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INNOVATION PERFORMANCE OF EU COUNTRIES IN THE CONTEXT OF RESEARCH AND DEVELOPMENT EXPENDITURES*

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Abstract. Innovations are essential to economic reality, mainly due to growing domestic, international or world competition. The contribution is focused on comparing the innovation performance of EU countries with an emphasis on Slovakia using the European Innovation Scoreboard and the Regional Innovation Scoreboard. The aim is to verify the dependence of the innovation performance of EU countries on research and development expenditure. According to the European Innovation Scoreboard 2023, the classification of Member States into performance groups remains unchanged compared to the previous year, still showing a geographical concentration. Performance gaps between Member States narrowed between 2016 and 2023. Slovakia belongs to countries with a relative performance below 70% of the European Union average, while its innovation performance is growing more slowly than in the EU. According to the Regional Innovation Scoreboard 2023, all regions of Slovakia belong to the emerging innovators of the upper third, except the Bratislava region, which is included in the group of moderate innovators of the upper third. All regions have increased their performance. An increase in research and development expenditures is required to improve the current situation in the innovation policy of the Slovak Republic. This conclusion is derived considering a significant interdependence between research and development expenditures and innovation performance was confirmed by regression analysis.

Keywords: Innovations; research and development (R&D); the EU

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JEL Classifications: O11, O30

1. Introduction

In the European Union, innovation is crucial for increasing competitiveness in a worldwide globalized economy. Since the Slovak Republic is a part of its structures, the need for innovation and innovation policy becomes very

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important. It is evident that today, relying on the comparative advantages of cheaper costs is no longer possible. It is necessary to achieve sustainable economic growth by effectively applying innovations. With the help of the national innovation policy, it is desirable to create an innovation system that will actively support the implementation of innovations in enterprises, improve cooperation between the private and public sectors, coordination within entities involved in innovation activities, and transfer of technologies and results of research and development (R&D) into practice.

Influenced by various factors, innovation performance varies from country to country. In this context, the need to measure the innovation performance of the economy is gaining importance.

There are several ways to measure and evaluate the country's innovation performance. The article provides an evaluation of the innovation performance of the Slovak Republic through a comparison with EU countries using the European Innovation Scoreboard (EIS) and the Regional Innovation Scoreboard (RIS). The evaluation of the innovation performance of countries in the EIS 2023 is based on the so-called Summary Innovation Index (SII), which is also the basis for determining performance group membership (innovation leaders, strong innovators, moderate innovators and emerging innovators).

Amount of expenditure and intensity of R&D, i.e. the share of R&D expenditure on GDP (GERD% - Gross Expenditure on R&D), are two of the key indicators used to monitor the resources devoted to science and technology worldwide.

As we will document in the part Results, the innovation leaders are spending significantly more on R&D than countries that are the least successful innovators. A typical example is Sweden, which, in the long term, spends on R&D compared with the GDP, the most considerable financial amount and belongs to innovation leaders in the EIS.

Following this fact, our research is based on an assumption of correlation between the expenditure on R&D and the innovation performance, i.e. a higher % in spending on R&D should consequently also increase the innovation performance of an individual country.

The goal is to verify the dependence of a country's innovation performance on R&D expenditure. The author used statistical methods to achieve this goal, especially regression and correlation analysis. It was confirmed that there is a significant interdependence between R&D expenditure and innovation performance.

2. Theoretical background

In contrast to other policies already implemented at national or regional levels, innovation policies are a relatively new issue (Halásková and Halasková, 2015). As Pazour and Kučera (2009) state, innovation policy is closely connected with R&D policy. Their common aim is to support R&D. Innovation is understood as a result of successful R&D. Schot and Steinmueller (2018) state that there are three frames for innovation policy: R&D, systems of innovation and transformative change.

Total R&D expenditures on GDP (GERD) are a crucial R&D indicator. Several authors dealt with the relationship between GERD and innovation performance, mainly through regression analysis. In connection with the allocated total R&D expenditure, researchers' main interest is evaluating R&D efficiency (e.g. Conte et al., 2009 or Aristovnik, 2012).

According to empirical studies, regions with a high intensity of R&D activities are also the most efficient performers. Bednář and Halásková (2018) determined both static and dynamic components of convergence and

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divergence in innovation performance and R&D expenditures for aggregated data within Western European NUTS 2 regions in the years 2009-2012. Boschma (2005) indicates that geographical proximity has positive and negative effects on innovations. Similarly, Morollón and Garcia (2023) analyzed the geographical distribution of the investment effort in R&D in the European Union. It has been observed that there is undoubtedly an intense concentration of European R&D funds in the most dynamic areas capable of promoting more advanced and competitive research projects. Cooke (2001) presents a systematic account of the idea and content of regional innovation systems following discoveries made by regional scientists, economic geographers and innovation analysts.

