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Innovation performance of EU countries in context of R&D: R&D trap risk in Slovakia?

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Abstract

Expenditures in research and development (R&D) and their transformation in innovations are unanimously considered in the academic literature to be one of the key drivers of sustainable economic growth, total factor productivity, as well as the competitiveness of companies and national economies. The paper examines the dependence of the level of innovation performance of European countries on the countries' expenditures on R&D. Although this dependence appears to be significant and long-term stable, there are significant differences in the evaluation of individual partial components of the innovation performance of countries according to the index used within the European Innovation Scoreboard. The mentioned findings indicate that the process of transformation of R&D into innovative performance is just as important as the amount of R&D expenditure itself. Using the example of the economy of the Slovak Republic, its comparison with EU countries and the Quintuple Helix model, the contribution further demonstrates how the low level of R&D spending in connection with insufficiently developed country subsystems (helices) can lead to economic paradoxes and, without systemic changes, to the unsustainable development path or to the risk of R&D spending trap.

Keywords: Innovations, Research and development, The European Innovations Scoreboard, The Summary Innovations Index, GERCH, The Quintuple Helix model

Introduction

Expenditures in R&D over their transformation in innovation and innovation performance have been considered for several decades by both in the theoretical literature and by economic policy makers as one of the main driving forces of the competitiveness and performance of companies, clusters, regions and national economies in a worldwide globalized economy. Even though the current ambition of the European Union (EU)[1] is to continue in the growth of competitiveness and resilience. At the same time, the EU is conceived as an economic space for the real convergence of the performance and standard of living of newly entering economies towards higher standards, achieved in the founding and at the same time the most economically and technologically advanced EU member states.

[1] In April 2024, the EU has set three key strategic orientations for the EU's research & innovation funding for the three last years of the EU programme (2025–2027): Green transition. Digital transition. More resilient, competitive, inclusive and democratic Europe with the nine priorities. https://ncpflanders.be/news/horizon-europe-strategic-plan-2025–2027-adopted.

The pandemic crisis of COVID 19 has negatively contributed to the slowdown of the process of real convergence in some newly acceding countries. As a result of the fiscal restrictions of some countries and the redistribution of government expenditures to save human lives, to maintain employment, and to fiscal incentives to overcome the recession, several EU countries, including the Slovak Republic, also show a low level of spending on R&D per Gross Domestic Product (GDP).

Slovak Republic, as a result of the slowdown in GDP catching up in the Purchasing Power Parity (PPP) standard to the EU average and with low R&D spending on GDP, shows signs of not only slowing down the convergence process, but also heading into the trap of low R&D spending. And this despite the fact that since 2005 it has been led by the World Bank as a country with a high level of income. That is why the need for not only the traditional political proclamation meaning and increase of R&D expenditures, but even more important deep systemic change in innovation and innovation policy becomes first priority for the strategy of returning to the irreversible convergence development of the Slovak economy. Because it is no longer possible to rely on the traditional comparative advantages such cheaper costs of labour or corporate tax rates in the new EU states including Slovakia, it is necessary to achieve sustainable economic growth through the effective application of new innovations. In the above-mentioned direction, the scientific literature provides several proven guidelines for economies with Helix concepts on how to get out of the trap of low spending on R&D. And not only through the increase of such expenses, but especially for their rational allocation in cooperation with key subjects of the entire chain of the innovation process and its implementation.

The motivation of the paper is to contribute to the scientific debate in two main directions. The first goal is to supplement empirical evidence and knowledge on whether and how R&D spending was reflected in the innovation performance of EU countries in the period after the pandemic shock. The second goal is to use the Helix approach to analyse the innovation performance of the Slovak economy and for overcoming bottlenecks in relative lower innovation performance that the Slovak Republic exhibited in 2023. The article fully aligns with the Journal core themes per its aims and scope, which is supported with the relevant literature corroborating this.

For this purpose, the contribution presents in the first part an overview of key theoretical works, aimed at examining the impact of R&D expenditures and strategies on the innovative performance of economies. The second part is dedicated to the current relevant thematic analytical and empirical findings and facts, especially about the trend of convergence and competitiveness of the economy of Slovakia and their sources, further about the trends and contexts about the development of the innovative performance of the Slovak economy. The third part presents the methodology, data and creation of research hypotheses, the results of which are the content of the fourth part. The conclusion, in addition to a concentrated summary of the current findings, provides definitions of key economic, social and political gaps, which limit the potential return of Slovakia's economy to the trajectory of sustainable convergence with the developed countries of the EU and for avoiding the risk of falling into the trap of low R&D expenditures (Arman et al., 2022).

Key theoretical starting points

One of the basic microeconomic cornerstones of non-classical theory and the role of innovation for sustainable development is the concept of creative destruction by Schumpeter (1934, 1942), according to which the ability of companies to permanently innovate leads to the destruction of their innovatively lagging rivals. This concept rather idealistically assumes that competing companies operate in the same competitive environment, without individual price and other advantages.

Porter also considered innovation to be a key source of competitiveness not only for companies, but also for national economies and regions. In contrast to macroeconomic approaches to competitiveness, based on the standard "top-down" approach, his research focused on the competition of firms, which gradually led through the concepts of "clusters" and "diamonds" to his view of the importance of the business environment and other factors for a sustainable economic the growth of firms and national economies in a globalized environment. The role of governments was seen by Porter (2000) and other authors in public interventions especially by the creation and support of the quality of the business environment and the quality of services by public institutions.

Theories of endogenous economic growth assume that technological progress is the driving force of long-term economic growth Uzawa (1965), Lucas (1988), combining capital accumulation with technical progress as a source of growth. Further development of endogenous growth theory assumed that technological shifts are significantly dependent on the level of research and development (R&D)—Romer (1990), Aghion and Howit (1992), Grossman and Helpan (1991). The aforementioned theories assumed that there is a proportion between the total productivity of production factors (TFP) and the level of R&D measured either by the number of R&D workforces or by spending on R&D. At the same time, they implicitly assume that R&D expenditures lead to the growth of the economic performance of national economies without defining in more detail the channels of their transformation into innovations.

