruction and Development, the Organization for Economic Co-operation and Development (OECD), the European Union, and The World Intellectual Property Organization (WIPO). Complex indices serve them to classify member states and create rankings from the point of view of their innovative capacity and the results of innovative activities. The Knowledge Index (KI) and the Knowledge Economy Index (KEI) were created for the World Bank and were based on the assessment of four groups of factors (the so-called pillars). These include economic incentives and the institutional regime, education, innovation, and information and communication technologies. Similar indices grouped under four pillars (institutions for innovation, skills for innovation, innovation system, and ICT infrastructure) are used by the European Bank for Reconstruction and Development.

The OECD compares the innovative potential and the effects of its use in the framework of cyclic Science, Technology, and Innovation Scoreboard reports. In this case, OECD states are compared in five areas: Investing in Knowledge, Talent, and Skills, Connecting to Knowledge, Unlocking Innovation in Firms, Competing in the Global Economy, Empowering Society with Science and Technology (Karahan, 2017). WIPO experts, in cooperation with well-known business schools, INSEAD and Cornell University, draw up annual innovation reports of the states around the world with the use of the complex Global Innovation Index (GII) structured under indices which set out such pillars of innovation as institutions, human resources and research, infrastructure, market experience, the experience of undertakings, effects in knowledge and technology and effects in creativity (Cornell University, INSEAD, WIPO, 2020).

The innovativeness of European Union members is compared under the Summary Innovation Index (SII), published in the annual reports of the European Innovation Scoreboard (between 2001 and 2009 as well as between 2016 and 2020) and the Innovation Union Scoreboard (between 2010 and 2015). Partial indices attributed to two categories and three thematic groups are used to create a composite index. The indices of the contribution to innovative activities make up the first category, whereas the second comprises those that present the effects of this activity. The following areas (thematic groups) along with the areas of analysis are distinguished amongst the significantly analyzed scopes: catalysts (human resources, open, excellent, and attractive research systems as well as financing and support), activities of undertakings (enterprise investment projects, connections, and entrepreneurship as well as intellectual assets) and results (economic effects) (European Union, 2020).

The application of the presented methods to assess and compare the innovativeness of various states, although ordinary, reveals some problems while being applied. One of them is such that an attempt is made to assess the performance of national innovation systems with a single digit (a composite index). Karahan (2017) emphasizes that this type of research misses a systemic analysis that would make possible an in-depth interpretation of the relationship between the elements of the national innovation system. Econometric studies on the dynamics of the innovation process by Griffith, Redding, and Van Reenen (2004) made up a response to these limitations. Scientists were trying to set out the impact of R&D and human capital on the total productivity of factors of production. These studies confirmed this impact. In the case of R&D, they showed that innovation and technology transfer stimulate productivity growth and that human capital works in the same way as it supports innovation and absorption. However, it results from the studies by Castellacci and Nater (2013) that there are long-term structural links in the NIS, which set out the innovative capability and the economy's absorption capability. In terms of innovation, they bring about the complementarity of these two areas as their effect.

Other methods were also applied to study the NIS. As suggested by Karadayi and Ekinci (2019), research in this area can be divided into four groups, the research method used for the analysis taken into consideration. The authors claim that the research was mainly done using the non-parametric DEA method (Data Envelopment Analysis), parametric SFA (Stochastic Frontier Analysis), Malmquist productivity index, and regression analysis methods. Most of the studies are done with the use of the DEA and Malmquist productivity index methods. Both methods are related to each other, which will be presented later in the article. Jurickova, Pilik, and Kwarteng (2019) gave a brief overview of NIS research from 1997 to 2016. The research on the efficiency and productivity of NIS is very varied in many aspects. The authors applied various DEA models to measure efficiency (Jurickova, Pilik, and Kwarteng, 2019; Lu, Kweh, and Huang, 2014; Afzal, 2014).

In order to rank the efficiency, they applied DEA models with super-efficiency (Guan and Chen, 2012), and to assess changes in productivity, they applied the Malmquist index (Zabala-Iturriagagoitia *et al.*, 2020). It shall be underlined that the authors applied various solutions for the assumptions of the DEA model itself, i.e., an output-oriented model (Karadayi and Ekinci, 2019), an input-oriented model (Pan, Hung, and Lu, 2010), a model with constant returns of scale (Jurickova, Pilik, and Kwarteng, 2019) and a model with variable returns of scale (Afzal, 2014). The research applied both standard DEA models, e.g., CCR and BCC (Jurickova, Pilik, and Kwarteng, 2019; Afzal, 2014), and advanced ones, e.g., network DEA (Lu, Kweh and Huang, 2014; Guan and Chen, 2012; Carayannis, Grigoroudis and Goletsis, 2016) which were first of all used to analyze sub-processes or stages of the transformation of inputs into output within the innovation system. The studies have applied radial DEA models, e.g., CCR and BCC (Jurickova, Pilik, and Kwarteng, 2019; Afzal, 2014), and non-radial models, e.g., SBM (Lu, Kweh and Huang, 2014).

However, researchers applied radial DEA models much more frequently than non-radial ones. Some authors have used two-stage analysis to identify factors that have an impact on the level of efficiency. For this purpose, in the second stage, the procedure of Tobit/OLS regression (Afzal, 2014) or that of Simar and Wilson (2007) were usually applied, but the latter would be used more frequently (Lu, Kweh, and Huang, 2014). In their research, the authors used both raw (Jurickova, Pilik, and Kwarteng, 2019) and index data (Afzal, 2014; Zabala-Iturriagagoitia *et al.,* 2020) coming from various databases (e.g., SII, World Bank, etc.). The choice of appropriate input and output data depended to a greater extent on the purpose of the analysis and the previous research on the subject. That is why some authors adopted variables exclusively for some aspects of the innovation system (Karadayi and Ekinci, 2019, Jurickova, Pilik, and Kwarteng, 2019).

In contrast, others applied a much more comprehensive range of data to illustrate it comprehensively (Zabala-Iturriagagoitia, Aparicio, Ortiz, Carayannis, and Grigoroudis, 2020). In the hitherto studies, either exclusively efficiency or productivity has been measured without referring them to international innovation rankings (Afzal, 2014), or the results of efficiency or productivity achieved have been compared with ranking indices, e.g., SII. Jurickova, Pilik, and Kwarteng (2019) can be placed in the other group of studies that showed that the high states in the European Union's innovation rankings between 2005 and 2016 are not technically efficient.

Although they show high rates of innovation, they fail to apply correctly the resources introduced into the innovation system, and the expenditures are incurred ineffectively. Zabala-Iturriagagoitia, Aparicio, Ortiz, Carayannis, and Grigoroudis, (2020) came to similar conclusions. Under SII data from 2011 to 2018, the authors measured changes in the productivity of national innovation systems in 33 European Union states applying the (global) Malmquist index. Other procedures were also applied, the bilateral comparisons with the use of DEA (Pan, Hung, and Lu, 2010) or met frontier approach (Kontolaimou, Giotopoulos, and Tsakanikas, 2016) included, in order to take into consideration the differences between developed and developing states or between European and Asian states.

