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The Innovation Gap of National Innovation Systems in the European Union

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Abstract

The main aim of the paper is to assess the innovation gap between the national innovation systems (NIS) of the European Union (EU) and the average level of innovation of EU economies. The study takes into account NIS identified in the literature, i.e., (a) developed systems and (b) developing systems.

In the theoretical part of the paper, the literature in the fields of NIS and the innovation gap is reviewed, the definitions and selected classifications of NIS around the world are presented, and the concept of the innovation gap between countries is defined. In the empirical part, the level of innovation in EU economies is assessed using Hellwig's synthetic development indicator. In order to measure the level of innovation in individual NISs, arithmetic means of national values of the synthetic measure of development (innovation) are used. The innovation gap is calculated as the quotient between the level of innovation of individual NISs analyzed in the study and the average level of innovation in EU economies. The study covered 2010 and 2021.

The paper formulates the following research hypothesis: the level of innovation in EU economies is determined by the type of NIS. Consequently, developing system countries are less innovative and, thus, are characterized by an innovation gap in relation to the EU average. The results of the study confirm the hypothesis. The relationship between the innovation level of the EU economies and the type of NIS, as well as the assessment of the innovation gap between the national innovation systems of the EU and the average level of innovation of the EU economies, constitute the value-added of the paper.

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Introduction

For several decades, innovations have been an important area of research for economists worldwide. On a microeconomic scale, the implementation of innovations leads to an increase in enterprises' competitiveness through lowering production costs, improving the quality of products and expanding their range, or better meeting consumers' needs. These activities increase the competitiveness of enterprises and, consequently, entire economies. On a macroeconomic scale, innovations are perceived as one of the main factors of economic growth and development. Innovation is always the result of the interaction between people, organizations, and their environment. This understanding of innovation is in line with the national innovation system (NIS) concept, which plays an important role in the innovation policy of all developed market economies.

The main aim of the paper is to assess the innovation gap between the NISs of the European Union (EU) and the average level of innovation of EU economies. The study takes into account the NISs identified in the literature (Godinho, Mendonca, and Pereira 2003), i.e., (a) developed systems, which include dynamic, stable, and unevenly developed systems, and (b) developing systems, comprising catching up and unbalanced systems.

The paper formulates the following research hypothesis: the level of innovation in EU economies is determined by the type of NIS. Consequently, developing system countries are less innovative and are thus characterized by an innovation gap in relation to the EU average. The results of the study confirm the hypothesis. The relationship between the innovation level of the EU economies and the type of NIS, as well as the assessment of the innovation gap between the national innovation systems of the EU and the average level of innovation of the EU economies, constitute the value-added of the paper.

In the theoretical part of the paper, the literature in the fields of NISs and the innovation gap is reviewed, the definitions and selected classifications of NISs around the world are presented, and the concept of the innovation gap between countries is defined. In the empirical part, the level of innovation in EU economies is assessed using Hellwig's synthetic development indicator, called the synthetic measure of development (SMD) (Panek 2009). In order to measure the level of innovation in individual NISs, arithmetic means of national values of the synthetic measure of development (innovation) are used. The innovation gap is calculated as the quotient between the level of innovation of the individual NISs and the average level of innovation in EU economies.

The study covered 2010 and 2021. For several variables, the most recent data come from 2020. The choice of years was dictated by the availability of the most recent statistical data and the desire to show the innovation gap of NIS over an extended time horizon. The data used in the study were obtained from Eurostat and OECD databases.

The concept and classifications of the national innovation system. The definition of the innovation gap

The NIS concept was created in the late 1980s and has become the focus of the following economists: Freeman (1992), Lundvall (1992), Nelson and Rosenberg (1993), Patel and Pavitt (1994) and Edquist (1997). Research on NIS continues in the 21st century. The definitions formulated by contemporary authors are presented in Table 1.

