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COMPARING THE EFFICIENCY OF TECHNOLOGY AND INNOVATION OF THE EU AND SELECTED COUNTRIES: THE EFFECTS OF EU FRAMEWORK PROGRAMS

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Objective: This study has two purposes. The first is to determine the relatively impact of EU framework programs (Lisbon Strategy to Horizon 2020) on the level of technological efficiency by comparing them with EU members and non-EU members selected countries. This paper also to compare technology efficiency of the EU member countries separately and as a union. The second is purpose to evaluate technological efficiency scores and the economic growth rates of the EU and the selected countries.
Originality/Relevance: The relative efficiency of the technology and innovation of the EU was compared with other selected countries for 2000, 2005, 2010, 2015 and 2018 and evaluated. In previous studies, we could not find a study evaluating the long-term impact of the European Union's framework programs and its efficiency of innovation.
Methodology/approach: For measuring efficiency, DEA method was used with two inputs and four outputs which is represented the technology and innovations.
Main results: The evidence shows that the efficiency of the technology and innovation of the EU was quite low in 2000, and it has reached an increasing trend over the years and reached the full efficient in 2015 and 2018. The analyses which were done separately for 26 EU countries, the efficiency scores are relatively low among EU countries. It reveals that the EU provides a strong platform for R&D collaborations for creative destruction.
Social/management contributions: The EU should continue to design promoting cooperation networks, frameworks programs to support stable economic growth patterns and long-term technology-based growth targets, considering the distinctive features of its economic system.

Keywords: Technology and Innovation, Creative Destruction, Efficiency, DEA, European Union, Framework Program.

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COMPARANDO LA EFICIENCIA DE LA TECNOLOGÍA Y LA INNOVACIÓN DE LA UE Y PAÍSES SELECCIONADOS: LOS EFECTOS DE LOS PROGRAMAS MARCO DE LA UE

RESUMEN

Objetivo del estudio: Este estudio tiene dos propósitos. El primero es determinar el impacto relativo de los programas marco de la UE (de la Estrategia de Lisboa a Horizonte 2020) en el nivel de eficiencia tecnológica, comparándolos con países seleccionados miembros y no miembros de la UE. Este artículo también busca comparar la eficiencia tecnológica de los países miembros de la UE por separado y como unión. El segundo propósito es evaluar los puntajes de eficiencia tecnológica y las tasas de crecimiento económico de la UE y los países seleccionados.
Originalidad/Relevancia: Se comparó la eficiencia relativa de la tecnología y la innovación de la UE con otros países seleccionados para los años 2000, 2005, 2010, 2015 y 2018 y se evaluó. En estudios anteriores, no encontramos un estudio que evaluara el impacto a largo plazo de los programas marco de la Unión Europea y su eficiencia en la innovación.
Metodología/enfoque: Para medir la eficiencia, se utilizó el método DEA con dos inputs y cuatro outputs que representan la tecnología y las innovaciones.
Principais resultados: La evidencia muestra que la eficiencia de la tecnología y la innovación de la UE fue bastante baja en 2000, y ha mostrado una tendencia creciente a lo largo de los años y alcanzó plena eficiencia en 2015 y 2018. Los análisis realizados por separado para los 26 países de la UE muestran que los puntajes de eficiencia son relativamente bajos entre los países de la UE. Esto revela que la UE proporciona una plataforma sólida para la colaboración en I+D para la destrucción creativa.
Aportes: La UE debe seguir diseñando redes de cooperación y programas marco para apoyar patrones de crecimiento económico estables y objetivos de crecimiento a largo plazo basados en la tecnología, teniendo en cuenta las características distintivas de su sistema económico.

Palabras-clave: Tecnología e innovación, destrucción creativa, eficiencia, DEA, Unión Europea, Programa Marco.

COMPARANDO A EFICIÊNCIA DA TECNOLOGIA E INOVAÇÃO DA UE E PAÍSES SELECIONADOS: OS EFEITOS DOS PROGRAMAS-QUADRO DA UE

RESUMO

Objetivo do estudo: Este estudo tem dois objetivos. O primeiro é determinar o impacto relativo dos programas-quadro da UE (Estratégia de Lisboa até o Horizonte 2020) no nível de eficiência tecnológica, comparando-os com países selecionados membros e não membros da UE. Este artigo também tem como objetivo comparar a eficiência tecnológica dos países membros da UE separadamente e como união. O segundo objetivo é avaliar os escores de eficiência tecnológica e as taxas de crescimento econômico da UE e dos países selecionados.
Originalidade/Relevância: A eficiência relativa da tecnologia e inovação da UE foi comparada com outros países selecionados para os anos de 2000, 2005, 2010, 2015 e 2018 e avaliada. Em estudos anteriores, não encontramos um estudo que avaliasse o impacto de longo prazo dos programas-quadro da União Europeia e sua eficiência em termos de inovação.
Metodologia/Abordagem: Para medir a eficiência, foi utilizado o método DEA com dois inputs e quatro outputs que representam a tecnologia e as inovações.
Principais resultados: As evidências mostram que a eficiência da tecnologia e inovação da UE era bastante baixa em 2000, mas alcançou uma tendência crescente ao longo dos anos e atingiu plena eficiência em 2015 e 2018. Nas análises feitas separadamente para os 26 países da UE, os escores de

eficiência são relativamente baixos entre os países da UE. Isso revela que a UE oferece uma plataforma sólida para colaborações em P&D para a destruição criativa.
Contribuições: A UE deve continuar a projetar redes de cooperação e programas-quadro para apoiar padrões estáveis de crescimento econômico e metas de crescimento de longo prazo baseadas em tecnologia, considerando as características distintivas de seu sistema econômico.

Palavras-chave: Tecnologia e Inovação, Destruição Criativa, Eficiência, DEA, União Europeia, Programa-Quadro.

1 Introduction

The principle of "creative destruction" has undoubtedly worked in this transformation of production processes and industry. Creative destruction refers to the continuous product and process innovation mechanism, where new production units replace the obsolete. The creative destruction was invented by the Austrian economist Joseph Schumpeter (1942), who considered it ‘the essential fact about capitalism. Schumpeter accepts the creative destruction process that will occur with technological development as the driving force of economic development (Schumpeter, 2012). The concept of creative destruction emerging in the west is not only built on devastation, but also brings to the fore the economic process, where the old ones are replaced the new simultaneously. Schumpeterian creative destruction describes the situation of breaking the market balance with a new technology developed and reaching a new equilibrium. The restructuring process caused by creative destruction enables economic performance and not only long-run growth, but also economic fluctuations, structural adjustment and regular functioning of factor markets (Schumpeter, 2012).

Creative destruction has led to a paradigm shift in the economy in many ways and has highlighted the competitiveness of productivity-based innovation. The recent acceleration of technological and innovation development processes has also increased the diversity of the variables examined in monitoring these processes. In other words, it is necessary to examine more than one variable that represents technology and innovation processes simultaneously rather than univariate models representing technology in comparing and analyzing the creative destruction process of countries. Therefore, comparable technology input variables for countries and the outputs/outcomes that demonstrate the technology and innovation power created as a result must be analyzed together.