Many authors dealt with the influence of innovations and performance of companies (e.g. Kulicke and Krupp, 1987; Du et al., 2020; Radenovic et al., 2023; Fedyunina and Radosevic, 2022; Zhang et al., 2022; Akad and Deger, 2023; Naidoo, 2023; Khorshid et al., 2023). Wang and Guan (2017) identified a positive correlation between the state government subsidy of the enterprise sector and the innovation performance of this sector. Cohen and Levinthal (1989) suggest that R&D generates new information and enhances the firm's ability to assimilate and exploit existing information. Albulescu and Draghici (2016) argue that innovation performance is not only due to higher business support. Private and public funds should support R&D.

Wang and Thornhill (2010) mentioned possibilities of how to finance R&D on microlevel. Gertler (2001) concludes that while regional and firm-level arguments, on their own, do not provide an adequate explanatory framework for understanding how firms' practices are determined, national-level theory needs to be made supple enough to accommodate a significant role for regional institutions and the agency of the firm.

Sarpong et al. (2023) propose a sustainable pathway model for achieving an economically viable sustainable innovation system. Many other authors also recognize the crucial importance of investments in R&D for more sophisticated and sustainable innovations (e.g., Holt et al., 2021; Xu et al., 2021; Ganda, 2019).

Regarding Slovakia, there have yet to be many empirical studies realized. Fabova and Janakova (2015) stated that the low innovation performance of the SR is the reason for its low competitiveness. Ivanová and Masárová (2018) evaluated the innovation performance of regions of the Visegrad Group, emphasizing human capital. Janoskova and Kral (2019) analyzed the impact of the SII indicators in terms of the total value of the SII using samples from the V4 countries.

Kučera and Fiľa (2022) proved a significant interdependence between R&D expenditure, innovation performance and the EU countries' economic development level. Higher R&D expenditures are an essential precondition for faster economic growth, represented by GDP per capita. Technological progress influences GDP and dynamic growth is not possible without innovation.

3. Research methodology

Concerning verifying the dependence of the innovative performance of the country on R&D expenditure, a hypothesis was set, and its integrity was verified through regression analysis (Figure 1).

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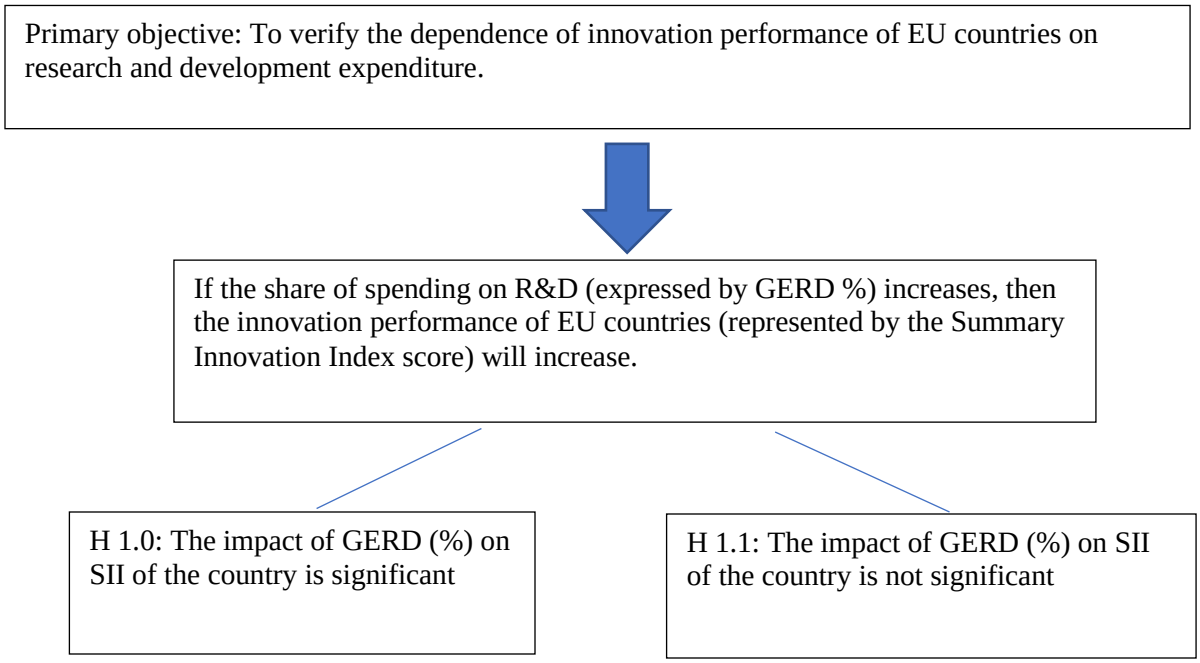