Many followers or recent studies and authors dealt with the influence of innovations and performance of companies (e.g. Akad & Deger, 2023; Du et al., 2020; Fedyunina & Radosevic, 2022; Kulicke & Krupp, 1987; Naidoo, 2023; Radenovic 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 not only generates new information, but also 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. R&D should be supported by private, but also by public funds. Wang and Thornhill (2010) mentioned possibilities how to finance R&D on micro-level. 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.

Currently, the channels of transfer of financial resources to R&D to the innovative performance of companies and national economies are increasingly complex and sophisticated. Already Miles (2005) drew attention to the growing importance of the Knowledge-Intensive Business Services (KIBS) sector, which has been fast growing in

the OECD countries in recent decades. The author divides KIBS into two broad types: (i) traditional KIBS which include accounting and bookkeeping services, advertising and marketing services and legal services, etc.; (ii) new technology-based services which include professional, scientific and technical support services, information services, high-tech training and consulting services. The former users of KIBS typically used new technology and the latter usually served it as agents of the transfer and diffusion of new technology.

Morollón and Garcia (2023) analysed the geographical distribution of the investment effort in R&D in the European Union. It has been observed that there is certainly a strong 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.

According to Clarysse et al. (2011), Teece (1986), knowledge-based companies usually require time to build the value of the knowledge base and thus resist competitors. During this period, the value of intangible assets may increase, but as a rule, tangible assets do not. Such companies often have to invest in intangible assets, such as know-how for specific customer relationships, which does not lead to growth in firm performance in the short term.

Sarpong et al. (2023) propose a sustainability pathway model to achieve 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 system (e.g. Ganda, 2019; Holt et al., 2021; Xu et al., 2021). The effective system is considered a high priority of the EU, especially when achieving the effectiveness of public incentives in stimulating additional levels of business R&D expenditure. Especially if public incentives encourage moral hazard behaviour by firms, the public spending effects may be very low, especially in the short term. And this despite the fact that such expenses usually lead to additional effects, such increase of quality or knowledge in research and academic sector.

Influenced by a variety of factors, innovation performance varies from one country to another. In this context, the need to measure the innovation performance of the economy is gaining importance, while innovation is understood not only as a result of successful transforming process of R&D expenditures in innovations, firm and national economic performance—measured by production, labour or total factor productivity growth.

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. In connection with the allocated total R&D expenditure, the main interest of researchers is in the evaluation of R&D efficiency (Conte et al., 2009; or Aristovnik, 2012). There are also several ways how to measure and evaluate the innovation performance of the country. The EU methodology and evaluation of the innovation performance which is also used in this paper is

based on European Innovation Scoreboard (EIS) or the so-called Summary Innovation Index (SII).[2]

Low R&D in countries signal future problems of their sustainable growth, regardless of their performance and inclusion in the groups of low, middle, or high-income countries according to the methodology of the World Bank. Arman et al. (2022) point out how countries that have long relied only on the comparative advantages of abundant natural resources and low prices of energy inputs may, due to low current R&D expenditures and without the development of the R&D sector, end up in the so-called traps of low R&D spending. Such a risk is also taken by some newly acceding EU countries, which rely on relatively low labour prices, low corporate taxes and the transfer of innovations, especially ground-breaking ones, to the economy by attracting new foreign direct investments with a variety of support policies.

Schot and Steinmueller (2018) state that there are three frames for innovation policy: R&D, systems of innovation and transformative change, which can lead to well-performed innovation performance of a country. A broader concept for explaining the transfer of R&D spending to a country's innovation performance is provided by the theory of the knowledge economy. This assumes that the prerequisite for the successful and permanent implementation of innovations in a country's firms is the creation of a knowledge base (Grant, 1996; Möller and Rajala, 2007). Competition between firms in the market (Teece, 2014) gradually develops from individual firms to various forms and elements of the ecosystem up to the national level of the economy, while the heterogeneity of the members of the innovation ecosystem also contributes to their common benefit. Alternative forms of ecosystems (Anand et al., 2007) allow their members and firms to share, in addition to innovation knowledge, other strategic industrial knowledge, marketing skills, etc. Ecosystem members and their various modern organizational platforms differ depending on the goals. However, they usually involve private research centers, networking of experts, startups, universities, government, small businesses, multinational corporations (Talmar et al., 2018). Their synthesis at national levels has generated a knowledge base of the country, which is specific for each country and is a dynamically evolving system. These systems enable the permanent development, transfer or adaptation of innovations in the country and thus shift its innovation performance through a variety of channels away from systematic expenditures on R&D.

The main elements of such national knowledge bases can be illustrated using the Helix approach. The theoretical literature has gradually developed and expanded the Helix approach as a tool to explain the broader concept of sustainable development of country societies based on R&D. Including the application of the Helix model for evaluating the consequences of COVID 19 in the educational system Hossain et al. (2023). Each helix model could offer useful insights serving as conceptual or analytical tools for studying various issues of development of contemporary society. Not only as a conceptual tool, but also a base for empirical studies (Cai & Lattu, 2022).

The Triple Helix innovation model focuses on partnership of university–industry–government relations. The so-called Quadruple Helix model embeds the Triple Helix by

[2] The 2023 EIS classifies EU countries into four groups based on their innovation scores. Innovation Leaders exceed 125% of the EU average, with countries like Denmark, Sweden, Finland, the Netherlands and Belgium leading the way.

including the fourth helix player the "media-based and culture-based public" and "civil society". The most actual Quintuple Helix innovation model additionally added the fifth element "natural environments of society", which is a more appropriate model for recent EU research and innovation strategy (Martini, 2023; Stier and Smit 2021). Based on deep systematical ordered development and quoted original works of the authors (such Carayannis & Campbell, 2006, 2009, 2010; Etzkowitz & Leydesdorff, 2000; Gibbons et al., 1994) Carayannis et al. (2012) provide a chronological development of the helix approach, up to the Quintuple Helix and its alternative expansion on the six currently existing models of knowledge creation and innovation creativity model.