However, despite many studies differentiated in many aspects, there are still to be research gaps in the discussed topics. Firstly, the studies conducted have analyzed NIS either in one or at a maximum of two aspects. Up to now, authors have either studied the efficiency separately with the application of DEA models, or ranked it, applying modified DEA models with super-efficiency, or else estimated the changes in productivity with the use of the Malmquist index, or else they would only use the first two approaches together (Guan and Chen, 2012), or the first and third approaches (Zabala-Iturriagagoitia *et al.*, 2020). However, no comprehensive studies to put together these three research aspects have been done. Secondly, non-radial DEA models have been used sporadically to measure efficiency, but so far, the Malmquist index based on the non-radial SBM model has not been applied to estimate changes in productivity over time within these topics. Thirdly, up to now, one DEA model has not been used to measure NIS in three aspects (i.e., efficiency, ranking, change in productivity). Fourthly, a three-step study under SII data has not been done. That is why it was decided to fill in the research gaps found out.

3. Research Methodology

The DEA method is assumed to have begun with a paper by Charnes, Cooper, and Rhodes (1978), in which the CCR model with the constant returns to scale (CRS) was presented. Then, Banker, Charnes, and Cooper (1984) suggested the BCC model with the variable returns to scale (VRS). The CCR and BCC are radial models, i.e., depending on the model's orientation, either proportional reduction of all inputs or proportional increase in all outputs can occur, that is why Tone (2001) proposed a new non-radial SBM model (Slacks-Based Measure). Non-radial models, contrary to radial models, allow, depending on the orientation, for a disproportionate (differentiated) increase in outputs or reduction of inputs. In economic practice, the assumption of non-radial models is of crucial importance while measuring efficiency. The output-oriented SBM under constant-returns-to-scale (SBM-O-C) is defined by Tone (2017a):

$$\begin{aligned} 1\big/\rho^* &= \max 1 + \frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{rh}} \\ x_{ih} &= \textstyle\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \\ y_{rh} &= \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \\ \lambda_j &\geq 0, s_i^- \geq 0, s_r^+ \geq 0 \end{aligned} \tag{1}$$

where:
x - vectors of inputs, y - vectors of inputs, λ - intensity vector, s^- and $s^+$are called the input and output slacks, respectively.

However, classical models (e.g., CCR, BCC, and SBM) generally set out a few entities that have achieved the efficiency index equal to one. That is why it is impossible to set out the ranking of efficient entities. The solution would be to use a model with super-efficiency that sets out indices for efficient entities above one. Tone (2002) presented the Super SBM model that applies the above concept of measurement. The output-oriented Super SBM under constant-returns-to-scale (Super SBM-O-C) is defined Tone (2017b):

$$
\begin{aligned}
&1\Big/\delta^{*} = max\,1 - \frac{1}{s}\sum_{r=1}^{s}\frac{s_r^{+}}{y_{rh}} \\
&x_h + s^{-} = \textstyle\sum_{j=1, j\neq h}^{n} x_j\lambda_j \\
&y_h - s^{+} = \sum_{j=1, j\neq h}^{n} y_j\lambda_j \\
&\lambda \geq 0, s^{-} \geq 0, s^{+} \geq 0
\end{aligned} \tag{2}
$$

The above models measure the level of efficiency in one period only. That is why, Färe, Grosskopf, Lindgren, and Roos (1992; 1994), based on the work by Caves, Christensen, and Diewert (1982), presented the Malmquist productivity index (MI) calculated with the application of radial DEA models to measure changes in productivity between two periods. Färe, Grosskopf, Lindgren, and Roos, (1992) proposed input-based Malmquist productivity index, and later Färe, Grosskopf, Lindgren, and Roos, (1994) suggested output-based Malmquist productivity index. Then, Tone (2004) proposed that the Malmquist index shall be calculated using the non-radial SBM model. The output-oriented Malmquist index calculated with the use of a non-radial SBM (MI-O SBM) is defined by Tone (2004):

$$MI = \left[\frac{\delta^1((x_o y_o)^2)}{\delta^1((x_o y_o)^1)} \times \frac{\delta^2((x_o y_o)^2)}{\delta^2((x_o y_o)^1)}\right]^{1/2} \tag{3}$$

Calculation of the defined Malmquist index (3) consists in solving four linear programming problems: $\delta^1((x_o y_o)^1)$, $\delta^2((x_o y_o)^2)$, $\delta^1((x_o y_o)^2)$, $\delta^2((x_o y_o)^1)$, with the SBM model. Two of them relate to measurements over the same period (t = 1 or t = 2), and the other two relate to intertemporal results. The Malmquist SBM index (Tone, 2004), similarly to its radial form Färe, Grosskopf, Lindgren;and Roos, (1992, 1994), can also be decomposed into two elements: EC (efficiency change) or "catch-up" effect and TC (technical change) or "frontier shift" effect which set out the impact of individual factors on the change in productivity over time (Färe *et al.*, 1994; Tone, 2004)**:**

$$MI = EC \times TE = \frac{\delta^2((x_o y_o)^2)}{\delta^1((x_o y_o)^1)} \times \left[\frac{\delta^1((x_o y_o)^2)}{\delta^2((x_o y_o)^2)} \times \frac{\delta^1((x_o y_o)^1)}{\delta^2((x_o y_o)^1)}\right]^{1/2} \tag{4}$$

If the MI equals one, then the productivity remains the same. However, when the index is more significant than one, there is an increase in productivity, and when it is below one, there is a decrease in productivity. The EC and TE components results for which the frontier value is also 1 (which means no change) are interpreted similarly.

In Europe, the most popular tool for measuring and evaluating the innovation system in individual states and throughout the European Union (EU) is SII. The variables adopted to build the SII are related to the EU policy and Community development objectives, which were contained, among other things, in the Europe 2020 Strategy (European Commission, 2010). To measure the efficiency and changes in the productivity of the innovation system in the European states, it was decided to adopt SII sub-indices (Table 1) for analysis. While assessing the structure of SII from the prospect of the Europe 2020 Strategy, it can be seen that the innovation system should impact measurable economic benefits in terms of employment, as well as sales of innovations and export of products and services. That is why the Employment Impacts (y1) and Sales Impacts (y2) sub-indices were assumed as output and the remaining sub-indices (x1- x8) as input. Statistical characteristics of the variables assumed for the research are presented in Table A1 in the appendix.

