“R&D expenditure as a determinant of the aggregate innovation index in the V4 countries”

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R&D EXPENDITURE AS A DETERMINANT OF THE AGGREGATE INNOVATION INDEX IN THE V4 COUNTRIES

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Abstract

Innovation is critical to modern economies' development; new process requirements within Industry 4.0 highlight its significance and necessity. This study aims to identify the relationship between R&D expenditure and the aggregate innovation index in the V4 countries. The statistical data from 2014 to 2021 are taken from the European Commission and Eurostat databases. The analysis focuses on identifying the degree of correlation between the standardized score of the Aggregate Innovation Index and the amount of R&D expenditure in countries of the Visegrad Group. The study uses the following methods: the Shapiro-Wilk test (to verify the normality of the samples), Pearson's correlation coefficient (to check the degree of tightness of dependency), the Tukey test (to examine which countries have statistically significant differences), and chi-squared test (X2-test). Among the V4 countries, the Czech Republic was the best performer in the aggregate innovation index. Hungary showed the second-highest score, Slovakia ranked third place, and Poland had the lowest score. The findings indicate a positive correlation between R&D expenditures and the aggregate innovation index in all V4 countries. However, the relationship is statistically significant only in the Czech Republic and Poland. These results were confirmed by the Tukey test of differences within the correlation coefficients, which showed only a statistically significant difference within the correlation coefficients between Poland and Slovakia (1.790) and between Poland and Hungary (–1.640), respectively.

Keywords Czechia, Hungary, innovation, innovation performance, Poland, research and development, Slovakia

JEL Classification O10, O30, O32, O33

INTRODUCTION

Research and development are one of the innovation implementation prerequisites. Its implementation is considered in the 21st century as one of the most significant determinants of economic performance enhancement in individual countries. Innovation is of great importance because it brings a multiplier effect for different areas of the economy in the long term. The enhanced interest in these areas intensified in the second half of the 20th century in connection with knowledge economy development. The Industry 4.0-related processes development later reinforced it. However, to flourish, countries need to take a systematic approach to develop all these areas. Although the benefits of systematically investing in research and development and thus fostering innovation are undoubted, many countries, including the V4 countries, are still cautious about increasing respective investments. These are primarily countries whose economies are based mainly on industrial production and agricultural production, or low labor costs, and in which the research and development area is given insufficient attention, despite the fact that its results are increasingly being applied in these areas as well.

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Globalization processes have brought close cooperation among countries and competition between them for the best possible status within the various indicators evaluation, particularly innovation performance. For this reason, many international organizations have set up their own criteria for assessing innovation performance in recent years. A wide range of indicators is considered in these assessments, with R&D expenditure as its integral part. For example, the European Commission releases the Aggregate Innovation Index, which attempts to give the most objective picture of innovation performance in European countries. In the early years of observing, this summary indicator was obtained by aggregating 25 indicators to measure innovation performance. The latest European Innovation Scoreboard of 2021 is based on the same indicator framework. However, it consists of 32 indicators grouped into 12 dimensions, such as human resources, R&D expenditure, attractive research systems, fixed R&D investment, and information technology usage (European Commission, 2021). However, the European Commission has not explored the significance of the impact of these sub-indicators on the final Aggregate Innovation Index value. Overall, only a few studies in this area provide considerable scope for research action.

1. LITERATURE REVIEW

This innovation-focused analysis builds on research findings in innovation, innovation performance, and research investment. The starting point was publications that have presented the content definition and determination of categories such as innovation and innovation performance, the assessment of factors affecting innovation performance, as well as new trends in this exploring issue, such as open innovation, eco-innovation, and the significance of human capital for innovation development.

The issue of defining innovation has been elaborated by Taylor (2017), who summarized different approaches to defining innovation. He defined innovation as "a creative process in which new or improved ideas are successfully developed and applied to results that are practical and valuable." Other authors describe innovation as a method and technology to reach new customer groups. Garcia and Calantone (2002) state that innovation can have a different definition depending on the area being implemented. Therefore, a uniform method is needed for classifying innovations. It is suggested that practitioners and academics talk with a common understanding of how a specific innovation type is identified and how the innovation process may be unique.

In the last two decades, the issue of open innovation and its sustainability has resonated in scientific studies, being linked to environmental and social impacts on society. Ebersberger et al. (2012) provide some interesting results. For example, open innovation practices strongly affect innovation performance, broad-based approaches have the strongest impact, and collective open innovation strategies appear more critical than individual practices. Moreover, intramural investments are still crucial for innovation performance, emphasizing that open innovation is not a substitute for building internal knowledge.

Chesbrough et al. (2018) considered a value perspective of open innovation. Value in open innovation is driven not only by the value creation of actors but also by their ability to capture value. Other authors address the broader context of open innovation, such as sustainable open innovation and innovation performance, the role of technological capability for sustainable open innovation, business model, perspective and sustainable open innovation, and university collaboration (Bigliardi & Filippell, 2022).