Figure 1. Aim and hypotheses
Source: own processing

The primary sources of information include the secondary data in the European Innovation Scoreboard 2022 (for the Summary Innovation Index) and the related EUROSTAT datasets within the EU countries (for the amount of expenditure on R&D). The Limitation of the research lies in the fact that the research data on GERD for 2022 has yet to be published. Another limiting factor is that the number of EU member states is stable.

Due to the data availability (GERD %) for 2022, SII 2022 and GERD 2021 data were used. EIS 2022 evaluates countries for the year 2021.

The analytical tools used include regression and correlation analysis. The analysis was used to confirm or refute the hypothesis. It examines a possible correlation between two indicators. The author assumes that the value of the dependent variable (Y – innovation performance) is affected by a change in the value of an independent variable (X – expenditure into R&D).

4. Results and discussion

4.1 Innovation performance of EU countries

One of the most recognized indices for evaluating countries' innovation performance is the European Innovation Scoreboard, which can be described as an overview of the innovation results of countries. It provides a comparative analysis of the innovation performance of the countries of the European Union according to several

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indicators. It has been operating under the auspices of the European Commission (EC) since 2011. It helps countries assess the strengths and weaknesses of national innovation systems or identify challenges they should address to improve in the given areas. The survey also evaluates the European Union's overall position in innovation, science and research compared to the advanced world economies of other countries such as the USA, Canada, China, and Japan (EC, 2023a).

The latest edition of the European Innovation Scoreboard 2023 distinguishes between four main types of activities with 12 innovation dimensions, capturing 32 indicators. The EIS 2023 uses data related to the actual performance in 2022 for 11 indicators, 2021 for six indicators, 2020 for 13 indicators and 2019 for two indicators.

Each main group includes an equal number of indicators. The indicators that are included in the measurement are listed in *Table 1*. The indicators change and are supplemented from year to year. Each group and all indicators have the same weight, based on which the so-called performance score is calculated - the SII. In addition to determining the value of the index, the given country's development is monitored over time and compared with other countries of the European Union (EC, 2023a).

Table 1. The EIS 2023: indicators

FRAMEWORK CONDITIONS	**INNOVATION ACTIVITIES**
Human resources	Innovators
1.1.1 New doctorate graduates (in STEM)	3.1.1 SMEs with product innovations
1.1.2 Population aged 25-34 with tertiary education	3.1.2 SMEs with business process innovations
1.1.3 Lifelong learning	
Attractive research systems	Linkages
1.2.1 International scientific co-publications	3.2.1 Innovative SMEs collaborating with others
1.2.2 Top 10% most cited publications	3.2.2 Public-private co-publications
1.2.3 Foreign doctorate students	3.2.3 Job-to-job mobility of Human Resources in Science & Technology
Digitalization	Intellectual assets
1.3.1 Broadband penetration	3.3.1 PCT patent applications
	3.3.2 Trademark applications
1.3.2 Individuals who have above basic overall digital skills	3.3.3 Design applications
INVESTMENTS	**IMPACTS**
Finance and support	Employment impacts
2.1.1 R&D expenditure in the public sector	4.1.1 Employment in knowledge-intensive activities
2.1.2 Venture capital expenditures	4.1.2 Employment in innovative enterprises
2.1.3 Direct government funding and government tax	Sales impacts
Firm investments	4.2.1 Medium and high-tech product exports
2.2.1 R&D expenditure in the business sector	4.2.2 Knowledge-intensive services exports
2.2.2 Non-R&D innovation expenditures	4.2.3 Sales of product innovations
2.2.3 Innovation expenditures per person employed in	Environmental sustainability
Use of information technologies	4.3.1 Resource productivity
2.3.1 Enterprises providing training to develop or upgrade ICT skills of their personnel	4.3.2 Air emissions by fine particulates PM2.5 in industry
2.3.2 Employed ICT specialists	4.3.3 development of environment-related technologies

Source: own compilation according to the EIS 2023

The SII is the basis for the classification of EU countries into four performance groups:
• ***Innovation Leaders*** are all countries with a relative performance in 2023 above 125% of the EU average in 2023.
• ***Strong Innovators*** are all countries with a relative performance in 2023 between 100% and 125% of the EU average in 2023.

