

RESEARCH PAPER

Econometric analysis and forecasting of R&D intensity as a basis for a comparative study of Slovakia and the EU27 towards 2030 targets*Emília Duřová Spiřáková¹, Janka Majerníková²*¹Technical university of Kořice, Faculty of Economics, Department of Finance, Němcovej 32, 040 01 Kořice, Slovakia²Technical university of Kořice, Faculty of Mechanical Engineering, Department of Technology, Materials and Computer Supported Production, Mäsiarska 74, 040 01 Kořice, Slovakia

*Corresponding author: emilia.dulova.spisakova@tuke.sk, tel.: +421 55/622 2145, Department of Finance, Faculty of Economics, Technical university of Kořice, 040 01, Kořice, Slovakia

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ABSTRACT

This paper examines the development and future prospects of research and development (R&D) intensity in the Slovak Republic, compared with the EU27 average, in the context of the Europe 2020 framework and the 2030 Agenda targets. R&D intensity, expressed as a percentage of GDP, is analyzed as a key determinant of innovation performance and industrial competitiveness. The study is based on a comparative statistical analysis of Eurostat data covering the period 2010-2024 and on econometric forecasting using the Ordinary Least Squares (OLS) method. Linear regression models were constructed to estimate average annual growth rates and project R&D intensity through 2030. The results reveal a persistent structural gap between Slovakia and the EU average. While the EU27 exhibits an average annual increase of 0.038 percentage points, Slovakia records only 0.024 percentage points. Under the current linear trend, R&D intensity is projected to reach 2.44% of GDP in the EU and 1.14% in Slovakia by 2030, indicating that neither the European 3% target nor the Slovak national target of 2% is likely to be achieved. A paired t-test further confirms the existence of a statistically significant innovation gap. The findings highlight the need for stronger private-sector participation and more effective allocation of public resources, particularly in applied research and advanced materials development, as essential preconditions for enhancing technological upgrading and long-term competitiveness.

Keywords: 2030 targets; Advanced technologies; Econometric forecasting; Innovation gap; Innovative materials; R&D funding.

INTRODUCTION

Following the conclusion of the Europe 2020 strategic cycle, research, development, and innovation activities have become critical to sustainable development and global competitiveness. The Lisbon Strategy and the subsequent Europe 2020 Strategy established the fundamental pillars for strengthening the EU economy, defining a quantitative target to allocate at least 3% of GDP to R&D [2, 3]. At the core of these frameworks was the assumption that effective R&D funding represents the key to smart, sustainable, and inclusive growth. These European efforts are now strategically aligned with the global 2030 Agenda for Sustainable Development [1]. Specifically, SDG 9 ("Industry, Innovation and Infrastructure") emphasizes that technological progress and innovation are essential prerequisites for reducing inequalities and supporting long-term economic growth [4, 5]. This integration is vital because R&D investment correlates not only with economic performance but also with the quality of education (SDG 4) and environmental sustainability [6].

The achievement of these goals is directly dependent on the capacity of national economies to implement new materials and advanced technologies. In the context of the green and digital transition, investment in innovative materials and smart manufacturing represents a fundamental prerequisite for maintaining industrial leadership [7, 8]. This is particularly crucial for small, open economies where sectors like the automotive industry form the backbone of national GDP. Without continuous support for sectoral innovations and the modernization of production processes, these economies risk losing their competitive advantage and failing to meet the practical needs of the current global market [9].

In academic literature, R&D funding is perceived as a determining factor for technological transformation. Reaching the 3% threshold for R&D expenditure is critical for the EU to keep pace with global leaders such as the USA or China [10]. Within this context, it is emphasized that the growth rate of R&D investment must be an absolute priority for improving European economies [11]. Furthermore, a significant correlation has been identified between economic growth in the EU and these investments [12].

Technological performance and its link to research subsidies have also been examined, confirming that meeting financial targets directly conditions innovative outputs [13]. The importance of knowledge for a developed society is further

highlighted in the literature [14], as is the role of innovation in corporate value and firm performance [15, 16].

A significant problem identified in the literature is geographical variation, as R&D expenditure is highly concentrated in North-Western EU states [17]. Comparative analyses indicate that countries such as Sweden and Germany successfully linked Europe 2020 targets to their national strategies, while states such as Romania and Bulgaria struggle with low innovation absorption rates [18]. For moderate innovators like Slovakia, the key issue is not only the volume of funding but also its structure. Using the TOPSIS method, variability in goal attainment was identified, with progress particularly evident in Slovenia and the Czech Republic, while other states stagnated [19]. It is further warned that the uneven distribution of funds may limit local competitiveness [20], as persistent challenges in distribution mechanisms prevent balanced growth in innovation [21]. Additional barriers identified include administrative inefficiency and a lack of coherent national strategies [22].