Table 1. *Output and input data assumed for the research*

	Sub-Index from SII:	Explanation of data in sub-index from SII
Input	x_1 – Human Resources x_2 – Research Systems x_3 – Innovation friendly Environment x_4 – Finance and Support x_5 – Firm Investments x_6 – Innovators x_7 – Linkages x_8 – Intellectual Assets	x_1: New doctoral studies graduates, population completed tertiary education, lifelong learning x_2: International scientific co-publications, scientific publications among top 10% most cited, foreign doctoral students x_3: Broadband penetration, opportunity-driven entrepreneurship x_4: R&D expenditure in the public sector, venture capital expenditures x_5: R&D expenditure in the business sector, non-R&D innovation expenditures, enterprises providing ICT training x_6: SMEs with product or process innovations, SMEs with marketing or organisational innovations, SMEs innovating in-house x_7: Innovative SMEs collaborating with others, public-private co-publications, private co-funding of public R&D expenditures x_8: PCT patent applications, trademark applications, design applications
Output	y_1 – Employment Impacts y_2 – Sales Impacts	y_1: Employment in knowledge-intensive activities, employment fast-growing firms innovative sectors y_2: Medium & high-tech product exports, knowledge-intensive services exports, sales of new-to-market/new-to-firm innovations

Source: *Own research.*

The difference in methodology between this research and the SII study needs emphasizing as it determines the results obtained. In the SII study, all variables are treated the same way; their influence on the ranking is the same. There is no division into variables of inputs and outputs of the innovation system. This means that all variables and indices shall be of the highest value possible. The SII composite innovation index is the unweighted average of all indices (Barbero, Zabala-Iturriagagoitia, and Zofio, 2021). The above approach is far from identifying the efficiency of the innovation system in a given state and throughout the EU. The SII study did not measure or assess the relationship between the inputs used to generate outputs, which makes up a fundamental limitation (Edquis*t et al.*, 2018). It is worth underlining that the authors of the second significant innovation ranking, i.e., GII (Cornell University, INSEAD, WIPO, 2020), not only assessed the innovation of economies based on the main index and sub-indices but also took advantage of the DEA method to assess efficiency (see Table A3 in appendix), which was missing in the SII survey. It needs adding that once their research is completed, Carayannis, Grigoroudis, and Goletsis (2016) noted that the bases of the theory and practice of innovation should be revised, the definition, along with operationalization and interpretation of research, measures, and indices of innovation, such as SII included.

That is why the decision was taken to fill in the gap found out and extend the SII analysis to include the study of the efficiency in individual years and the changes in productivity between years. In this study, the authors focus on studying the efficiency of the innovation system, or else on measuring the relation between the inputs applied and the appropriate number of outputs being generated.

For the decision-makers of innovation policy, both in the regions and states, to generate as many widely understood innovations as possible is more important than to reduce the resources used to generate them as they will translate into a competitive advantage of the economy. Thus, the SBM, Super SBM, and MI-SBM models output-oriented were selected to be used. The state which obtains more outputs from the given inputs will be more efficient than those other understudies. As the EIS sub-index data, which are normalized, were applied for the study, models with constant returns to scale were used at each research stage (SBM, Super SBM, MI-SBM). The approach is compliant with the assumption presented in the literature "if the data set consists of normalized numbers, the CRS model might be an appropriate candidate" (Cooper, Seiford, and Tone, 2007). It is worth noting that the CRS models have an advantage over the VRS models, as feasible solutions are not missing therein, as is the case of the latter, mainly while calculating the Malmquist index (Cooper, Seiford, and Tone, 2007).

To ensure consistency between the various stages of the study, the same period between 2012 and 2019 was adopted for analysis. Twenty-seven European states were chosen for the study (Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, The Netherlands, Poland, Portugal, Sweden, Slovenia, Slovakia, and the United Kingdom).

4. Results

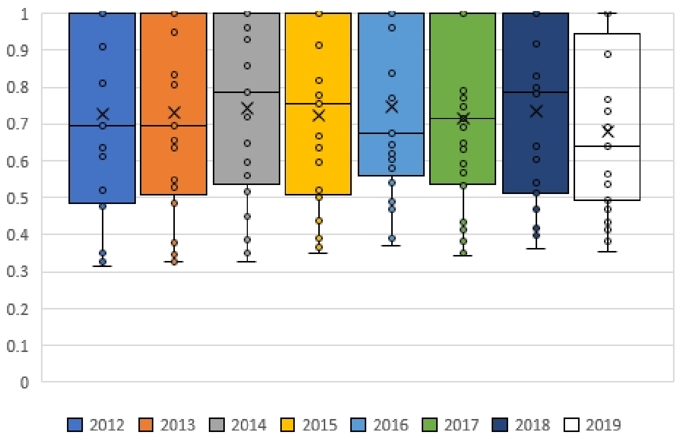
The average level of efficiency of the innovation system in the case of 27 European states oscillated around 70% between 2012 and 2019 (Figure 1). Between 2012 and 2014, there was an insignificant increase in the average efficiency. However, from 2015 to 2019, alternating increases and drops in the average efficiency value are noticed. The 2019 decline inefficiency was more significant than in earlier periods, which contributed to the significant decrease in the efficiency index in the following states: Cyprus, Greece, and Latvia. Interestingly, there was a slow process in the analyzed period, which reduced the efficiency of disproportions between individual states.

The average efficiency value being produced in the entire studied sample in the analyzed period is needed to present the level of efficiency in individual states (Figure 2). The highest average efficiency level between 2012 and 2019, equal to 100%, was achieved by as many as five states, Bulgaria, Hungary, Malta, Poland, and Slovakia, and the lowest by Finland (35%). It is worthy of attention that there was a surge-like drop in the efficiency indices by more than ten percentage points between France and Portugal. The lowest efficiency values between 2012 and 2015 and between 2018 and 2019 were achieved by Finland, while by Austria in 2016 and Lithuania in 2017. In 2012, 2013, and 2016, thirteen states achieved higher efficiency than the average for the entire sample. However, in 2014, 2015, and 2017, there were already 14 states, and in 2018 as many as 15 states. The situation changed in 2019, as only 12 states recorded differences in efficiency compared to the entire sample average. The states which joined the EU after 2004 obtained higher efficiency indices than the average efficiency and than those that started to belong there earlier more frequently.

The most significant deviation of the efficiency results (st. dev. 0.17-0.12) in the researched period between 2012 and 2019 was observed in the following states, Cyprus, Croatia, Latvia, Greece, The Netherlands, Italy, and the United Kingdom.

However, no efficiency indices were noted in Bulgaria, Hungary, Malta, Poland, and Slovakia. The country's membership in one of the four efficiency groups was determined based on the classification proposed in the SII. The first group of "Innovation Leaders" (above 125% of the average efficiency) includes eight states. There were 7 "Strong Innovators" (between 95% and 125%), 11 "Moderate Innovators" (between 50% and 95%), and only one country qualified for the "Modest Innovators" group (below 50% average efficiency).

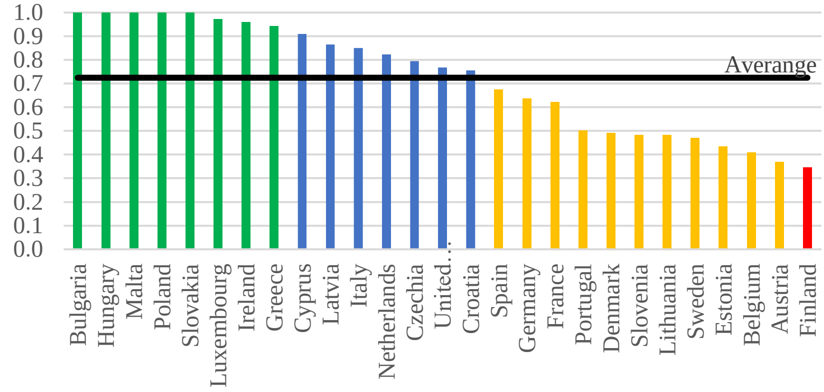
Figure 1. *Total performance level of 27 states between 2012 and 2019*