Table 1. Definitions of the national innovation system

A network of economic agents, together with the institutions and policies that influence their innovative behavior and performance.	Mytelka (2003)
An evolutionary system in which enterprises in interaction with each other and supported by institutions and organizations such as industry associations, R&D, innovation and productivity centers, standard setting bodies, universities and vocational training centers, information gathering and analysis services, and banking and other financing mechanisms play a key role in bringing new products, new processes and new forms of organization into economic use.	Wangwe (2003)
Creating an efficient innovation system and business environment that encourages innovation and entrepreneurship, comprising firms, science and research centers, universities, think tanks, and other organizations that can tap into and contribute to the growing stock of global knowledge, which can adapt it to local needs, and that can use it to create new products, services, and ways of doing business.	Goel et al. (2004)
A network of interacting policies, institutions and organizations whose holistic functionality depends on the quality of cooperation between the various component parts.	Manzini (2012)
A unity of enterprises of various patterns of ownership that individually or through interaction with each other provide the formation and dispersion of innovation technologies within a definite state; […] it encourages the implementation of the derived technologies into production and development of new products saleable in the world market; among such organizations there are scientific institutions (R&D institutes, institutes of higher education, private laboratories, scientific departments of corporations – all of them can be summarized under the term „creators of innovation"); then, „infrastructural" enterprises–technoparks, innovative technology centers, venture funds; agencies conditioning the innovation climate and governmental bodies: ministries and specialized departments; the small, medium and big businesses as the first and the final consumer and as one of the primary initiators of innovation.	Garifullin, Ablaev (2015)
A multilevel concept where national, regional and sectoral innovation systems can coexist and co-evolve together in the same country.	Carayannis, Grigoroudis, Goletsis (2016)

A network of economic agents, together with the institutions and policies that influence their innovative behavior and performance.	Mytelka (2003)
The institutions, human capital and interactions among them that facilitate the creation and diffusion of knowledge.	Maloney (2017)
An innovation system encompasses all the organizations and institutions involved in the innovation process and the *na onal* innovation system gives special attention to those institutions and organizations which are located in or rooted in a nation state. The system is open and one crucial characteristic of the national innovation system is its capacity to absorb and use knowledge developed abroad.	Chaminade, Lundvall, Haneef (2018)

Source: the authors' own compilation.

The literature on the subject also includes many typologies of national innovation systems, distinguished based on various criteria (Schmoch, Rammer, and Legler 2006; Weresa 2014, pp. 66–70), e.g., from the point of view of the type of innovation that dominates in a given system, and the areas that determine the development of the system (Patel and Pavitt 1991, pp. 35–58; Schmoch, Rammer, and Legler 2006). The criteria also include institutional factors (e.g., educational, scientific, technological, and innovation regulations) (Amable, Barre, and Boyer 2008; Kotlebova, Arendas, and Chovancova 2020, pp. 717–734) and how science and the economy interact (OECD 2000, pp. 168–172; Bal-Domańska, Sobczak, and Stańczyk 2020; Gorączkowska 2020).

An attempt at a multi-level NIS typology is a universal approach using hierarchical cluster analysis based on the following classification criteria (developed by Godinho, Mendonça, and Pereira, and is hereinafter referred to as the GMP classification) (Weresa 2012; Dworak, Grzelak, and Roszko-Wójtowicz 2022):

- the internal market, described by the following indicators: GDP in absolute terms, GDP per capita, and population density;
- institutional conditions, measured by income inequality, life expectancy, demographic structure, and corruption index;
- tangible and intangible investments, as shown by expenditure on R&D and education per capita and as a % of GDP;
- theoretical and applied knowledge, described in terms of the percentage of the population with secondary and tertiary education, the percentage of students of exact sciences, the number of research workers in relation to total employment, and the number of publications per capita;
- the structure of the economy, presented by the share of high-tech industries in exports and GDP, and the turnover of domestic R&D companies on a global scale in relation to GDP;

- connections between the economy and the environment, measured by the balance of foreign trade and direct investment in relation to GDP, broadband Internet connections;
- knowledge diffusion, described by the following indicators: Internet access, cellular network density, number of ISO 9000 and ISO 1400 certificates per capita;
- innovation, measured by the number of patents and trademarks per capita.