Recent studies analysing the V4 countries have found that key determinants of innovativeness include business R&D expenditure, which positively affects the number of patents and trademarks [23]. Furthermore, education levels and the number of ICT specialists are decisive for innovation potential, as well as for the overall efficiency of investments made within the EU [24]. Finally, public funding is identified as a necessary impulse; however, without an adequate response from the private sector, it cannot generate the required growth dynamics [5].

The role of the state in the R&D funding process is becoming increasingly complex. In sectors where the risk level is too high for private investors, such as renewable energy sources, public resources are considered indispensable [25], aligning with SDG 7 (Affordable and Clean Energy). However, the effectiveness of these investments depends on the quality of the institutional environment. There is a demonstrated need to optimize financial mechanisms to address multiple SDG targets simultaneously, thereby eliminating inefficient resource fragmentation [26].

Furthermore, it is argued that R&D investment must be accompanied by smart specialization policies [27]. Increasing budgets quantitatively without a clear focus on high-value-added sectors, such as the development of innovative materials and nanotechnologies, may not lead to the desired increase in competitiveness. This perspective emphasizes the necessity of collaborative networks between

universities and industry [28]. Additionally, the use of observatories to monitor the performance of innovation systems across regions has been proposed [29]. At the global level, international cooperation in research remains essential, especially in addressing public health crises [30].

The relationship between the volume of R&D investment and innovation output in materials research is non-linear and highly dependent on sectoral orientation. Innovative materials are considered “Key Enabling Technologies”, the development of which requires capital-intensive infrastructure and long-term funding stability [31]. In the context of the metallurgical industry, evidence suggests that countries capable of maintaining an R&D intensity above the 2% of GDP threshold (such as Germany or Austria) exhibit significantly higher rates of patent activity in smart materials and advanced metal processing technologies. Conversely, countries with low R&D intensity (including Slovakia) often fall into the “middle-income trap”, where industry produces materials with low levels of innovation. Several authors emphasize that the transition toward sustainable metallurgy and a circular economy is virtually unfeasible without massive support for applied research in metal recycling and new alloys [32].

The main objective of this scientific paper was to analyze the dynamics of R&D funding intensity in the Slovak Republic in comparison with the average of the EU27 countries and to evaluate the degree of convergence toward the strategic goals set in the Europe 2020 strategy and the 2030 Agenda for Sustainable Development. Through econometric modeling using the OLS method, the work focused on predicting future trends and identifying key barriers preventing the achievement of the target value of 3% of GDP at the EU level and 2% of GDP at the national level of the Slovak Republic. To fulfill this objective, the following research questions were formulated. **RQ1:** Did EU member states exhibit convergence toward the strategic goal of investing 3% of GDP in R&D during the observed period? **RQ2:** To what extent is national target of Slovakia and Europe-wide target in the field of R&D realistically achievable while maintaining the current investment dynamics? **RQ3:** Were there statistically significant differences in R&D funding intensity between the Slovak Republic and the EU27 average?

METHODS

The objective of the chosen methodology was to provide a robust framework for evaluating the dynamics of R&D expenditure and verifying the degree of convergence toward strategic targets. The research process was divided into two key phases: a comparative statistical analysis of historical data and econometric modeling of future development.

Data Source and Processing

The data source consisted of secondary statistical data from the official Eurostat database, specifically the indicator: Total intramural R&D expenditure (GERD) as a % of GDP. The observed period covers 2010 to 2024, capturing the impact of the Europe 2020 strategic framework and the transition to the 2030 Agenda. This range was considered sufficient to eliminate short-term fluctuations. The analysis was conducted for the EU27 aggregate and for the Slovak Republic specifically. The data were cleaned of extreme values and normalized for the purposes of regression analysis.

Econometric Modeling and Forecasting (OLS Method)

To quantify developmental tendencies and predict the state by 2030, the Ordinary Least Squares (OLS) method was applied within a linear regression model. This approach enabled the identification of the average annual increase and the determination of the direction of the linear trend. The model was specified as follows:

$$y_t = \beta_0 + \beta_1 \cdot x_t + \varepsilon_t \quad (1)$$

Where:

- y_t - the dependent variable representing R&D intensity in a given year t ,
- x_t - the independent (explanatory) variable, which is the time factor (years),
- β_0 - the constant (intercept), representing the theoretical value at time 0,
- β_1 - the slope of the regression line (regression coefficient), which interprets the average annual change in intensity in percentage points,
- ε_t - the random error-term of the model.