The innovation sustainability issue is generally associated with the environmental and social aspects and the sustainability of corporate social responsibility. Sica (2018) defines eco-innovation and confronts his definition with authors who define the category of eco-innovation in terms of content, such as Bossle et al. (2016). According to Klewitz and Hansen (2014), ecological innovations and sustainability-oriented innovations (SOI) are currently highlighted, i.e., the integration of ecological and social aspects in small and medium-sized enterprises (SMEs).

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The innovation sustainability issue and its impact on firms' competitiveness have been widely described. Horbach et al. (2012) argue that competitive market pressure drives environmental innovation more than government regulation, motivating innovation activities in sustainability and competitiveness. García-Sánchez et al. (2020) argue that although environmental innovation strategies do not yield higher returns, they are highly valued by the capital market. This is particularly true in areas with more significant economic growth and resource availability. Ključnikov et al. (2022) concluded that innovation performance has no demonstrable impact on risk management in SMEs, with managers' access to funding or educational attainment playing a much more significant role. However, in the context of the innovation performance of SMEs, it should be noted that since 2020, it has also been affected by the Covid-19 pandemic outbreak (Xiao & Su, 2022).

Martinez-Conesa et al. (2017) address the issue of SMEs' social responsibility and innovation performance. Their results support a partial mediation effect of innovation performance on the relationship between CSR and company performance. Khattak (2023) and Musa et al. (2018) have the same opinion. According to Rozsa et al. (2021), CSR-involved entrepreneurs consider employees to be the most important asset of their business, so they are more willing to take risks in areas related to personnel risk and put a higher added value on seeing employees strive to improve their performance. Gavurova et al. (2022) stated that CSR is crucial in creating a competitive advantage. Managers are aware of this fact and the existing link between building an organization's reputation and creating business opportunities. However, researchers show that perceptions of CSR are also highly dependent on the business size.

Civelek et al. (2021) conclude that the significant constraints of SMEs regarding innovation activities are the lack of finance and human resources, intellectual property protection, and the educational status of owners/entrepreneurs (this is mainly related to family-run SMEs). According to Hervas-Oliver et al. (2021), increasing spending on research and development may only sometimes bring the expected effect in SMEs because these SMEs have specificities. In regions, SMEs rely more on external resources and cooperation among enterprises. Lewandowska and Stopa (2020), regarding the employment of individuals in innovative firms, state that highly skilled employees will be most competitive on the labor market when having the option to change occupations and jobs freely. Issues of sustainability and social responsibility are reflected within the financing of innovative activities in enterprises with an impact on the economy's economic performance.

When assessing the impact of innovation on economic growth, it is crucial to consider other factors as well. Reznakova and Stefankova (2022) state, "the impact of foreign knowledge on an economy depends on its technological capacity. The infusion of foreign knowledge promotes the growth of high-growth economies but hinders the growth of less technologically sophisticated ones." Sokolov-Mladenović et al. (2016) unequivocally confirmed that investments in research and development always positively affect the real pace of economic growth, even in conditions of a financial crisis. Runiewicz-Wardyn (2009) analyzed the differences in innovation performance between the EU and the US. It was found that the US and the EU spend different amounts of money on R&D. There is also a difference in the industrial structure between the two countries, affecting the different levels of research. The internationalization degree of their economies is different. Moreover, there is also a difference in how much research activities are linked to their implementation.

Garbuz and Topala (2017), on the other hand, argue that the development of a sustainable innovation-based economy and its competitiveness is closely related to consistent investment in research and practical training of professionals for it. Humbatova and Hajiyev (2019) take a similar approach to this issue. Accordingly, funding science and research is considered one of the priorities of sustainable development in most countries. Dworak (2020) also stresses the significance of financial support for research activities. This is mainly because the implementation of research contributes to the creation of innovation capacities, leading to the improvement of the overall economic structure (Leite & Cardoso, 2023). Roszko-Wójtowicz and Białek (2017) investigated the relationship between the innovation capacity of economies and their sub-indicators. Also, Janoskova and Kral (2019) assessed the impact of sub-indicators, which make up the Aggregate Innovation Index as an innovation performance indicator in EU countries, on its overall value.

Innovative performance is a comprehensive concept that consists of many aspects. As the literature analysis shows, there are several perspectives on this issue. It can be assessed at both micro and macro levels from national and international perspectives. As the situation at the micro level tends to be highly dependent on the macro level (Sun et al., 2022), it is also influenced by geographical location. The empirical part of this paper focuses on assessing the relationship between the research investment and the complex innovation performance indicator in the V4 countries.

This study aims to identify and evaluate the dependency between the R&D expenditure and the Aggregate Innovation Index in the V4 countries.

2. METHOD

The base for research was the statistical data from 2014 to 2021, obtained from the European Commission and Eurostat databases. The study focused on finding the correlation rate between the standardized score of the Aggregate Innovation Index and the amount of R&D expenditure per capita in euros. The choice of those indicators was motivated by the fact that the Aggregate Innovation Index measures countries' innovation performance, and the implementation of R&D is a prerequisite for any innovation. In addition, R&D expenditure, whether in public administration or the corporate sector, also enters as one of the variables within the aggregate innovation index calculation.

