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TÁC ĐỘNG CỦA HOẠT ĐỘNG R&D TỚI ĐỔI MỚI SÁNG TẠO CỦA 27 QUỐC GIA THUỘC EU HƯỚNG TỚI MỤC TIÊU 09 CỦA PHÁT TRIỂN BỀN VỮNG

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Tóm tắt

Nghiên cứu này khám phá mối quan hệ giữa nghiên cứu và phát triển (R&D), đổi mới và việc đạt được mục tiêu 9.5 trong Mục tiêu phát triển bền vững 9 (SDG9) tại 27 quốc gia thuộc Liên minh Châu Âu (EU). Sử dụng phân tích hồi quy bội, nghiên cứu xem xét tác động của cường độ R&D theo ngành, tỷ lệ nhà nghiên cứu trên một triệu dân và phân bổ ngân sách chính phủ cho R&D đối với việc đạt được mục tiêu 9,5 của SDG9 (SDG9,5). Các phát hiện này chứng minh mối liên hệ tích cực giữa cường độ R&D, chi tiêu R&D trong chính phủ và các khu vực giáo dục đại học, cũng như số lượng nhà nghiên cứu và đổi mới, trong khi tồn tại mối quan hệ tiêu cực giữa chi tiêu R&D trong khu vực doanh nghiệp tư nhân và đổi mới. Dựa trên những phát hiện này, nghiên cứu cũng đưa ra các khuyến nghị chính sách để hoàn thành SDG9.5.

IMPACTS OF R&D ACTIVITIES ON INNOVATION IN 27 EU COUNTRIES TOWARD SUSTAINABLE DEVELOPMENT GOAL 9 (SGD 9)

Abstract

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This study explores the relationship between research and development (R&D), innovation, and the achievement of target 9.5 in Sustainable Development Goal 9 (SDG9) in 27 European Union (EU) countries. Using multiple regression analysis, the study examines the impact of R&D intensity by sector, the ratio of researchers per million inhabitants, and government budget allocations for R&D on the achievement of target 9.5 of SDG9 (SDG9.5). The findings demonstrate a positive association between R&D intensity, R&D spending in the government and higher education sectors, as well as the number of researchers, and innovation, whereas a negative relationship exists between R&D expenditure in the private enterprise sector and innovation. Based on these findings, the study also offers policy recommendations for completing SDG9.5.

Keywords: R&D, innovation, SDG9, target 9.5, EU27

1. Introduction

The United Nations adopted and endorsed the 2030 Agenda for Sustainable Development in September 2015; it is a set of well-considered policies intended to strike a balance between environmental preservation and economic development, while also taking into account the need to address the gaps that currently exist between highly industrialized and developing nations. There are 17 Sustainable Development Goals (SDGs) in the Agenda, each with a unique focus. For the European Union (EU), entrepreneurship, innovation, and R&D activities are essential factors that help overcome global societal challenges and set the path to economic prosperity sustainably (Vollenbroek, 2002, p. 200).

SDG9 urges nations to develop resilient infrastructure, advance inclusive and sustainable industrialization, and promote innovation to address the myriad of political, economic, and sustainability difficulties the EU is currently facing. Rapid and persistent improvements in everyone's level of life are made possible by inclusive and sustainable industrial development, which is a significant source of revenue. Competitiveness, economic expansion, job creation, labor productivity, and resource efficiency are all fueled by innovation and R&D. They are also crucial for combating the COVID-19 pandemic and its economic and social ramifications as well as assisting the EU's economic recovery. R&D and innovation are essential for bringing about the European Green Deal and the Digital Single Market, in general. By undergoing a 'green transformation', industry plays a leading role in achieving a clean, competitive, and circular economy.

This research is conducted in 27 countries in the European Union for 10 years, from 2011 to 2021; focuses on analyzing the relationship between R&D investment and innovation, on that basis, proposing ways to achieve SDG9 in nations of the EU. The research will focus mainly on Target 9.5 in SDG9 (SDG9.5), which is to enhance research and upgrade industrial technologies.

By analyzing their R&D expenditure, government budget, and researcher amounts, we aim to understand the factors that enable EU countries to effectively transition from R&D to innovation and contribute to achieving SDG9. The main objectives of this study are: (1) To identify the key factors that have allowed EU27 to shift from R&D to innovation; (2)

To analyze the funding mechanisms and innovation systems in place across the EU countries and identify the role they play in fostering innovation and achieving SDG9.