Source: *Own research.*

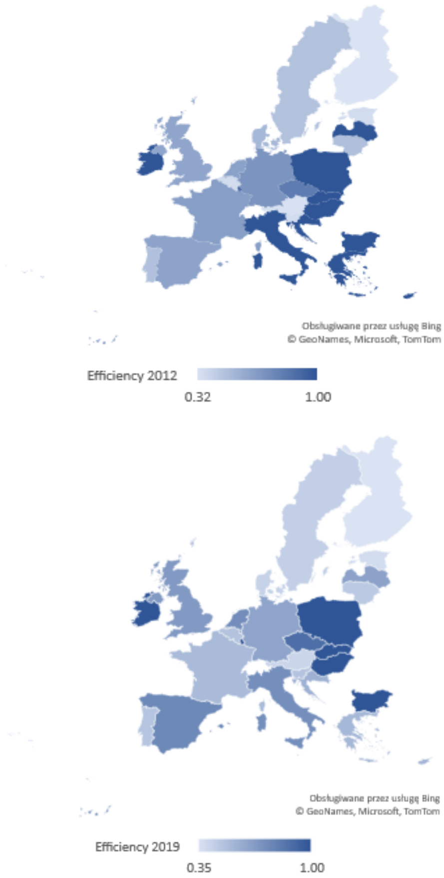
Figure 3 shows the geographical distribution of efficiency indicators at the beginning (2012) and end (2019) of the study period. More countries achieved 100% efficiency in 2012 than in 2019, respectively 11 and 7. Figure 3 shows that Central European countries score relatively higher than, for example, Scandinavian countries.

Figure 2. *Average level of efficiency between 2012 and 2019 in the case of individual states*



Source: *Own research.*

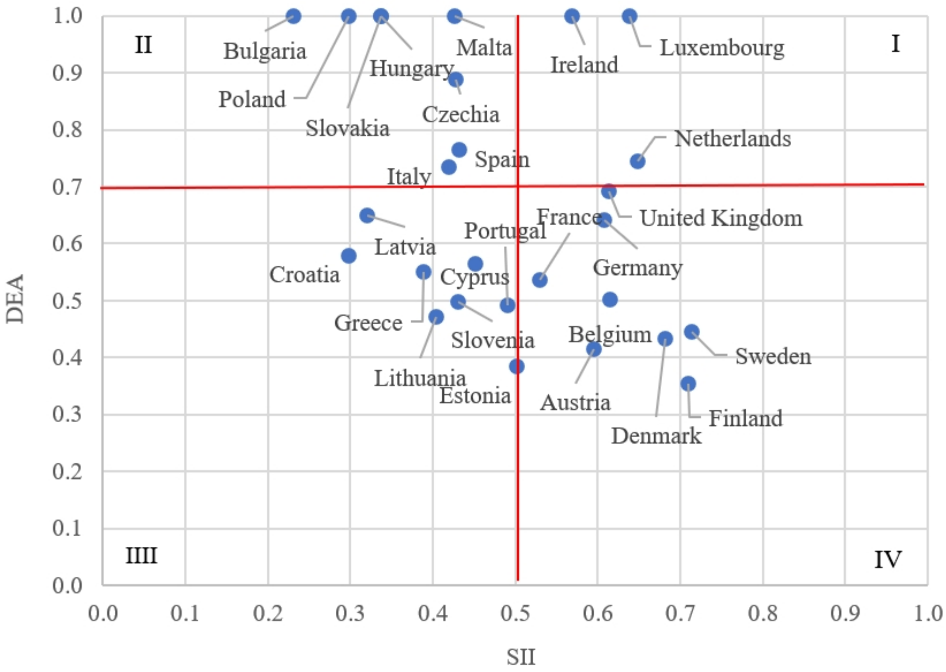
Figure 3. *Geographical distribution of efficiency indicators in 2012 and 2019*



Source: *Own research.*

The research proposal (Cornell University, INSEAD, WIPO, 2020) decided to compare the SII indices with the DEA efficiency scores (Fig. 4). Countries in quadrants I and IV have high potential (above average SII), but only countries in quadrant I use their resources more efficiently (above average DEA efficiency). Although some countries (quadrant II) have a much lower SII potential than developed countries (below the EU average), they gain much more economic benefit than countries considered to be innovation leaders (according to the SII ranking).

Figure 4. *Compare efficiency DEA score and SII indicators in 2019*



Source: *Own research.*

In the following research stage, the ranking of the innovation system efficiency in the European states was based on the Super SBM-O-C model. In Table 2, the places taken by individual states in the efficiency ranking are shown. Between 2012 and 2013 and between 2018 and 2019, Hungary, Malta, and Slovakia took the top three places, but their order changed in the other period. It needs emphasizing that in the analyzed period, Hungary did not find its place on the podium only in 2014, and Slovakia between 2015 and 2017. On the other hand, Malta was in the top three most efficient states between 2012 and 2019. A change amongst ranking leaders occurred between 2014 and 2017. Poland came third in 2014, 2016, and 2017, whereas Greece was second in 2015. It shall be underlined that in the top ten most efficient entities in the entire period between 2012 and 2019, more states joined the EU after 2004 than the states of the so-called" old Union."

On the one hand, the results may indicate that the newly admitted states are developing more efficiently than those with more significant innovation potential. Perhaps this is related to their taking advantage of EU funds and the need to square up restrictively both the achieved effects and the allocation of funds. On the other hand, it can be assumed that the states of the "old Union" have a much broader approach to developing the innovation system through qualitative growth (e.g., networking), which has not been analyzed in this study.

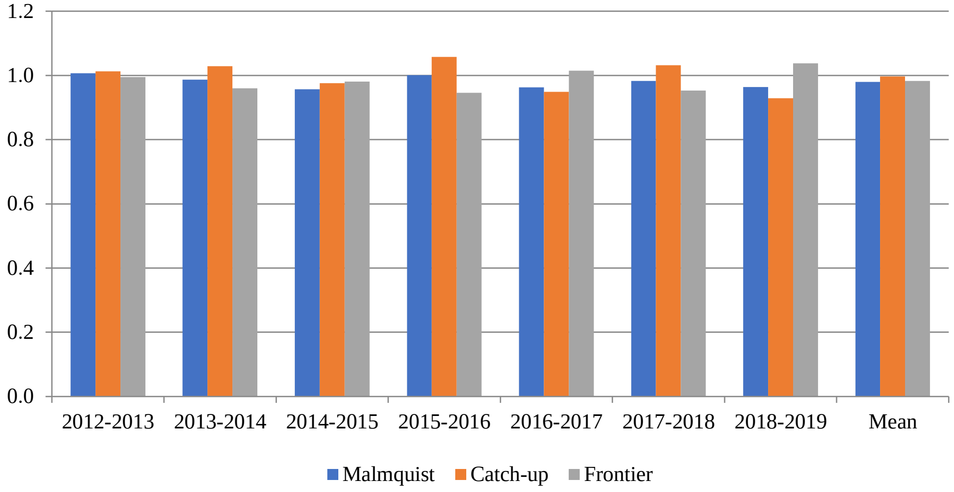
Table 2. *Positions taken by states in the efficiency ranking in individual years*

