Balkans JETSS (2025) 1: 1-16
DOI: https://doi.org/10.31410/Balkans.JETSS.2025.8.1.1-16

Review Paper

Changes in the Innovation Performance of the Visegrad Countries During Their EU Membership

Julianna Csugány[1]
Tamás Tánczos[2]

Received: May 15, 2025 / Revised: June 30, 2025 / Accepted: June 30, 2025

Abstract: *In 2024, the Visegrad countries – Czechia, Slovakia, Poland, and Hungary – mark 20 years of EU membership. This paper analyses innovation performance trends from 2004 to 2023 using the European Innovation Scoreboard (EIS) framework. The research question investigates whether there is convergence or divergence in innovation performance within the Visegrad Group and between the group and the EU, and in which areas this occurs. The hypothesis assumes no convergence within the group, as strengths and weaknesses remain stable over time. However, EU support has fostered improved innovation performance, suggesting convergence toward the EU average. The practical significance lies in identifying innovation policy gaps and informing decision-makers on how to strengthen regional innovation ecosystems. The findings contribute to designing targeted, effective innovation strategies that can enhance economic performance and competitiveness in the Visegrad region.*

Keywords: *Innovation performance, Visegrad countries, Comparative analysis, European Innovation Scoreboard.*

JEL Classification: O30 · O38 · P16 · F15 · O52 · O57

✉ csugany.julianna@uni-eszterhazy.hu
[1] Eszterházy Károly Catholic University, HU-3300, Eger, Egészségház utca 4., Hungary
[2] Eszterházy Károly Catholic University, HU-3300, Eger, Egészségház utca 4., Hungary

1. INTRODUCTION

Czechia, Hungary, Poland, and Slovakia joined the European Union alongside six other countries in 2004. These Central and Eastern European countries are collectively referred to as the Visegrad Group (V4) due to their shared historical and cultural roots. The V4 was established in the early 1990s following the significant economic transformation of these countries, aiming to foster political, economic, and cultural cooperation. The group also sought to coordinate efforts to enhance their chances of achieving common goals, as outlined in the Visegrad Declaration (1991). Despite their shared historical traditions and geographical proximity, the development paths of these countries have diverged. While there are similarities in the development of V4 countries such as the importance of foreign direct investment and export-oriented economies, differences in institutions and factor endowments have resulted in varying economic performances.

Joining the European Union in 2004 provided the V4 countries with an opportunity to accelerate their development. They benefited from significant EU funding, gained access to the EU internal market, made it possible for them to participate in international collaborations, and attracted increased foreign capital inflows due to their EU membership. This created opportunities to enhance competitiveness, modernize the region's economy, and prioritize the development of the innovation ecosystem within the framework of the European Union. This is important because, in the 21st century, innovation has emerged as a key driver of competitiveness and economic growth, making it a crucial factor for the further development of the V4 countries. The science, technology, and innovation policy tools implemented in the V4 countries, following the logic of the linear model of innovation, show a significant degree of similarity (Havas, 2024). Nevertheless, the effectiveness of innovation activities varies across the countries.

It is widely accepted that there is a positive relationship between economic growth and innovation, a connection empirically confirmed by Pece et al. (2015) for CEE countries through multiple regression models. Before joining the EU, both the economic and innovation performance of the V4 countries lagged behind the EU average. Among the Visegrad countries, Czechia is the most developed, partly due to its strong innovation performance and industrial capacity. Poland's economic performance has increased the most during its EU membership; however, its innovation performance remains weak because its innovation system is underdeveloped, preventing the country from fully exploiting the benefits of research and development and innovation (R&D&I). At the time of EU accession, Hungary's economic performance exceeded that of Poland and Slovakia. By 2023, however, Poland had surpassed Hungary, and Slovakia had caught up. While Hungary has improved its innovation capacity, the domestic companies' innovation capacity remains low, with research, development, and innovation primarily tied to international firms. Slovakia's GDP has also grown dynamically since joining the EU; however, the country lags behind in innovation rankings due to weak conditions for fostering innovation.

This research aims to analyse the innovation performance of Visegrad countries during their EU membership period from 2004 to 2023. The study seeks to highlight the main innovation trends, emphasizing the relative strengths and weaknesses of each country. By utilizing the European Innovation Scoreboard, a comparative analysis can be conducted to evaluate the performance of the Visegrad countries across different fields of innovation.

This paper begins by presenting the theoretical background of the research, including statistical insights into the innovation performance of the Visegrad countries, and formulates the research question and hypotheses. It then outlines the measurement framework and methodology used in the study. Finally, the paper summarizes the results of the comparative analysis and draws conclusions about changes in the innovation performance of the Visegrad countries as EU Member States.

2. THE THEORETICAL BACKGROUND OF THE RESEARCH

Innovation performance significantly determines a country's competitiveness and economic growth, as it reflects how effectively a country can exploit the benefits of dynamic technological changes. The innovation activity in the Visegrad Group was quite low before the countries joined the EU. In the context of EU accession, Borsi (2006) analysed the prospects for the V4 countries to catch up and integrate into the European Research Area. By examining R&D indicators, he introduced the concept of the 'Visegrad paradox,' building on the European paradox, as a key constraint to the V4 countries' ability to advance in innovation. This paradox highlights that, despite a relatively high number of researchers compared to Gross Domestic Expenditure on R&D (GERD), Business Expenditure on R&D (BERD), and GDP, the innovation performance of the V4 countries does not align with their scientific output.

Over the past two decades, the Visegrad countries have made significant efforts to improve their innovation systems by leveraging the opportunities provided by EU membership. According to the European Innovation Scoreboard, in 2004, Poland had the weakest innovation performance among EU countries, while Czechia ranked 17th, Hungary 19th, and Slovakia 21st out of 25 EU member states. By 2023, all Visegrad countries had improved their innovation positions. The latest European Innovation Scoreboard indicates that Czechia's innovation performance is now close to the EU average, and Hungary's performance has significantly improved in recent years. Czechia and Hungary, classified as moderate innovators, ranked 14th and 21st, respectively, while Slovakia and Poland, categorized as emerging innovators, ranked 23rd and 24th out of 27 EU countries. According to Prokop et al. (2017), Hungary's innovation system operated efficiently in the first half of the 2010s. The country successfully utilized EU funds, effectively converted innovation inputs into outputs, and Hungarian companies adapted well to external R&D results. In Slovakia, Braha et al. (2015) emphasized that R&D activities remain weakly supported by both public and private funding. The productivity of innovation is low, and there is a limited share of enterprises applying innovation in their business activities. In Poland, no significant improvement in innovation performance has been observed despite its dynamic economic growth. Vukoszavlyev (2019) also observed an improving trend in R&D performance in the V4 countries based on time series indicators. Czechia stands out as the best performer in innovation within the group, though differences persist among the countries, influenced by varying innovation methodologies.