Schot and Steinmueller (2018) define the Quintuple Helix model as a tool "to make sustainable development determination for progress therefore means that each of the five described subsystems (helices) has a special and necessary asset at its disposal, with a social (societal) and academic (scientific) relevance for use". The education system, as the first helices subsystem, refers to the "academia", "universities", "higher education systems", and schools. In this helix, the "human capital" such students, teachers, scientists/researchers, academic entrepreneurs, etc., of a national level is being formed by diffusion and research of knowledge. The economic system as the second helix subsystem includes "industries/industries", "firms", services and banks focusing on quality and performance of 'economic capital', such as entrepreneurship, machines, products, technology, money, etc. of the national level. The natural environment is the third subsystem which determines a sustainable development and provides people with a "natural capital" such resources, plants, variety of animals, etc. The fourth media-based and culture-based public subsystem combines two forms of "capital"—"social capital" and "capital of information" such as news, communication, social networks, etc. The political system, as a fifth subsystem or political capital, is also of crucial importance for R&D and innovation performance of a country, because it formulates forward looking creation of ideas, laws, plans, politicians, etc., and is ensuring their implementation on the national level but also on the international political cooperation level. In addition to innovations for sustainable development, according to Silvestre and Țîrcă (2019), the knowledge base of each country, as well as the individual forms of Helix capital, are subject to permanent innovations. Each Helix national mix at a different level of development and with a different weight of preferences pursues its development goals, whether economic, ecological, social or even power. This is also the basis for explaining some potential anomalies and different connections between the high level of R&D expenditure and the innovation performance of countries.

Slovak innovation and economic performance paradox

Regarding Slovakia's innovation performance, there have not been many empirical studies realized yet. In contrast to other policies that have already been implemented at national or regional levels, innovation policies are rather a 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 support of R&D. Innovation is understood as a result of successful R&D. Fabova and Janakova (2015) stated that low innovation performance of the SR is the reason for its low competitiveness. Ivanová and Masárová (2018) evaluated the innovation performance of regions of

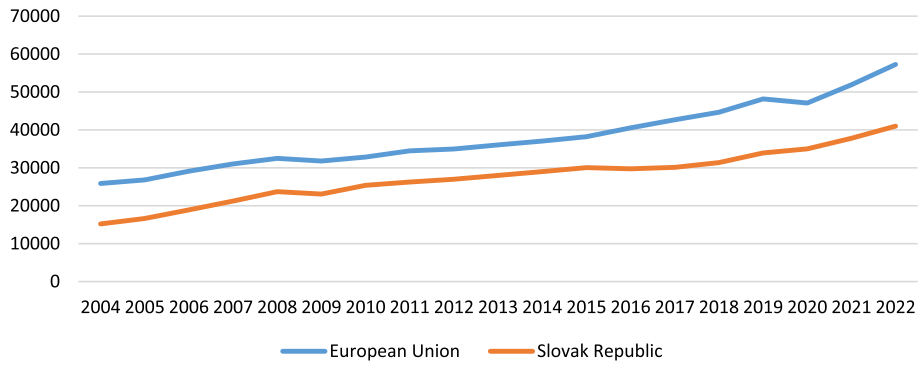

Fig. 1 Development of GDP per capita in PPP for the Slovak Republic and the EU. Source: World Bank

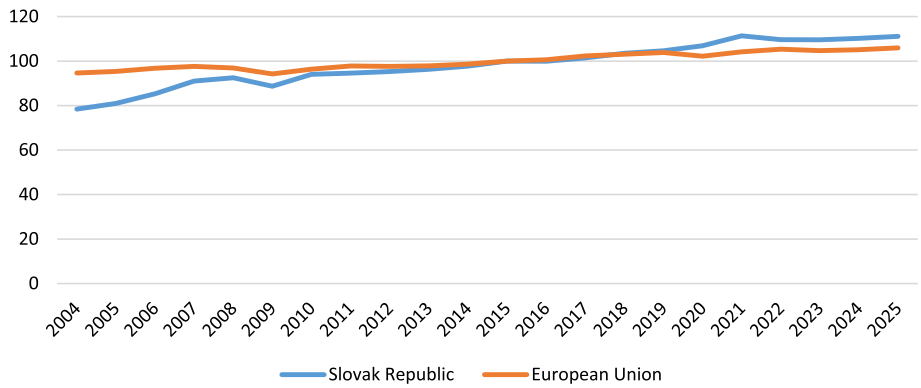

Fig. 2 Development of total factor productivity the Slovak Republic and the EU. Source: Ameco Database

the Visegrad Group with an emphasis on human capital. Janoskova and Kral (2019) analysed 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 level of economic development of the EU countries. Higher R&D expenditures are a basic precondition for faster economic growth which is basically represented by GDP per capita.

Several studies in Slovakia have attempted to explain the impact of technological progress on GDP growth using macroeconomic econometric approaches. On the basis of panel regression, Ochotnický et al. (2020) found the main driving force of the growth of total factor productivity in 28 European countries in the period from 2005 to 2019 and expressed through the Solow residual in the order of importance technological readiness, human capital, business and tax environment and creativity. Paper used fixed effects model focusing on the impact within the countries and suggested that technological readiness is an important driving force behind TFP growth the paper only partially confirmed the impact of the remaining explanatory variables.

Regarding the basic indicators of innovative and economic performance with the EU, one important paradox can be deduced from the following trends and when compared with the EU (Figs. 1, 2).

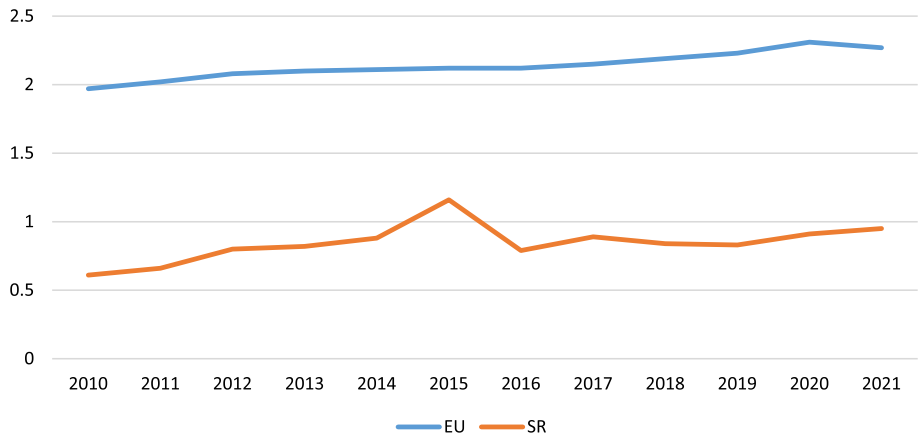

Fig. 3 Development of expenditure on R&D (GERD) in the period 2010–2021 for the Slovak Republic and the EU. Source: Own processing according to EUROSTAT data