Country	Average	2012	2013	2014	2015	2016	2017	2018	2019
Malta	1.3	2	2	1	1	1	1	1	1
Hungary	2.5	1	1	5	3	2	2	3	3
Slovakia	3.3	3	3	2	4	6	4	2	2
Poland	4.0	4	4	3	7	3	3	4	4
Bulgaria	5.0	5	6	4	5	5	5	5	5
Greece	7.6	8	8	9	2	4	6	7	17
Cyprus	8.4	6	5	6	6	8	14	6	16
Luxembourg	9.1	12	11	8	8	10	9	9	6
Ireland	9.3	10	10	13	11	7	8	8	7
Italy	10.9	7	7	10	12	13	13	14	11
Latvia	11.0	9	9	15	16	9	7	10	13
Netherlands	11.6	16	15	11	9	11	10	11	10
Czechia	12.1	13	12	14	13	14	11	12	8
Croatia	13.6	11	13	7	14	15	17	17	15
United Kingdom	13.6	18	18	12	10	12	12	15	12
Spain	15.3	17	16	18	17	17	15	13	9
Germany	16.4	14	14	19	18	20	16	16	14
France	16.9	15	17	16	15	18	18	18	18
Slovenia	20.8	25	23	23	19	16	21	19	20
Portugal	21.0	21	22	21	21	22	20	20	21
Denmark	21.5	19	20	20	20	24	22	23	24
Lithuania	21.9	20	19	17	25	21	27	24	22
Sweden	22.3	22	21	22	22	23	24	21	23
Belgium	23.1	23	25	24	24	25	23	22	19
Estonia	23.4	24	24	26	23	19	19	26	26
Austria	25.8	26	27	25	26	27	25	25	25
Finland	26.6	27	26	27	27	26	26	27	27

Notes: *States according to the average ranking.*
Source: *Own research.*

At the last stage, the changes in productivity in the following years were estimated based on MI- SBM-O. The average values of the Malmquist index, catch-up, and frontier effect are presented in Figure 5. Changes in MI in the analyzed period are insignificant within the range of 0.96-1.01. Similar small intervals were observed in catch-up (0.93-1.06) and frontier effect (0.95-1.04). The research results indicate that there was an increase between 2012 and 2013, and in the period between 2015 and 2016, there was no change in MI. In the remaining periods between 2013 and 2015, between 2016 and 2019, the MI decreased. Thus, it means a reduction in productivity in the analyzed years.

Figure 5. *Geometric average of Malmquist index, catch-up and frontier effect in individual years*

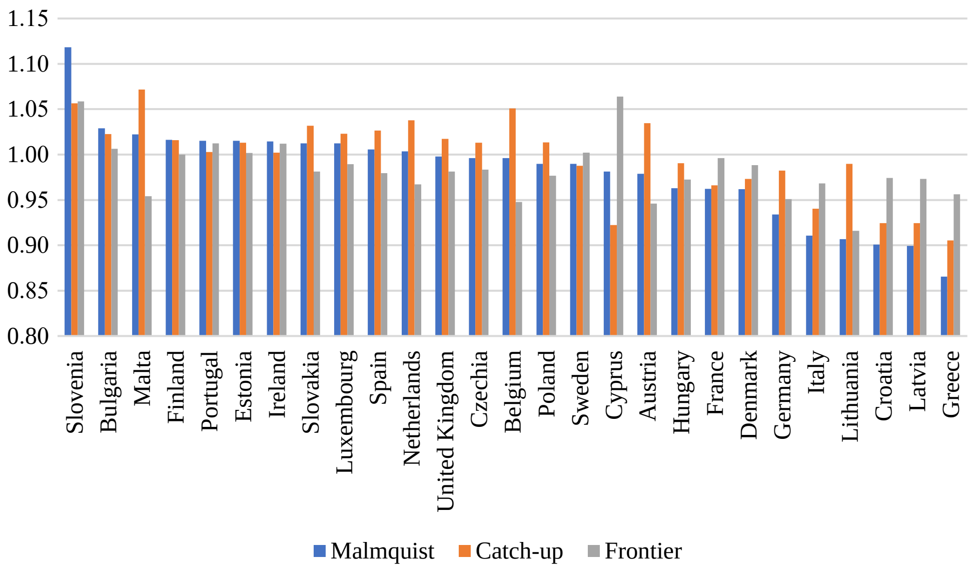


Source: *Own research.*

An increase in the catch-up effect was observed in four and the frontier effect in only two periods (from 2016 to 2017 and from 2018 to 2019). This means that between 2012 and 2019, the actual efficiency of the innovation system changed more frequently in individual states than the efficiency frontier effect between the two periods. The most significant increase in MI was observed in Slovenia, then Bulgaria and Malta, and the lowest in Greece (Fig. 6). On the other hand, the most significant increase in the catch-up effect was noticed in the case of Malta (1.07) and in the frontier effect – occurred in Cyprus (1.06). It needs emphasizing that 11 states increased their average productivity in the period between 2012 and 2019.

For the overwhelming majority of the surveyed states, the increase in productivity was caused by an increase in the efficiency of a given entity between individual years (catch-up effect). Only in the case of 6 states did the frontier effect positively impact the increase in productivity. The most significant deviation of MI (st. dev. 0.26-0.28) between individual years was observed in the following states: Cyprus, Estonia, Malta, Lithuania, and Latvia. In Cyprus, Estonia, and Malta, there was a single significant decline in MI in one period. On the other hand, a significant change in MI occurred twice in the other two states, i.e., Lithuania and Latvia.

Figure 6. *Geometric average of Malmquist index, catch-up and frontier effect in individual states*



Notes: *The indices are ranked in descending order, according to Malmquist index*
Source: *Own research.*

Now, it is worth stating that the results to which came this research and the Zabala-Iturriagagoitia, Aparicio, Ortiz, Carayannis, and Grigoroudis (2020) analysis, although carried out based on the same SII data from between 2012 and 2018, differ from each other in consequence of different research assumptions, i.e., other output variables, different number of states subjected to the research, and the use of varied models (radial DEA and Malmquist index with its modification – global Malmquist index, and other specification of orientation and returns-to-scale: input-oriented with the VRS). That is why the results obtained in each research overlap only to an insignificant degree, which is related to the basic assumptions of the DEA method, whose results of relative technical efficiency depend on the number of objects surveyed, variables, and model specification assumed for the research. Nevertheless, it shall be emphasized that this very research filled the research gap in the analyzed topic.

5. Conclusions

The research carried out brings the following conclusions. From 2012 to 2019, the average level of NIS efficiency of the European states adopted for the research was kept at a similar level above 70%, while in 2019, it dropped to 68%. In several years, a few analyzed states, such as Bulgaria, Hungary, Malta, Poland, and Slovakia, achieved 100% NIS efficiency. This may be evidence of the stability of these states, despite the internal and external conditions being variable. Higher efficiency results were achieved more frequently by states that joined the EU after 2004. Perhaps, it is related both with the catch-up effect with developed states and the EU's financial aid and the need to account in detail for the effects of the investments undertaken. Between 2012 and 2013, Hungary was the most efficient state, whereas between 2014 and 2019, it was Malta. This suggests that these states can generate more economic benefits from their outlays than developed states with enormous innovative potential.