There are significant regional differences in innovation performance not only between the Visegrad countries but also within each of them. The innovation activity concentrated in capital regions, such as Prague in Czechia, Budapest in Hungary, Warsaw in Poland, and Bratislava in Slovakia, because of their advanced infrastructure, higher concentration of skilled labour, and better access to resources required by innovation. Examining the relationship between economic growth and innovation performance at the NUTS III level, Szendi's (2023) analysis revealed a concentration of innovative and economic capacity in metropolitan areas within the V4 group, as well as in the western regions of Czechia and Slovakia. In contrast, the remaining areas of these countries are characterized by low levels of innovation and economic performance. The European Union aims to reduce these regional imbalances by strengthening the innovation potential of underperforming regions. Czupich (2018) highlighted that the highest innovation potential within the Visegrad Group relates to the capital regions of Czechia and Hungary, characterized by high levels of entrepreneurship, advanced education, and increased R&D activity among enterprises. However, Hudec (2015) found that, outside the capital regions, not only Czech but also Polish regions demonstrated efficiency in innovation when measured by R&D expenditures as inputs and patents as outputs. Some years later, Ivanová and Masárová (2018, 2019) evaluated the innovation performance of Visegrad countries' NUTS II regions using the data from the Regional Innovation Index, and they concluded that the highest innovation performance is performed by the regions of Prague and Bratislava, so the capital regions of Czechia and Slovakia.

Several authors have sought to explore the causes of regional disparities in innovation performance. Lux (2020) emphasized that R&D spending in the Visegrad countries is lower than the EU average, which contributes to the lower efficiency of their innovation systems. Using a spatial econometric approach, Wibisono (2023) highlighted the essential role of regional knowledge inputs, such as R&D expenditure and R&D personnel, in fostering innovation in the Visegrad Group. The study emphasized the importance of public sector R&D funding support and the capabilities of R&D personnel in promoting innovation. Hunady et al. (2017), employing panel Granger causality and panel regression analysis, examined the relationship between regional economic development and R&D investment, controlling for the number of R&D employees. They found a strong positive correlation and significant regional disparities in innovation performance. Similarly, Ivanová and Masárová's (2019) detailed analysis revealed that the largest relative differences among Visegrad Group regions are observed in public-private co-publications, international scientific co-publications, SMEs with marketing or organizational innovations, and innovative SMEs collaborating with others. These findings suggest substantial disparities in both the input and output sides of innovation activities. In contrast, the smallest differences were found in exports of medium-high/high-technology intensive manufacturing, most-cited scientific publications, trademark applications, and non-R&D innovation expenditures. Jabłońska (2024) analysed the relationship between specific innovation dimensions and the rate of entrepreneurship in a group of moderate innovator countries – including the Visegrad countries – as classified by the European Innovation Scoreboard for the period 2013–2019. The study found a strong positive correlation between the quality and quantity of entrepreneurial innovations and the entrepreneurship rate in the V4 countries. This implies that pro-innovative activities undertaken by operating enterprises strongly correlate with decisions to start new businesses (Jabłońska, 2024, pp. 7–8). Finally, Ivanová and Masárová (2018) emphasized that persistent and widening regional discrepancies in human capital remain a significant challenge across Visegrad regions.

It can be concluded that significant differences exist within each Visegrad country, primarily due to insufficient human capital, inadequate public and private funding, and low levels of business innovation activity required to drive innovation.

2.1. Statistical Facts About the Innovation Performance of the Visegrad Countries

The strong, positive relationship between a country's innovation and economic performance is supported by Schumpeter (1934/1980), as well as the exogenous and endogenous growth models (Solow, 1956; Romer 1986; Lucas 1988), which emphasize that technological progress enhances economic growth. The new wave of technological progress, driven by digitalization, can accelerate economic growth, as Mhaka and Taonezvi (2024) also point out, provided that countries establish an adequate foundation for development. However, without access to the internet and digital skills, the benefits of digitalization cannot be fully realized within an economy. Over the last two decades, there has been an improvement in both the economic and innovation performance of the Visegrad countries. The COVID-19 pandemic accelerated the diffusion of digital technologies, leading to a rearrangement within the V4 group.

Based on World bank data, the relative economic performance of the Visegrad countries, measured by GDP per capita (PPP, constant 2021 international $) compared to the EU average, ranged from 49.1% to 80.9% in 2004, while in 2023, the range had improved to 72.2% to 91.3%, as reported in the WB (2024). This indicates that the relative performance of all Visegrad countries significantly improved during their EU membership. Specifically, Czechia's performance increased from 80.9% to 91.3%, Hungary's from 62.3% to 74.5%, Poland's from 49.1% to 81.5%, and Slovakia's from 50.6% to 72.2%. Figure 1 illustrates the changes in GDP per capita, PPP (constant 2021 international $) for the V4 countries during their EU membership.

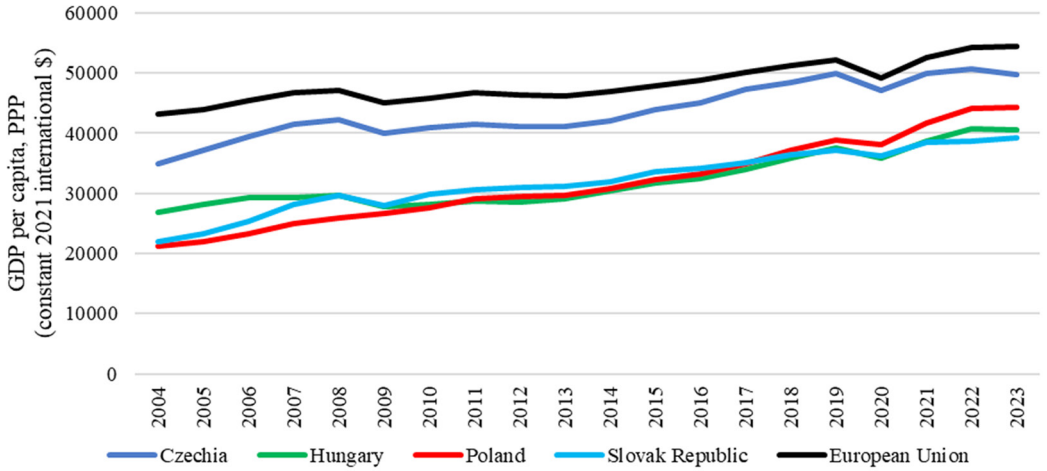

Figure 1. Changes in GDP per capita, PPP (constant 2021 international $) of V4 countries between 2004 and 2023

Source: WB (2024)

Figure 1 illustrates the rearrangement within the V4 group alongside the countries' substantial progress in catching up to the EU average. Poland's economic growth was the most dynamic in the analysed period (3.9% per year on average) and because of this, it overtook both Hungary and Slovakia by 2023. The average growth rate per year was 3.1% in Slovakia, 2.2% in Hungary, and 1,9% in Czechia. The economic development of the V4 countries followed a similar trajectory during the analysed period, achieving economic growth above the EU average; however, the competitiveness and efficiency of their innovation systems lagged behind that of Western European countries. Figure 2 illustrates the World Competitiveness Rankings of Visegrad countries over the last five years.