This paper aims to examine the impact of EU innovation programs on technological efficiency in comparison to selected countries, as well as to analyze the technological efficiency of EU member countries both individually and as a whole. The goal is to add to the economic literature and contribute to the discussion surrounding the EU's technological policy agenda.

The secondary objective of this study is to compare the technological efficiency scores and economic growth rates of both the EU and leading technology and innovation countries. The aim is to assess the efficiency of the EU's technology and innovation-based strategies and target practices, as compared to developed and emerging countries in the current scenario. Data Envelopment Analysis (DEA) method, which is used in measurement of efficiency in many areas, was used in the analysis. This study estimates countries innovation efficiency measures assuming (at least implicitly) that all examined countries use the same technology to transform innovation inputs to innovation outputs. For measuring efficiency, it was used with two inputs and four outputs which is represented the technology and innovations. Two input and four output variables were used in the study to determine the relative efficiency of EU countries and selected countries in developing creative technology and innovation. The change in efficiency levels for 2000, 2005, 2010, 2015 and 2018 was evaluated. It was investigated how the effectiveness between the use of innovation and technology and the capacity to create innovation changed in the process.

The paper is organized as follows. The next section discusses the existing conceptual and empirical literature of impact of technology and innovation. The technology and innovation over the European Framework Programs are explained in the Section 3. Section 4 presents variable and method. Section 5 discusses the results of the empirical analysis. Finally, the last section concludes the paper.

2 Literature Review: The Evaluation of Technology and Innovation Efficiency

Schumpeterian innovation-based economic growth model has brought technology-oriented economies to the fore. This approach also based on making growth sustainable and efficient. In the modern economy, which is often referred to as the knowledge economy, innovation and technology are the key indicators of producing value-added products. It is this technology and defeatism that is the main driver of countries' productivity growth, competitiveness, and economic development (Griffith et al., 2004; Kontolaimou et al., 2016).

The limited growth of countries with limited resources and the new situations brought by the information era increases the importance of technology knowledge in science and economic policies (Antonelli, 2009: 619). Research and development (R&D) activities, which are at the fundamental of technological development, and their support by means of incentives and subsidies are also an important part of this process. These abilities of countries that cannot develop and produce science and technology and cannot put their innovation skills on a solid ground are not permanent (OECD, 1998: 9). Therefore, it is necessary to give importance "know-how" through learning by doing and learning by research, which should be given importance in the production processes leading to creative destruction. Effective use of many input variables such as R&D expenditures, number of qualified engineers and scientists employed for the development of "know how" is critical for developing innovation and technology. Also, the good functioning and efficiency of the creative destruction process depends on the strength and concurrency of the relationship between labor knowledge and capital (Caballero and Hammour, 1996).

Today, transitioning to information economy with the increasing importance of information has made technological development inevitable for sustainable high growth and accompanying welfare society. In this context, the capacity to innovate and create technology undoubtedly plays an important role in explaining the economic development differences between countries. The technology and innovation developments put the economy into a continuous restructuring process. Thus, it is ensured that countries reach higher living standards and their competitiveness is supported (OECD, 2018). On the other hand, new production processes, namely "creative destructions" occurred by economies, make economic growth sustainable.

Innovations resulting from creative destruction provide cumulative gains to countries. Innovation activities in the production process of particular industry, creating new products create monopoly power and increase the average level of technology. The changing wage structure stimulates new production capital and employment allocation among profitable sectors, so product prices are positively changed compared to other sectors (Dosi et. al., 1990:152)

There are lots of empirical evidence to prove that Schumpeterian economic growth model based on the creative destruction process is the most effective way for sustainable well-being and this is an important phenomenon in the center of economic growth, productivity, and competitiveness in market economies (Hall and Mairesse, 1995; Caballero and. Hammour, 1996; Foster et al, 2001; Griffith et al. 2004; Goel et al. 2008; Altın ve Kaya,2009; Coccia, 2012; Antonelli and Fassio, 2015; Tsamadias et al. 2019). These pioneering studies investigating the impact of technology and innovation processes on the economy have mainly examined with some models by using a single technology variable, for example, R&D expenditure, high technology investments or high technology product export variables. On the other hand, in some studies considering microeconomic level, it is revealed that the development of innovation and technological knowledge of companies and enterprises makes significant contributions. The firms obtaining higher information technology efficiency are also those that achieve superior growth (Cruz-Cázares et al. 2013; Duran et al. 2016; Bianchini et al. 2018; Martínez-Alonso et al. 2020).

The effectiveness of national innovation and technology activities, which constitute the main research problem of this study, has also been discussed in previous studies. A number of studies used the of innovation and efficiency to analyze the effectiveness of the innovation and research and development process (Lee and Park, 2005; Sharma and Thomas, 2008; Guan and Zuo 2014; Kontolaimou et al. 2016; Zemtsov and Kotsemir, 2019). Efficiency in the context of national innovation systems also examined (Guan and Chen, 2012). There is the relatively limited attention to the efficient use of innovation resources at the national level in the literature. In particular, the relative comparison of the technology and innovation processes of countries provides a perspective beyond a country's examination. This study focuses on filling the gap in the relative comparison of the EU's technology and innovation efficiency. It helps to compare the technology and innovation-oriented creative destruction processes of EU countries with selected countries and to compare the impact of the framework programs that the EU attaches importance to its welfare and competitiveness strategy.

3 A Brief Glance of EU's Technology and Innovation over the European Framework Programs

The goals of technology and innovation programs in the EU can be defined as solving the "European paradox". One of the most comprehensive policy documents of the EU is the report titled "Green Paper on Innovation" published in 1995. In this report, the problem arises from the fact that EU countries are successful in the scientific field, but cannot transform scientific inventions into technological innovations, so that scientific research results cannot be utilized for economic and social development, and a new technology and innovation policy framework is drawn for EU countries (European Commission, 1995). Thus, the EU begins with a contradiction that initially invested in knowledge but failed to achieve the desired success. Although it focused on the use of resources for the creative destruction process in the EU goals, it could not achieve sufficient success. Therefore, determining the strategies that produce scientific knowledge and turn it into technology and innovation has been a critical element for the EU.

Innovation and technology are one of the priority areas of the EU recently. The main basis of this priority is to increase the rising of economic development and the social benefit by investing in knowledge. EU aims to stand out in global competition with innovation and new ideas. Therefore, enforcing innovation labs and creative institutions and organizations with network structure, and encouraging universities and public research centers to be more open and international are the core of creative destruction policies. Over time, growing attention has been paid in European innovation policy to reducing the wide regional variation in research and innovation performance in the EU (European Commission 2013). European Framework Programs for research and technological development, such as Lisbon Strategy, the FP7 in 2007–2013 and Horizon 2020 (or FP8) in 2014–2020, are primarily aimed at promoting research excellence in Europe (Muscio and Ciffolilli, 2020: 171).