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• ***Moderate Innovators*** are all countries with a relative performance in 2023 between 70% and 100% of the EU average in 2023.
• ***Emerging Innovators*** are all countries with a relative performance in 2023 below 70% of the EU average in 2023 (EC, 2023a).

Figure 2 shows Denmark is the best-placed country in the EIS 2023, overtaking Sweden. Sweden has held the leading position for several years. Other innovation leaders are the countries of Finland, the Netherlands and Belgium (in the shades of dark green). Austria, Germany, Luxembourg, Ireland, Cyprus, and France are "strong innovators" (in the shades of light green), and Estonia, Slovenia, Czech Republic, Italy, Spain, Malta, Portugal, Lithuania, Greece and Hungary are considered to be "moderate innovators" (in the shades of yellow). Croatia, Poland, Latvia, Bulgaria, Romania, and Slovakia belong to the group of "emerging innovators" (in the shades of orange).

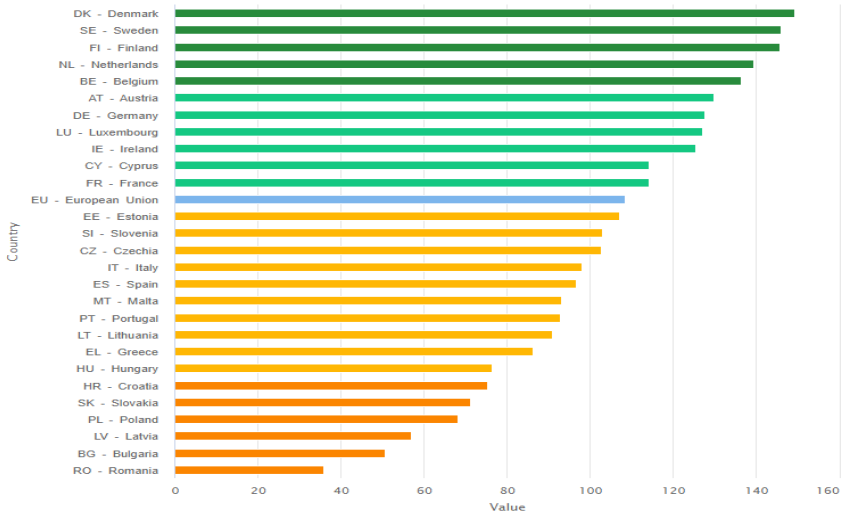

Figure 2. Score of SII for EU countries

Source: EC 2023a

In the EIS 2023, the distribution of Member States within the performance groups remains unchanged compared to the previous year. Hungary has made significant progress and moved into the higher-performing "moderate innovators" group. At the same time, France and Luxembourg have seen a slight decline in performance compared to the EU eight years ago. It highlights the need for continuous efforts to improve innovation capabilities in these regions.

Between 2016 and 2023, performance gaps between Member States narrowed, notably within the "strong innovators" and "moderate innovators" groups. However, the distribution of performance groups still shows a geographical concentration. Northern and Western Europe are home to innovation leaders and the most vital innovators, while Southern and Eastern Europe are home to the most moderate and emerging innovators.

The global position of the EU has mostly stayed the same since last year. The EU has closed part of its performance gap with Australia. China's performance level is almost at the same level as the EU. Regarding innovations, Slovakia's strengths lie in the automotive and engineering industries. The IT sector is growing relatively quickly, too. The performance of the Slovak Republic as an innovator is at the level of 65.6% of the European average, which is above the average of emerging innovators (54.0%). However, innovation performance is growing more slowly than in the EU, thus moving away from the EU's performance. According to the EC, Slovakia's relatively strong points in the area of innovation include the export of medium and high-tech goods, the sale of innovative products, lifelong learning, and spending on innovations that are not related to R&D.

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Based on a survey, the EC considers Job-to-job mobility of Human Resources in Science & Technology, R&D expenditure in the business sector, government support for business R&D, low number of patent applications and low-risk capital investments to be the weak points of the country. Compared to the previous assessment (EIS 2022), Slovakia recorded the most significant improvement in lifelong learning, the sale of innovative products and the innovation of business processes. On the other hand, the most significant year-on-year deterioration occurred in technologies related to the environment, in the category of innovative SMEs cooperating with others and designing applications.