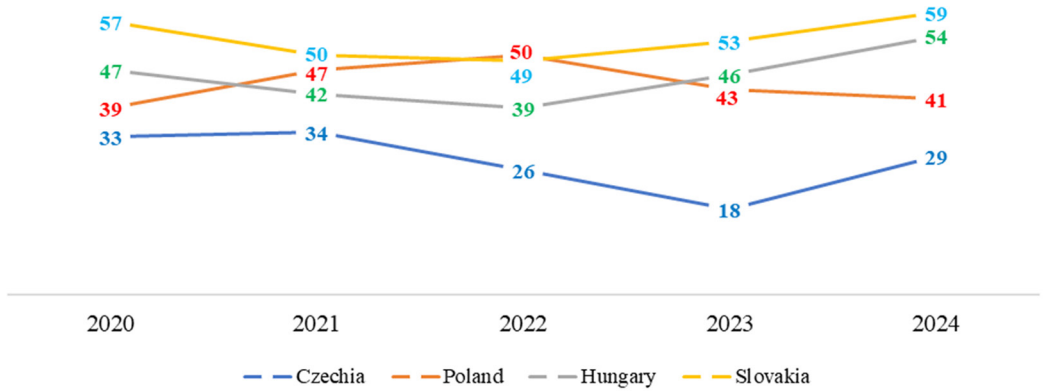

Figure 2. World Competitiveness Rankings of Visegrad Countries, 2020–2024

Source: IMD World Competitiveness Yearbook (2024)

Based on Figure 2, it can be observed that a similar shift in competitiveness occurred within the Visegrad group, as indicated by the change in GDP per capita. Poland's improvement in competitiveness is also noticeable, although it shows greater volatility compared to its economic growth. After a decline following 2020, Poland experienced a significant recovery from the low point of 2022, but it still did not regain its 2020 ranking. Czechia achieved its best ranking in 2023, placing 18th in the competitiveness rankings. Within the EU, only Denmark (the most

competitive country), Ireland, the Netherlands, Sweden, Finland, and Belgium ranked higher. However, Czechia's competitiveness ranking deteriorated significantly by 2024. Hungary's ranking has worsened overall over the past five years. While an improvement was observed up to 2022, its ranking declined afterward. Slovakia remains the least competitive among the V4 countries, following a similar trend to Hungary.

Innovation significantly influences both a country's competitiveness and economic growth. This is confirmed in the Visegrad countries, where the correlation between economic performance, measured by GDP per capita, and innovation performance, measured by the Global Innovation Index, is strong and positive (r=0.738). Ivanová and Čepel (2018) observed that the position of V4 countries in global competitiveness rankings varies depending on their innovation performance. The Global Innovation Index (GII), introduced in 2007, ranked Czechia 32nd, Slovakia 35th, Hungary 36th, and Poland 56th this year. This shows that the innovation performance of the Visegrad countries was relatively similar, with the exception of Poland, which lagged behind (Dutta & Caulkin, 2007). Analyzing the period from 2012 to 2015 using the Global Innovation Index, Corejova and Al Kassiri (2017) concluded that two Visegrad countries (Czechia and Hungary) performed better in innovation output subindexes (such as knowledge and technology outputs, and creative outputs), while the other two (Poland and Slovakia) excelled in innovation input subindexes (including institutions, human capital and research, infrastructure, market, and business sophistication). The authors observed that Hungary's innovative performance deteriorated in both areas, while Poland showed weaker performance in the field of innovation outputs. In contrast, the other countries improved their rankings during this period. According to the latest Global Innovation Index (GII) ranking from 2023, the ranks of Czechia and Hungary have remained relatively stable since 2007. In contrast, Poland's innovation performance has improved, while Slovakia's ranking has declined over this period. Table 1 presents the GII rankings and the main subindices for the Visegrad countries.

Table 1. Rankings of Visegrad countries in the Global Innovation Index 2023

	Czechia	Hungary	Poland	Slovakia
GII rank	31	35	41	45
Output rank	27	33	36	45
Input rank	34	36	50	51

Source: WIPO (2023)

Table 1 shows that in 2023, all Visegrad countries had better rankings for innovation outputs than for innovation inputs, indicating stronger performance in the measurable effectiveness of innovation activities. According to WIPO (2023), Czechia, Hungary, and Slovakia excelled in knowledge and technology outputs, while Poland performed better in creative outputs. Czechia ranked among the best performers in most input categories, such as human capital and research, infrastructure, and business sophistication. Hungary demonstrated strong performance in business sophistication but fell into the second quartile in other input categories. Slovakia performed best in knowledge and technology outputs. In contrast, Czechia, Slovakia, and Poland ranked in the third quartile for market sophistication, indicating weaker performance in this area. Additionally, Poland also ranked in the third quartile for institutions.

Based on statistical evidence, it can be concluded that the innovation performance of the Visegrad countries improved during their EU membership, with each country focusing on different areas in the development of its innovation ecosystem. This led to varying results not only in innovation performance but also in the competitiveness of the V4 countries.

2.2. Research Question and Hypothesis

This paper aims to compare the innovation performance of the Visegrad countries - Czechia, Hungary, Poland, and Slovakia - between 2004 and 2023, using the European Innovation Scoreboard (EIS) to analyse how EU membership has influenced their innovation activity. The research focuses on how the determinants of innovation performance have changed during the period of EU membership in each of the Visegrad countries. *The research question is whether there is convergence or divergence in innovation performance within the Visegrad Group and between the Visegrad Group and the EU, and in which areas this can be observed.* This question is particularly relevant given the strategic importance of innovation in driving economic growth, competitiveness, and regional cohesion in the EU. Understanding the direction and extent of convergence helps evaluate the effectiveness of EU innovation policies and structural support in narrowing the innovation gap between regions. It also sheds light on persistent disparities and structural weaknesses that may require targeted policy interventions.