In order to understand the future foresight and the general framework of science and technology policy that Europe intends to pursue in the medium term, it is beneficial to look at the basic pillars of this policy. According to the Lisbon Strategy (2000), the European Union has determined to be the most dynamic and competitive information-based economy in the world to maintain economic growth, employment and cohesion (European Council, 2000). In the EU, technology has turned into a structure containing a large amount of information in the 2000s. In a sense, this refers to an economic and political union that accepts the knowledge-based technology, innovation and science development capacity as the key in the process of creative destruction.

Thus, the science and technology policy of the EU; it is formulated in the form of "making functionality for the information triangle (Triple Helix) consisting of research, industry and government. Investing in knowledge is surely the best and possibly the only way for the EU to strengthen economic growth and create more, better jobs, while assuring social progress and the sustainability. In addition, many countries in the EU bring and support the national innovation system model (NIS) to strengthen the production of scientific research and technological innovations. The simultaneous and efficient operation of human resources and economic resources in this area is ensured within the innovation system (European Commission, 2005).

Following the EU Lisbon Strategy (2000), the targets foreseen in 2010 are; to accelerate the transition to a knowledge-based economy and society, to strengthen R&D activities on this basis, to increase competitiveness and innovation ability, to invest in manpower and to support the development of an appropriate macroeconomic environment within this framework. In addition, goals have been expanded within the scope of developing entrepreneurial climate and sustainable ecological policies. The EU has paid attention to increasing the share of R&D expenditures in GDP to 3% (European Communities, 2004, 2005).

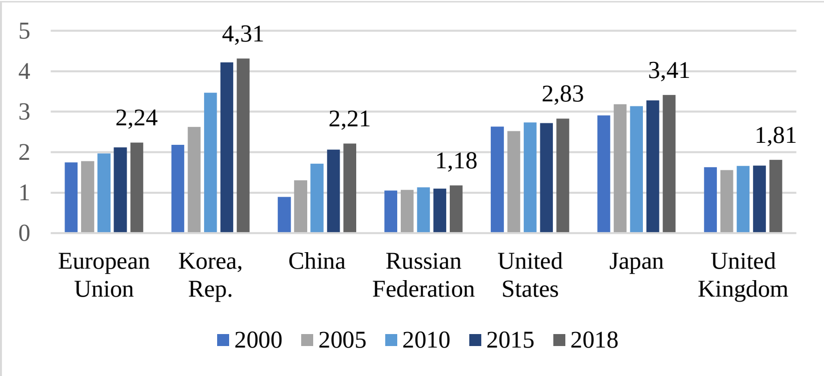
As the Lisbon process continues in the EU, due to the contraction wave and the global economic crisis, the strategy targets were not fully achieved, and the unemployment and economic growth problem continued. The Lisbon Strategy (2010), which was formed with the need to strengthen the fundamental structure of the EU, has now passed. The fact that the global financial crisis that emerged in 2008 which was also effective in the EU reveals that the Lisbon Strategy was limited in achieving its goals. Based on the Lisbon Strategy, the European Commission has developed the "Horizon 2020" strategy, which will complement existing strategies with a new and more advanced perspective. In November 2011, the Commission brought forward its legislative package for Horizon 2020, the EU's current FP for 2014-2020. Horizon 2020 is the first EU program to integrate R&D, with strengthened support for public-private partnerships (PPPs), innovative SMEs and the use of financial instruments. Horizon 2020 also aims for a better uptake and use of results by companies, investors, public authorities, other researchers and policymakers

The Horizon 2020 Strategy is focused on three goals. 1. Excellent Science: creating value from knowledge. EU's position as a world leader in science with a dedicated budget of EUR 24.4 billion (including an increase in funding of 77%). 2. Industrial Leadership: aims to help secure industrial leadership in innovation with a budget of EUR 17.01 billion. This includes an investment of EUR 13.5 billion in key technologies, as well as greater access to capital and support for SMEs. 3. Societal Challenges: EUR 29.68 billion is set aside to address seven European societal challenges: creating a competitive and environmentally friendly economy that uses natural resources economically (European Commission, 2011).

The acceleration of technology and innovation-based growth strategies of the EU after 2000 is significant with the evaluation of its efforts or resource allocation. It has achieved a positive trend in the increase of R&D expenditures, which is the main fundamental input target of the EU for creative technology and innovation. While the share of R&D expenditures in GDP in the EU was 1.74% in 2000, this ratio increased to 1.96% in 2010 in the projected targets, but still the desired target could not be reached as of 2018 (Figure 1). The R&D expenditures by sectors of performance gives information about the country's transition to innovation and high-tech structure. In the EU and in these countries, R&D expenditures of the private sector business are more than those made by the government.

Figure 1

R&D expenditure in GDP

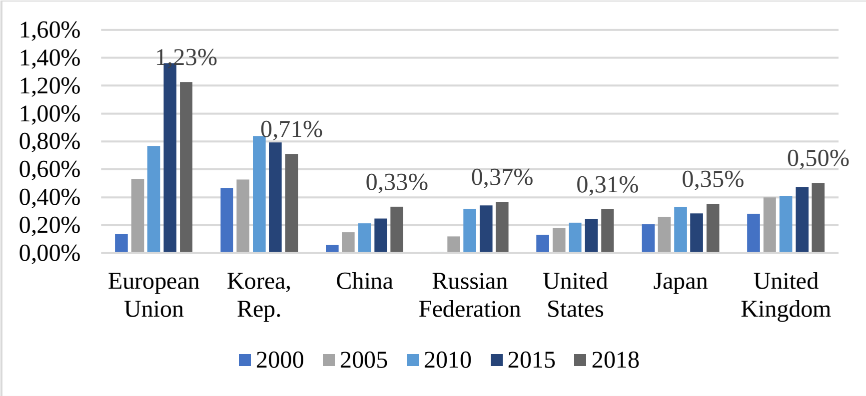


Source: World Bank, Science & Technology Indicators

Moreover, the creative destruction is not only considered as part of the knowledge or technology produced within the country. Globalization also enables creative technologies by purchasing and developing information in innovation processes. When evaluated in this way, while R&D expenditures can be presumed as activating the position with only country source, the success of redevelopment by purchasing innovation and technology can also be accepted as an indicator. In EU, the intellectual property, payments in GDP for innovation and technology has increased significantly. But as the output of this, intellectual property receipts in GDP is relatively less. In other words, the share of the intellectual property right payments received by the EU in the process of knowledge, innovation and technology development has a lesser share than GDP. In fact, the EU has the relatively highest intellectual property payments in GDP. On the other hand, the US and Japan, whose rivals for the EU, intellectual property receipts are significantly higher than the payments for creative innovation and technology (Figure 2 and Figure 3).