The reliability of the constructed OLS regression models was evaluated through diagnostic tests. The Durbin-Watson test was employed to assess potential autocorrelation in the residuals. To verify the normality of the error term distribution, the Jarque-Bera test was applied to assess the skewness and kurtosis

of the residuals. Furthermore, the Breusch-Pagan test was used to examine the presence of heteroscedasticity, ensuring a constant variance of the error-terms over the analyzed period. These tests are crucial for confirming that the estimated trend coefficients and subsequent predictions for 2030 are statistically consistent and unbiased. Additionally, the coefficient of determination (R^2) was used to express the proportion of variability explained by the model. The statistical significance of the model was tested using the F-test (Significance F) at a significance level of $\alpha = 0.05$.

The Durbin-Watson Test (Autocorrelation) measures the relationship between successive errors over time.

$$d = \frac{\sum_{t=2}^n (e_t - e_{t-1})^2}{\sum_{t=1}^n e_t^2} \quad (2)$$

Where:

- e_t - the residual at time t .

The Jarque-Bera Test (Normality) combines skewness and kurtosis to determine whether the residuals follow a Gaussian (normal) distribution.

$$JB = \frac{n}{6} \left(S^2 + \frac{(K-3)^2}{4} \right) \quad (3)$$

Where:

- n - the number of observations,
- S - the skewness,
- K - the kurtosis.

The Breusch-Pagan test is used to examine the presence of heteroscedasticity, ensuring a constant variance of error-terms over the analyzed period. This test is typically expressed as the Lagrange Multiplier (LM) statistic from an auxiliary regression of the squared residuals.

$$LM = n \cdot R_{aux}^2 \quad (4)$$

Where:

- n - the number of observations,
- R_{aux}^2 - the coefficient of determination from the auxiliary regression, where the squared residuals are the dependent variable.

The coefficient of determination indicates how much of the indicator's total variability is explained by the model.

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad (5)$$

Where:

- SS_{res} - the residual sum of squares,
- SS_{tot} - the total sum of squares.

F-test for overall model significance:

$$F = \frac{\frac{SS_{reg}}{k}}{\frac{SS_{res}}{n-k-1}} \quad (6)$$

Where:

- SS_{reg} - the regression sum of squares,
- SS_{res} - the residual sum of squares,
- k - the number of independent variables,
- n - the number of observations.

Testing the Innovation Gap (Paired t-test)

To verify the hypothesis regarding the existence of a significant difference between the innovation performance of the Slovak Republic and the EU27 average, a paired t-test for means was utilized. This test is suitable for comparing two related datasets (the same indicator at the same time for two subjects). The test criterion examines whether the mean difference between pairs of observations is zero ($H_0: \mu_d=0$). Formula for the t-test statistic:

$$t = \frac{\bar{d}}{\frac{s_d}{\sqrt{n}}} \quad (7)$$

Where:

- $\bar{d}$ - the mean of the differences between the pairs,
- s_d - the standard deviation of the differences,
- n - the number of pairs.

RESULTS

Innovation is a determinant of economic growth, shaping the dynamics of the business cycle and the resulting income levels by stimulating labour and capital productivity. Its strategic importance lies in strengthening the competitiveness of national economies within global value chains, enabling a transition to higher-value-added activities and mitigating comparative disadvantages arising from wage competition from emerging markets.

Effective innovation policy requires the synergistic effect of structural measures, primarily targeting human capital development through education, supporting the entrepreneurial ecosystem, and stimulating R&D expenditure. R&D intensity,

defined as the ratio of R&D expenditure to GDP, remains a key indicator in this area. Within the European Union, however, during the period of the Europe 2020 strategy (2010-2020), there was only a marginal increase in this indicator and significant regional disparities among individual member states persist.

From the perspective of methodology and data comparability, relative indicators are preferred over absolute values in the analysis, thereby eliminating distortions caused by differences in the sizes of the economies under study. The primary subjects of investigation are the share of R&D expenditure in GDP and expenditure per capita (Fig. 1).

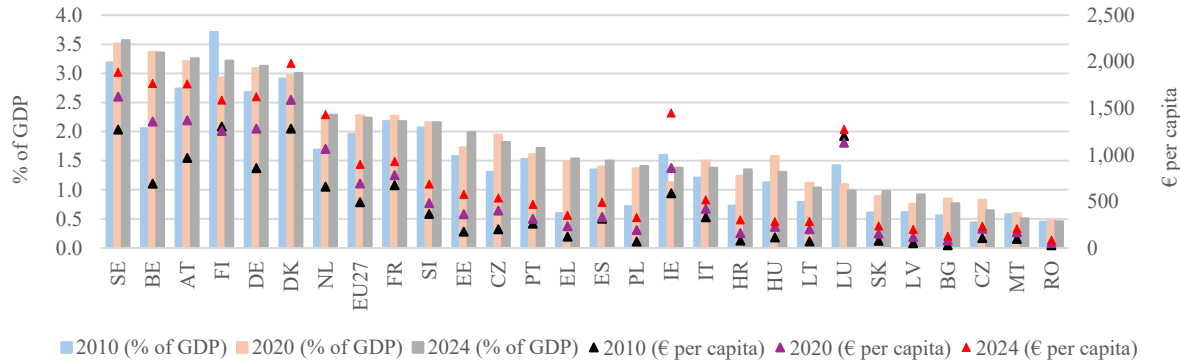


Fig. 1 R&D expenditure in EU member states (% GDP, € per capita)