A significant challenge in the time-series comparison is that the EIS measurement framework has undergone changes over the analysed period, limiting the dimensions of innovation that can be consistently compared over the long term. Consequently, the analysis focuses on the comparison of key drivers of innovation. It is assumed that each country exhibits specific features of innovation that lead to differing innovation capabilities. Additionally, each country has adapted EU funding for innovation development according to its own capacities. As a result, the Visegrad countries have followed unique innovation development paths, leading to variations in their innovation and economic efficiency. *The hypothesis is that there is no convergence within the Visegrad Group, as the strengths and weaknesses remain constant over time.* However, *the overall innovation performance of the V4 countries has improved due to EU support aimed at fostering conditions for innovation. Therefore, the V4 group is converging toward the EU average.*

3. MEASUREMENT FRAMEWORK AND METHODOLOGY

The European Innovation Scoreboard (EIS) provides information across several fields of innovation, making it suitable for analysing the innovation performance of the four Visegrad countries. The EIS facilitates the calculation of the Summary Innovation Index (SII) using a range of indicators, allowing for comparative analysis among European countries. Appendix 1 outlines the changes in its measurement framework between 2004 and 2023. This framework encompasses indicators that reflect the main drivers and outputs of innovation. In 2004, it included only 22 indicators grouped into four categories (*human resources for innovation; the creation of new knowledge; the transmission and application of knowledge; innovation finance, output, and markets*). The EIS 2023 adopts a more detailed approach to innovation, distinguishing four main types of activities - *Framework Conditions, Investments, Innovation Activities, and Impacts* - across 12 innovation dimensions, encompassing a total of 32 indicators.

There are 10 areas for which indicators are available in both versions of the EIS, allowing for a comparison of the Visegrad countries' performance in these fields between 2004 and 2023. These areas include the population with tertiary education, participation in lifelong learning, internet access, public and business R&D expenditures, innovation expenditures, venture capital investments, SMEs' innovation activity, patents, employment impacts, and sales impacts. While the indicators remain similar, some changes in measurement have been introduced to improve the comparability of innovation performance across European countries. In the 2004 version of the EIS, key areas missing from the framework included publication activity, sustainability, other forms of intellectual property beyond patents, and the use of information technology. To compare the innovation performance of the Visegrad countries, descriptive statistics were primarily utilized.

4. EMPIRICAL RESULTS

As a first step in the analysis, the changes in the overall innovation performance of the Visegrad countries during their EU membership are compared. At the time of joining the EU, all countries were classified among the lowest-performing innovation groups. However, by 2023, Czechia had approached the EU average, and the performance of the other countries had also improved significantly.

As Figure 3 illustrates, there was a significant improvement in innovation performance across all Visegrad countries. However, when analysing the relative performance of the V4 countries using the Summary Innovation Index (SII), no substantial change is observed in Hungary's and Slovakia's innovation performance relative to the EU average. In contrast, Czechia and Poland demonstrated convergence toward better-performing countries. Czechia's SII was 75% of the EU average in 2004, but during its EU membership, its innovation performance improved significantly, reaching 94.7% of the EU average by 2023. Poland, which was the worst-performing country in 2004 with an SII of 38.9% of the EU average, also saw substantial improvement, achieving 65.6% of the EU average in 2023. Despite these changes, the innovation ranking of the V4 countries remained consistent throughout their EU membership, with Czechia being the top performer, followed by Hungary, Slovakia, and Poland. It is interesting that Poland surpasses both Hungary and Slovakia in terms of economic performance and competitiveness, yet it lags behind them in the comprehensive assessment of innovation performance, indicating a slower convergence in the field of innovation. Because of this, when using the EIS framework to compare innovation performance of Visegrad countries, no rearrangement within the V4 group was observed between 2004 and 2023.

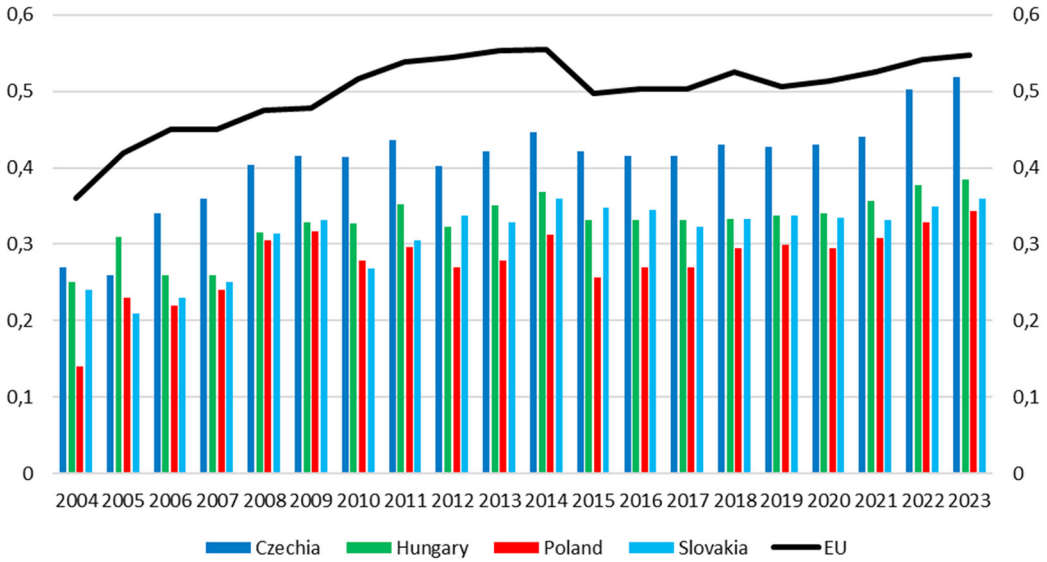

Figure 3. Changes in the Summary Innovation Index of Visegrad Countries and their relative performance compared to the EU average (2004–2023)
Source: Own construction based on EC (2004-2023).

In the next step of the analysis, the different fields of innovation were compared for the year when the countries joined the EU. Table 2 presents a comparison of the relative strengths (indicating indicators that are above or close to the EU average) and relative weaknesses (indicating the lowest relative performance) of the V4 countries, based on the main drivers and outputs of innovation as measured by the indicators in the 2004 EIS.