Figure 2

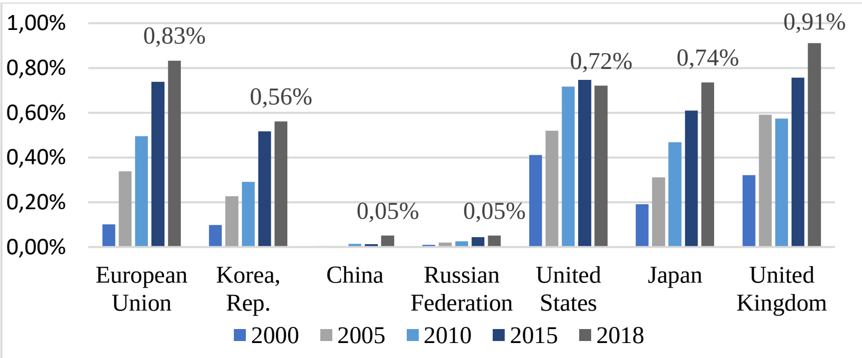
Charges for the use of intellectual property, payments in GDP



Source: World Bank, Science & Technology Indicators

Figure 3

Charges for the use of intellectual property, receipts in GDP

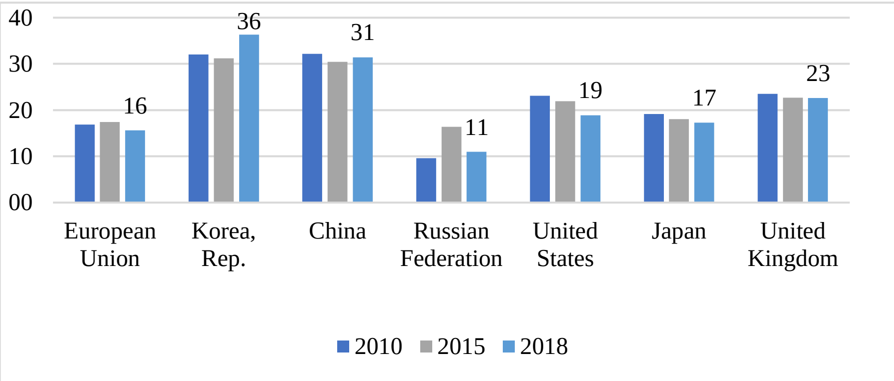


Source: World Bank, Science & Technology Indicators

At the same time, the share of high technology export in the manufacturing industry, the added value created in the industry and patent applications are important evaluation criteria as an output in investments made for innovation and technology. The EU is only ahead of Russia in the share of high-tech exports. It is noteworthy that there has been a decrease in this rate recently. In terms of the industry added value of the EU Industry in GDP, it lags behind South Korea, China and Russia. It also showed a general downward trend over the years. Perhaps, in patent applications, one of the most decisive indicators of the creative demolition process, the EU has not made much progress in its innovation and technology development goals. The serious upward trend in China can be considered as anxious for protecting the EU's competitiveness. It has shown a slow development acceleration compared to other competitors around the goals that the EU attaches strategic importance to in the process of developing contemporary creative destruction and innovation. In other words, the output components that are important in the effective operation of the creative technology and innovation process can be said to be dissatisfactory, at least for the developed economies (Figure 4,5 and 6).

Figure 4

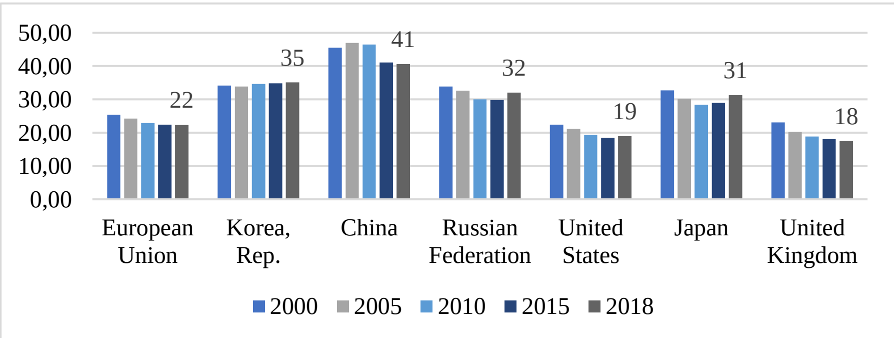
High-technology export (% of manufactured exported)



Source: World Bank, Science & Technology Indicators.

Figure 5

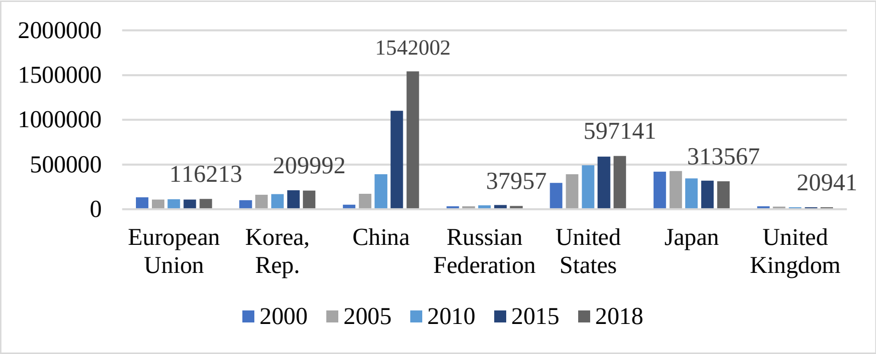
Industry (including construction), value added (% of GDP)



Source: World Bank, Science & Technology Indicators

Figure 6

Patent applications



Source: World Bank, Science & Technology Indicators

The goal of the EU to become one of the leading countries in the world in its capacity to create information, technology and innovation is closely related to its effort to increase R&D spending in this process (Coccia,2012). However, in doing so, the only goal is not only to increase spending on this area, but also to create high value-added production and ultimately economic growth that will turn it into creative destruction. In the literature, actually there is no study directly systematically measuring the efficiency based on technology and innovation variables that represent the creative destruction process of EU and other countries. Therefore, it is considered that this study, which analyzes many of the variables of technology and innovation, directly analyzes the relative efficiency of the creative destruction process for the EU, is a pioneer.

4 Measuring of Efficiency of Creative Destruction in EU

4.1 Methodology

Strengthening the technology development capacity has limited resource input as in all areas. Technology and innovation are costly because they are based on knowledge. Although knowledge is non-exhaustible or limited exhaustible source of production input (Antonelli, 2018), the production of knowledge is costly. The creative destruction process of the countries is possible by transforming the investment inputs made into technology and knowledge into processes that create economic value as much as possible. Therefore, it is significant to conduct the technology and innovation process effectively.

Efficiency in general is the ability to create high output using minimum input. The acquisition of technological and innovation power, which requires high resource cost, also depends on the outcome of high innovation power obtained against the costs incurred. Thus, the effort to increase the amount of output obtained economically against many technology inputs used in the process is critical.

The relative efficiency of creative destruction processes in terms of technology and innovation development in the EU and some selected countries were determined by DEA method. The method is useful as it analyzes multiple inputs and multiple outputs measured in different measurement units by weighing them simultaneously.