The remainder of this paper is structured into four main parts: (a) literature review, in which papers approach the topic specific to the relationship between research - development - innovation, and sustainable development are discussed, (b) methodology and data, a section that explains the econometric approach, the source and method of data collection and processing, (c) results and lastly (d) conclusion.

2. Literature review

2.1. Innovation

Innovation is the process of creating value by applying novel solutions to meaningful problems (Davila et al., 2012). On a national scale, Innovation is developed as a system, which is known as National System of Innovation (NSI). NSI is accepted by many scholars and utilized in various studies, as Asheim and Isaksen defined NSI "An innovation system consists of a production structure (techno-economic structures) and an institutional infrastructure (political–institutional structures)." (Asheim & Isaksen, 1997). Another study by Mytelka at Aalborg University (2003) stated that NSI is "A network of economic agents, together with the institutions and policies that influence their innovative behavior and performance".

Previous studies have emphasized the multifaceted nature of innovation, highlighting its dynamic and iterative characteristics. Schumpeter described innovation as a "creative destruction" process that drives economic progress through the introduction of new products, methods of production, markets, and forms of organization. Rogers, in his book, identified innovation as a diffusion process involving the adoption, adaptation, and dissemination of new ideas across individuals and organizations (QUINLAN, 2008).

Innovation is essential for economic growth, social development, and environmental sustainability, as it can generate new sources of revenue or reduce costs by creating new markets or increasing market share; enhance customer satisfaction or loyalty by offering better quality, functionality, design, or convenience; foster learning and knowledge creation by stimulating curiosity, experimentation, feedback, and adaptation; solve complex problems or challenges by finding new ways of thinking, collaborating, or acting; and create positive social or environmental impact by improving well-being, equity, inclusion, or resilience (Davila et al., 2012).

2.2. R&D and Innovation

Research and development (R&D) is a term that encompasses the activities undertaken by firms or governments to create new or improved products, services, processes, or technologies. R&D is a key driver of innovation and economic growth, as it can lead to new or improved products or processes that enhance productivity, efficiency, quality, customer satisfaction, and competitiveness. Investing in R&D can lead to spillover effects, where the benefits extend beyond the organization conducting the research. These spillovers can manifest as knowledge diffusion, industry collaborations, and the creation of new job opportunities. R&D also contributes to the accumulation of intellectual capital, including patents, copyrights, and trademarks, which can be valuable assets and generate economic returns. Additionally, R&D has the potential to address societal challenges and improve quality of life. It can drive advancements in healthcare, energy, transportation, and other critical sectors, leading to improved standards of living, increased sustainability, and enhanced well-being.

2.2.1. R&D intensity (RDI) and innovation

R&D intensity (RDI) refers to the amount of investment a company or industry allocates towards R&D activities. There is a strong correlation between R&D intensity and innovation. Companies and industries that invest more in R&D are more likely to drive innovation and create new and improved products or services. This investment allows them to develop new technologies, improve existing products, and adapt to changing market demands.

Numerous studies have explored the relationship between R&D intensity and innovation, which is consistently positive. Higher levels of R&D investment tend to result in increased innovation outputs. This relationship can be observed across various industries and sectors. A study by Belderbos, Carree, and Lokshin analyzed a large sample of Dutch manufacturing firms to found that higher R&D intensity was associated with greater innovation performance (Belderbos et al., 2004). Similarly, research by Cincera and Veugelers analyzed data from European firms and found a positive relationship between R&D intensity and innovation outcomes (Cincera & Veugelers, 2013).

2.2.2. Researcher personnel (RPI) and innovation

Researchers per million inhabitants (RPI) is a commonly used metric to measure a country's research personnel. RPI evaluates a country's investment in R&D and innovation capabilities. Higher RPI results in more knowledge generation, cooperation, networking, technology transfer, and improved research infrastructure and financing. A higher RPI stimulates innovative companies and provides funding for research initiatives, eventually increasing levels of innovation.

Griliches analyzed the relationship between R&D personnel and innovation output across industries in the United States. He found a positive correlation between R&D personnel and patents, suggesting that a higher RPI contributes to increased innovation (Griliches, 1998). Baesu analyze determinants of high-tech sector innovation performance in EU countries using panel data analysis, comparing fixed and random effects models from 1994–2011. The result shows that the innovation output in the high-tech industry is positively influenced by the number of R&D personnel (Baesu et al., 2015).