Since the correlation coefficient can be used as a measure of statistical dependency if the random vector *X*, *Y* has an approximately normal distribution, firstly, it was necessary to test the normality of the samples for each of the countries observed. At this stage, the Shapiro-Wilk normality test was employed:

$$W = \frac{\left(\sum_{i=1}^{m} a_i^{(n)} (x_{n-i+1}^{*} - x_i^{*})\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}, \qquad (1)$$

where x_i is the smallest number in the set; $\bar{x}$ is the mean of the set; the coefficients $a_i^{(n)}$ are spreadsheet values; m is a vector, with $m = n/2$ when n is even, or m = $(n - 1)/2$ when n is not even.

If $W \leq W(n, \alpha)$, then at the α significance level, the tested hypothesis is rejected on the baseline set normal distribution.

To calculate the correlation, Pearson's correlation coefficient was used:

$$r_{xy} = \left(n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right) \times$$

$$\times \frac{1}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right]}}. \qquad (2)$$

where: n is the number of observations; x is the independent variable; y is the dependent variable.

For the variables X and Y, the study set the normalized score value of the Aggregate Innovation Index, respectively, the R&D expenditure per capita value. The correlation coefficient can take values from –1 to 1. If the result is positive, both variables have changed in the same direction. If the result is negative, the variables have changed in the opposite direction. If the result is zero, the observed variables are independent. According to the coefficient value, the degree of dependency tightness was determined.

As part of this analysis, the correlation coefficients for each country were also tested. This determined whether the correlation coefficients were statistically significantly different from each other. In calculations, the formula (3) was used:

$$\chi 2 = \sum_{i=1}^{k} (n_i - 3).(z_i - b)^2, \qquad (3)$$

$$\text{where} \quad b = \frac{1}{n - 3k} \sum_{i=1}^{k} (n_i - 3) z_i,$$

where z_i is the Fisher transform of the correlation coefficient.

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At last, the Tukey test and chi-squared test (X^2-test) assessed which countries have statistically significant differences. For each pair of countries, the study was searching whether the inequality is applicable:

$$|z_i - z_j| \geq q_{k,\infty}(\alpha) \cdot \sqrt{\frac{1}{2} \cdot \left(\frac{1}{n_i - 3} + \frac{1}{n_j - 3} \right)}, \quad (4)$$

where z_i is the Fisher transform of the correlation coefficient; $q_{k,\infty}(a)$ are the spreadsheet values for α = 0.05 and 0.01, respectively.

3. RESULTS

The European Commission (2021) divides countries based on their innovation performance into four groups. However, the countries observed with innovation performance below 100% are classified only into two of them (moderate and early innovators). Figure 1 shows the scores achieved in the Aggregate Innovation Index and the level of R&D spending in the V4 countries.

Among the V4 countries, the Czech Republic was the best performer in the Aggregate Innovation Index over the observed period, with a range of 0.391 to 0.441, and was classified as a moderate innovator. It also had the highest per capita R&D expenditure values among the V4 countries. They increased from €294 in 2014 to €444 in 2021. Hungary showed the second highest score within the Aggregate Innovation Index, except in 2015; it also ranked second among the V4 countries in R&D investment. The Aggregate Innovation Index increased from 0.330 to 0.357 between 2014 and 2021, and R&D expenditure increased from €145 per capita to €260 per capita. Slovakia ranked third among the V4 countries surveyed within the Aggregate Innovation Index but has been ranked as the last in R&D investment since 2018. The Aggregate Innovation Index increased from 0.304 in 2014 to 0.332 in 2021, and R&D expenditure amounted to €168 per capita in 2021, with a noticeable decline in 2016. Poland had the lowest Aggregate Innovation Index score throughout the observed period (values between 0.240-0.308 in 2014–2021), but the gap between it and Hungary/Slovakia gradually diminished.

Hungary, Poland, and Slovakia were all classified as early innovators based on the results of the Aggregate Innovation Index. R&D expenditure is often considered a basis for innovation implementation and is also one of the components from which the Aggregate Innovation Index is constructed. Therefore, it is worth exploring whether the R&D expenditure development is related to the Aggregate Innovation Index development in the V4 countries that lag behind the EU average in innovation performance.

Source: Own processing by EISB, Eurostat.