Data Envelopment Analysis (DEA) encapsulates it according to the performance of all decision making units (DMUs) to be evaluated. DEA is suitable not only for for-profit firms, but also for non-profit organizations that include public services, as well as DMUs such as countries, cities etc. Thus, it provides flexibility in evaluating the efficiencies of each cluster of organizations that produce similar outputs using similar inputs. As a result of these evaluations, the DMUs are scored between zero and one, and these values represent the degree of efficiencies. It also identifies DMUs that receive a full efficiency score (in the "efficiency limit"). All DMUs in this situation are efficient DMUs and can therefore serve as benchmarks for influencing improvements in the future performance of DMUs evaluated in this way. In addition, DEA specifies the sources and amounts of inefficiency in inputs and outputs for each DMUs along with these scores (Cooper et al, 2006: XIX-XX).

A piecewise linear convex hull approach to boundary estimation was proposed, which was proposed by Farrell (1957) as a mathematical programming method for efficiency measurement. However, this method of measuring efficiency did not receive widespread attention until the article by Charnes, Cooper and Rhodes (1978) where the term DEA was first used. In the article, a model based on the assumption of constant returns to scale (CRS) is proposed. Since then, many articles have been published expanding and popularizing DEA applications. In subsequent research, the variable returns to scale (VRS) model was widely used (Coelli et al, 2005:162).

There are two basic models of DEA which are allowed multiple inputs and multiple outputs as well. CCR model (Charnes et al, 1978) measures the technical efficiency of a given observed DMU assuming constant returns to scale (CRS). BCC model (Banker et al, 1984) is extended the CCR model to allow variable returns to scale (VRS) and showed that solutions to both CCR and BCC allowed a decomposition of CCR efficiency into technical and scale components (Ruggiero, 2011:7).

Let x and y represent inputs and outputs, respectively. Let the subscripts i and j represent the ith input, and y_j output, respectively. Accordingly, let the total number of inputs and outputs be represented by I and J, respectively, with I and $J > 0$. In DEA, multiple weighted inputs and weighted outputs are added linearly. Thus, a firm's virtual input is obtained because the linear weighted sum of all its inputs can be represented as Equation 1.

$$Virtual\ Input = \sum_{i=1}^{I} u_i x_i \qquad (1)$$

Where u_i is the weight assigned to input x_i during the aggregation, and u_i is 0. Similarly, the virtual output of a firm is obtained as the linear weighted sum of all its outputs can be shown as Equation 2.

$$Virtual\ Output = \sum_{j=1}^{J} v_j y_j \qquad (2)$$

Where v_j is the weight assigned to output y_j during the aggregation. Also v_j is 0. Given these virtual inputs and outputs, the *Efficiency* of the DMU in converting the inputs to outputs can be defined as the ratio of outputs to inputs and can be shown as Equation 3.

$$Efficiency = \frac{Virtual\ Output}{Virtual\ Input} = \frac{\sum_{j=1}^{J} v_j y_j}{\sum_{i=1}^{I} u_i x_i} \qquad (3)$$

The evaluation of weights is the most important issue at this stage. This issue presents some difficulties as the weighting phase varies. For example, a company that stands out with a particular product will want to give more weight to that product. Thus, it wants to emphasize the truth by giving more weight to its strength. Therefore, the weighting should be flexible and reflect the requirements (performance) of each DMU individually. The problem of assigning a weight value is addressed in DEA by assigning a unique set of weights for each DMU. The weight value for a DMU is performed using mathematical programming. Thus, the efficiency scores of other DMUs calculated using the same weight set are weighted to obtain the highest efficiency score they can achieve, provided that they are limited between 0 and 1. DMUs in which efficiency is maximized are normally referred to as *reference* or *base* DMUs. Let there be N DMUs whose efficiency will be compared within the scope of the research. Let's take one of the DMUs, for example the mth DMU, and maximize its efficiency according to Equation 3. Here, if the mth DMU is the reference DMU, the new mathematical program will be as shown in Equation 4 (Ramanathan, 2003, p.38-40):

$$maxE_m = \frac{\sum_{j=1}^{J} v_{jm} y_{jm}}{\sum_{i=1}^{I} u_{im} x_{im}}$$

subject to

$$0 \leq \frac{\sum_{j=1}^{J} v_{jm} y_{jm}}{\sum_{i=1}^{I} u_{im} x_{im}} \leq 1;\ n = 1,2,K,N \qquad (3)$$

$$v_{jm}, u_{im} \geq 0;\ i = 1,2,K,I; j = 1,2,K,J$$

Where;

E_m is the efficiency of the mth DMU,

y_{jm} is jth output of the mth DMU,

v_{jm} is the weight of that output,

x_{im} is ith input of the mth DMU,

u_{im} is the weight of that input, and

y_{jn} and x_{in} are jth output and ith input, respectively, of the nth DMU, $n = 1, 2, \ldots, N$.

Note that here n includes m.

4.2 Variables and Dataset

In order to determine the efficiency scores firstly stage 26 EU countries[3] were considered in the analysis separately and compared efficiency scores across 50 countries. Then secondly, it was analyzed by handling EU as a decision unit across 26 countries. The purpose of the implementation of these two stages is to observe the performance of EU member states to other countries, both for each member separately and for the union as a whole. Analyzes were made separately for the years 2000, 2005, 2010, 2015 and 2018, and the changing was observed

[3] Netherlands and Luxembourg were not included in the analysis because their some data were not available.

over the years. The reason why the analyses were carried out until 2018 is not appropriate for comparison, as it is evaluated that after this year data is under the effect of COVID-19.

Two input and four output[4] variables were used in the study to determine the relative efficiency of EU countries and selected countries in developing creative technology and innovation. The selected variables are common input and output variables for the countries analyzed and were preferred because they are the variables that represent the creative destruction process. The variables used in analysis selected by following previous studied as well (Lee and Park, 2005; Sharma and Thomas, 2008; Guan and Zuo 2014; Kontolaimou et al., 2016; Zemtsov and Kotsemir, 2019).