Table 2. Relative strengths and weaknesses in innovation among Visegrad Countries in 2004

Country	CZECHIA	HUNGARY	POLAND	SLOVAKIA
Innovation performance group	Moderate innovators *75.0%*	Moderate innovators *69.4%*	Moderate innovators *38.9%*	Moderate innovators *66.67%*
	of the EU average			
Relative strengths	Employment in medium/high-tech manufacturing			Employment in medium/high-tech manufacturing
	Sales 'new-to-market' products	SMEs involved in innovation cooperation		Innovation expenditures
	ICT expenditures			
		High-tech manufacturing value-added share		Sales new-to-market products
Relative weaknesses	S&E graduates		Business R&D expenditures	
	EPO and UPSTO high-tech patents and all EPO and UPSTO patents			
	High-tech and early-stage venture capital			Early-stage venture capital
			High-tech manufacturing value-added share	SMEs innovating in-house and involved in innovation cooperation

Source: Own construction based on EC (2005).

At the beginning of the analysed period, the common strengths of the V4 countries were ICT expenditures and the employment impact of innovation, as measured by employment in medium- and high-tech manufacturing (with a missing value for Poland). It can be concluded that in 2004, the relative strengths of the V4 countries were primarily in the dimensions of innovation finance, outputs, and markets. In contrast, their relative weaknesses were associated with risky financing, human resources, business innovation activity, and intellectual assets, reflecting deficiencies on the input side or drivers of innovation. Venture capital, which is critical for financing risky innovative projects, was particularly low in the V4 countries. Additionally, patenting activity was also limited, closely tied to the relatively low levels of business innovation activity.

The EU has made substantial investments to enhance the innovation ecosystems in its member states and has established the Innovation Union. Between 2004 and 2023, the EIS measurement framework underwent significant changes, allowing for a more detailed analysis of innovation performance. All V4 countries showed improvement in participation in lifelong learning, which became one of Slovakia's relative strengths in 2023 (108.8% of the EU average). The proportion of the population with tertiary education increased in Slovakia and Poland, where the rates were notably low in 2004. However, there was a decline in Hungary and stable relative performance in Czechia in this area of human conditions, as this remained a relative weakness for these countries. R&D expenditures increased in all V4 countries, primarily driven by the business sector, with enterprises showing higher levels of innovation activity. Venture capital expenditures rose in Czechia, Hungary, and Poland, but it remained one of Slovakia's relative weaknesses. The employment impacts of innovation continued to be strong in Czechia, exceeding the EU average. At the same time, a decline was observed in the other V4 countries, whose relative performance dropped to 50–60% of the EU average. Intellectual assets, however, remained a persistent weakness across all countries.

In 2023, Czechia and Hungary were classified as Moderate Innovators, with Czechia's relative performance exceeding the group average (94.7%), while Hungary ranked the lowest within this

group (70.4%). Slovakia and Poland were categorized as Emerging Innovators, with both countries' innovation performance surpassing the group average (65.6% for Slovakia and 62.8% for Poland). Figure 4 provides a comparison of the V4 countries across the 12 innovation dimensions.

Figure 4 illustrates that the V4 countries differ significantly across most fields of innovation. Czechia has a notable advantage in firm investments, innovation activities (as measured by SMEs' product and business process innovations), and employment effects. Slovakia and Poland lagged behind Czechia and Hungary in most areas, particularly in attractive research systems, finance and support, sales impacts, and environmental sustainability. Slovakia performs best in human resources, thanks to its above-average participation in lifelong learning, and is comparable to Czechia in sales impacts. However, it falls significantly behind in finance and support, as well as in linkages. Poland stands out in digitalization, with the highest broadband penetration in the V4 group. This could enable Poland to catch up in both competitiveness and economic growth. It also has a substantial advantage in intellectual assets, driven by design applications, which were 150.5% of the EU average. Nevertheless, Poland lags in sales impacts, environmental sustainability, attractive research systems, and employment impacts. Hungary's innovation performance is comparable to Czechia's in areas such as attractive research systems, digitalization, finance and support, and linkages. However, it shows the weakest performance in intellectual assets and human resources. By analyzing which factors significantly determine the overall innovation performance in these countries, it can be concluded that employment effects (r=0.997), innovators (r=0.987), and firm investments (r=0.984) show a very strong correlation with the SII. In these areas, Czechia performs well. However, there is only a slight effect of digitalization (r=0.133) and human resources (r=0.337) on innovation performance, where Poland and Slovakia excel. This is because these countries are lagging behind.

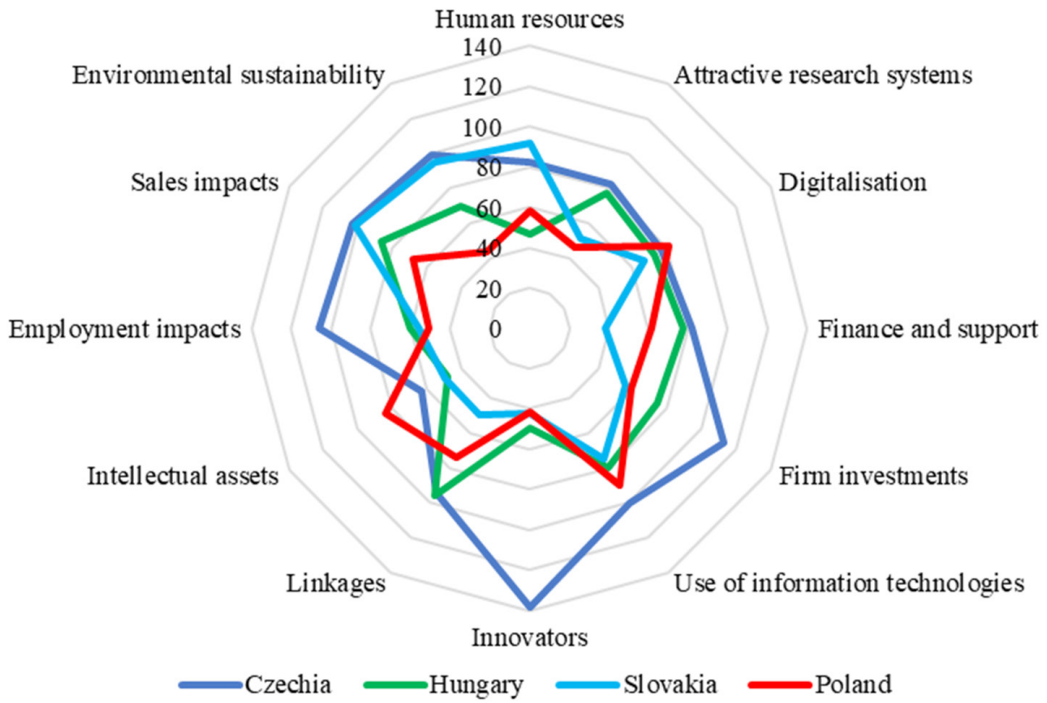

Figure 4. The comparison of Visegrad countries in the innovation dimensions of EIS 2023
Source: Own construction based on EC (2023).