2.2.3. Government budget allocations for R&D (GBARD) and innovation

The OECD defines GBARD as all expenditure commitments covered by sources of government income anticipated in the budget, such as taxation. GBARD (funder-based approach) assesses government support for R&D using information from government budgets (OECD, 2015).

Several previous researches have also mentioned the relationship between GBARD and innovation on business level. The research by Dritsaki suggests that R&D funding by the government was found to have a significant positive relationship with the global innovation index—GII in EU countries (Dritsaki & Dritsaki, 2023). Another study by Czarnitzki examining the effect of R&D tax credits on innovation activities of Canadian manufacturing firms confirmed that tax credits lead to additional innovation output (Czarnitzki et al., 2011). In another perspective, Zhang found that the support of R&D projects by federal agencies has helped to increase the quantity of patent records (Zhang et al., 2022). However, the authors find a lack of research conducted on national level, which is the main focus of this study.

2.2.4. R&D expenditure in Government sector (GOVERD) and innovation

R&D expenditure in Government sector (GOVERD) is defined by OECD as an accurate measure of government funding for intramural R&D performed in the economy as a fraction of GDP expenditure on R&D (GERD). According to OECD, GOVERD takes into account R&D that is funded from foreign sources but does not consider domestic funding for R&D that is carried out outside the country. Importantly, not all GOVERD is necessarily financed by the government, it can be funded by the business sector (OECD, 2015).

Numerous studies have examined the relationship between GOVERD and its impact on innovation. However, there is considerable variation in the empirical findings across these studies (Dimos & Pugh, 2016). Some scholars argue that R&D expenditures complement the financing of a firm's R&D spending (Bronzini & Piselli, 2016), whereas others suggest that government R&D expenditures crowd out private R&D spending (Boeing, 2016; David et al., 2000). Vicente attribute these disparities primarily to differences in methodologies, country samples, and variables employed (Zúñiga-Vicente et al., 2014). Notably, most research studies have typically overlooked the influence of institutional quality when examining the impact of R&D on innovation, which constitutes a central focus of this paper.

2.2.5. R&D expenditure in Business enterprise sector (BERD) and innovation

Businesses' innovation efforts are frequently seen as the main force behind technical advancement and long-term prosperity (Czarnitzki & Delanote, 2013). Spending money on R&D in business is primarily done to increase innovation performance and, ultimately, the firm's market competitiveness, which can be seen in the financial health of the company. Some studies found a positive effect of R&D spending on the growth of the firm (Pieri et al., 2018) in both the short and long run (Huňady & Pisár, 2021). Others have also demonstrated that raising R&D investment levels over a certain point is unproductive or even harmful to innovation outcomes (Graves & Langowitz, 1996). While business and government R&D spending may be easily assessed, it is more challenging to gauge how these expenditures affect innovation (Huňady & Pisár, 2021). There are numerous papers studying the effect of private sector R&D on the firm's innovation through the lens of patents (Acs & Audretsch, 1990; Bronzini & Piselli, 2016; Cardinal & Hatfield, 2000; Peeters & van Pottelsberghe de la Potterie, 2007), but none measure the impact on the overall innovation performance of a country. According to the OECD (2021), a broader perspective is required to fully evaluate R&D and innovation contributions to the collection of SDGs, such as R&D budgets and other R&D indicators.

2.2.6. R&D expenditure in Higher education sector (HERD) and innovation

The Human Capital Theory (Becker, 1962; Rosen, 1976) suggests that investment in education is necessary to develop and improve human capital. By acquiring new knowledge and skills, individuals are better equipped to perform tasks, generate innovative ideas, and adapt to changing economic conditions. This investment in human capital benefits individuals and contributes to overall economic growth and productivity. The Knowledge Spillover Theory, hypothesized by Alfred Marshall in 1980, further indicates that investment in R&D activities in higher education may produce new knowledge and ideas that spread across the economy (Audretsch & Feldman, 1996). Universities and research institutes often conduct basic and applied research, which can lead to technological advances and innovation outside of the academic context.