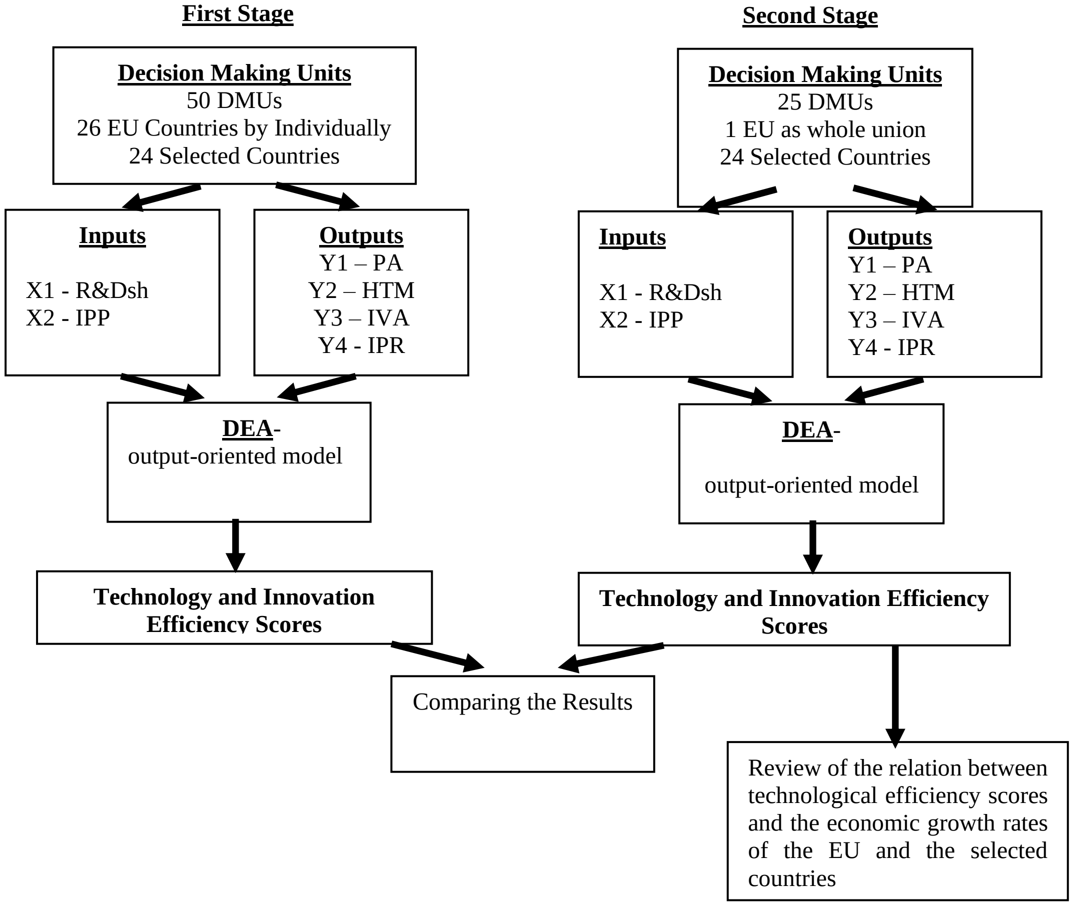
Input variables (X); the share of R&D expenditures in GDP (R&Dsh- X1), charges for the use of intellectual property payments (BoP, current US $) (IPP-X2). Output variables (Y); patent applications (PA-Y1), the share of high technology in the manufacturing industry (HTM-Y2), the added value of the industry in GDP (IVA-Y3) and charges for the use of intellectual property, receipts (BoP, current US $) (IPR-Y4). All input and output variables were obtained from the World Bank database.

Since technology and innovation processes offer increasing returns instead of constant returns to scale, an output-oriented model is preferred because it seeks to maximize creative destruction. The analysis have conducted assuming that there is variable returns to scale (BCC) and using an output-oriented model. The description of the efficiency of technology and innovation measurement application models are shown in Figure 7. Considering the two purposes of the study, the DEA models used in two stages are presented, so that the application models have clarified.

[4] The variable “high-technology export” (% of manufactured exported) is not available for 2000 and 2005. For this reason, two inputs and three outputs were used for these years.

Figure 7

Research Model for Application



Before the represent the findings, in order to reveal descriptive statistical data about input and output variables, the statistics for all variables for conducted analysis has shown in Table 1.

Table 1

Descriptive Statistics for Variables by Years

Variables	Years	N	Minimum	Maximum	Mean		Standart Deviation	Skewness	Curtosis
					Statistics	Standart Error			
R&Dsh	2000	50	.02	3.75	1.1580	.12595	.89057	1.082	.502
	2005	50	.03	3.38	1.2340	.12696	.89775	.884	-.211
	2010	50	.10	3.73	1.4096	.13711	.96951	.749	-.474
	2015	50	.15	4.22	1.5124	.13963	.98734	.822	-.168
	2018	50	.15	4.31	1.5798	.14593	1.03188	.733	-.317
IPP (Million)	2000	50	2.92	16607.00	1807.7113	494.55741	3497.04898	2.999	9.290
	2005	50	4.20	25577.00	2905.2260	722.18970	5106.65231	2.857	9.023
	2010	50	5.47	37458.29	4467.4411	1092.29042	7723.65963	2.880	9.056
	2015	50	9.98	76444.49	6141.0784	1790.89493	12663.53950	4.110	20.121
	2018	50	8.38	85119.03	7370.5621	2133.74609	15087.86329	3.748	15.932
PA	2000	50	53.00	419543	24284.60	10233.99812	72365.29466	4.597	21.956
	2005	50	38.00	427078	29883.16	12051.89834	85219.79045	3.918	15.433
	2010	50	8.00	490226	35054.44	14147.15847	100035.51688	3.615	12.602
	2015	50	7.00	1101864	52344.74	25435.57224	179856.65615	4.857	25.519
	2018	50	4.00	1542002	60856.12	33224.21766	234930.69607	5.599	33.917
HTM	2010	50	.95	52.34	15.8152	1.72241	12.17925	1.388	1.753
	2015	50	.79	52.42	15.7884	1.50975	10.67555	1.400	2.775
	2018	50	.05	52.77	14.9578	1.56566	11.07086	1.709	3.676
IVA	2000	50	17.69	48.32	27.8476	.83744	5.92161	1.200	2.853
	2005	50	17.80	47.02	27.6026	.88430	6.25292	1.043	1.837
	2010	50	13.83	46.50	26.2038	.91376	6.46128	.785	1.126
	2015	50	10.17	41.11	25.1730	.91599	6.47704	.277	.319
	2018	50	12.05	40.65	25.1742	.89460	6.32574	.269	.003
IPR (Million)	2000	50	0.03	51807.00	1786.1486	1052.75354	7444.09169	6.478	43.881
	2005	50	0.51	74448.00	2993.1608	1539.28684	10884.40161	6.080	39.762
	2010	50	0.74	107522.00	4423.1887	2216.12148	15670.34529	6.115	40.136
	2015	50	1.95	124769.00	5935.0860	2634.13753	18626.16509	5.631	35.234
	2018	50	7.00	128748.00	7147.8355	2826.62111	19987.22951	5.014	28.878

Source: Calculated by the authors

5 Results

Table 2 shows the DEA results based on the input and output variables used in determining the efficiency of the creative destruction process with technology and innovation-oriented strategy and target practices in the EU. There is a significant increase in the DEA efficiency scores of the EU (as one decision unit) over the years. In other words, the efficiency score of the EU across 24 selected countries increased in the following years when it was relatively weak (69.3) in 2000, and especially 2015 and 2018 reached the full efficient score (100). This shows that the EU achieved success in science and technology policies in 2000 and beyond, and that the creative destruction process worked efficiently. It shows that the strong concurrency of the relationship between technology and innovation input and output variables. It can be stated that the EU's innovation and technology-based policies allowed it to be relatively best innovation and technological efficiency among the group of countries. In addition, the technology, information and innovation policies of the EU within the framework of strategic partnerships with union members reflect the strength of the transformation that collaborative endeavor. In other words, the potential for strong creative destruction of synergy in between EU countries with the dissemination of technology and information sharing is quite evident. This situation shows the EU's power to achieve a significant positive externality in information and technology processes within the scope of common goals and the innovation and knowledge-based network structure comes to the fore in the EU as well. Indeed, if 26 EU countries are included in the analysis separately, the efficiency scores are relatively low.