A comparative analysis of innovation intensity across European Union member states from 2010 to 2024 reveals considerable heterogeneity in development. While some economies dynamically strengthened their positions, others showed signs of stagnation or even regression. The average R&D expenditure within the EU27 increased from 1.96% to 2.24% of GDP during the observed period, corresponding to a positive trend in nominal expenditure per capita, which rose from 490.77 € to 897.23 €. The group of innovation leaders consists mainly of Northern EU countries. Special attention should be paid to Belgium, which increased its innovation intensity by more than 1.3 percentage points over 14 years, making it one of the most progressive innovation systems in Europe. In terms of nominal expenditure per capita, Denmark leads with nearly 2,000 € per capita, underscoring the high level of capital concentration in the Union's most advanced economies.

In contrast to these growth trajectories, the data also identify countries with minimal progress or even a decline in relative innovation intensity. The most significant decrease in the share of R&D expenditure in GDP during the observed period was recorded in Finland, where the level fell from 3.71% in 2010 to 3.22% in 2024. Although the country continues to maintain a position above the three-percent threshold, this downward trend indicates structural changes in the national innovation system that may affect its leadership position in the long term. This situation has been significantly contributed to by the business enterprise sector, which has been recording a declining share of R&D expenditure in GDP over the past decade. Similarly, France exhibits a stagnant trend, with its share of expenditure in GDP remaining unchanged at 2.18%, as does Slovenia, which recorded only a marginal increase of 0.09 percentage points to 2.16% of GDP.

These disparities are even more striking when considering nominal investment per capita, where despite moderate percentage progress in countries such as Estonia (575.45 €) or the Czech Republic (536.26 €), these values remain far below the levels of Germany (1,624.45 €) or the Netherlands (1,431.09 €). The persistent investment gap between innovation leaders and stagnating countries suggests that without more decisive structural reforms and targeted expenditure stimulus, lagging economies risk consolidating their positions in lower-value-added segments, thereby deepening the innovation duality and fragmentation of the European Research Area.

Fulfilment of the Europe 2020 strategy targets by EU member states

Regarding the success of innovation strategy implementation, only four EU member states achieved their established national target values in 2020 (Fig. 2). The most significant positive result was recorded by Belgium, which exceeded its

national target by 0.40 percentage points, against a goal of 3.00% of GDP. The second country with an investment surplus was Germany, which showed a slight positive deviation of 0.13 percentage points above the established three-percent threshold. Cyprus and Greece also joined the group of successful national strategy implementers, successfully saturating their strategic plans despite lower nominal investment values. Denmark and Italy can be categorized as countries that almost completely fulfilled their target values, with their investment levels lagging only marginally below the set targets.

The Czech Republic was not included in this part of the comparative analysis due to inconsistency in the reporting of national targets. The Czech strategic target is explicitly tied to government sector expenditure (1% limit).

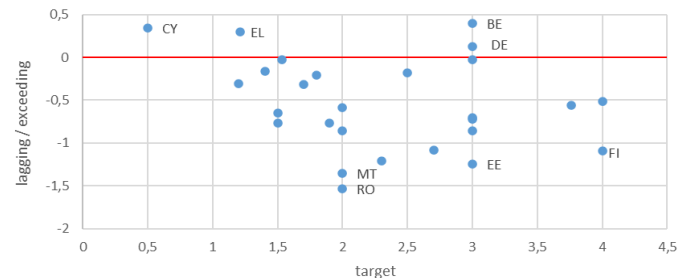


Fig. 2 Exceeding/lagging behind the national R&D target in 2020

The other analyzed countries, including the overall EU27 average, show a negative deviation, suggesting that the established targets were too ambitious for most economies, or that their achievement was slowed by unfavorable external factors. At the opposite end of the scale are states where the gap between the declared goal and the achieved reality is most striking, with Estonia and Finland showing the largest deficits. Estonia lagged behind its target by 1.25 percentage points and Finland by 1.09 percentage points. In the case of Finland, this is amplified by the fact that it aimed for a high level of 4.00% of GDP, which it failed to achieve despite nominally belonging to the European leaders. Similarly, ambitious Sweden fell short of its goal by 0.51 percentage points, although it actually achieves one of the highest R&D intensity rates in the Union at 3.49% of GDP.