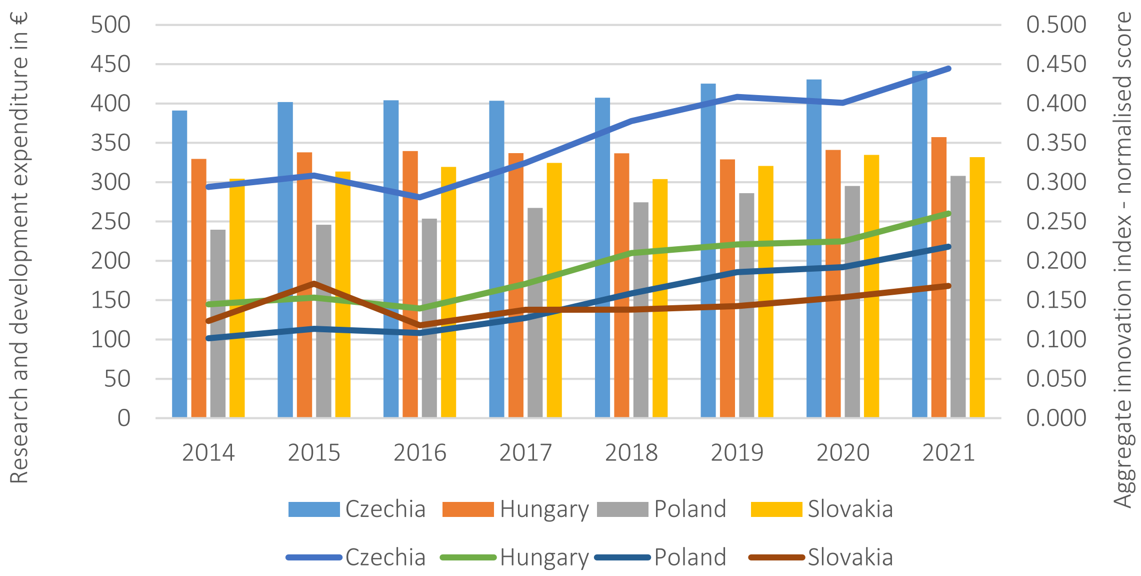

Figure 1. Development of Aggregate Innovation Index and R&D expenditure in V4 countries

Table 1. Test statistics – Slovakia

Source: Own processing by EISB, Eurostat.

α = 0.05	Aggregate innovation index – Normalized score	Per capita expenditure on research and development [€]
2014	0.304	123.6
2015	0.313	171
2016	0.319	118.1
2017	0.324	137.8
2018	0.304	138
2019	0.321	142.5
2020	0.335	153.7
2021	0.332	168.2
Shapiro-Wilk normality test	0.594	0.604
Pearson correlation coefficient	0.427	
Correlation coefficient significance test	0.291	
Determination coefficient	0.182	

3.1. Slovakia

Based on the Shapiro-Wilk test *p*-values (0.594; 0.604) > *α* (0.05), the samples have an approximately normal distribution and can be considered to be randomly selected from a baseline set with a normal distribution. Pearson's correlation coefficient r = 0.427, which means there is a medium tightness of dependence between the normalized score values of Aggregate Innovation Index and the R&D expenditure values in Slovakia, captured in Figure 2. The coefficient of determination r^2 = 0.182. Thus, the chosen model has explained only a small part of the variability between the observed variables. In contrast, other phenomena not shown here can enter into the correlation between the Aggregate Innovation Index and R&D expenditures, which was also confirmed by the significance test of the correlation coefficient.

As part of the analysis, in addition to identifying the tightness of dependence, it was also necessary to determine whether the results could be generalized to the entire baseline set. Therefore, the study tested H_0 on the observed trait independence. Since the probability value of the correlation coefficient significance test is bigger than the chosen significance level of *p* (0.291) > *α* (0.05), it was concluded that there is no statistically significant dependence between the normalized score of the Aggregate Innovation Index and the amount of per capita R&D expenditure in euros in Slovakia. Thus, factors other than the dynamics of R&D expenditure must significantly impact the Aggregate Innovation Index. However, such a result is not

Source: Own processing.

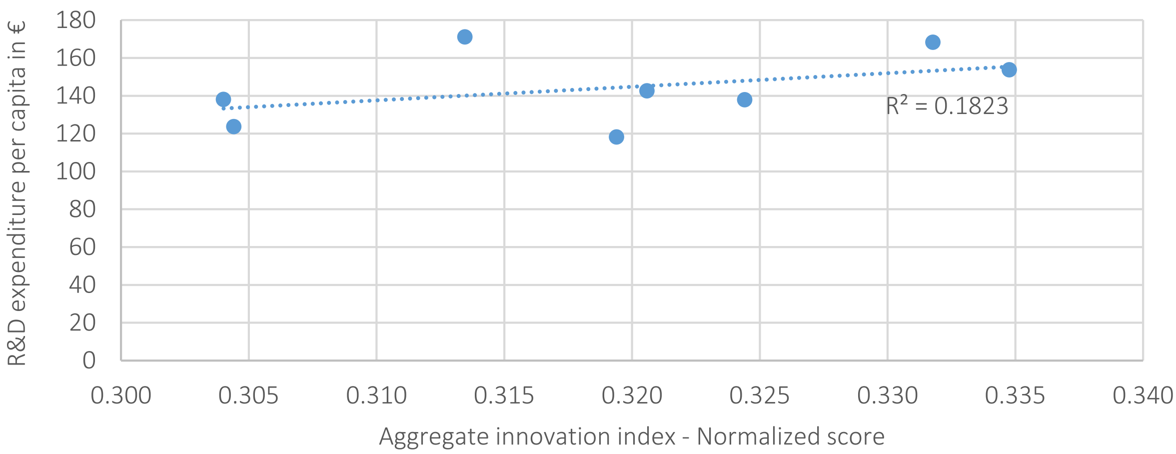

Figure 2. Correlation analysis – Slovakia

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Table 2. Test statistics – Czechia

Source: Own processing by EISB, Eurostat.