Innovations are essential in developing socio-economic development not only of countries and regions. The Regional Innovation Scoreboard, a supplement to the EIS, deals with the evaluation of the innovation performance of the regions. The assessment occurs similarly to the EIS, and the regions' innovation activity is measured at the country level. The number of indicators in the RIS is reduced from 32 to 21, mainly due to the unavailability of data at the regional level. Most indicators are identical; some are removed, and others are changed or estimated. The indicators used in the RIS 2023 are included in Table 2 (EC, 2023b). The average performance score, the RII, is calculated from the indicators. Based on the value of the RII, the regions are divided into four performance groups: innovation leaders, strong innovators, moderate innovators and emerging innovators. Unlike the EIS, each group has three more subgroups, with the upper third indicated by a (+) sign and the lower third by a (-) sign.

According to RIS 2023, Slovakia is an Emerging Innovator and includes four regions: Bratislava region, Západné Slovensko, Stredné Slovensko, Východné Slovensko. Bratislava region (SK01), the capital region, is a Moderate Innovator +, and the other three regions are Emerging Innovators + (Figure 3). Performance has increased for all regions. Only for Stredné Slovensko (SK03), performance increased at a higher rate than that of the EU (8.5); for the other regions, performance increased at a lower rate.

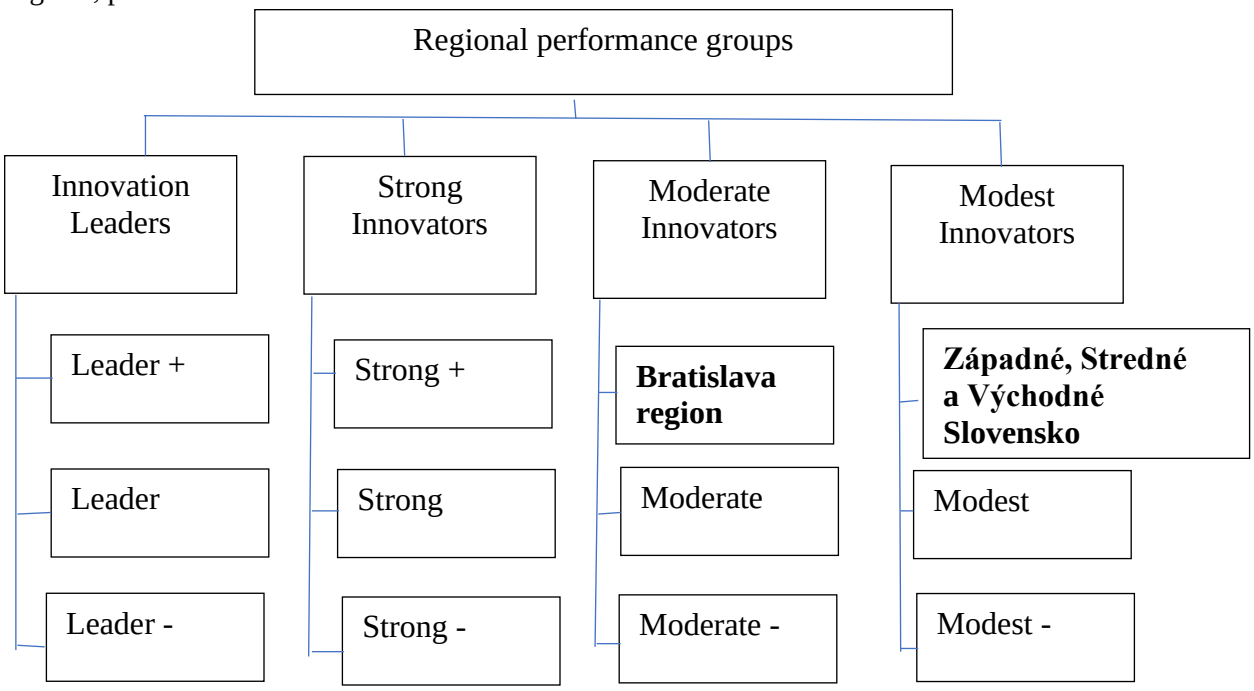

Figure 3. Position of SR's regions within regional performance groups
Source: own processing according to the RIS 2023

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The level of sub–indicators influences the overall assessment of regions' innovation performance. Table 2 shows the scores of indicators for regions in Slovakia compared to the European average.