Table 3 highlights the relative strengths and weaknesses of the V4 countries based on the EIS 2023. Czechia's performance exceeded the EU average in several areas, including doctorate graduates, international scientific co-publications, foreign doctorate students, innovation expenditures per employee, enterprises providing ICT training, employment in innovative enterprises, medium and high-tech goods exports, sales of innovative products, and air emissions by fine particulate matter. This indicates that Czechia lagged behind the EU average primarily in intellectual assets, digitalization, and finance and support.

Table 3. Relative strengths and weaknesses in innovation among Visegrad Countries in 2023

Country	CZECHIA	HUNGARY	POLAND	SLOVAKIA
Innovation performance group	Moderate innovators		Emerging innovators	
	94.7%	*70,4%*	*62.8%*	*65.6%*
	of the EU average			
Relative strengths	Non-R&D Innovation expenditures	Foreign doctoral students	Enterprises providing ICT training	Lifelong learning
	Business process innovators	Government support for business R&D	Design applications	Sales of innovative products
	Product innovators	Medium and high-tech goods exports	Trademark applications	Medium and high-tech goods exports
	Innovative SMEs collaborating with others		Population with tertiary education	Air emissions by fine particulate matter
	Public-private co-publications			Non-R&D Innovation expenditures
		Job-to-job mobility of HRST		
Relative weaknesses	Most cited publications	Business process innovators		R&D expenditure in the business sector
	PCT patent applications	Design applications	PCT patent applications	
	Population with tertiary education		Environment-related technologies	Venture capital expenditures
	Job-to-job mobility of HRST	Doctorate graduates		Job-to-job mobility of HRST
	Government support for business R&D	Employment in innovative enterprises	Innovation expenditures per employee	Government support for business R&D

Source: Own construction based on EC (2023).

According to the country analysis in the European Innovation Scoreboard 2023, there was a significant increase in SMEs' innovation activity and venture capital investments in Czechia. Hungary showed improvements in the human conditions for R&D activity, including foreign doctorate students, job-to-job mobility of HRST (Human Resources in Science and Technology), and publication activity. Slovakia made progress in lifelong learning and publications, while Poland experienced a notable rise in innovation activity within the business sector in recent years. In contrast, a decline was observed in finance and support in both Czechia and Hungary, as well as in environment-related technology in Poland and Slovakia.

Analysing recent trends, the EIS 2023 concluded that the performance gap between Slovakia and Hungary and the EU average is widening, whereas this gap is narrowing for Czechia and Poland (EC, 2023). In the year of joining the EU, Poland's relative performance compared to the EU average was 38.9%, but the country has improved significantly, reaching 62.8% by 2023. There has been a significant improvement in education and ICT infrastructure related to the R&D&I,

creating the basis of innovation activity. However, the innovation capability of Polish enterprises remains low. Czechia has shown moderate improvement in innovation performance, starting from 75% and has almost reached the EU average by 2023, with a relative performance of 94.7%. The innovation activity of the Czech industrial sector is traditionally strong, with innovative enterprises ensuring high-level innovation performance, sound employment effects, and favourable financing possibilities. The strengths of innovation in Czechia are closely related to the business sector, where the circumstances favour innovation.

In contrast, Hungary's relative performance has remained almost constant (69.4% in 2004 and 70.4% in 2023), while Slovakia's relative performance worsened, falling from 66.7% to 65.6% of the EU average. The weaknesses of Hungary are related to the human resource conditions for innovation and the low innovation capability of Hungarian SMEs. The improvement is mainly linked to marginal areas of innovation, with no significant development in critical fields, particularly in business innovation activity and human resources. Slovakia's relative innovation performance had worsened by 2023 within the V4 group. While the human resource conditions, supported by lifelong learning programs, and the employment and sales impacts of innovation are favourable, the innovation activity in the business sector remains low, and there is no effective research system to enable innovation in the country. These statements are consistent with Hanáčková and Takáč (2024), whose TOPSIS analysis identifies several barriers to innovation within the V4, such as the lack of financial resources for innovative activities, especially in the private sector, the high costs associated with innovation, and difficulties in accessing state or grant funding.

In the final step of the analysis, the R&D expenditures were analysed because some authors emphasized the problem with insufficient financing as a constraint of efficient innovation. Ivanová and Žárská (2023) pointed out that there is a positive correlation between R&D expenditures and the aggregate innovation index in all V4 countries. Figure 5 shows the evolution of gross domestic expenditure, business enterprise expenditure, and higher education expenditure on R&D as a percentage of GDP in 2004 and 2022.

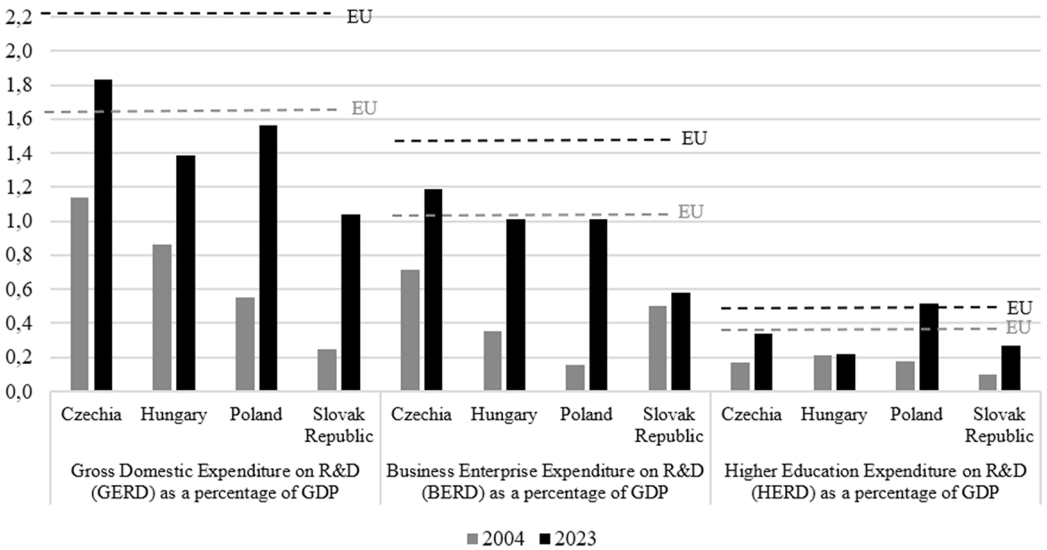

Figure 5. The evolution of R&D expenditures in the Visegrad Countries and the EU average in 2004 and 2023

Source: Own construction based on OECD (2024) and Eurostat (2024)