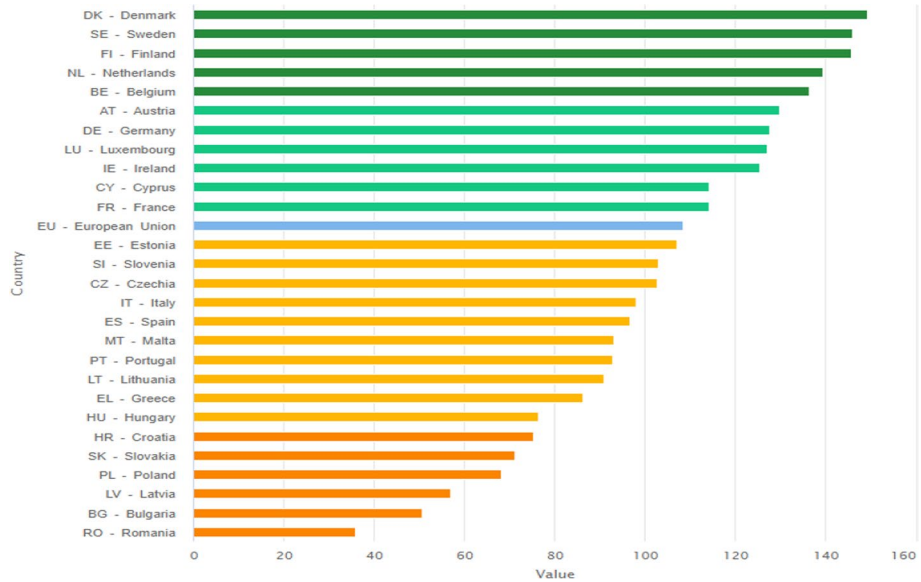

Fig. 4 Slovakia's position in European Innovation Scoreboard (EIS) in 2023 (Source: EC 2023a)

As Fig. 3 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 investments in R&D negatively affects Slovakia's overall innovation performance and also its economic competitiveness (Fig. 4).

Figure 5 shows a comparison of 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) and Denmark (2.81%), etc. The Slovak Republic invested only 0.95% of GDP in R&D in 2021, which was 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.

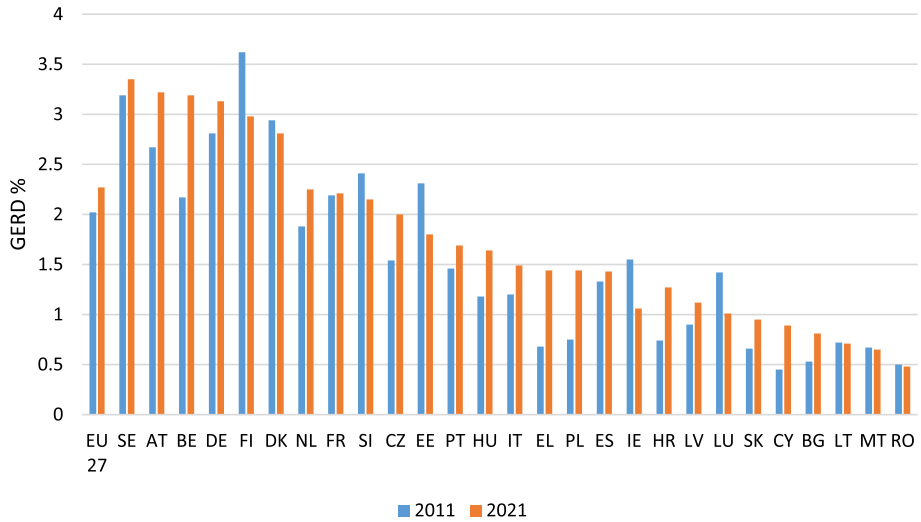

Fig. 5 GERD (%) in EU countries (Source: Own processing according to EUROSTAT data)

The Slovak paradox of productivity: "despite the ever-higher TFP growth compared to the EU average, practically since 2015, the economy of the Slovak Republic has shown a slowdown in the growth dynamics of GDP per capita in PPP compared to the EU average". Even more alarming for the long-term sustainable development of the economy is the permanently undersized development and level of the GERD, and especially the resulting assessment and position of the Slovak Republic at the bottom of the ranking of EU countries according to the EIS.

At the same time, according to EIS 2023, the distribution of Member States within the performance groups remains largely unchanged compared to the previous year. Significant progress has been made by Hungary, which has moved into the higher performing group of "moderate innovators", while 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.

Data and methodology

There are several ways how to measure and evaluate the innovation performance of the country. 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). The main sources of information include the secondary data contained in the European Innovation Scoreboard 2023 and the related EUROSTAT datasets of GERD within the EU countries for the amount of expenditure into R&D in the period 2016–2022. As it will be showed, a limiting factor for testing the second hypothesis is, that the GERD indicator for EU member states is stable and with relatively small differences in the time.

Methodology which is used in paper is based on two approaches: (a) traditional econometric testing of connection between GERD and EIS levels of EU countries; (b) qualitative analysis of Slovak Republic EIS positions and its subpositons through the

lens of the Quintuple Helix model (Cai & Lattu, 2022; Carayannis & Campbell, 2010; Carayannis et al., 2012; Hossain et al. 2023).

Dependency between GERD and EIS

The analytical tools used include the regression analysis. The analysis was used to confirm or refute the hypotheses. It examines a possible correlation between two indicators. The authors assume 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). With regard to the verification of the dependence of the innovative performance of the country on R&D expenditure, two hypotheses were set and its veracity verified through regression analysis (Fig. 6).