Based on the above-mentioned measures, two main types of NIS were distinguished: (1) developed innovative systems, (2) developing innovative systems. Within these NIS types, three sub-types are distinguished in each group, some of which have their types listed.[1] This typology is presented in Table 2.

Table 2. Typology of national innovation systems according to Godinho, Mendonça, and Pereira (the GMP classification)

NIS Type	NIS Subtype	NIS Kind	Countries belonging to a given NIS Type
T.0	Hongkong		
T.1. Developed innovation systems	T.1.1. Dynamic NIS	Ireland, the Netherlands, Switzerland, Finland, Sweden, Singapore	
	T.1.2. Stable functioning NIS	T.1.2.1.	Germany, Great Britain, France, Italy, South Korea, Taiwan
		T.1.2.2.	USA, Japan
		T.1.2.3.	Canada, Norway, Australia, Austria, New Zealand, Spain
	T.1.3. Unevenly developed NIS	Denmark, Belgium, Luxembourg	
T.2. Developing innovation systems	T.2.1. Catching up NIS	T.2.1.1.	Portugal, Greece, Poland, Hungary, the Czech Republic, Slovenia
		T.2.1.2.	Malaysia, Malta
		T.2.1.3.	Latvia, Estonia, Lithuania, Slovakia, Ukraine
	T.2.2. Unbalanced NIS	T.2.2.1.	Russia
		T.2.2.2.	China, Brazil, South Africa, Thailand, Argentina, India, Mexico
		T.2.2.3.	Turkey, Colombia, Bulgaria, Indonesia, the Philippines, Peru, Romania
		T.2.2.4.	Egypt, Cyprus, Chile, Venezuela
	T.2.3. Unshaped NIS	T.2.3.1.	Algeria, Iran, Vietnam, Morocco, Bangladesh
		T.2.3.2.	Pakistan, Kenya, Ethiopia, Tanzania, Sudan, Nigeria, Congo, Myanmar

Source: Weresa 2012, p. 46; Godinho, Mendonca, and Pereira 2003.

1 The classification includes all the countries that currently belong to the EU, with the exception of Croatia.

The theoretical background for the innovation gap is formed by different studies on the technological gap in the world economy (Posner 1961, pp. 323–341; Krugman 1979) and recently in Central European countries (Kubielas 2013; 2016, pp. 7–10; Kowalski 2020, pp. 1966–1981).

Kubielas (2013, p. 137) defines the innovation gap as the differences in technological advancement between countries. He proposes a number of methods to measure its size, e,g, the distance between the level of technological activity of a particular country and the countries at the technological frontier, calculated either as a ratio of the number of patents per capita or the share of research expenditure in value-added or national income. The literature review also shows indirect measures such as the share of high-tech products in exports in relation to a similar indicator for the technology frontier (Sałamaga 2020, p. 362), the relationship between the performance (labor productivity) of a given branch of the country in relation to the country on the technological frontier or in aggregate terms the relation of GDP per capita to the corresponding indicator of the technological frontier (Kubielas 2013, p. 137).

The last two approaches identify the technological gap with a productivity or income gap. The global technological frontier is deemed to be the GDP level that can be achieved using the given inputs of capital and labor and the best possible technologies (Growiec 2012). This level of GDP is now achieved by the U.S. economy, in which the distribution of specialization (between the four Pavitt sectors) is the standard for a technology leader (Kubielas 2016, p. 7). The highest competitive advantages are demonstrated by the science-based sector, followed by the specialized supplier sectors; the consecutive sectors; the scale-intensive and traditional, supplier-dominated sectors are characterized by negative indices of the revealed comparative advantage, of which the traditional is the lowest on the scale of revealed advantages of the U.S. economy (Kubielas 2013, p. 153).