α = 0.05	Aggregate innovation index - normalized score	Research and development expenditure per capita [€]
2014	0.391	294
2015	0.402	308.4
2016	0.404	280.8
2017	0.403	324.5
2018	0.407	377.6
2019	0.425	408.3
2020	0.431	400.8
2021	0.441	444.4
Shapiro-Wilk normality test	0.383	0.464
Pearson correlation coefficient	0.913	
Correlation coefficient significance test	0.002	
Determination coefficient	0.834	

surprising, as the level of R&D expenditure in Slovakia is only slowly increasing, with its share in GDP still below 1%. However, the Slovak Republic has still not managed to meet one of the Europe 2020 targets, which for Member States was to invest at least 3% of GDP in R&D by 2020.

3.2. The Czech Republic

Based on the Shapiro-Wilk test *p*-values (0.383; 0.464) > α (0.05), the selected sets have an approximately normal distribution and can be considered as a random selection from a baseline set with a normal distribution. The calculated Pearson correlation coefficient (r = 0.913) indicates an almost perfect positive linear relation between the normalized Aggregate Innovation Index score and R&D expenditure in the Czech Republic. The situation is shown in Figure 3. The determination coefficient r^2 = 0.834, which means that the model explains 83.4% of the total variability, and thus the given model has been chosen correctly.

As in the case of Slovakia, apart from identifying the tightness of dependence, it was also assessed whether the results could be generalized to the entire baseline set in the case of the Czech Republic. Also, the study tested H_0 on the observed traits independence. Since the probability value of the correlation coefficient significance test was less than the chosen significance level of p (0.002) < α (0.05), there is a statistically significant dependence between the normalized score of the Aggregate Innovation Index and the amount of R&D expenditure per capita in euros in the Czech Republic, unlike in Slovakia. This is because the increase in

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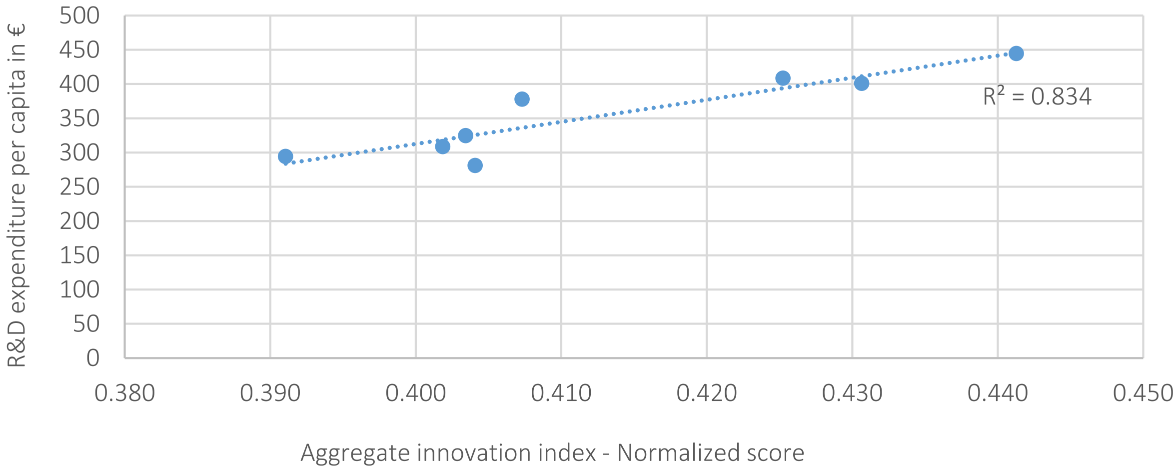

Figure 3. Correlation analysis – Czechia

Table 3. Test statistics – Poland

Source: Own processing by EISB, Eurostat.

α = 0.05	Aggregate innovation index - normalized score	Research and development expenditure per capita [€]
2014	0.240	101.6
2015	0.246	113.6
2016	0.254	108.3
2017	0.267	127.3
2018	0.274	158.5
2019	0.286	185.6
2020	0.295	192
2021	0.308	218.1
Shapiro-Wilk normality test	0.848	0.336
Pearson correlation coefficient	0.978	
Correlation coefficient significance test	0.000	
Determination coefficient	0.956	

R&D expenditure in the Czech Republic is much more dynamic than in Slovakia, both in absolute and relative terms. For example, the share of R&D expenditure here reached 2% in 2021. Therefore, the value of the Aggregate Innovation Index is also increasing more dynamically.