The challenge for 2030

Given that the Union as a whole, as well as the vast majority of its member states, failed to meet the established innovation-intensity ambitions by 2020, the target of achieving R&D expenditure of 3.00% of GDP was set as a key benchmark for 2030. However, current data analysis for 2024 suggests a persistent polarization of the European Research Area, where only a limited group of countries currently meets this goal, while a significant portion of member states exhibits a substantial lag.

In the current comparison, six countries have already exceeded the 3% of GDP threshold (Fig. 3), establishing themselves as the Union's innovation leaders. Sweden exhibits the highest R&D intensity (3.57%), followed by Belgium (3.36%), Austria (3.26%), Finland (3.22%), Germany (3.13%), and Denmark (3.01%). These states constitute the core of the European innovation system, and their current values serve as a stabilizing factor in achieving the EU's common goal by the end of the decade.

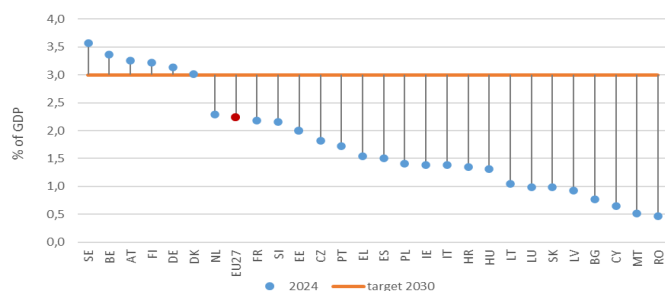


Fig. 3 Distance from the 3% target for 2030 in R&D expenditure

Considering the EU27 average, which reached 2.24% of GDP in 2024, it is evident that achieving the 2030 target will require accelerating investment by an additional 0.76 percentage points over the next six years. The countries closest to this average are the Netherlands (2.29%), France (2.18%), and Slovenia (2.16%), forming a middle group of countries with real potential to reach the 3% target if current growth dynamics are maintained. Estonia (1.99%) and the Czech Republic (1.82%) also show progress; however, their distance from the target requires systemic stimuli to strengthen, in particular, business research.

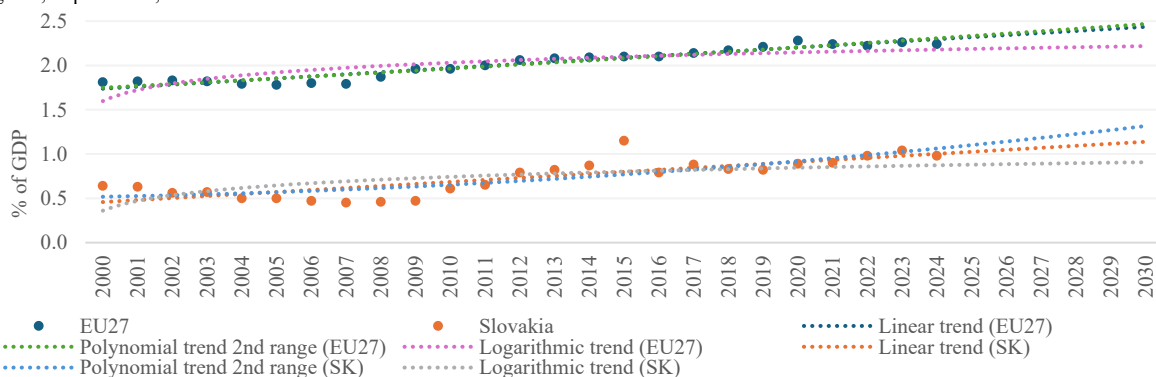


Fig. 4 Forecasting R&D intensity in EU27 and Slovakia

The linear model constructed for the EU27 aggregate exhibits a high degree of correlation and is statistically robust. The coefficient of determination ($R^2=0.9271$) indicates that the selected time variable explains more than 92% of the variability of the observed indicator (Table 1). The statistical significance of the model was confirmed by the F-test ($p<0.001$), and the slope coefficient was also highly significant.

In the case of the Slovak Republic, the regression model (Table 2) also demonstrated statistical significance ($p<0.001$), albeit with a lower explanatory power ($R^2=0.6685$). This suggests that innovation development in the domestic economy is more prone to fluctuations and the influence of exogenous factors than the EU average.