The Triple Helix Model (Etzkowitz & Leydesdorff, 1995) emphasizes the collaboration and interaction between academia, industry, and government in stimulating innovation. R&D expenditure in the higher education sector can facilitate collaborations with businesses, resulting in knowledge transfer, commercialization of research outputs, and the development of innovative goods and services. Lopes argue that the population with tertiary education constitutes an effective instrument of innovation policy (Lopes et al., 2021).

2.3. Sustainable Development Goal 9 (SDG9)

2.3.1 SDG9 definition

Sustainable Development Goal 9 (SDG9) aims to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. SDG9 recognizes the crucial role of infrastructure and innovation in achieving sustainable development and advancing economic growth. This goal emphasizes the need for affordable and reliable access to basic infrastructure services, such as transportation, energy, and communication, especially in developing countries. SDG9 includes eight critical targets, illustrated in **Figure 1**.

SDG9 focuses on the impact of manufacturing activities on production, employment, and the environment (Kynčlová et al., 2020). SDG9 is widely recognized for its importance in achieving sustainable development. Scholars have emphasized that sustainable industrialization can raise living standards and provide jobs, and that infrastructure development is a key factor in economic progress. Sinan once stated World leaders adopted SDG-9 for infrastructure and industrial investments in the 2030 Agenda for Sustainable

Development to combat inequalities and combat climate change (Küfeoğlu, 2022). João emphasize the importance of science and technology in implementing the Sustainable Development Goals (SDGs) (João et al., 2022). They cite Strohschneider's concept of approaches, stating that science can contribute by explaining interconnections, understanding thresholds, effective spillovers, and breakpoints, and supporting the evaluation and monitoring of SDGs' achievement, especially SDG9. Also, the 2030 Agenda aims to support developing and underdeveloped countries in achieving sustainable economic growth, social and grassroots development, and combating climate change. As a result, a collaborative effort from governments, non-governmental organizations, the private sector, and universities is needed to find solutions to these challenges (*Destination 2030*, n.d.).

Figure 1. The targets of SDG9

Source: *United Nations 2021*

The literature study, taken as a whole, emphasizes the necessity of rigorous planning and coordination to guarantee that investments in infrastructure, industrialization, and innovation promote results for sustainable development.

2.3.2 SDG9 and R&D

The literature suggests that R&D is a critical enabler of sustainable development and achieving SDG9. The research of Ahmad Salman articulated the relationship between SDG9 and R&D as "sustainable development goal 9 promotes R&D expenditure as a proportion of the GDP and the number of researchers per million inhabitants" (Salman et al., 2020).

One target included in SDG9 that has a close relationship with R&D is the SDG9.5 target: Enhance research and upgrade industrial technologies. One study has highlighted the definition of the SDG9.5 and the remarkable role of R&D in achieving SDG9: "SDG9.5 deals with enhancing scientific research and capabilities, especially in developing countries. Inequality in access to knowledge creates a barrier to scientific research. Much of the latest research is behind gated journals. This inequality in access is even greater in the developing world, where many institutions do not have the budget to subscribe to these journals" (Cyr & Connaway, 2020). Based on that, a study by Sinan Küfeoğlu pointed out that the fifth goal of SDG9 is to improve research, modernize industrial technologies, increase R&D spending, and use indicators like new product development or infrastructure that is already in place. According to the SDG Progress report (*The Sustainable Development Goals Report 2021*, 2021), global R&D spending has increased, accounting for 1.7% of global GDP in 2014.

2.4. Hypothesis development

The "OECD Main Science and Technology Indicators Highlights on R&D expenditure, March 2021 release" (OECD, 2023) stated the "Limited directionality of government R&D support towards specific SDGs" while R&D intensity and other R&D indicators are used to track progress toward SDG9, a broader viewpoint is required to fully evaluate R&D and innovation contribution to the collection of SDGs. Budgets for R&D do not cleanly fit into predefined categories and lack the specificity of some SDGs. However, governments frequently assign R&D planning and expenditure decisions to public agencies and, in many cases, commercial players for a variety of reasons, which poses a difficulty for SDG association and interpretation. For example, generic institutional support for universities and the majority of R&D tax incentives for businesses are examples of non-directed funding approaches for R&D. Such sponsored R&D may potentially have an impact on multiple SDGs simultaneously. Sponsored R&D have the potential to impact multiple Sustainable Development Goals (SDGs) simultaneously, particularly in the case of fundamental research. However, the impact may not be immediately visible, and it may take several years to translate into tangible solutions. Such solutions may also require further investments to materialize.