Helix quintuple approach-based evaluation of EIS by individual country

The EIS 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 indicators and has been operating under the auspices of the European Commission since 2011. It helps countries assess the strengths

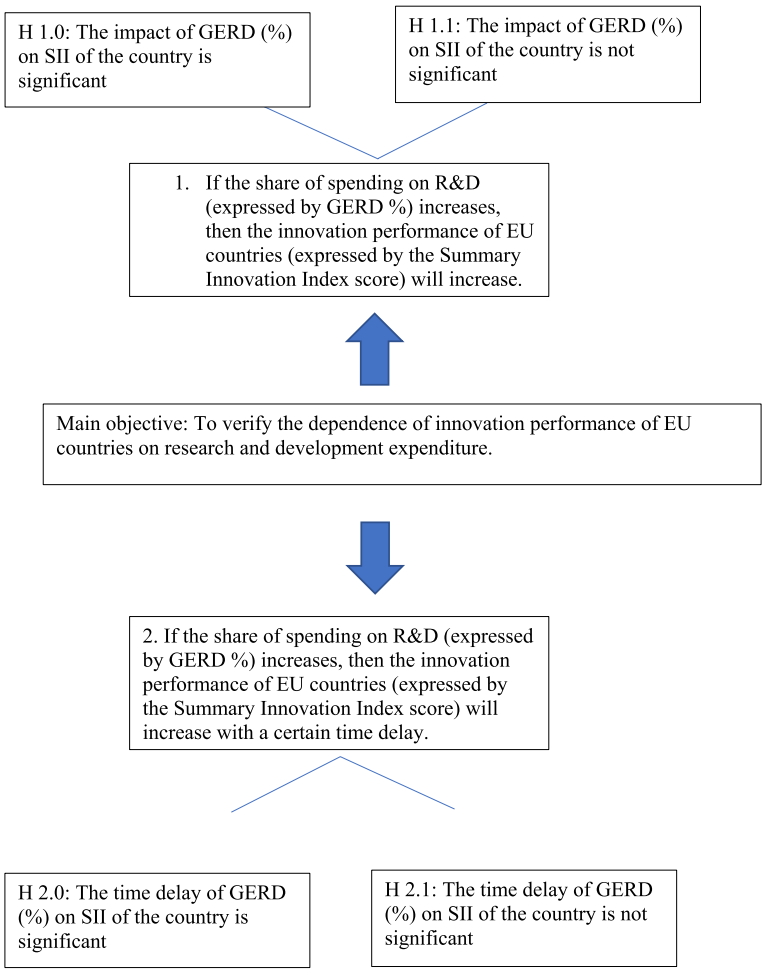

Fig. 6 Main aim and hypotheses (Source: Own processing)

and weaknesses of national innovation systems or identify challenges that they should address if they want to improve in the given areas. The survey also evaluates the overall position of the European Union in the field of innovation, science and research compared to the advanced world economies of other countries such as the USA, Canada, China, Japan and others (EC, 2023).

The EIS 2023 distinguishes between four main types of activities with 12 innovation dimensions, capturing in total 32 indicators—see Annex. The EIS uses data related to the performance in 2022 for 11 indicators, 2021 for six indicators, 2020 for 13 indicators, and 2019 for two indicators. Development of the given country is monitored over time and compared with other countries of the European Union (EC, 2023). The yearly published reports for each EU country show the stay and comparison of the country with the EU average total EIS levels and its subindicator with evaluation of the relatively strengths, relatively weaknesses and relatively strong increase/decrease in the recent level with the reached stay in comparison to previous year and year 2016.

Pretože je numericky a metodologicky náročné merať poznatkovú bázu krajín, článok pre hodnotenie úrovne poznatkovej bázy SR využíva reverzný postup jej odvodenia smerom od hodnotenia EIS. By using the Quintuple Helix criteria or 5 helix capitals lenses and its comparison with the result of EIS country profile subcriterias levels we will try to find:

- the recent comparative advantages and disadvantages of the Slovak innovation performance,
- in which Helix sub-capitals is the Slovak society on the sustainable development path,
- which subcriteria of EIS indicate the systematical needs for changes by overcoming the low R&D trap risk in the future.

Research results

The first subchapter brings results of investigations the results of testing the dependence of innovation performance of EU countries on R&D expenditures. The second subchapter presents findings, which result from the application of the principles of Quintuple Helix on the recent Slovak's EIS country profile.

Evaluation of the innovation performance of EU countries

To analyse the dependence between the investments in R&D and innovation performance, we applied regression analysis. 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. The dependence of innovation performance of EU countries on R&D expenditures is visible from Table 1, which is the result of the regression analysis.

Since significance F—F test for 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.

Table 1 The regression analysis output: R&D expenditure (2021) and innovation performance (SII 2022). Source: Own research

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

Table 2 Summary of correlation and regression analysis output. Source: Own research

Hypothesis	**Confirmation/refusal**	**Multiple *R***	***R*-square**	**Significance *F***
H1	Yes	0.74	0.55	8.48E−06
H1.0	Yes			
H1.1	No			

The linear model used to analyse the dependence between between the investments in R&D and innovation performance has proved to be statistically significant (Table 2).

Graphical interpretation of the result from the regression analysis is shown in Fig. 7, which confirms that there is a positive relationship between the amount of R&D expenditure and the innovation index (SII).