The robustness of the proposed regression models was verified through diagnostic testing of the residuals. The Jarque-Bera test confirmed the normality of the

A critical situation in the context of the 2030 target can be observed at the bottom of the ranking, where as many as thirteen member states have an R&D intensity below the 1.50% GDP threshold. The greatest convergence challenge is faced by countries such as Romania (0.46%), Malta (0.51%), and Cyprus (0.65%), which currently do not even reach one-quarter of the target value. Slovakia also belongs to this group of countries with a significant innovation deficit, lagging behind the common EU target by more than two percentage points with a value of 0.98% of GDP. For these economies, including Bulgaria (0.77%), Latvia (0.92%), and Poland (1.41%), the 2030 target represents an extremely ambitious benchmark, the achievement of which would require an unprecedented increase in both public and private investment in R&D activities. Based on the aforementioned facts, it is therefore possible to answer **RQ1: the degree of convergence toward the strategic target of 3% of GDP in the EU is insufficient.**

Forecasting R&D intensity in relation to the 2030 target

Following the analysis of the current state, a forecast of R&D expenditure intensity development up to 2030 was conducted for the European Union and the Slovak Republic. It should be noted that Slovakia is one of the few member states to have established a specific target value for R&D funding for 2030.

To assess the feasibility of the strategic 3% GDP target at the EU level and the specific national target for the Slovak Republic set at 2% of GDP by 2030, a time-series analysis using the Ordinary Least Squares (OLS) method was applied. This methodology allows for the extrapolation of current development trends and the estimation of the average annual increase in R&D intensity, while testing the assumption of a linear trend sustained through the end of the observed period.

In the modeling process, both linear and non-linear (quadratic) functional forms were tested (Fig. 4). Although the quadratic model exhibited a slightly higher explanatory power (expressed by the coefficient of determination R^2) in certain cases, it was rejected due to the statistical insignificance of the individual regression coefficients. For correct scientific interpretation, it is essential that not only the model as a whole (F-test) but also its partial explanatory variables (t-test) are statistically significant at the chosen significance level ($\alpha=0.05$). Since the quadratic term failed to meet this criterion in most cases, a linear trend was chosen for the forecast as a more robust and statistically sound tool, in accordance with the principle of parsimony.

distribution of the random error-terms (SR: $p=0.17$; EU27: $p=0.68$). The absence of heteroscedasticity was demonstrated by the Breusch-Pagan test (SR: $p=0.81$; EU27: $p=0.26$), confirming constant error variance. Although the Durbin-Watson test indicated the presence of positive autocorrelation (SR: 0.83; EU27: 1.02), this phenomenon is consistent with the nature of the analyzed macroeconomic time series and does not compromise the consistency of the trend estimates.

An analysis of the regression coefficient β_1 estimates that R&D intensity within the EU is growing at an average rate of 0.038 percentage points annually. If the current trend in the R&D expenditure-to-GDP ratio in the EU continues along this linear path, R&D intensity would reach 2.44% of GDP by 2030 (Table 3). This implies that, maintaining the current dynamics, the 3% GDP target will not be met at the EU27 level, with an expected deficit of 0.56 percentage points in the target year.

A critical finding emerges from the slope coefficient (β_1) for Slovakia: the average annual increase in R&D intensity is only 0.024 percentage points. Similarly, if the current trend in R&D expenditure followed a linear path, Slovakia would exhibit a research intensity of 1.14% of GDP in 2030 (Table 3). In the context of the national

target for the SR (2% of GDP), the forecast indicates a significant shortfall of 0.86 percentage points.

These facts allow us to answer **RQ2: maintaining a linear trend, the targets for both the EU27 and Slovakia are unrealistic, and a chronic misalignment exists between ambition and reality.**

Table 1 Results of regression analysis for EU27

Regression Statistics						
Multiple R	0,9629					
R Square	0,9271					
Adjusted R Square	0,9239					
Standard Error	0,0491					
Observations	25					

	df	SS	MS	F	Significance F	
Regression	1	0,7044	0,7044	292,5066	1,426E-14	
Residual	23	0,0554	0,0024			
Total	24	0,7597				

	Coefficients	Stand. Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1,7142	0,0202	84,724	3,29E-30	1,672	1,756
X Variable1	0,0233	0,0013	17,103	1,42E-14	0,020	0,026

Table 2 Results of regression analysis for Slovakia

Regression Statistics						
Multiple R	0,8123					
R Square	0,6598					
Adjusted R Square	0,6450					
Standard Error	0,1224					
Observations	25					

	df	SS	MS	F	Significance F	
Regression	1	0,6685	0,6685	44,6085	8,1834E-07	
Residual	23	0,3447	0,0150			
Total	24	1,0132				

	Coefficients	Stand. Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0,4352	0,0505	8,622	1,159E-08	0,331	0,539
X Variable1	0,0227	0,0034	6,679	8,183E-07	0,016	0,029

Table 3 Expected development of expenditure on research and development in EU27 and Slovakia until 2030