This study aims to fulfill a minor part of the research gap. We hypothesize that:

H1: R&D intensity in all sectors has a significant positive impact on Innovation.

H2: Number of researchers has a significant positive impact on Innovation.

H3: R&D expenditure in Business enterprise sector has a significant positive impact on Innovation.

H4: R&D expenditure in Government sector has a significant positive impact on Innovation.

H5: R&D expenditure in Higher education sector has a significant positive impact on Innovation.

H6: Government budget allocations for R&D have a significant positive impact on Innovation.

3. Methodology and data

3.1. Methodology

3.1.1. Data collection techniques

This study uses a sample of 27 European Union nations from 2011 to 2021. The panel has a total of 230 observations due to some missing observations. Secondary data is used. The database was mostly compiled through access to the World Bank, OECD, and Eustats, all of which are officially recognized international sources. **Table 1** shows the variables used in the empirical analysis and the data source.

Table 1. Variables

Abbreviation	Variable	Source
INN	Innovation Index	The global economy
RDI	R&D intensity	Eurostat
BERD	R & D expenditure in Business enterprise sector	OECD
GOVERD	R&D expenditure in Government sector	Worldbank
HERD	R&D expenditure in Higher education sector	OECD
GBARD	Government budget allocations for R&D	Eurostat
RPI	Researchers per million inhabitants	OECD, Eurostat

3.1.2. Data analysis techniques

As previously stated, we estimate the model using panel data, which strives to explain the effects of R&D investment on innovation of the 27 European Union nations between 2011 and 2021. We employed a linear model specification, therefore the calculated coefficients are constant elasticities that reflect the change in the dependent variable due to a unit change in the explanatory variables. The model appears as follows:

$$INNit = \beta_0 + \beta_1 * RDIit + \beta_2 * BERDit + \beta_3 * GOVERDit + \beta_4 * HERDit + \beta_5 * GBARDit + \beta_6 * RPI + \mu$$

Three methods of estimation are used to estimate the above equation.

The fixed effects (FE) model captures the country-specific heterogeneity in the constant part (as it is different from country to country). By including fixed effects for each individual or entity, it captures time-invariant differences, eliminating bias and providing more accurate estimates of coefficients of interest. However, it cannot account for time-varying factors or changes in the relationship between dependent and independent variables over time (Gurka et al., 2012).

The fixed effects (FE) robust model addresses heteroscedasticity and correlation within clusters by estimating robust standard errors that consider the potential correlation of observations within each cluster. This approach allows more reliable inference and hypothesis testing for hierarchical or clustered data, such as regions or industries. However, it can be computationally intensive and may require larger sample sizes for accurate results.

The random effects (RE) model estimates within-group and between-group effects by assuming random, uncorrelated, unobserved heterogeneity with independent variables. This approach may be used to estimate average effects across entities or time-invariant heterogeneity. It is more efficient than fixed effect regression, especially when large entities are involved. However, it assumes random effects are uncorrelated with independent variables, which may not always be true in practice (Gurka et al., 2012).

3.2. Proxy to measure

3.2.1. Dependent variables

The research group selected the Innovation index as the dependent variable as Innovation is a critical enabler of achieving SDG9. The Innovation Index (Global Innovation Index) is “an annual ranking of countries by their capacity for, and success in, innovation” (WIPO, 2022). This Index is calculated by averaging the scores of two subindices: Innovation Input Sub-Index and Innovation Output Sub-Index, which consist of seven pillars. By tracking changes in institutions, human capital and research, infrastructure, market sophistication, business sophistication, knowledge and technology outputs, and creative outputs, the Index helps policymakers assess their country's innovation ecosystem and identify areas for improvement. With these various indicators, the performance of the economies can also be tracked and their advancements can be compared to other economies in the same region. Through the promotion of innovation and investment in infrastructure, SDG9 and the Innovation Index work together to enhance economic growth, increase productivity, and create more sustainable societies.

Several studies have highlighted the importance of innovation in achieving SDG9. For example, a study by the United Nations Development Programme (UNDP) found that countries investing in innovation tend to do better in achieving the SDGs. Another study by OECD showed that innovation can help to address sustainability challenges by promoting the development of new technologies and processes that can reduce environmental impacts and promote sustainable development. Sinan Küfeoğlu's study highlights the importance of industry-innovation cooperation in developing sustainable infrastructure, focusing on achieving specific objectives through infrastructure improvement.