If we focus on countries that invest a larger 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 Fig. 7 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 can be Cyprus. Its performance in the EIS is increasing (37.9%—points) at a rate much higher than that of the EU (9.9%—points), so Cyprus contributes to narrowing the gap between the EU and leading innovation nations, such as Canada, the Republic of Korea, and the Unites States. Despite Cyprus's progress in the ranking, investments in R&D remain low, both from the public and private sectors. This can be due to a number of factors that affect the value of the innovation score. Cyprus shows strengths in areas such as progress in

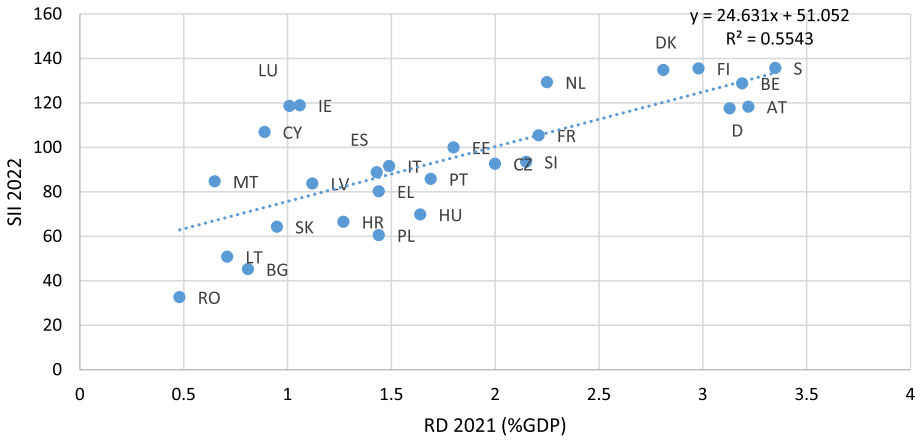

Fig. 7 Interdependence between R&D spending and SII 2022. Source: Own processing according to EUROSTAT data and EIS. Note: Sweden S, Austria AT, Belgium BE, Germany D, Finland FI, Denmark DK, Netherlands NL, France FR, Slovenia SI, Czechia CZ, Estonia EE, Portugal PT, Hungary HU, Italy IT, Greece EL, Poland PL, Spain ES, Ireland IE, Croatia HR, Lithuania LV, Luxembourg LU, Slovakia SK, Cyprus CY, Bulgaria BG, Latvia LT, Malta MT, Romania RO

innovation, high levels of research, an attractive research system, and increasing collaboration within its ecosystem. Additionally, more businesses are integrating innovation into their operations. In this regard, a key initiative, the "Disrupt" programme, the first of its kind in Cyprus, providing mixed funding, should be mentioned. The programme has allocated €10.5 million in public funding to seven innovative companies, leveraging €12.5 million in additional investments from funds in Cyprus and abroad. This programme aims to help these companies scale their operations and introduce products to international markets. Evaluating the effectiveness, it was observed that time was needed for these products to mature. For further integration of innovation into the Cypriot economy, the Research and Innovation Foundation (RIF) offers a comprehensive toolbox of programmes aimed at traditional sectors and supporting also startups and scaling businesses. These growing enterprises, through other innovation programmes, have moved beyond the initial stages and are now rapidly expanding, attracting both private and self-investments. Their importance is in introducing new products to markets in sectors that previously seemed beyond Cyprus's reach, such as defence technologies, biotechnology, cosmetics, pharmaceuticals, food, and sports.

We used Cyprus as a positive example of successful innovation policy without high R&D investments. For Slovakia, it will be also crucial to adapt measures to boost private sector R&D contributions.

In order to improve the innovation environment and increase the innovation activity of Slovak companies, we propose several recommendations that could increase the innovation performance of the Slovak Republic: set up a national innovation system with a clear direction and strategy, simplify the rules and make aid for innovating companies more effective (for example, a lower tax on employee training), simplify access to public research infrastructure, create specialized innovation hubs accessible to the wider business and academic public, support innovative industrial parks and clusters to a greater extent, motivate enterprises to implement innovative activities (expenditure on innovations as a tax-deductible item, co-financing of innovative activities, media visibility of

innovative enterprises), promote innovative enterprises to a greater extent at international presentation events, connect enterprises, research institutions and universities to a greater extent, provide electronic consulting in the field of the possibilities of using public support tools related to the introduction of innovations in the company.

In this regard, it sounds positively that the National Strategy for Research, Development and Innovation 2030 was approved in the Slovak Republic, containing a plan with 91 measures that have 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).

It is important to note that Slovakia has a short history of innovation support. The number of explicit national innovation measures in Slovakia has been very low compared to other EU countries. Innovation support focused on improving framework conditions for business environment (e.g. tax credits), social development and reform processes. The National Strategy for Research, Development and Innovation 2030 seems to be a change in direction from the strategy of attracting foreign direct investments and "relying on" imported knowledge from multinational companies.

The testing the second hypotesis brings some limited results. First of all we find, that the GERD levels of the EU country are relatively stable, what leads to the strong multicolinearity effect of the time legged GERD levels (between 1 and 5 years time lag) and to the statistically insignificant regression result.

Some promising results were brought by the comparison of the regression strength and the significance of the model parameters, where the dependence of the EIS in 2023 on the GERD values with a shift of 1 to 5 years was gradually tested. In this case, the strength of dependence gradually increased slightly with shifts in GERD up to a peak with a shift of 4 years (see Annex, Table 4), while a shift of 5 years already showed a decrease in the significance of the regression and model parameters with a time shift of GERD. At the same time, all models with shifts showed strong regression dependence and statistical significance.

Slovakia's recent innovation performance and quintuple helix model as a basic system of knowledge base

According to the EIS country profile, Slovakia is an Emerging Innovator with performance at 65.6% of the EU average. Performance relative to EU in 2023 was relative height in evaluation of quality of 3 from 12 SII main subindex levels—human resources, sales impacts, and environmental sustainability (Fig. 8).

From the perspective of the Quintuple Helix model, the relative innovation performance of Slovakia's economy compared to the EU indicates sustainable development only in the area of two helices: (1) "human capital" and (3) "natural capital". Despite the above-average level achieved by the Slovak Republic for Innovation-based sales impacts (export), which in accordance with the Quintuple Helix model, a part of the Helix (2) "economic capital", perhaps due mainly to the low level of finance and support of R&D expenditures in private and public sector, as well as other components with impacts on Helice (2), is considered as unsustainable from the point of view of innovative