In the literature, there is also the concept of the innovation gap, understood as the distance of individual economies to the modern technological frontier, which is identified with the last stage of socio-economic development of economies, i.e., the emergence of a knowledge-based economy (Dworak 2012, pp. 27–32). To investigate this approach to the innovation gap, there should be a point of reference, which involves the initial conditions of building a knowledge-based economy formulated in the literature (e.g., Kleer 2009).

The United Nations defines the innovation gap generally as the distance between those who have access to technologies and know how to use them effectively and those who do not (Kraciuk 2006). The innovation gap can be considered from the perspective of creating new technology in the home country, as well as from the perspective of its transfer from other countries and effective adaptation to the needs and national capabilities.

In summary, measuring the innovation gap means estimating the distance between the economy and the most developed economies of Europe and the world, known today

as knowledge-based economies, in many areas, e.g., innovation, education, and the institutional system. Estimating the innovation gap is possible by comparing synthetic measures of innovation (Mielcarek 2013; Weresa 2014, p. 64).

Assessing the innovation gap between the national innovation systems in the European Union based on an original synthetic indicator of economic innovation

The innovation level of EU economies in 2010 and 2021 was first assessed (for several variables mentioned below, i.e., X1, X2, X3, X4, and X5, the most recent data come from 2020). The complexity of innovation means that there is no one-size-fits-all indicator to measure it at the macroeconomic level. We assessed innovation using Zellwig's synthetic development indicator, called the synthetic measure of development (SMD). The selection of potential diagnostic variables was based on the Oslo methodology (OECD/Eurostat 2018). The input data set included 13 variables – potential diagnostic indicators (Eurostat n.d.):

X1 – R&D expenditure in euro per capita – all sectors,

X2 – R&D expenditure in euro per capita – business enterprise sector,

X3 – R&D expenditure in euro per capita – government sector,

X4 – R&D expenditure in euro per capita – high education sector,

X5 – High-tech patent applications to the EPO (European Patent Office) per million inhabitants,

X6 – EU trademark applications per million population,

X7 – Students in tertiary education by age group as a % of the corresponding age population,

X8 – Total high-tech trade in million euros as % of total (imports),

X9 – R&D personnel as % of the labor force,

X10 – High-tech exports as % of total exports,

X11 – Employment in knowledge-intensive activities as % of total employment,

X12 – Product or process innovative enterprises engaged in cooperation as % of innovative enterprises,

X13 – Triadic patent families per million inhabitants.

The set of potential diagnostic variables was verified in terms of the information value of the variables. This verification was performed using statistical procedures that took into account the discriminant and information capacity of the variables (Panek 2009, pp. 18–23). Three indicators were removed from the set of potential diagnostic indicators: X11 – due to low volatility and X2 and X4 – due to too much correlation with other indicators. Ultimately, the set of diagnostic features comprised the following indicators: X1, X3, X5, X6, X7, X8, X9, X10, X12, and X13.

As a result of applying Hellwig's economic development measure, a synthetic measure of economic innovation was determined for the EU countries in 2010 and 2021. Then, on its basis, the level of innovation of the national innovation systems of the European Union was assessed. It was assumed that the level of innovation of a given NIS is determined by the arithmetic mean of the synthetic measure of innovation of the economies of its constituent countries. In order to calculate the innovation gap, it was also necessary to determine the average EU level of innovation in 2010 and 2021, which was, respectively: 0.2250 and 0.1642.

The previous stages of the study allowed us to determine the innovation gap between individual NISs and the average level of innovation in EU economies. In the study, the innovation gap index is defined as the quotient between the value of the synthetic measure of innovation for a given NIS and the average value of the synthetic index of innovation of the EU countries' economies.

The indicator of the innovation gap takes the following form (Weresa 2014, p. 64):

$$L_{pt} = \frac{SII_{pt}}{SII_{UE_t}}, \tag{1}$$

where:

L_{pt} – the innovation gap index (innovation gap) for a given NIS in year t,

SII_{pt} – the value of the synthetic measure of innovation for a given NIS in year t,

SII_{UEt} – the mean value of the synthetic measure of innovation of the EU countries' economies.