3.2.2. Independent variables

- **RDI: R&D intensity**

R&D intensity for a country is defined as "the ratio of gross domestic expenditure on R&D (GERD) to GDP" (OECD, 2015). R&D intensity plays a critical role in achieving SDG9.5, as it determines the level of investment that developing countries make towards R&D activities. By increasing R&D intensity, these countries can build capacity, enhance their scientific and technological capability, and promote innovation. This can help these nations to address social, economic, and environmental challenges sustainably while fostering inclusive and sustainable development.

It is expected that R&D investment would have a positive and significant effect on the level of innovation. However, in this study, the authors also distinguish between different components of the overall investment in R&D, since the impact on innovation may follow different trends according to the sector undertaking the investment. In this respect, the model distinguishes between private (BERD), public (GOVERD), and higher education (HERD) R&D investment.

- **BERD** represents the R&D expenditure of the business enterprise (private) sector as a percentage of GDP.
- **GOVERD** covers the government expenditure on R&D, e.g., research centers, agencies, institutes, etc. (except for public universities), as a percentage of GDP.
- **HERD** represents the higher education sector expenditure on R&D.
- **RPI: Researchers per million inhabitants**

This is an important metric, as it represents the level of human capital available to conduct R&D activities (UNESCO Institute for Statistics). By increasing the number of researchers per million inhabitants, developing countries can build the capacity to generate new ideas, create innovative solutions, and promote sustainable development. Furthermore, this target can help to promote knowledge-sharing and exchange of expertise between developing and developed countries, which can further strengthen scientific research capabilities in developing nations.

- **GBARD: Government budget allocations for R&D**

According to OECD, GBARD encompasses all spending allocations met from sources of government revenue foreseen within the budget, such as taxation. GBARD measures government funding of R&D using data from government budgets (funder-based approach) (OECD, 2015).

A significant government budget allocation for R&D can provide the necessary financial resources to support scientific research and develop new technologies, products, and processes. This can enable developing countries to address social, economic, and environmental challenges while fostering sustainable development. Therefore, the authors expect that increasing government budget allocations for R&D in developing countries is essential to achieve SDG9.5 and advance scientific research capabilities in these nations.

3.3. Model specification

3.3.1. Descriptive statistics and interpretation for each variable

Table 2. Data statistical description (STATA)

Variable	Obs	Mean	Std. Dev.	Min	Max
INN	268	48.84851	7.387039	34.2	64.8
RDI	230	1.773814	.8647339	.3816107	3.618063
BERD	270	167.4241	109.1151	50.4	770.6
GOVERD	270	124.9126	125.0741	13	1659.3
HERD	270	152.1559	97.36694	44.8	678.3
GBARD	265	3139.598	5879.737	14.405	35610.25
RPI	270	3690.007	1766.214	790.688	8065.887

Source: *Authors, 2023*

This research uses data from 27 Europe Union countries (since 2020) from 2011 to 2020 with 270 observations so it can fairly reflect the relationship between R&D index and Innovation index:

• INN: The average Innovation index is 48.84851 with the standard deviation of 7.387039. The minimum amount is 34.2 and the maximum amount is 64.8. The range of variation between the maximum value and the minimum value of the variable INN is relatively large, indicating that there is a significant difference between innovation index among the countries over years.

• RDI: The average R&D expenditure as a percentage of GDP from 2011 to 2020 is 1.773814% with the standard deviation of 0.8647339. The minimum amount is 0.3816107% and the maximum amount is 3.618063%. The range of variation between the maximum value and the minimum value of the variable RDI is relatively large, indicating that there is a significant difference between R&D expenditure as percentage of GDP among the countries over years.

• BERD: The average R&D expenditure in Business enterprise sector from 2011 to 2020 is 167.4241 in constant USD PPPs (Index 2007 = 100) with the standard deviation of 109.1151. The minimum amount is 50.4 and the maximum amount is 770.6. The range of variation between the maximum value and the minimum value of the variable BERD is relatively large, indicating that there is a significant difference between R&D expenditure in Business enterprise sector among the countries over years.