Region	Trend	Regression function	2025	2026	2027	2028	2029	2030	Target
EU27	Linear	$y = 0,0238x + 1,7099$, $R^2 = 0,9256$	2,32	2,34	2,37	2,39	2,41	2,44	3
	Polynomial – 2 nd range	$y = 0,0003x^2 + 0,0173x + 1,7381$, $R^2 = 0,9298$	2,39	2,42	2,46	2,49	2,53	2,56	3
	Logarithmic	$y = 0,1766\ln(x) + 1,604$, $R^2 = 0,7041$	2,18	2,18	2,18	2,18	2,18	2,18	3
SK	Linear	$y = 0,0228x + 0,4339$, $R^2 = 0,6357$	1,03	1,05	1,07	1,09	1,12	1,14	2
	Polynomial – 2 nd range	$y = 0,0008x^2 + 0,0019x + 0,5244$, $R^2 = 0,6682$	1,13	1,18	1,22	1,27	1,31	1,36	2
	Logarithmic	$y = 0,1525\ln(x) + 0,371$, $R^2 = 0,3918$	0,87	0,87	0,87	0,87	0,87	0,87	2

Although Slovakia's national target is set more realistically than the ambitious 3% European benchmark, the regression analysis results confirm that even this reduced threshold will not be met at the current rate of investment growth. The Slovak Republic thus faces a double challenge: it not only fails to reach the rate of convergence toward the EU27 average but also fails to meet its own, more conservatively set strategic limits. The **analysis confirmed the existence of a significant "innovation gap" (RQ3)**. While the EU27 average for nominal expenditure per capita is 897 €, the Slovak Republic, with a value below 1% of GDP and low per capita expenditure, lags significantly behind. Moreover, the regression analysis showed that the annual growth rate of R&D intensity in Slovakia (0.024 percentage points) is lower than the EU average (0.038 percentage points), indicating a risk of further divergence of Slovakia from advanced European economies instead of the expected catch-up.

To exactly confirm the differences in R&D funding levels between the Slovak Republic and the EU27 average, a paired t-test for means was conducted for the key strategic period of 2010-2024 (**Table 4**). The results demonstrated that the average R&D investment intensity in the SR during this period reached 0.87% of GDP, in sharp contrast to the average level of 2.14% of GDP recorded in the EU27.

Slovakia's average annual deficit relative to the European average thus represents 1.27 percentage points.

The calculated p-value is significantly lower than the established significance level $\alpha=0.05$. This result allows rejection of the null hypothesis of equal means and scientifically confirms the existence of a deep, highly statistically significant innovation gap.

Table 4 Results of the Paired t-test for R&D intensity (2010-2024)

	SR	EU
Mean (% GDP)	0,8667	2,1433
Variance	0,0192	0,0096
Observations	15	15
Pearson Correlation	0,6362	
t Stat	-46,1173	
P(T<=t) two-tail	1,07E-16	
t Critical two-tail	2,144787	

Although a moderate correlation ($r=0.636$) was identified between the two data series, reflecting common reactions to external economic incentives, the absolute

difference in investment remains nearly constant over time. The findings confirm that the Slovak Republic is not achieving the necessary rate of convergence toward the EU average, and without a radical change in the funding system, the risk of further deepening the technological lag remains critically high.

DISCUSSION

The results of our analysis confirm that the process of convergence toward R&D funding targets and the support of innovation performance remains highly asymmetrical within the European Union. Although the Europe 2020 strategy has formally concluded, its legacy in the form of the 3% GDP target persists. Our findings show that while the EU27 average exhibits a slight upward trend, the European Union still significantly lags in meeting this target, with far-reaching implications for its global competitiveness.

According to our calculations and in line with recent reports [33], average R&D expenditure in the EU remains significantly below the established 3% threshold. This pan-European deficit stems from short-term national policies that lack the long-term strategic commitment necessary for sustainable investment in innovation [34]. As stated by the European Commission, the failure to reach this target directly threatens the EU's global competitiveness, leading to increased dependence on foreign innovation and stagnation in key economic sectors.

Our analysis revealed deep regional disparities that divide the Union between innovation leaders and lagging regions. While North-Western countries consistently exceed the 3% limit and successfully balance public and private resources [35], Southern and Eastern European countries exhibit a chronic lack of investment. Low R&D intensity in these countries correlates with lower productivity, locking member states into a cycle of underdevelopment [36]. The concentration of innovation funds in already developed regions further deepens disparities in EU territorial cohesion [20]. For Central and Eastern European countries, the historical legacy of centrally planned economies represents an additional barrier, having left behind inadequate innovation structures and underfunded scientific sectors [37].