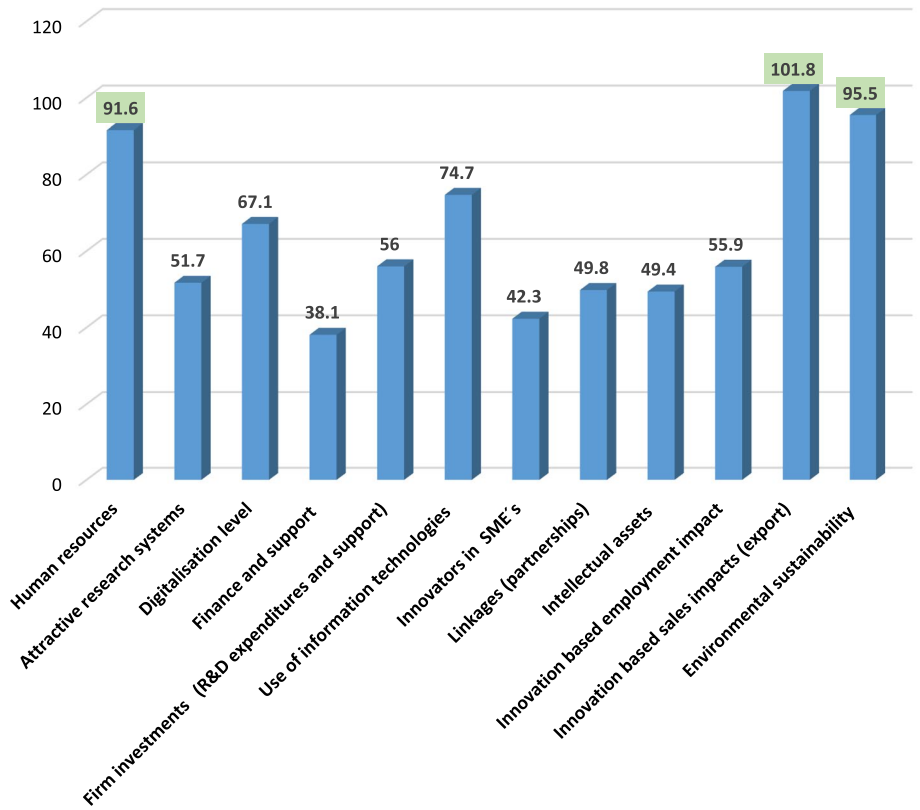

Fig. 8 Slovakia's main SII subindex levels (Source: own processing based on EIS 2023)

performance. Similar evaluations also apply to helices (4) and helices (5), which, in accordance with the following figure, illustrate the relationship between the SR scores for the 12 main components of the SII and the five components of the capital of the Quintuple Helix model. From the graph and from the level of subindexes for the economy of Slovakia, it further follows that the low innovation performance in the digitization subindex, in the attractiveness of the research system, as well as in the level of linkages (partnerships) negatively affects social and political capital in addition to economic capital (Fig. 9).

The EIS 2023 indicates that the relative strengths of the country are in the area medium and high-tech goods exports, sales of innovative products lifelong learning, air emissions by fine particulate matter and non-R&D Innovation expenditures. These five subindexes reflect the strong position of using human capital by the position of large-scale innovative foreign direct investments and companies allocated in the Slovak Republic, mainly in the automotive industry.

In opposite the relative weaknesses are job-to-job mobility of HRST, low R&D expenditure in the business sector, low government support for business R&D, low PCT patent applications and low venture capital expenditures. Figure 10 shows in addition the main short-term positive/negative changes in innovation performance over time against the performance of the country in 2022. Performance increased most strongly for human resources. Performance declined for environmental sustainability.

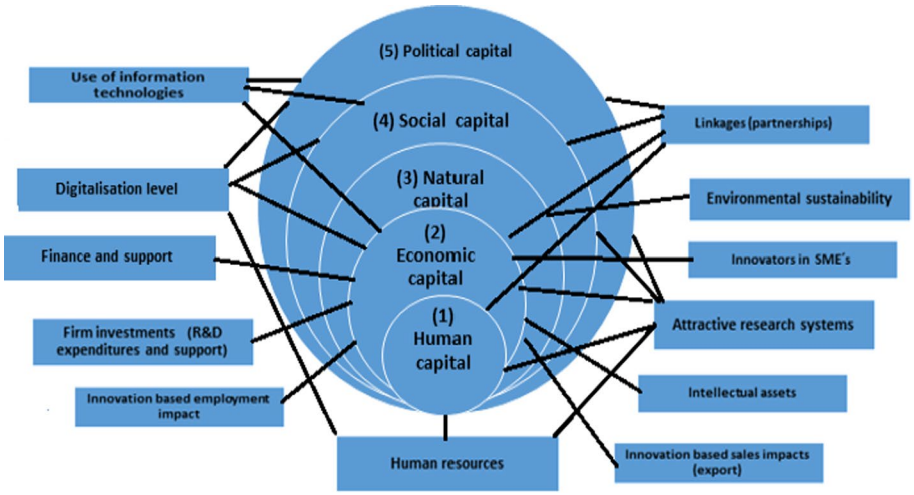

Fig. 9 Stylized interaction between 5 Helix capital component and SII subindex (Source: own processing)

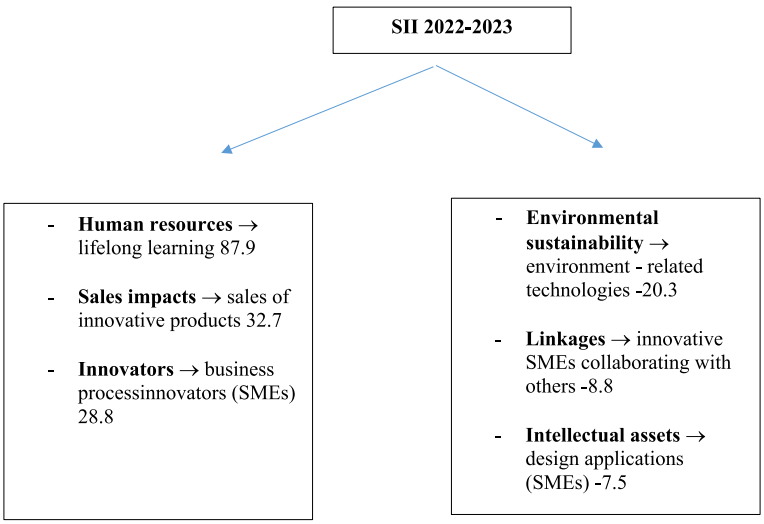

Fig. 10 Slovakia's strong increases/decreases since 2022 in EIS (Source: EC 2023a)

The paper opened some potential shifts in deeper research. For example for the further direction of innovation policy the sustainable development should be a priority. Meramveliotakis and Manioudis (2021) present Mill's theory of economic development, with an emphasis on a dialectical relation between knowledge/innovation (human capital) and nature (natural capital). Both innovation and nature play a pivotal role in accessing sustainable economic development. In their further work (Meramveliotakis & Manioudis, 2022) they list the elements, such as history, interdisciplinary approach, the analytical priority of social classes, that could be critical in enriching sustainable development.Similarly, Silvestre and Țîrcă (2019) state that the innovation process is complex because it typically deals with a large number of interconnected factors that impact, or are impacted by, the other factors. Vollenbroek argues that science does not automatically lead to a better quality of life. The balance of economical, ecological and social goals is required.