3.3. Poland

Based on the obtained in Shapiro-Wilk test *p*-values (0.848; 0.336) > α (0.05), in the case of Poland, the selected sets have an approximately normal distribution and can be considered as a random selection from a baseline set with a normal distribution. Pearson correlation coefficient $r = 0.987$, which means an almost perfect positive linear relation between the normalized score values of the Aggregate Innovation Index and the R&D expenditure values, as shown in Figure 4. The coefficient of determination $r^2 = 0.956$, concluding that the model has explained most of the variability among the observed variables.

3.4. Hungary

Based on the Shapiro-Wilk test results, where p (0.087; 0.394) > α (0.05), it was concluded that the samples have an approximately normal distribution and can be considered to be randomly selected from a baseline set with a normal distribution. The calculated Pearson correlation coefficient $r = 0.544$ indicates a strong tightness relationship between the normalized Aggregate Innovation Index score and the amount of R&D expenditure captured in Figure 5. The coefficient of determination $r^2 = 0.296$, so the chosen model has explained only a slightly bigger part of the variability between the observed variables than in the case of Slovakia. Based on this result, it can be assumed that in Hungary, other phenomena not

Source: Own processing.

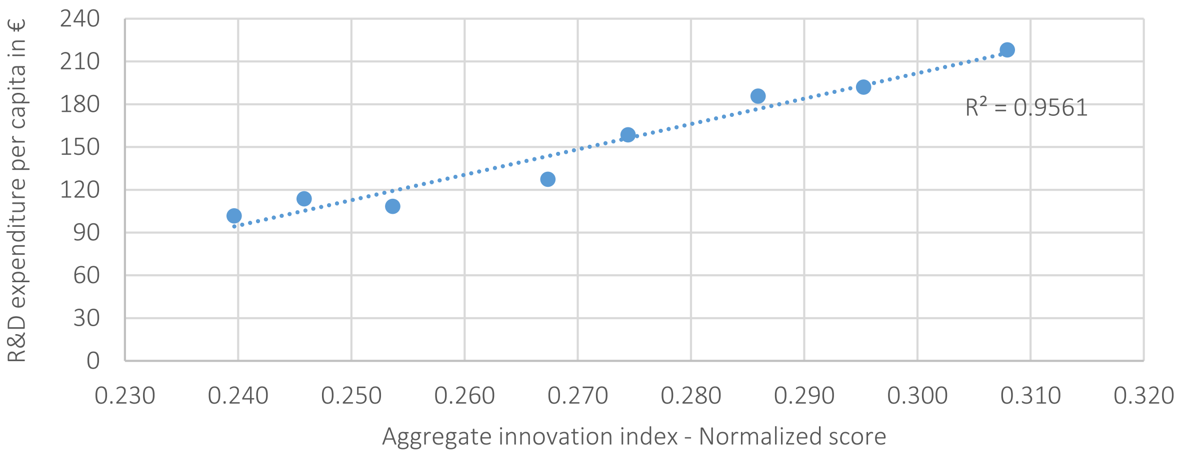

Figure 4. Correlation analysis – Poland

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Table 4. Test statistics – Hungary

Source: Own processing by EISB, Eurostat.

α = 0.05	Aggregate innovation index - normalized score	Research and development expenditure per capita [€]
2014	0.330	144.7
2015	0.338	153.3
2016	0.340	139.5
2017	0.337	170.8
2018	0.337	209.8
2019	0.329	220.9
2020	0.341	224.8
2021	0.357	260.1
Shapiro-Wilk normality test	0.087	0.394
Pearson correlation coefficient	0.544	
Correlation coefficient significance test	0.163	
Determination coefficient	0.296	

shown here enter into the correlation between the Aggregate Innovation Index and R&D expenditure. This is also confirmed by the correlation coefficient significance test, which showed no statistically significant dependence between observed variables in this country.

As well as in Hungary, in addition to investigating the tightness of dependence between the observed indicators, the study also examined whether the results can be generalized to the whole baseline set. H_0 was tested on the observed trait independence within this framework. Since the probability value of the correlation coefficient significance test was higher than the chosen significance level p (0.163) > α (0.05), there is generally no statistically significant dependence between the normalized score of Aggregate Innovation Index and the amount of R&D expenditure per capita in euros in Hungary, as in the case of the Slovak Republic. This implies that factors other than the evolution of R&D expenditure value must significantly affect the Aggregate Innovation Index in Hungary. Although the share of R&D expenditure in GDP is higher in Hungary than in Slovakia, reaching 1.65% in 2021, and in absolute terms, Hungary also exceeds Poland, the Aggregate Innovation Index has increased by less than half between 2014 and 2021 compared to Poland. This raises the question of how the R&D investment is effective in each country.

3.5. Summary assessment of the situation in the V4 countries

After analyzing the situation in each of the V4 countries separately, the study tested the consistency of correlation coefficients for each country.