Table 2. The RIS 2023: indicators

Indicator	Bratislava region		Západné Slovensko		Stredné Slovensko		Východné Slovensko	
	SK	EU	SK	EU	SK	EU	SK	EU
Population aged 25-34 having completed tertiary education	169	157	81	76	80	74	109	101
Population aged 25-64 participating in lifelong learning	203	79	58	22	87	34	113	44
International scientific co-publications	363	235	52	34	77	50	87	56
Most-cited scientific publications	75	26	98	35	157	56	112	40
Individuals who have above basic overall digital skills	110	80	99	72	101	73	96	69
R&D expenditures in the public sector	153	104	49	33	95	65	75	51
R&D expenditures in the business sector	116	66	101	58	85	48	88	50
Non-R&D innovation expenditures	75	72	117	114	100	96	119	116
Innovation expenditures per person employed	107	63	108	64	87	51	89	53
Employed ICT specialists	200	190	38	36	56	53	94	90
SMEs with product innovations	135	59	66	29	123	53	98	43
SMEs with business process innovations	135	69	72	37	127	65	81	41
Innovative SMEs collaborating with others	123	74	72	44	141	85	78	47
Public-private co-publications	217	195	70	63	86	78	96	86
PCT patent applications	106	42	114	46	80	32	87	35
Trademark applications	149	98	72	47	86	57	88	58
Design applications	81	54	101	67	117	78	103	69
Employment in knowledge-intensive activities	123	161	124	162	87	113	73	95
Employment in innovative SMEs	115	65	85	48	111	63	95	54
Sales of new-to-market and new-to-enterprise innovations	141	116	58	47	62	51	138	113
Air emissions in fine particulates (PM2.5) in Industry	117	85	105	76	96	70	92	67
Performance 2023 relative to EU in 2023	139.1	91.3	85.3	56.0	94.1	61.7	94.6	62.1

Source: own compilation according to the RIS 2023

4.2 Linear regression analysis

A fundamental element of the innovation process is R&D, as it provides new knowledge, technologies and innovative solutions. Countries that invest more in R&D have a more substantial base for innovation and are more likely to be able to implement innovation projects successfully. In addition, higher R&D spending can help companies maintain a competitive edge in innovation.

Figure 4 shows the development of expenditure on R&D in the period 2010-2021 for the Slovak Republic and the EU.

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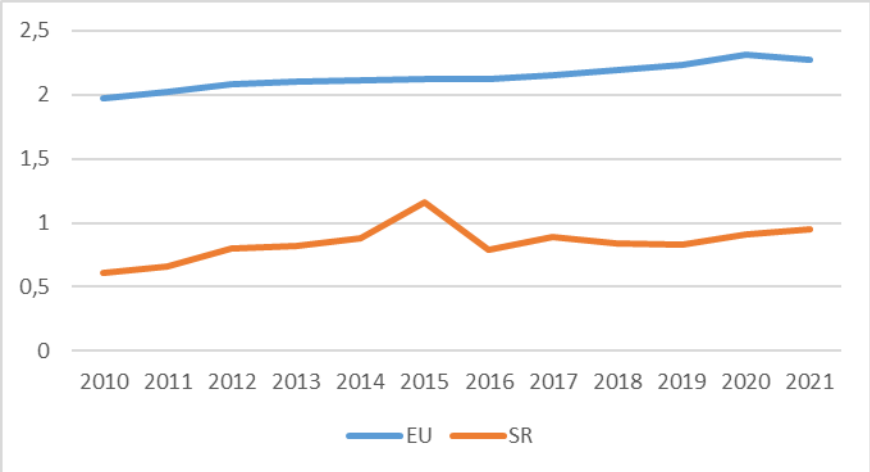

Figure 4. Development of expenditure on R&D in the period 2010-2021 for the Slovak Republic and the EU
Source: own processing according to EUROSTAT data

As Figure 4 depicts, the European average of spending on R&D is slightly above 2% of GDP, while the Slovak Republic does not even reach 1% of GDP. This lagging behind the countries of the European Union in the share of R&D investments negatively affects Slovakia's overall innovation performance and economic competitiveness.