Figure 5 illustrates that in 2004, all Visegrad countries significantly lagged behind the EU average in almost all forms of R&D expenditures. By 2023, Czechia exceeded the 2004 levels of GERD and BERD, but still did not reach the EU average. Poland has shown significant improvement in all expenditure areas, with HERD surpassing the EU average in 2023. Analysing R&D expenditures reveals that by 2023, Czechia has moved closer to the EU average in GERD and BERD, though a gap remains in HERD, where it has almost reached the 2004 EU average. In Hungary, the share of business R&D expenditures (BERD) significantly increased from 0.35% to 1.01%, but HERD stagnated at the 2004 level. While GERD also grew, Poland surpassed Hungary in both GERD and BERD, with BERD levels being the same in 2023. Both Poland and Slovakia substantially increased their R&D expenditure ratios, with Poland's GERD rising from 0.55% to 1.56%, and Slovakia's from 0.5% to 1.04%. In Slovakia, R&D expenditures grew primarily in higher education, with modest growth in business expenditures during the analysed period. Despite these improvements, the EU's 3% R&D expenditure target remained unmet, with the EU average standing at only 2.11% in 2022.

Analysing the relationship between factors related to innovation performance, it can be concluded that there is a strong positive correlation between the SII and GERD, as well as between SII and BERD ($r=0.827$ and $r=0.755$), which indicates that better financing generates more innovation. In the case of SII and HERD, there is a weak negative correlation ($r=-0.037$), which shows that higher education expenditures alone do not promote innovation performance effectively, as indicated by Poland.

5. CONCLUSION

The year 2024 marks 20 years of European Union membership for Czechia, Hungary, Slovakia, and Poland, collectively referred to as the Visegrad countries. This analysis focuses on the changes in their innovation performance, which is a key driver of economic growth and competitiveness. The research question was whether there is convergence or divergence in innovation performance within the Visegrad Group and between the Visegrad Group and the EU, and in which areas this can be observed. According to statistical data, the innovation performance of the Visegrad countries has improved significantly during their EU membership, partly due to the various forms of support aimed at enhancing innovation efficiency as previously hypothesized. The Summary Innovation Index (SII), which measures overall innovation performance, showed improvement during the period of EU membership. However, the relative position of these countries compared to the EU average has not changed significantly. In 2023, Poland was no longer the lowest-ranked country in the innovation rankings but remained in the worst-performing group, referred to as Emerging Innovators, alongside Slovakia. Czechia was near the EU average, and Hungary made rapid progress, joining the Moderate Innovators group.

It can be concluded that convergence within the V4 group has been observed in areas such as digitalization and the use of information technologies. It was not previously assumed. However, Czechia, as the best-performing country in the group, maintains a significant advantage in firm investments, innovation activities, and employment effects. Slovakia excelled in lifelong learning, Hungary led in linkages, and Poland stood out in design applications and broadband penetration.

Innovation is a critical factor for achieving high economic growth and competitiveness, prompting the Visegrad countries to focus on enhancing their innovation capabilities. However, conducting time-series analysis in the field of innovation is challenging due to frequent changes in measurement frameworks. The European Innovation Scoreboard provides a useful tool for comparing countries' performance in key innovation areas, allowing for conclusions about long-term trends. In the future, it would be worthwhile to compare V4 countries using other innovation measurement frameworks, stepping beyond the European context.

A more detailed analysis of specific innovation subfields could provide further insights into how the differing innovation ecosystems of countries with similar traditions and support systems can be effective. Consequently, EU membership has created a favourable environment for innovation development in the Visegrad countries, with significant financial support, opportunities for scientific cooperation, and innovation-promoting regulations and strategies. However, the extent of utilization and the results achieved vary among the individual countries. The Visegrad countries should focus more on addressing their weaknesses and capitalizing on their strengths to fully realize the region's innovation potential.

References

Borsi, B. (2006). A visegrádi országok perspektívája az Európai Kutatási és Innovációs Térségben (*Perspectives of the Visegrad countries in the European Research and Innovation Area). Információs Társadalom* (*Information Society)* 6 (3): 54-70. https://dx.doi.org/10.22503/inftars.VI.2006.3.4

Braha, K., Qineti, A., & Serenčéš, R. (2015). Innovation and Economic Growth: The Case of Slovakia. *Visegrad Journal of Bioeconomy and Sustainable Development* 4 (1): 7–13. https://doi.org/10.1515/vjbsd-2015-0002

Corejova, T., & Al Kassiri, M. (2017). Comparison of Innovation Performance Within Visegrad Countries. *Springer Proceedings in Business and Economics*, 139-149. https://doi.org/10.1007/978-3-319-48454-9_11

Czupich, M. (2018). The innovative potential of the Visegrad Group regions. *University Economic Bulletin* (38), 14-22. https://doi.org/10.31470/2306-546x-2018-38-14-22

Dutta, S., & Caulkin, S. (2007). The World's Top Innovators. *World Business* 24 Feb.

EC. (2005). *European Innovation Scoreboard 2004.* European Commission.

EC. (2023). *European Innovation Scoreboard 2023.* European Commission.

EC. (2005-2022). *European Innovation Scoreboard 2005-2022.* European Commission. Available at https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

Eurostat. (2024). *Gross domestic expenditure on R&D by sector of performance (GERD, BERD, HERD)* [Data set]. Available at: https://ec.europa.eu/eurostat/databrowser/view/rd_e_gerdtot/default/table?lang=en

Hanáčková, D., & Takáč, I. (2024). Innovation performance of V4 countries. *Entrepreneurship and Sustainability Issues*, 11(4), 293-310. https://doi.org/10.9770/jesi.2024.11.4(18)

Havas, A. (2024). Innováció és gazdasági teljesítmény a közép-európai országokban (Innovation and economic performance in four Central European countries). *KRTK-KTI Műhelytanulmányok (KRTK-KTI Working Papers) 2024/28.* https://kti.krtk.hu/wp-content/uploads/2024/12/KRTK-KTIWP202428.pdf

Hudec, O. (2015). Visegrad Countries and Regions: Innovation Performance and Efficiency. *Quality Innovation Prosperity*, 19(2), 55. https://doi.org/10.12776/qip.v19i2.593

Hunady, J., Pisar, P., Musa, H., & Musova, Z. (2017). Innovation support and economic development at the regional level: panel data evidence from Visegrad countries. *Journal of International Studies*, 10(3), 147-160. https://doi.org/10.14254/2071-8330.2017/10-3/11

IMD. (2024). *World Competitiveness Yearbook*. IMD World Competitiveness Center.

Ivanová, E., & Čepel, M. (2018). The impact of innovation performance on the competitiveness of the Visegrad 4 countries. *Journal of Competitiveness* 10 (1): 54-72.