A value of the innovation gap index exceeding 1 means that the analyzed system presents a higher level of innovation than the EU average. In contrast, a value lower than 1 indicates that an innovation gap exists between a given system and the EU average.

In order to assess the changes in the level of the innovation gap over time, a formula presenting the difference between the innovation gap index (L_{pt}) in a given year and the value of this index for the base year should be used. It is written as follows (Weresa 2014, p. 64):

$$D_{pt_1} = \left[\frac{SII_{pt_1}}{SII_{UEt_1}}\right] - \left[\frac{SII_{pt_0}}{SII_{UEt_0}}\right] \quad (2)$$

where:

D_{pt_1} – index of changes in the level of the innovation gap between a given NIS and the EU average in 2021 (t) compared to 2010 (t_0),

The index of the change in the innovation gap level (D_{pt_1}) takes values from –1 to +1. Negative values indicate an increase in the innovation gap between a given NIS and the EU average, while positive ones indicate a decrease. Nevertheless, the index only indicates the direction of change; it does not allow us to determine whether the distance shortens or the previously gained advantage is gradually being lost (Weresa 2014, p. 65). Therefore, it is necessary to analyze the index of changes in the level of innovation gap (D_{pt_1}) in relation to the index of the innovation gap (L_{pt}).

Table 3. The innovation gap index for a given NSI in relation to the EU average (L_{pt}), and the index of changes in the level of the innovation gap between a given NSI and the EU average (D_{pt_1}) between 2010 and 2021

			SII_{UEt}	SII_{pt}	L_{pt}	D_{pt_1}
2010	Dynamic NIS	NIS Subtype	0.2250	0.3474	1.544	
	Stable functioning NIS	Germany, Great Britain, France, Italy, Austria, Spain		0.2722	1.2097	
	Unevenly developed NIS	Denmark, Belgium, Luxembourg		0.3582	1.592	
	Catching up NIS	Portugal, Greece, Poland, Hungary, Czech Republic, Slovenia, Malta, Latvia, Estonia, Lithuania, Slovakia		0.1524	0.6773	
	Unbalanced NIS	Bulgaria, Romania, Cyprus		0.1287	0.572	
2021	Dynamic NIS	Ireland, Netherlands, Finland, Sweden	0.2289	0.3587	1.567	0.023
	Stable functioning NIS	Germany, Great Britain, France, Italy, Austria, Spain		0.2905	1.269	0.0593
	Unevenly developed NIS	Denmark, Belgium, Luxembourg		0.3786	1.653	0.061
	Catching up NIS	Portugal, Greece, Poland, Hungary, Czech Republic, Slovenia, Malta, Latvia, Estonia, Lithuania, Slovakia		0.1548	0.676	– 0.0013
	Unbalanced NIS	Bulgaria, Romania, Cyprus		0.0960	0.4193	– 0.1527

Source: author's own compilation based on Eurostat n.d.

Based on the data presented in Table 3, it can be concluded that in 2010, three NISs (developed NISs) – dynamic, stable, and unevenly developed systems – were characterized by a higher innovative position than the EU average. There was an innovation gap in relation to the EU average between the other NISs (developing NISs) – catching up and unbalanced systems. Additionally, in 2021, three systems (developed NISs) – dynamic, stable, and unevenly developed – were among the NISs with a higher innovation position than the EU average. The two remaining systems (developing NISs) – catching up and unbalanced – showed an innovation gap in relation to the EU average.

As for the innovation gap seen over time, it should be emphasized that from 2010 to 2021, the dynamic, stable, and unevenly developed NISs (developed NISs) improved their positions in relation to the EU average, while for the catching up and unbalanced NSIs (developing NISs), the innovation gap increased compared to the EU average.