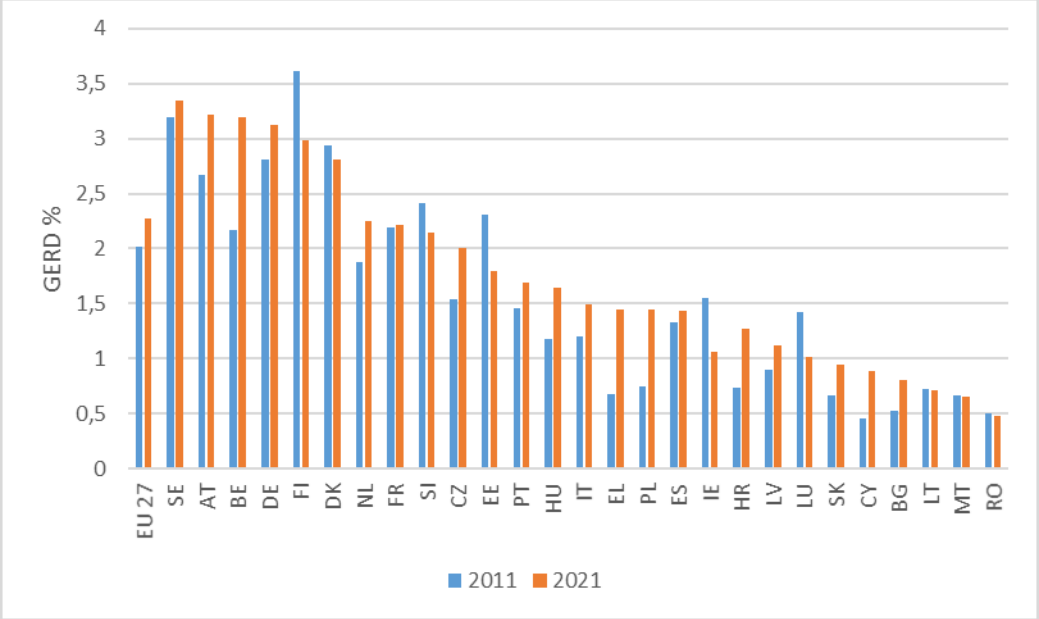

Figure 5. GERD (%) in EU countries
Source: own processing according to EUROSTAT data

Figure 5 compares R&D expenditures within the EU in 2011 and 2021. The highest investments in R&D were achieved by Sweden (3.35% of GDP), Austria (3.22% of GDP), Germany (3.13% of GDP), Finland (2.98% of GDP), Denmark (2.81%) etc. The Slovak Republic invested only 0.95% of GDP in R&D in 2021, significantly below the EU average (2.27% of GDP). This indicates that countries that invest more in R&D tend to achieve higher innovation scores.

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We applied regression analysis to analyze the dependence between the level of innovation performance and GDP per capita.

After the initial analysis through visual assessment using X to Y depending chart, we chose a suitable mathematical function of which the curve best reflects the relationship between observed variables. Considering the nature of the data applied, a linear function has been used.
Table 3 contains the result of the regression analysis.

Table 3. The regression analysis output: R&D expenditure and innovation performance

Regression Statistics	
Multiple R	0,744485153
R Square	0,554258144
Adjusted R Square	0,536428469
Standard Error	19,86454963
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12266,65413	12266,65	31,08627	8,48E-06
Residual	25	9865,008298	394,6003		
Total	26	22131,66243			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	51,05163965	8,612966523	5,9273	3,47E-06	33,3129	68,79038	33,3129	68,79038
X Variable 1	24,63145494	4,417796723	5,575507	8,48E-06	15,53283	33,73008	15,53283	33,73008

Source: Own research

Since the significance F – F test for the statistical significance of the model is at 8,48E-06, which is considerably less than 0,05, we accept the hypothesis of the model significance. The exponential model used to analyze the dependence between innovation performance and GDP per capita has proved to be statistically significant (Table 4).

Table 4. Summary of correlation and regression analysis output

hypothesis	Confirmation/refusal	Multiple R	R - square	Significance F
H1	YES	0,74	0,55	8,48E-06
H1.0	YES			
H1.1	NO			

Graphical interpretation of the result from the regression analysis is shown in *Figure 6*, which confirms a positive relationship between the amount of R&D expenditure and the innovation score (SII). The result follows an empirical study conducted in Slovakia (Kučera and Fiľa, 2022).

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If we focus on countries that invest a more significant percentage of GDP in R&D and are in the leading positions in this regard, such as Germany, Austria, Sweden, Finland or Belgium, according to Figure 6 they achieve a visibly better score in innovation performance. However, despite the high dependence between the amount of R&D expenditure and the value of the innovation score, there are exceptions. An example is Cyprus, whose R&D expenditure reaches an even lower percentage of GDP than Slovakia, and despite this, it is much better at evaluating innovative activity. This can be due to many factors affecting the innovation score's value. Cyprus has better results in the field of innovation in businesses and also in international cooperation in the field of R&D.