The total average NIS productivity increase was observed only in two periods between 2012 and 2013 and between 2015 and 2016, a decrease in three periods, and no change in one period. The catch-up effect had a positive effect on the MI more frequently than the frontier effect. As many as 15 states increased their average productivity between 2012 and 2019. The increase in the average productivity of individual states was mainly caused by the increase in their efficiency (catch-up effect). The results obtained in this research seem to confirm the correlation observed by Mastromarco and Simar (2021) between changes in inefficiency and the state's absorptive capability while studying human capital, which can also be referred to as the innovation system.

It is known that human capital is an essential factor in the innovation system. The authors, Mastromarco and Simar (2021), indicate that 'absorptive capability' plays a vital role in accelerating the technological catch-up (increase in the efficiency) but not on the technological changes (shifts in the frontier). This result seems to confirm the theoretical hypothesis that countries benefit from new technology (technological catch-up) only when they can exploit it, hence only when they have a high level of absorptive capability. States of the so-called "new Union" show high absorptive capability and try to catch up with developed states, and hence, they obtain higher results than other states more frequently.

Future research shall address analyzing the efficiency of the innovation system in the broader outlook, taking into account both the results of the GII and the Sustainable Development Goals or Eco-Innovation index EU (Pakulska, 2021). Another exciting area may be to evaluate the innovation activity of individual states separately, on the one hand, and on the other, the measurable economic benefits obtained from R&D activities. It may turn out that some states are very active and generate innovations but cannot or do not know how to convert them into economic benefits.

This, in turn, may testify to the low quality of these innovations or enterprises showing no interest in these solutions. In the future, carrying out a multi-level study (RIS, Sectoral Innovation Systems – SSI, NIS, Transnational Innovation systems – TIS, and Global Innovation System – GIS) would also be needed. They will allow capturing the network of connections and dependencies amongst various industries and entities that operate in the innovation system's framework. The approach suggested will extend the research conducted so far, for example, by Carayannis, Grigoroudis, and Goletsis (2016), who used a two-stage model to measure the efficiency of RIS and NIS.

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Appendix

Table A1. *Statistics of inputs and outputs in 2012-2019*

Year	Statistics	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2
2012	Max	0.80	0.81	0.78	0.77	0.78	0.93	0.73	0.82	0.76	0.80
	Min	0.16	0.03	0.07	0.10	0.15	0.12	0.10	0.12	0.21	0.15
	Average	0.42	0.37	0.33	0.41	0.43	0.52	0.43	0.44	0.45	0.50
	SD	0.18	0.23	0.19	0.20	0.15	0.23	0.19	0.19	0.16	0.16
2013	Max	0.80	0.78	0.78	0.72	0.76	0.93	0.73	0.83	0.76	0.80
	Min	0.16	0.04	0.07	0.14	0.15	0.12	0.12	0.16	0.21	0.14
	Average	0.42	0.38	0.33	0.41	0.43	0.52	0.43	0.46	0.45	0.50
	SD	0.18	0.23	0.19	0.19	0.15	0.23	0.19	0.19	0.16	0.16
2014	Max	0.80	0.84	0.80	0.69	0.77	0.78	0.72	0.83	0.76	0.75
	Min	0.17	0.06	0.04	0.16	0.26	0.08	0.13	0.19	0.22	0.15
	Average	0.42	0.40	0.33	0.41	0.44	0.48	0.42	0.47	0.46	0.49
	SD	0.18	0.24	0.20	0.17	0.15	0.21	0.19	0.19	0.16	0.17
2015	Max	0.80	0.89	0.82	0.79	0.77	0.78	0.74	0.82	0.81	0.75
	Min	0.17	0.07	0.08	0.11	0.21	0.08	0.12	0.19	0.24	0.15
	Average	0.42	0.40	0.34	0.42	0.45	0.48	0.42	0.47	0.47	0.50
	SD	0.18	0.24	0.19	0.18	0.14	0.21	0.19	0.18	0.16	0.17
2016	Max	0.81	0.84	0.88	0.84	0.75	0.84	0.73	0.83	0.90	0.88
	Min	0.19	0.08	0.09	0.12	0.22	0.04	0.10	0.19	0.23	0.17
	Average	0.43	0.41	0.37	0.44	0.44	0.47	0.43	0.47	0.46	0.51
	SD	0.18	0.23	0.19	0.19	0.15	0.23	0.20	0.19	0.17	0.18
2017	Max	0.81	0.89	1.00	0.81	0.76	0.84	0.76	0.78	0.80	0.86
	Min	0.19	0.09	0.12	0.11	0.20	0.04	0.10	0.18	0.16	0.18
	Average	0.44	0.43	0.43	0.43	0.44	0.47	0.43	0.47	0.46	0.50
	SD	0.18	0.23	0.21	0.20	0.15	0.23	0.19	0.18	0.15	0.18
2018	Max	0.79	0.92	1.00	0.79	0.79	0.92	0.78	0.81	0.89	0.84
	Min	0.19	0.09	0.14	0.09	0.21	0.08	0.09	0.19	0.19	0.23

	Average	0.46	0.45	0.47	0.44	0.47	0.53	0.44	0.46	0.49	0.52
	SD	0.18	0.24	0.21	0.21	0.14	0.24	0.20	0.18	0.16	0.15
2019	Max	0.79	0.88	1.00	0.83	0.81	0.92	0.81	0.75	0.89	0.84
	Min	0.19	0.11	0.22	0.07	0.23	0.08	0.07	0.17	0.25	0.25
	Average	0.46	0.46	0.53	0.48	0.49	0.53	0.44	0.45	0.52	0.53
	SD	0.18	0.23	0.22	0.21	0.13	0.24	0.20	0.17	0.17	0.15

Notes: *SD – Standard deviation.*
Source: *Own study.*

Table A2. *The level of efficiency of the innovation system of individual countries*

Country	2012	2013	2014	2015	2016	2017	2018	2019	Mean
Austria	0.33	0.33	0.35	0.36	0.37	0.38	0.42	0.41	0.37
Belgium	0.35	0.35	0.38	0.41	0.39	0.42	0.47	0.50	0.41
Bulgaria	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cyprus	1.00	1.00	1.00	1.00	1.00	0.72	1.00	0.56	0.91
Czechia	0.81	0.83	0.79	0.77	0.68	0.77	0.83	0.89	0.79
Germany	0.70	0.69	0.60	0.60	0.58	0.65	0.64	0.64	0.64
Denmark	0.52	0.53	0.56	0.51	0.47	0.43	0.47	0.43	0.49
Estonia	0.35	0.38	0.35	0.44	0.60	0.57	0.40	0.38	0.43
Greece	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.94
Spain	0.62	0.66	0.61	0.61	0.63	0.69	0.80	0.76	0.67
Finland	0.32	0.33	0.33	0.35	0.39	0.35	0.36	0.35	0.35
France	0.65	0.65	0.66	0.67	0.62	0.59	0.60	0.54	0.62
Croatia	1.00	0.81	1.00	0.75	0.65	0.63	0.61	0.58	0.76
Hungary	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ireland	1.00	1.00	0.86	0.82	1.00	1.00	1.00	1.00	0.96
Italy	1.00	1.00	1.00	0.78	0.77	0.73	0.79	0.73	0.85
Lithuania	0.49	0.55	0.65	0.39	0.54	0.34	0.43	0.47	0.48
Luxembourg	0.91	0.95	1.00	1.00	1.00	1.00	0.92	1.00	0.97
Latvia	1.00	1.00	0.72	0.63	1.00	1.00	0.92	0.65	0.87
Malta	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Netherlands	0.63	0.67	0.96	1.00	0.96	0.79	0.84	0.75	0.82
Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Portugal	0.48	0.48	0.52	0.50	0.49	0.54	0.51	0.49	0.50
Sweden	0.48	0.49	0.45	0.50	0.48	0.42	0.51	0.45	0.47
Slovenia	0.35	0.39	0.39	0.52	0.65	0.53	0.54	0.50	0.48
Slovakia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
United Kingdom	0.61	0.64	0.93	0.91	0.84	0.75	0.78	0.69	0.77