In this unfavorable European context, Slovakia's situation is particularly alarming. Our calculations are consistent with findings that rank the Slovak Republic, along with Bulgaria and Romania, among the EU countries with the lowest R&D efficiency [38]. Slovakia exhibits significant funding decline and instability, distancing it not only from the EU's 3% target but also from achieving its national target of 2% of GDP by 2030. If this country does not fundamentally change its funding policy, it risks becoming permanently trapped as an "assembly line" for technologically advanced economies, lacking its own capacity to generate high-tech innovations [18, 39].

For the Slovak Republic, the need to intensify R&D funding is compounded by its deep integration into the global automotive supply chain. This sector not only significantly contributes to the country's employment and economic performance but currently undergoes a radical transformation towards electromobility and sustainable materials. Our findings on the persistent investment gap suggest that Slovakia's current R&D dynamics are insufficient to meet the high costs of developing new technological standards. If funding for innovation activities continues to lag, the resulting technological gap will reduce the competitiveness of the domestic industry. The lack of capital inputs in this area directly limits the ability of domestic enterprises and research institutions to develop high-value-added innovative materials, such as advanced lightweight alloys or smart steel systems, which are essential for technological transformation and the transition to Industry 4.0 [40, 41]. To avoid the "middle-income trap", it is essential to redirect investments toward developing advanced materials and high-tech solutions that deliver greater added value within the European Research Area.

A fundamental barrier is Slovakia's extreme long-term dependence on public and European resources (34% of government resources, 22% of European resources). Such high dependence threatens the long-term sustainability of innovation strategies [42]. While the private sector takes the lead in the USA and among EU innovation leaders, private R&D investment in Slovakia is minimal and often channeled into subsidies rather than direct development activities [43]. Although programs like Horizon Europe increase the availability of funds, their absorption in countries such as the Slovak Republic is inconsistent [21], further weakening the innovation ecosystem. The involvement of the business sphere is an essential prerequisite for sustainable socioeconomic development [23].

The analysis results emphasize that for the Slovak environment, it is critical to direct both private and public investment into materials engineering and the development of innovative metal systems. These specific segments exhibit a high multiplier effect in industrial practice, where investments in advanced materials

processing strengthen technological sovereignty and confer a superior position within global value chains [44]. Prokop et al. add that Slovak firms insufficiently utilize foreign technologies and lack a coherent strategic framework for cooperation with the scientific community [45].

Low R&D funding has direct social consequences [46]. It negatively affects economic growth, productivity, and the economic resilience of countries during crises [47]. For Slovakia, this implies not only lower growth but also social risks associated with "brain drain" to more innovatively advanced parts of the EU [48]. If Slovakia and the EU do not increase investment in STEM education and research, their ability to adapt to global changes will remain limited [37]. The country may become an unattractive destination for researchers, which could weaken its capacity to meet the goals of the 2030 Agenda (specifically SDG 4 and SDG 9).

In light of these facts, it is essential for the Government of the Slovak Republic to adopt a coherent strategic framework to strengthen public-private partnerships (PPPs). Funding optimization should seek synergies between economic and environmental goals [26]. Inspiration should be drawn from Central and Eastern European models that more successfully utilize innovation mechanisms to strengthen national competitiveness. A priority must remain the support of applied research in newly developed materials, which form the foundation for innovation in the metallurgical and mechanical engineering sectors [49].

CONCLUSION

The econometric analysis confirmed the persistent structural lag of the Slovak Republic in R&D intensity. Using an OLS regression model based on data from 2010-2024, the study demonstrated that current linear growth dynamics are insufficient to meet either the EU-wide 3% GDP target or the Slovak national target of 2% GDP by 2030.

The forecast indicates that, under the existing trend, R&D intensity in the EU27 will reach approximately 2.44% of GDP by 2030, while Slovakia is expected to attain only 1.14% of GDP. These findings confirm a statistically significant and persistent innovation gap, as further validated by a paired t-test. Moreover, the lower annual growth rate of R&D intensity in Slovakia compared to the EU average suggests a risk of further divergence rather than convergence.

The results highlight three fundamental implications. First, the deepening innovation gap reflects insufficient structural transformation of the Slovak innovation ecosystem. Second, the mismatch between declared strategic objectives and actual development trends indicates that the 2030 targets are unrealistic under current funding dynamics. Third, without a substantial increase in private-sector participation and a more effective allocation of public resources, long-term competitiveness will remain constrained.

For an industrial economy strongly integrated into automotive and metallurgical value chains, R&D intensity represents not merely a macroeconomic indicator but a key precondition for technological upgrading. In this context, strengthening applied research in advanced materials and innovative metal systems is essential for increasing value added, supporting industrial decarbonization, and enhancing technological sovereignty.

Achieving the objectives of the 2030 Agenda, particularly SDG 9, will therefore depend on the ability to transform financial inputs into measurable innovation outputs and to ensure stronger alignment between public funding mechanisms and private investment incentives.

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