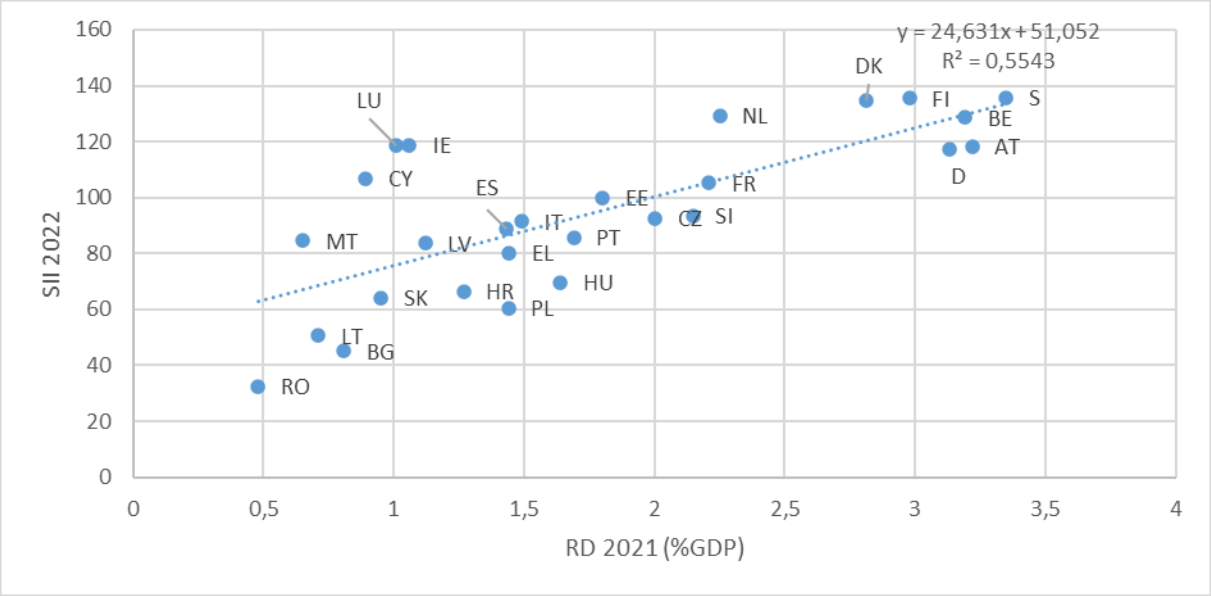

Figure 6. Interdependence between R&D spending and SII 2022
Source: own processing according to EUROSTAT data and EIS

Note: Sweden S, Austria AT, Belgium BE, Germany D, Finland FI, Denmark DK, Netherlands NL, France FR, Slovenia SI, Czechia CZ, Estonia EE, Portugal PT, Hungary HU, Italy IT, Greece EL, Poland PL, Spain ES, Ireland IE, Croatia HR, Lithuania LV, Luxembourg LU, Slovakia SK, Cyprus CY, Bulgaria BG, Latvia LT, Malta MT, Romania RO

In this regard, the National Strategy for Research, Development and Innovation 2030 was approved in the Slovak Republic, containing a plan with 91 measures with deadlines, key performance indicators and an attached budget. By 2030, public spending on R&D is set to increase by an average of 14% per year, reaching around €1 billion by the end of the decade. Together with private investment in research, the aim is to bring the country's R&D intensity – GERD – to the level of the EU average of 2% (ERA Portal SR, 2023).

Conclusions

Innovations are a prerequisite for increasing the competitiveness of the economy. Their primary driving force is R&D. Every country of the EU is therefore trying to increase R&D spending while focusing on ensuring its efficiency.

The contribution provides an evaluation of the innovation performance of the SR through a comparison with EU countries using the EIS. According to the EIS 2023, the distribution of Member States within the performance groups remains unchanged compared to the previous year, still showing geographical concentration. Between 2016 and 2023, performance gaps between Member States narrowed. Slovakia is among the countries with a

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relative performance below 70% of the European Union average, while its innovation performance is growing more slowly than in the EU. According to the RIS 2023, all regions of Slovakia are placed among the emerging innovators of the upper third, except the Bratislava region, which is included in the group of moderate innovators of the upper third. Performance has increased for all regions. A positive relationship between the amount of R&D expenditure and the innovation score (the SII) was confirmed by regression analysis. As the research data on GERD for the year 2022 were not published when the survey was realized, the SII 2022 and GERD 2021 data were used. Another limiting factor of the research lies in the number of stable EU member states. We did not monitor the contribution of individual components of innovation or their number; we observed the contribution of the overall innovation performance of the EU countries. The study's novelty is that only some empirical studies have been realized. Moreover, the realized study also compares the SR's innovation performance with EU countries. Its result follows empirical research conducted in Slovakia (Kučera and Fiľa, 2022).

Following the results, the author considers an increase in spending on R&D to be a necessary condition for improving the current situation in the innovation policy of the SR.

Regarding further research directions, as innovations (as well as the SII) depend on many factors, we suggest creating a multiple regression model in the future to refine the results. It will also be interesting to see the development of innovation performance of the SR and its position within the world, resp. EU or V4 countries in future rankings. That could help determine the strengths and weaknesses of the national innovation system and identify challenges that the SR should address if it wants to improve in the given areas.

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