Source: *Own study.*

Table A3. *Compare efficiency DEA score and ranking indicators in 2019*

Country	GII				SII	
	Summary GII[1]*	Outputs index[2]*	Inputs index[3]*	DEA [4]*	Summary SII[5]*	DEA (Our study)
Austria	50.1	39.1	61.2	0.6	0.60	0.41
Belgium	49.1	38.6	59.6	0.6	0.61	0.50
Bulgaria	40	34	46	0.7	0.23	1.00
Cyprus	45.7	38.2	53.2	0.7	0.45	0.56
Czechia	48.3	41.9	54.7	0.8	0.43	0.89
Germany	56.5	50.4	62.7	0.8	0.61	0.64
Denmark	57.5	48.3	66.8	0.7	0.68	0.43
Estonia	48.3	40.5	56.1	0.7	0.50	0.38
Greece	36.8	25.5	48	0.5	0.39	0.55
Spain	45.6	36.3	54.9	0.7	0.43	0.76
Finland	57	48.5	65.6	0.7	0.71	0.35
France	53.7	45.9	61.4	0.7	0.53	0.54
Croatia	37.3	28.2	46.3	0.6	0.30	0.58
Hungary	41.5	33.8	49.3	0.7	0.34	1.00
Ireland	53	46.4	59.7	0.8	0.57	1.00
Italy	45.7	39.1	52.4	0.7	0.42	0.73
Lithuania	39.2	29	49.4	0.6	0.40	0.47
Luxembourg	50.8	44.4	57.2	0.8	0.64	1.00
Latvia	41.1	32.6	49.6	0.7	0.32	0.65
Malta	46.4	40.1	52.6	0.8	0.43	1.00
Netherlands	58.8	53.1	64.5	0.8	0.65	0.75
Poland	40	30.8	49.1	0.6	0.30	1.00
Portugal	43.5	34.5	52.5	0.7	0.49	0.49
Sweden	62.5	55.7	69.2	0.8	0.71	0.45
Slovenia	42.9	31.7	54.1	0.6	0.43	0.50
Slovakia	39.7	32.9	46.5	0.7	0.34	1.00
United Kingdom	59.8	53.6	66	0.8	0.61	0.69
Mean	47.81	39.74	55.87	0.70	0.49	0.68

Note: [1] - The overall GII score is the simple average of the Input and Output Sub-Index scores. [2]* - The Innovation Output Sub-Index provides information about outputs that are the results of innovative activities within the economy. There are two output pillars: (6) Knowledge and technology outputs and (7) Creative outputs. [3]* - The Innovation Input Sub-Index is comprised of five input pillars that capture elements of the national economy that enable innovative activities: (1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication. [4]* - The Innovation Efficiency Ratio DEA is the ratio of the Output Sub-Index score over the Input Sub-Index score. It shows how much innovation output a given country is getting for its inputs. [5]* - The overall performance of each country's innovation system has been summarised in a composite indicator, the Summary Innovation Index. For each year, a composite Summary Innovation Index is calculated as the unweighted average of the rescaled scores for all indicators where all indicators receive the same weight (1/27 if data are available for all 27 indicators). Performance scores relative to the EU are then calculated as the SII of the respective country divided by the SII of the EU multiplied by 100.*

Source: *Own research base on: Cornell University, INSEAD, WIPO, 2020, European Union, 2020 and our study.*

Table A4. *Super-efficiency*

DMU	2012	2013	2014	2015	2016	2017	2018	2019
Austria	0.33	0.33	0.35	0.36	0.37	0.38	0.42	0.41
Belgium	0.35	0.35	0.38	0.41	0.39	0.42	0.47	0.50
Bulgaria	1.18	1.16	1.25	1.24	1.20	1.22	1.26	1.27
Cyprus	1.17	1.17	1.21	1.20	1.09	0.72	1.15	0.56
Czechia	0.81	0.83	0.79	0.77	0.68	0.77	0.83	0.89
Germany	0.70	0.69	0.60	0.60	0.58	0.65	0.64	0.64
Denmark	0.52	0.53	0.56	0.51	0.47	0.43	0.47	0.43
Estonia	0.35	0.38	0.35	0.44	0.60	0.57	0.40	0.38
Greece	1.12	1.11	1.11	1.26	1.21	1.17	1.11	0.55
Spain	0.62	0.66	0.61	0.61	0.63	0.69	0.80	0.76
Finland	0.32	0.33	0.33	0.35	0.39	0.35	0.36	0.35
France	0.65	0.65	0.66	0.67	0.62	0.59	0.60	0.54
Croatia	1.02	0.81	1.19	0.75	0.65	0.63	0.61	0.58
Hungary	1.41	1.39	1.24	1.26	1.42	1.44	1.35	1.37
Ireland	1.03	1.04	0.86	0.82	1.10	1.04	1.10	1.05
Italy	1.16	1.16	1.10	0.78	0.77	0.73	0.79	0.73
Lithuania	0.49	0.55	0.65	0.39	0.54	0.34	0.43	0.47
Luxembourg	0.91	0.95	1.14	1.11	1.00	1.03	0.92	1.06
Latvia	1.11	1.07	0.72	0.63	1.03	1.07	0.92	0.65
Malta	1.41	1.38	1.42	1.39	1.59	1.52	1.58	1.64
Netherlands	0.63	0.67	0.96	1.02	0.96	0.79	0.84	0.75
Poland	1.24	1.26	1.27	1.19	1.36	1.34	1.30	1.31
Portugal	0.48	0.48	0.52	0.50	0.49	0.54	0.51	0.49
Sweden	0.48	0.49	0.45	0.50	0.48	0.42	0.51	0.45
Slovenia	0.35	0.39	0.39	0.52	0.65	0.53	0.54	0.50
Slovakia	1.29	1.31	1.39	1.24	1.15	1.28	1.35	1.43
United Kingdom	0.61	0.64	0.93	0.91	0.84	0.75	0.78	0.69