Source: Own processing.

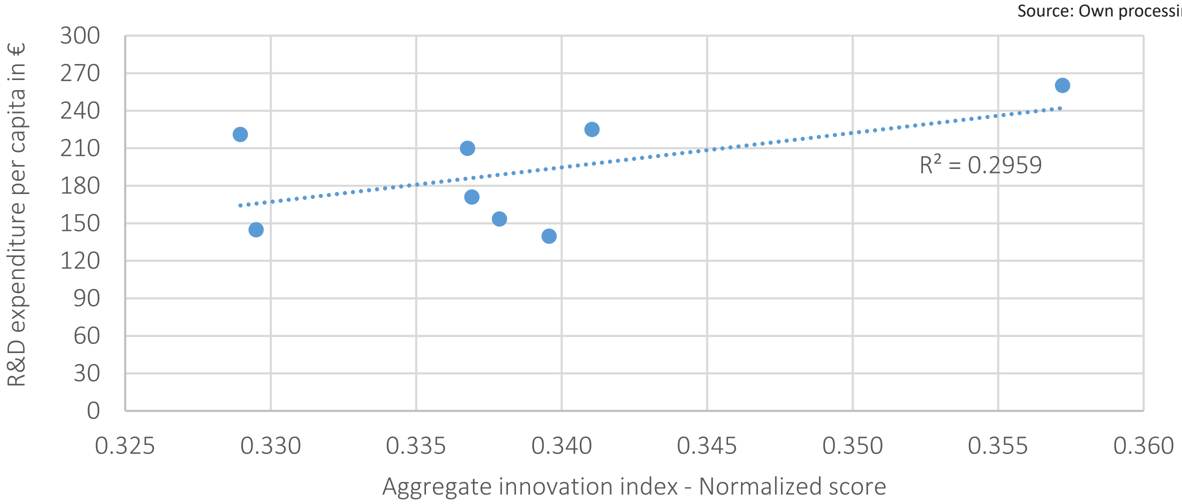

Figure 5. Correlation analysis – Hungary

The χ^2 test checked the correlation of the four correlation coefficients and showed that the correlation coefficients are statistically significantly different among the countries.

Table 5. Correlation coefficients compliance test

Source: Own processing.

Test statistic	Test result	Country	Correlation coefficients
χ^2	10.567	Czechia	0.913
$\chi^2_{critical\ (3)}$	7.815	Hungary	0.544
p-value	0.014	Poland	0.978
evaluation	sig.	Slovakia	0.427

The result of the correlation coefficients compliance test p (0.014) < α (0.05) implies that there is a statistically significantly different correlation between the normalized score of the Aggregate Innovation Index and R&D expenditure per capita within the countries. Therefore, H_0 was rejected (the Aggregate Innovation Index score and R&D expenditure relationship is the same within all observed countries). Since H_0 was denied, H_1 was confirmed – the dependence between the Aggregate Innovation Index and R&D expenditures is different within the countries studied. The next step used the Tukey test for differences in correlation coefficients to determine which countries have statistically significant differences.

There is a statistically significant difference in the correlation coefficient between Poland and Slovakia and between Poland and Hungary. This results from the fact that in Poland, there is a statistically significantly higher correlation between the normalized score of the Aggregate Innovation Index and the amount of R&D expenditure per capita in euros. In Slovakia and Hungary, the impact of expenditure on the Aggregate Innovation Index was found to be statistically significantly lower compared to Poland, where there is the highest impact of expenditure on the Aggregate Innovation Index among the V4 countries. The Czech Republic has the second highest correlation, also surpassing Slovakia and Hungary, although not significantly.

Regarding the correlations, it should be noted that the high tightness of dependence among the observed variables means that they progress proportionally, i.e., that the Aggregate Innovation Index values are increasing approximately as dynamically as R&D expenditure. While a high dependence indicates proportionality development, a lower dependence must be interpreted with an emphasis on detailed monitoring of both variable development. Thus, based on the Pearson correlation coefficient in Poland and the Czech Republic, it is possible to talk about proportionality development. However, this is not the case regarding the other two countries.

As shown in Figure 1, in Hungary, although investment in R&D increased quite dynamically, this was not reflected in Aggregate Innovation Index values, which stagnated or even decreased in some years. Slovakia has also seen years when the Aggregate Innovation Index dropped year-on-year, but the same trend has been observed for R&D expenditure. In 2016, in particular, it fell quite significantly compared to the previous year, which may have been one of the main reasons that distorted the proportionality development. Although the analyses answered the question regarding the relationship between the variables observed in the V4 countries, they did not identify the origin of those differences. As

Table 6. Tukey test of differences in correlation coefficients

Source: Own processing.