Ivanová, E., & Masárová, J. (2018). Evaluation of innovation performance of Visegrad countries regions putting a stress on human capital. *Sociálno-ekonomická revue* (*Social and Economic Revue)* 16 (2): 27-34.

Ivanová, E., & Masárová, J. (2019). Differences in innovation performance of Visegrad Group regions. In *3rd International Scientific Conference – EMAN 2019 – Economics and Management: How to Cope With Disrupted Times, Ljubljana, Slovenia, March 28:* 635-640. https://doi.org/10.31410/EMAN.2019.635

Ivanová, E., & Žárská, V. (2023). R&D expenditure as a determinant of the aggregate innovation index in the V4 countries. *Innovative Marketing*, 19(2):87-100. https://doi.org/10.21511/im.19(2).2023.08

Jabłońska, M. (2024). The Impact of Innovation on Business Development. The Example of Moderate Innovators and the Visegrad Group Countries. *Comparative Economic Research. Central and Eastern Europe* 27 (1): 7-29.

Lucas, R. E., Jr. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3-42. https://doi.org/10.1016/0304-3932(88)90168-7

Lux, G. (2020). Nemzeti innovációs rendszerek a visegrádi országokban (Innovation systems in Visegrad countries). *Marketing & Menedzsment* 54 (1): 39-48.

Mhaka, S., & Taonezvi, L. (2024). Does Digitalization Increase Economic Growth? Evidence from SADC Countries. *Managing Global Transitions*, 22(3). https://doi.org/10.26493/1854-6935.22.201-229

OECD. (2024). *Main Science and Technology Indicators*. https://data-explorer.oecd.org/vis?tm=-Main%20Science%20and%20Technology%20Indicators&pg=0&snb=3&df[ds]=dsDisseminateFinalDMZ&df[id]=DSD_MSTI%40DF_MSTI&df[ag]=OECD.STI.STP&df[vs]=1.3&dq=.A.G%2BT_RS...&lom=LASTNPERIODS&lo=5&to[TIME_PERIOD]=false

Pece, A. M., Simona, O. E. O., & Salisteanu, F. (2015). Innovation and Economic Growth: An Empirical Analysis for CEE Countries. *Procedia Economics and Finance*, 26, 461-467. https://doi.org/10.1016/s2212-5671(15)00874-6

Prokop, V., Stejskal, J., & Kuvíková, H. (2017). The Different Drivers of Innovation Activities in European Countries: A Comparative Study of Czech, Slovak, and Hungarian Manufacturing Firms. *Ekonomický Časopis* 65 (1): 31–45.

Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *Journal of Political Economy* 94 (5): 1002–1037.

Schumpeter, J. A. (1934/1980). *The Theory of Economic Development*. Routledge.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. The Quarterly Journal of Economics, 70(1), 65. https://doi.org/10.2307/1884513

Szendi, D. (2023). A gazdasági teljesítmény és az innováció összefüggései a V4+2 országokban (The relationship between economic performance and innovation in the V4+2 countries)'. In *Tanulmányok és köszöntők Sikos T. Tamás tiszteletére: A Miskolci Egyetem Gazdaságtudományi Karának Jubileumi tanulmánykötete (Studies and Tributes in Honor of Tamás Sikos T.: The Jubilee Volume of the Faculty of Economics at the University of Miskolc),* edited by Veresné Somosi, M., Lipták, K., and Varga, K., 182-90. https://mek.oszk.hu/24900/24939/24939.pdf

Visegrad Declaration. (1991). Available at https://www.visegradgroup.eu/home/documents/visegrad-declarations/visegrad-declaration-110412

Vukoszavlyev, S. (2019). Comparison of R&D Innovation Indicators of the Visegrád Group. *International Journal of Engineering and Management Sciences* 4 (2): 162-172.

Wibisono, E. (2023). Knowledge input and innovation in Visegrad Group (V4) regions: A spatial econometric approach. Bulletin of Geography. *Socio-economic Series* (59), 111-130. https://doi.org/10.12775/bgss-2023-0008

WB. (2024). *World Development Indicators*. World Bank.

WIPO (World Intellectual Property Organization). (2023). *Global Innovation Index 2023*: *Innovation in the face of uncertainty.* Geneva: WIPO.

Appendix 1
Changes in the measurement framework between 2004 and 2023

	SUMMARY INNOVATION INDEX 2023		SUMMARY INNOVATION INDEX 2004
Main types of activities	**Innovation dimension**	**Indicator**	**Indicator**
FRAMEWORK CONDITIONS	Human resources	New doctoral graduates (in STEM)	S & E graduates/ 20-29 years
		Population aged 25-34 with a tertiary education	Population with tertiary education
		Lifelong learning	Participation in lifelong learning
	Attractive research systems	International scientific co-publications	
		Top 10% most cited publications	
		Foreign doctoral students	
	Digitalisation	Broadband penetration	Composite indicator on Internet access
		Individuals who have above basic overall digital skills	
INVESTMENTS	Finance and support	R&D expenditure in the public sector	Public R&D/GDP
		Venture capital expenditures	High-tech venture capital share Early-stage venture capital/GDP
		Direct government funding and government tax support for business R&D	
	Firm investments	R&D expenditure in the business sector	Business R&D/GDP
		Non-R&D innovation expenditures	ICT expenditures/GDP
		Innovation expenditures per person employed in innovation-active enterprises	Innovation expenditures/turnover
	Use of information technologies	Enterprises providing training to develop or upgrade the ICT skills of their personnel	
		Employed ICT specialists	
INNOVATION ACTIVITIES	Innovators	SMEs with product innovations	SMEs innovating in-house
		SMEs with business process innovations	SMEs being non-technical innovators
	Linkages	Innovative SMEs collaborating with others	SMEs involved in innovation cooperation
		Public-private co-publications	
		Job-to-job mobility of Human Resources in Science & Technology	
	Intellectual assets	PCT patent applications	High-tech EPO & USPTO patents/population EPO & USPTO patents/population
		Trademark applications	
		Design applications	
IMPACTS	Employment impacts	Employment in knowledge-intensive activities	Employment in medium/high-tech manufacturing
		Employment in innovative enterprises	Employment in high-tech services
	Sales impacts	Medium and high-tech product exports	High-tech manufacturing value-added share
		Knowledge-intensive services exports	
		Sales of product innovations	Sales 'new-to-market' products/turnover Sales 'new to firm' products/turnover
	Environmental sustainability	Resource productivity	
		Air emissions by fine particulates PM2.5 in the industry	
		Development of environment-related technologies	

Source: EC (2005) and EC (2023)