Conclusions

R&D expenditure-based innovations are a prerequisite for increasing the competitiveness of the economy and sustainable development. Every country of the EU and also the EU as a unique socio-economic, envinromental and political system is therefore trying to increase spending on R&D, 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 largely unchanged compared to the previous year. Between 2016 and 2023, performance gaps between Member States narrowed. Slovakia is among the countries with a relative performance below 70% of the European Union average, while its innovation performance is growing more slowly than in the EU.

The novelty of the study could be seen in two directions. The first are the tests of dependence between the level of innovation performance and R&D expenditures shares on GDP with the different time lags. Because that there have not been many empirical studies about Slovakia innovation performance realized yet, the second novelty of the paper can be seen in an attempt for evaluation of the Slovak economy innovation performance (SII) and its subindexes in the lens of the Quintuple Helix model.

Regarding the first direction, the linear model used to analyse the dependence between the level of innovation performance (EIS) and GERD (R&D expenditures to GDP) in EU countries has proven to be statistically significant and showed strong dependency between the two indicators used. Some promising results were brought by the comparison of the regression strength and the significance of the model parameters, where the dependence of the EIS in 2023 on the GERD values with a shift of 1 to 5 years was gradually tested. In this case, the strength of dependence gradually increased slightly with shifts in GERD up to a peak with a shift of 4 years, while a shift of 5 years already showed a decrease in the significance of the regression and model parameters with a time shift of GERD. All models with shifts showed strong regression dependence and statistical significance but because the countries show a relatively stable share of R&D expenditures to GDP in the examined period, it is possible with some simplifications to only claim that the current innovation performance of countries is the result of their continuous R&D expenditures in the past years.

As for the second direction and purpose of the contribution, in the lens of the Quintuple Helix model, the relative current innovation performance of Slovakia's economy compared to the EU (SII) indicates sustainable development only in the area of two helices or capitals—human and natural. Despite some paradoxes of the economy of the Slovak Republic and the above-average level achieved by the Slovak Republic for innovation-based sales impacts (export), which in accordance with the Quintuple Helix model is a part of economic capital, perhaps mainly due to the low level of finance and support of R&D expenditures in private and public sector, as well as other components, consider the economic capital of the Slovak Republic as unsustainable from the point of view of innovative performance.

Similar assessments also apply to the country's social and political capital. From the graphic illustration and from the low level values of subindexes for Slovakia's economy, it further follows that the low innovation performance in the digitization subindex, in the attractiveness of the research system, as well as in the level of linkage

(partnerships) negatively affects social and political capital in addition to economic capital. Overcoming these weaknesses of society, relevant changes in policies and a social atmosphere based on cooperation appear to be a key prerequisite for the economy's rise to come on the sustainable development path.

Without deeper empirical research, a simple graphical comparison of the development of GDP per capita in PPP for the Slovak Republic and the EU with the position of the Slovak Republic according to the EIS clearly signals a strong interdependence and thus the risk of the entire society entering the path of a trap of low R&D, with an impact on the slower dynamics of future sustainable growth. We see this as a key message of this contribution for further in-depth research.

Annex

See Tables 3, 4.

Table 3 European Innovation Scoreboard 2023: indicators. Source: Own processing according to EIS 2023

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

Note: The European Innovation Scoreboard 2023 distinguishes between four main types of activities with 12 innovation dimensions (highlighted in italics), capturing in total 32 indicators

Table 4 The regression analysis output: R&D expenditure (2018) and innovation performance (SII 2023)

Summary output	
Regression statistics	
Multiple R	0.757014412
R square	0.573070821
Adjusted *R* square	0.555993653
Standard error	20.12473492
Observations	27

ANOVA

	df	**SS**	**MS**	***F***	**Significance *F***
Regression	1	13591.04352	13591.04352	33.55772	4.87E−06
Residual	25	10125.12389	405.0049557		
Total	26	23716.16741			

	Coefficients	**Standard error**	***t* Stat**	***P*-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	59.36878882	8.262440966	7.185381302	1.57E−07	42.35197	76.3856	42.35197311	76.38560453
X Variable 1	26.12225862	4.50935568	5.792902685	4.87E−06	16.83507	35.40945	16.83506675	35.40945049

Abbreviations

R&D	Research and development
EIS	European Innovation Scoreboard
SII	Summary Innovation Index
GERD	Gross expenditure on research and development
EC	European Commission
EU	European Union
GDP	Gross Domestic Product
TFP	Total factor productivity
KIBS	Knowledge-intensive business services
OECD	The Organisation for Economic Co-operation and Development
PPP	Purchasing power parity

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Author contributions
Katarína Belanová processed the basic idea, the first version of the paper, carried out econometric estimations of the original and other models of the expanded paper, participated in the processing of conclusions, in the final editing of the modified paper after reviewers. Pavol Ochotnický based on the comments of reviewers and editors, modified the structure of the paper, processed the new theoretical starting points and expanded them with the development of Helix models. He modified the hypotheses, processed the evaluation of the innovative performance of SR from the point of view of the Helix model and participated in the processing of concussions and the final editing of the text.Rudolf Sivák particpated in processing theoretical starting points, participated in the processing of concussions and the final editing of the text.

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Availability of data and materials
The authors used secondary data from the EC—European Innovation Scoreboards 2022, 2023 available at https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en, as well as from

Eurostat Database available at http://epp.eurostat.ec.europa.eu. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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