Moreover, the efficiency scores of Albania, Bosnia and Herzegovina, North Macedonia and Turkey that are EU candidate members could provide strong support in terms of innovation and the technological efficiency potential in EU. On the other hand, the EU has achieved a serious success against the USA, China, the Russian Federation, Japan and S. Korea which have high economic development and are the core of technology. While some of these countries scores have been regressing, the EU has reached a full efficient level during the 2000 Lisbon Strategy, which the EU aims to stand out in global competitiveness with its innovation and new information and completed 2010 process.

Table 2

Efficiency Scores of Creative Destruction for EU and Selected Countries

Countries / Years	2000		2005		2010		2015		2018	
Austria	58.67		61.10		63.87		66.74		70.33	
Belgium	52.93		60.75		55.25		52.44		58.26	
Bulgaria	83.88		79.00		78.95		75.59		81.02	
Cyprus	70.02		63.02		100		95.14		100	
Czech Republic	98.71		88.49		84.58		89.34		86.97	
Germany	62.64		60.36		68.22		81.85		99.37	
Denmark	62.86		62.93		60.93		64.13		87.37	
Spain	58.85		59.19		56.08		53.31		53.86	
Estonia	91.93		99.67		92.87		100		100	
Finland	81.43		73.61		69.11		98.08		100	
France	48.16		51.84		60.06		62.12		57.27	
United Kingdom	54.88		55.36		54.55		57.59		81.61	
Greece	51.22		47.16		41.79		53.44		56.2	
Croatia	74.66		71.18		68.41		67.74		63.12	
Hungary	70.34		67.09		67.76		69.41		77.83	
Ireland	65.71		64.5		55.41		100		100	
Italy	51.66		52.2		53.99		55.55		58.65	
Lithuania	95.89		100		94.57		100		100	
Latvia	81.92		70.58		75.01		100		100	
Malta	100		64.49		100		100		100	
Poland	61.79		68.31		74.04		80.73		77.02	
Portugal	61.42		58.01		52.1		51.99		52.99	100
Romania	100		95.18		100		96.49	100	86.04	
Slovak Republic	92.39		97.79	93.49	93.69	97.43	82.13		100	
Slovenia	95.83	69.3	92.49		72.4		83.14		86.94	
Sweden	64.60		81.77		100		75.1		72.33	
Albania	93.78	96.05	100	100	100	100	100	100	100	100
Bosnia and Herz.	100	100	100	100	100	100	100	100	100	100
North Macedonia	84.31	89.17	78.71	79.6	84.08	86.86	91.29	91.29	83.07	85.25
Turkey	78.32	85.96	66.99	66.99	63.4	64.34	75.11	75.11	80.76	80.76
Argentina	59.05	59.05	73.55	73.55	65.57	67.69	70.57	70.60	65.29	65.69
Australia	54.71	54.71	57.66	57.66	61.2	61.2	61.38	61.38	63.12	63.12
Brazil	48.73	48.73	58.69	58.69	56.16	56.16	50.35	50.35	47.3	47.3
Canada	65.60	65.6	65.06	65.06	61.52	61.52	64.47	64.47	60.89	60.77
Switzerland	82.45	82.45	70.5	70.5	68.69	68.69	71.48	71.48	84.29	84.29
Chile	89.24	89.52	100	100	100	100	100	100	90.98	98.52
China	100	100	100	100	100	100	100	100	100	100
Egypt, Arab Rep.	100	100	100	100	100	100	100	100	100	100
India	69.21	69.85	100	100	77.13	78.62	83.60	83.6	80.59	86.53
Japan	100	100	100	100	82.25	82.25	89.72	89.72	100	100
Korea, Rep.	79.70	79.70	100	100	80.75	80.75	91.29	91.29	93.56	93.56
Mexico	100	100	85.1	85.1	100	100	100	100	100	100
Malaysia	100	100	100	100	100	100	100	100	100	100
Norway	83.66	83.66	100	100	92.82	96.77	98.31	98.31	97.22	97.22
Russian Federation	100	100	80.91	80.91	71.79	72.31	79.14	79.19	86.13	86.24
Singapore	67.49	67.49	67.2	67.2	100	100	100	100	100	100
Tunisia	100	100	100	100	100	100	100	100	100	100
Ukraine	64.05	64.05	77.7	77.7	67.62	69.05	66.45	66.44	72.00	78.78
United States	100	100	100	100	100	100	100	100	100	100
South Africa	74.34	74.67	63.78	63.78	69.47	70.98	71.52	71.52	71.71	71.71

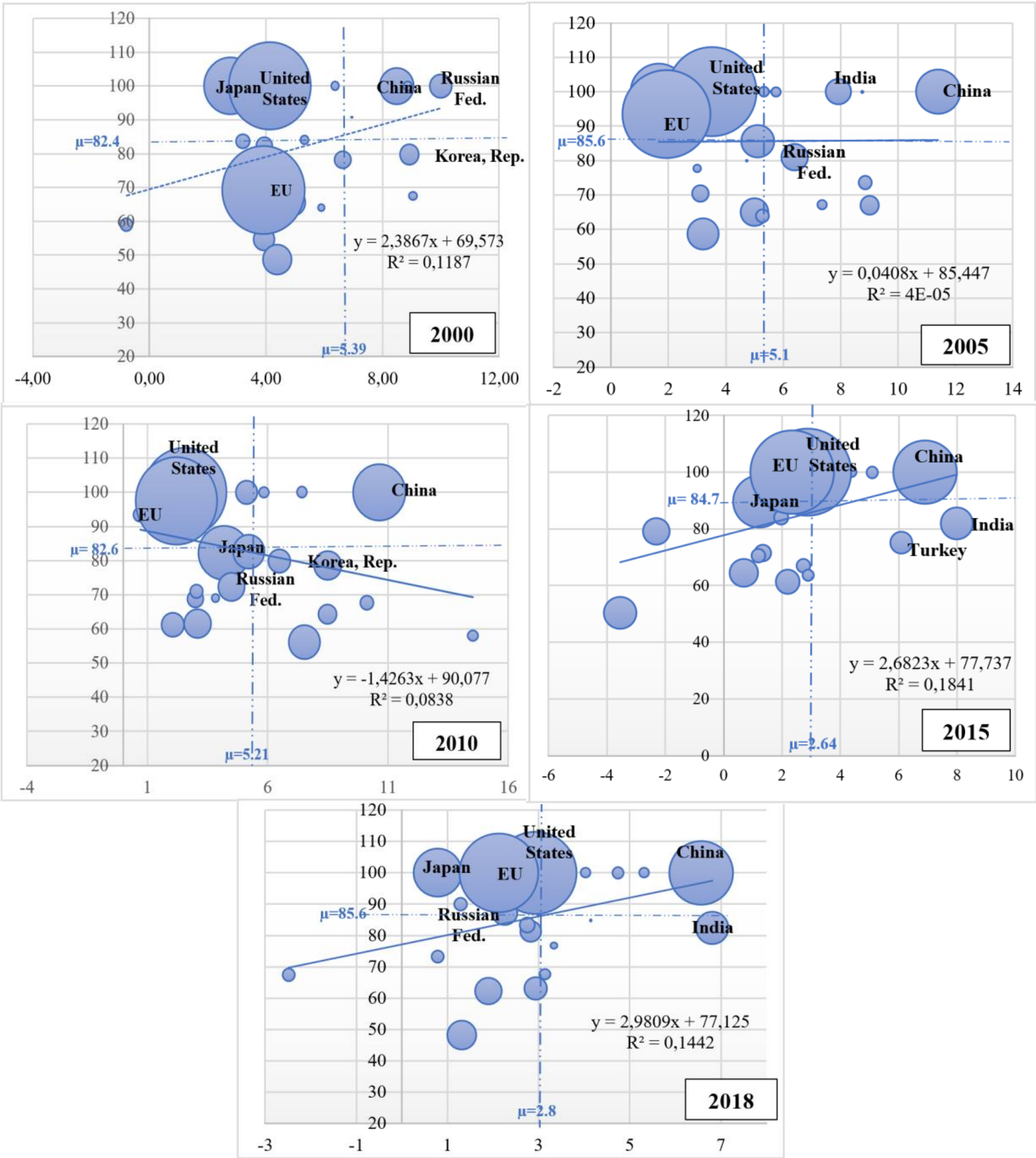
Source: Calculated by the authors.