Conclusions

The research hypothesis formulated in the introduction to the paper has been positively verified – the level of innovation of EU economies is determined by the type of NIS. Thus, countries belonging to the developed NISs (i.e., Ireland, the Netherlands, Finland, Sweden, Germany, Great Britain, France, Italy, Austria, Spain, Denmark, Belgium, and Luxembourg) are characterized by an innovative advantage over countries belonging to the developing NISs (Portugal, Greece, Poland, Hungary, the Czech Republic, Slovenia, Malta, Latvia, Estonia, Lithuania, Slovakia, Bulgaria, Romania, and Cyprus).

The developed NISs owe their advance in innovation rankings to the synergy of several factors: an appropriate state policy that is based on supporting the R&D and education sphere (Roszko-Wójtowicz and Grzelak 2020, p. 658), creating an efficient and friendly institutional environment, as well as mobilizing social capital, which is conducive to the development of creativity and cooperation skills.

The developing NISs, which are predominantly new EU member states[2], were characterized by the presence of an innovation gap in relation to the EU average, which means that despite many benefits that resulted from integration with the EU, they still have not closed the innovation gap to the most developed European economies. Nevertheless, the gap did narrow slightly. The developing NISs are not effective; they are burdened with the following drawbacks: the dependence of many elements of these systems on the public finance sector, the relatively low level of public and private expenditure on R&D, the unfavorable structure of scientific research, the lack of permanent links between science and industry, which results from insuffi-

2 The developing NISs include countries that joined the European Union in 2004 and 2007, and Portugal and Greece.

cient social capital, low-quality education, and a lack of institutions and incentives for patent activity, which leads to low patent rates in these countries.

The added value of the paper is the demonstration of the relationship between the level of innovation of the EU economies and the type of NIS, as well as the assessment of the innovation gap between the national innovation systems of the European Union and the average level of innovation of the EU economies.

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Luka innowacyjna narodowych systemów innowacji w Unii Europejskiej

Głównym celem artykułu jest próba oceny luki innowacyjnej dzielącej narodowe systemy innowacji Unii Europejskiej od przeciętnego poziomu innowacyjności gospodarek krajów UE. W badaniu uwzględniono narodowe systemy innowacji (NSI) wyodrębnione w literaturze przedmiotu, tj. (a) systemy rozwinięte i (b) systemy się rozwijające.

W części teoretycznej artykułu dokonano przeglądu literatury przedmiotu w zakresie problematyki NSI i luki innowacyjnej, przedstawiono definicje i wybrane klasyfikacje NSI na świecie, jak również zdefiniowano pojęcie luki innowacyjnej między krajami. W części empirycznej oceniono poziom innowacyjności gospodarek krajów UE za pomocą syntetycznego miernika rozwoju Z. Hellwiga. Z kolei do pomiaru poziomu innowacyjności poszczególnych NSI zastosowano średnie arytmetyczne krajowych wartości syntetycznego miernika rozwoju (innowacyjności). Lukę innowacyjną obliczono między poziomem innowacyjności wyodrębnionych w badaniu NSI a średnim poziomem innowacyjności gospodarek UE. Badaniem objęto lata 2010 i 2021.

W artykule została sformułowana następująca hipoteza badawcza: poziom innowacyjności gospodarek krajów UE jest determinowany rodzajem NSI i w związku z tym kraje należące

do systemów rozwijających się są mniej innowacyjne i tym samym charakteryzują się luką innowacyjną w stosunku do średniej unijnej. Wyniki analizy pozwoliły pozytywnie zweryfikować tę hipotezę.
Wartością dodaną prezentacji wyników analizy zmieszczonej w artykule jest wskazanie związku między poziomem innowacyjności gospodarek krajów UE i rodzajem NSI, jak również oszacowanie luki innowacyjnej między narodowymi systemami innowacji UE a średnim poziomem innowacyjności gospodarek krajów UE.

Słowa kluczowe: innowacja, innowacyjność gospodarki, narodowy system innowacji, luka innowacyjna