Relationship	Differences in the Fisher transformation of the correlation coefficient between countries	Tukey test between particular countries	Statistical significance
Czechia – Hungary	0.940	1.623	no
Czechia – Poland	–0.700	1.623	no
Czechia – Slovakia	1.090	1.623	no
Hungary – Poland	–1.640	1.623	sig.
Hungary – Slovakia	0.150	1.623	no
Poland – Slovakia	1.790	1.623	sig.

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a result, the study speculates that expenditure in countries with lower correlation coefficient values needs to be spent more efficiently. Still, the study also assumes that another variable has a dominant influence on the Aggregate Innovation Index in these countries, which could be an issue of further research.

4. DISCUSSION

When assessing the innovation performance of countries, the convenience of the indicators by means of which this performance is to be assessed should be statistically verified using appropriate tests (Roszko-Wójtowicz & Białek, 2017). The same procedure was applied in this study. Although conducting research and investing in this area are generally considered one of the most critical prerequisites for innovation adoption (Eriksson et al., 2022), in two of the four observed countries, the statistical significance concerning the Aggregate Innovation Index has not been shown.

Neither in Hungary nor Slovakia is R&D expenditure the variable significantly affecting the Aggregate Innovation Index score. However, the analyses have shown a positive linear relationship between these variables in Poland and the Czech Republic. Similar conclusions were also reached by Janoskova and Kral (2019), who found that in the Czech Republic, public expenditure on R&D determines the achieved value of the Aggregate Innovation Index the most.

Regarding the Aggregate Innovation Index, public R&D expenditure and private R&D expenditure are usually assessed separately (European Commission, 2021). This study dealt with the total R&D expenditure for all sectors. Dworak (2020) also stressed the R&D expenditure significance regardless of the sector where implemented. Other studies also confirm that the innovation performance of EU Member States is mainly influenced by adequate R&D funding or the increasing percentage of employees in this field (Roszko-Wójtowicz & Białek, 2019). Therefore, the unproved statistical significance of this category concerning the Aggregate Innovation Index does not mean that R&D expenditure is not essential for these countries but reflects its insufficient level or inefficient expenditure, which would need to be further explored in the future.

Although the statistical significance of the variables observed has been confirmed in only two V4 countries, all of them are below the EU average in terms of innovation performance. They also spend less than the EU average on R&D, which only confirms the finding of the European Commission (2021) that individual performance groups of countries in terms of innovation performance tend to be geographically concentrated. However, the Tukey significance test of differences within the correlation coefficients (see Table 6) showed that there could be significant differences even among countries with similar innovation performance. However, they are not usually shown in all areas.

None of the V4 countries meets the European Commission's target for EU Member States to spend at least 3% of GDP on R&D. When it comes to the economic capabilities of the V4 countries and the structure of their economies, this is partly understandable, but R&D expenditure should not be seen as a burden but as an investment, even though its effects will not be seen immediately but only over some time (Augustia et al., 2020). Although the study has only paid attention to the amount of R&D investment, there are other ways to promote it besides increasing investment in particular areas related to innovation performance. Some authors suggest that, for example, an increase in different types of human capital supply also generally leads to an increase in innovation performance (Teslenko et al., 2021) or that the Aggregate Innovation Index should also be assessed in relation to other indicators which it is constructed from (Onea, 2020). Thus, future studies should focus on clarifying why R&D investment in Hungary and Slovakia did not show a statistically significant correlation with the Aggregate Innovation Index. The paper is generally considered to be a prerequisite for innovation implementation and for identifying the variable that would show a high statistical correlation with the Aggregate Innovation Index in these countries.

CONCLUSION

The aim of this study was to identify the relationship between the most widely used indicator of innovation performance in European countries – the Aggregate Innovation Index – and R&D expenditure in the V4 countries. The analysis showed a positive correlation between the R&D expenditure and the Aggregate Innovation Index in all V4 countries. However, a significance test of the correlation coefficient showed that the relationship is statistically significant only in the Czech Republic (0.834) and Poland (0.956). This dependence is significant for neither Hungary (0.296) nor Slovakia (0.182), as indicated by the relatively low values reported for the coefficient of determination.

This finding was confirmed by the Tukey test of differences in correlation coefficients, which showed that there is only a statistically significant difference in the correlation coefficients between Poland and Slovakia and between Poland and Hungary. However, the Czech Republic also surpasses Hungary or Slovakia quite significantly. Considering the absolute increments in the Aggregate Innovation Index between 2014 and 2021, it is clear that the Tukey test reveals significant differences among countries with a more and less significant increase in this index over the observed period.

Although R&D expenditure in Hungary is higher than in Poland in absolute and relative terms, the Aggregate Innovation Index did not increase as dynamically over the observed period but followed Slovakia's dynamics, which spends the least on R&D among the V4 countries. Poland could thus become an example for Hungary, but also for Slovakia, that even in a country where R&D investment is lower, it is possible to achieve a dynamic evolution within the Aggregate Innovation Index, which could be primarily related to the efficiency of R&D spending, but which would need to be further assessed in more detail.

AUTHOR CONTRIBUTIONS

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Visualization: Veronika Žárska.
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