The impact of efficiency scores on economic growth is an important outcome of the creative destruction process. Therefore, the relationship between efficiency scores and the annual economic growth rates of countries was examined in the bubble chart in Figure 8. The bubble volume in the figure shows the value of GDP, which referred the sizes of the EU and other 24 selected countries. The average efficiency score of the EU and selected countries was 82.4 and the annual growth rate was 5.39% in 2000. In this period, the relative efficiency of innovation and technology of the EU was low, but also fell behind the average annual growth rate of other countries. The EU seems weak for average efficiency scores and growth rate according to economic size in 2000. Although the annual growth rate was slow, the efficiency of innovation and technology of the EU exceeded the average in 2005 and beyond. The EU has succeeded in effectively managing its process in technology and innovation development, but the global economic crisis in 2008 slacked its impact on economic growth. In 2018, the efficiency of innovation and technology is above average, but growth rate is very close to the average.

In every period, China reached both high annual growth and efficient innovation and technology process. The United States has also caught successful trend relatively. It should be emphasized that even though the EU remained behind of Russia and Japan, which are economically developed and have high technology improved capacity, EU surpassed them. It can be stated that the tough rivals of the EU are China and the United States in terms of the efficiency of the creative destruction process.

Figure 8

The Relationship Between Technology and Innovation Efficiency and Economic Growth



Note: The vertical and horizontal axes show efficiency score and annual economic growth, respectively

Source: Calculated and sketched by the authors

6 Discussion and Conclusion

Although policies towards developing technology and innovation in the EU have been on the agenda for a long time, research on efficient conduct of the process is very limited. However, the Framework Program objectives of technology and innovation development for the creative destruction of the EU point to a structure that not only spends for technology and innovation, but also provides a significant economic growth. In order to achieve these objectives, the creative destruction process has to conduct efficiently.

The analysis presented in this paper aims to examine the efficiency of creative destruction process which based on technology and innovation for 2000, 2005, 2010, 2015 and 2018 covered by the 2000 Lisbon Strategy and the Horizon 2020 policy target Framework Program.

The findings of this study provide significant insights into the efficiency of technology and innovation in the EU as compared to selected countries. Firstly, in terms of the impact of EU framework programs on technological efficiency, the study shows that the implementation of these programs has resulted in a positive effect on the level of technological efficiency. This is evident from the comparison of the EU member countries and the selected non-EU member countries. The results in detailly, the efficiency of the technology and innovation process of the EU was quite low in 2000, and it has reached an increasing trend over the years and reached the full efficient in 2015 and 2018. It can be said that the "European Paradox", which means inefficient efforts for technology and innovation that emerged at the beginning, has been changed. The EU has captured full efficient countries in technology such as China, United States and Japan and has a good position in competition. Here, the role of the relative success of the input and output variables used for the efficiency of the technology and innovation process is important.

Although the EU has paid more for technology and innovation for creative destruction, it has turned into its full efficient by turning this in its favor relatively. However the study reveals that the EU still as a whole lags behind some of the leading technology and innovation countries, including the United States, Japan, and South Korea, in terms of technological efficiency scores and economic growth rates. This suggests that the EU needs to adopt more effective policies and strategies to enhance its technological efficiency and foster innovation.

Additionally, the study highlights the need for EU member countries to focus on their individual technological efficiency levels to ensure that the EU as a whole is more competitive globally. The analysis of individual EU member countries' technological efficiency reveals significant variations among them, with some countries performing well and others lagging behind. Therefore, member countries need to prioritize their technological efficiency levels and work towards achieving the EU's overall objectives. It reveals that although the EU differs from each other when efficiency scores consider to science, technology and innovation, the EU provides a strong platform for R&D collaborations for creative destruction. The economic literature already has provided evidence of the fundamental role of research and innovation policy in technological development and in promoting cooperation networks in Europe (Cecere and Corrocher 2015; Gambardella et. al. 2009; Paier and Scherngell 2011). It should be stated that EU candidates Albania, Bosnia and Herzegovina, Macedonia and Turkey's high efficiency scores would provide potential in terms of technology and innovation development for the EU as well.

It was observed that there is a positive relationship between the technology and innovation efficiency scores and economic growth rates of the EU and other selected countries. In the period when EU Framework Program began to strengthen, the efficiency scores have exceeded the average of other countries except 2000, but its impact on growth has been limited. The EU has significantly improved resource investments and improved its success in technology and innovation development. In fact, many previous studies have revealed that innovation and research and development capacity contributed to the economic growth (Altın ve Kaya, 2009; Coccia, 2012; Antonelli and Fassio, 2015; Tsamadias et al. 2019).

The study emphasizes the importance of continued efforts to enhance the EU's technological efficiency and innovation capacity. The findings suggest that the EU needs to further strengthen its framework programs and policies to keep pace with leading technology and innovation countries and foster economic growth. Within the EU framework programs, while determining the input targets, efficiency analysis for developing information, technology and innovation should be done by considering simultaneously. The EU should continue to design union-based policy frameworks to support stable economic growth patterns and long-term technology-based growth targets, considering the distinctive features of its economic system.

Authors' contributions

CONTRIBUTION	MANAVGAT GÖKÇE	DEMİRCİ AYHAN
Contextualization	X	X
Methodology	X	X
Validation	X	X
Formal analysis	X	X
Investigation	X	X
Resources	X	------
Data curation	…..	X
Original	X	X
Revision and editing	X	X
Viewing	X	X

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