Source: *Own research.*

Table A5*. Malmquist index*

Country	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	Mean
Austria	0.99	0.95	1.02	0.90	0.93	1.05	1.02	0.98
Belgium	0.97	0.97	1.04	0.92	0.97	1.05	1.07	1.00
Bulgaria	1.01	1.06	1.04	1.02	0.99	1.05	1.04	1.03
Cyprus	1.26	1.07	0.96	0.88	0.94	1.43	0.57	0.98
Czechia	1.02	1.01	1.01	0.75	1.17	0.98	1.10	1.00
Germany	1.00	0.91	0.96	0.84	0.96	0.89	1.00	0.93
Denmark	1.00	0.97	0.90	0.92	0.99	0.97	0.99	0.96
Estonia	1.07	0.93	1.22	1.46	1.01	0.61	1.00	1.02
Greece	0.98	0.97	1.16	0.86	0.85	0.91	0.50	0.87
Spain	1.04	0.89	0.98	0.98	1.02	1.13	1.01	1.01
Finland	1.02	1.01	1.04	1.10	0.96	0.95	1.03	1.02
France	0.99	1.01	0.99	0.93	1.04	0.88	0.91	0.96
Croatia	0.95	1.30	0.59	0.81	0.88	0.97	0.96	0.90
Hungary	0.97	0.81	1.01	1.23	1.02	0.73	1.05	0.96
Ireland	1.00	0.91	1.05	1.18	0.93	1.06	1.00	1.01
Italy	0.97	0.96	0.74	0.85	0.82	1.14	0.95	0.91
Lithuania	1.18	0.77	0.58	1.19	0.65	1.17	1.05	0.91
Luxembourg	1.03	1.15	0.99	0.85	1.04	0.88	1.19	1.01

Latvia	0.95	0.56	0.84	1.44	1.14	0.87	0.74	0.90
Malta	0.87	1.05	1.13	1.39	0.58	1.22	1.15	1.02
Netherlands	1.00	1.35	1.05	0.89	0.90	0.95	0.95	1.00
Poland	0.98	1.07	0.81	1.46	1.04	0.73	0.99	0.99
Portugal	1.00	1.02	1.12	0.89	1.06	0.99	1.05	1.02
Sweden	1.02	0.90	1.09	0.91	0.94	1.15	0.94	0.99
Slovenia	1.03	1.10	1.09	1.14	1.32	1.09	1.08	1.12
Slovakia	0.97	1.03	0.84	0.86	1.27	1.04	1.15	1.01
United Kingdom	0.98	1.31	0.96	0.90	0.92	1.01	0.96	1.00

Source: *Own research.*

Table A6. *Catch-up effect*

Country	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	Mean
Austria	1.00	1.07	1.04	1.01	1.03	1.09	1.00	1.03
Belgium	0.98	1.11	1.05	0.97	1.06	1.12	1.07	1.05
Bulgaria	1.00	1.06	1.04	1.04	0.96	1.08	0.99	1.02
Cyprus	1.03	1.04	1.03	0.94	0.69	1.42	0.56	0.92
Czechia	1.06	1.01	1.05	0.74	1.14	1.07	1.07	1.01
Germany	0.96	0.86	1.02	0.98	1.09	0.99	1.00	0.98
Denmark	1.01	1.06	0.92	0.92	0.92	1.08	0.92	0.97
Estonia	1.08	0.93	1.25	1.46	0.89	0.70	0.96	1.01
Greece	1.01	0.97	1.25	0.94	0.95	0.92	0.49	0.91
Spain	1.03	0.93	1.14	0.98	1.02	1.20	0.93	1.03
Finland	1.04	1.00	1.06	1.11	0.90	1.04	0.97	1.02
France	0.96	1.01	1.02	0.93	1.11	0.87	0.89	0.97
Croatia	0.94	1.31	0.61	0.87	0.97	0.97	0.94	0.92
Hungary	0.97	0.80	1.03	1.29	1.02	0.86	1.03	0.99
Ireland	1.01	0.84	0.95	1.36	0.94	1.07	0.93	1.00
Italy	0.97	0.95	0.75	0.99	0.98	1.04	0.93	0.94
Lithuania	1.09	1.20	0.59	1.41	0.62	1.25	1.10	0.99
Luxembourg	1.04	1.22	0.97	0.89	1.03	0.91	1.14	1.02
Latvia	0.95	0.69	0.86	1.61	1.05	0.86	0.70	0.92
Malta	0.96	1.06	0.96	1.49	0.84	1.16	1.15	1.07
Netherlands	1.05	1.44	1.06	0.95	0.82	1.09	0.95	1.04
Poland	1.02	1.02	0.90	1.26	0.97	0.95	1.01	1.01
Portugal	1.00	1.06	0.98	0.97	1.11	0.95	0.95	1.00
Sweden	1.01	0.92	1.11	0.95	0.87	1.26	0.85	0.99
Slovenia	1.12	1.00	1.34	1.24	0.83	1.02	0.94	1.06
Slovakia	1.03	1.13	0.81	0.89	1.18	1.11	1.14	1.03
United Kingdom	1.04	1.46	0.99	0.92	0.88	1.05	0.88	1.02

Source: *Own study.*

Table A7. *Frontier effect*

Country	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	Mean
Austria	0.98	0.89	0.98	0.89	0.90	0.96	1.02	0.95
Belgium	1.00	0.87	0.98	0.95	0.91	0.93	1.00	0.95
Bulgaria	1.01	0.99	1.01	0.98	1.03	0.98	1.05	1.01
Cyprus	1.21	1.03	0.94	0.94	1.35	1.01	1.03	1.06
Czechia	0.96	1.00	0.96	1.01	1.02	0.92	1.02	0.98
Germany	1.04	1.06	0.95	0.85	0.88	0.90	0.99	0.95
Denmark	0.99	0.92	0.98	1.00	1.08	0.89	1.07	0.99
Estonia	0.99	1.01	0.98	1.01	1.14	0.87	1.04	1.00
Greece	0.97	1.00	0.93	0.91	0.89	0.99	1.01	0.96
Spain	1.02	0.96	0.86	1.00	1.01	0.94	1.09	0.98
Finland	0.98	1.01	0.98	0.99	1.07	0.91	1.06	1.00
France	1.03	1.00	0.97	1.00	0.94	1.01	1.02	1.00
Croatia	1.01	0.99	0.96	0.93	0.91	1.00	1.02	0.97
Hungary	1.00	1.01	0.98	0.96	0.99	0.85	1.01	0.97
Ireland	1.00	1.08	1.10	0.87	0.99	0.99	1.07	1.01
Italy	1.00	1.01	0.99	0.85	0.83	1.10	1.02	0.97
Lithuania	1.08	0.64	0.98	0.84	1.05	0.94	0.96	0.92
Luxembourg	0.99	0.94	1.02	0.96	1.01	0.96	1.05	0.99
Latvia	0.99	0.82	0.98	0.89	1.08	1.02	1.06	0.97
Malta	0.90	0.99	1.17	0.93	0.69	1.06	1.01	0.95
Netherlands	0.95	0.94	0.99	0.94	1.10	0.87	1.00	0.97
Poland	0.96	1.04	0.90	1.15	1.08	0.77	0.99	0.98
Portugal	0.99	0.96	1.15	0.92	0.96	1.04	1.11	1.01
Sweden	1.01	0.98	0.98	0.96	1.08	0.92	1.10	1.00
Slovenia	0.92	1.10	0.82	0.93	1.59	1.07	1.14	1.06
Slovakia	0.95	0.91	1.03	0.96	1.08	0.94	1.01	0.98
United Kingdom	0.95	0.89	0.97	0.98	1.04	0.96	1.09	0.98

Source: *Own study.*