• GOVERD: The average R&D expenditure in Government sector from 2011 to 2020 is 124.9126 in constant USD PPPs (Index 2007 = 100) with the standard deviation of 125.0741. The minimum amount is 13 and the maximum amount is 1659.3. The range of variation between the maximum value and the minimum value of the variable GOVERD is vast, indicating that there is a significant difference between R&D expenditure in the Government sector among the countries over years.

• HERD: The average R&D expenditure in Higher education sector from 2011 to 2020 is 152.1559 in constant USD PPPs (Index 2007 = 100) with the standard deviation of 97.36694. The minimum amount is 44.8 and the maximum amount is 678.3. This implies that the orientations of countries' R&D development in the context of higher education are diverse.

• GBARD: The average Government budget allocations for R&D from 2011 to 2020 is 3139.598 million euros with the standard deviation of 5879.737. The minimum amount is 14.405 and the maximum amount is 35610.25 million euros. The range of variation between the maximum budget and the minimum budget of the variable GBARD is very large, indicating that there is a significant difference between Government budget allocations for R&D among countries.

• RPI: The average Researchers per million inhabitants from 2011 to 2020 is 3690.007 researchers per million inhabitants with the standard deviation of 1766.214. The minimum amount is 790.688 and the maximum amount is 8065.887 researchers per million inhabitants. The variation between the minimum and maximum value is very high which indicates that these indexes vary a lot.

3.3.2 Correlation matrix between variables

Table 3. Correlation matrix between the variables (STATA)

	INN	RDI	BERD	GOVERD	HERD	GBARD	RPI

INN	1.0000						
RDI	**0.7485**	1.0000					
BERD	**-0.3688**	**-0.1649**	1.0000				
GOVERD	0.0305	-0.0144	-0.0936	1.0000			
HERD	**0.1310**	-0.1027	0.0947	**0.1303**	1.0000		
GBARD	**0.3303**	**0.3878**	**-0.1590**	-0.0497	-0.1042	1.0000	
RPI	**0.7756**	**0.8340**	**-0.2253**	-0.0954	**0.1309**	**0.2139**	1.0000

Source: *Authors, 2023*

(bolded numbers: $p < 0.05$)

• r(INN, RDI) = 0.7485: Innovation index and R&D expenditure as a percentage of GDP is positively correlated and the level of correlation between the 2 variables is strong, as expected.

• r(INN, BERD) = -0.3688: Innovation index and R&D expenditure in Business enterprise sector are negatively correlated and the level of correlation between the 2 variables is weak. In this case, it contradicts the H3 hypothesis.

• r(INN, GOVERD) = 0.0305: Innovation index and R&D expenditure in Government sector are positively correlated and the level of correlation between the 2 variables is very weak, as expected.

• r(INN, HERD) = 0.1310: Innovation index and R&D expenditure in Higher education sector are positively correlated and the level of correlation between the 2 variables is very weak, as expected.

• r(INN, GBARD) = 0.3303: Innovation index and R&D expenditure in Higher education sector are positively correlated as expected and the level of correlation between the 2 variables is weak, as expected.

• r(INN, RPI) = 0.3303: Innovation index and Researchers per million inhabitants are positively correlated as expected and the level of correlation between the 2 variables is weak, as expected.

In general, the correlation between independent variables in the model is not too significant. The highest correlation is 0.8340, which is the correlation between R&D expenditure as a percentage of GDP and Researchers per million inhabitants. To ensure the accuracy of the model, besides considering the correlation coefficient between the pairs of individual variables, the authors conduct a multicollinearity test.

Table 4. Testing the existence of multicollinearity (STATA)

Variable	VIF	1/VIF
RDI	5.32	0.188116
RPI	4.93	0.203015
HERD	1.48	0.674951
GBARD	1.41	0.708778
GOVERD	1.30	0.771259
BERD	1.17	0.851878
Mean VIF	2.60	

Source: *Authors, 2023*

From this result, we have: Mean VIF (=2.60) is smaller than 10. Thus, we can conclude that there is no perfect multicollinearity among our regressors, that is the correlation between two variables different from and a low chance of unreliable outcomes in the model. Our sample data satisfy the assumption that there is no perfect multicollinearity of the Gauss-Markov Classical Linear Regression Model assumptions.

4. Result

The study analyzes the regression model with panel data and obtains the estimation and testing results which are described in Table 4 as follow:

Table 5. Estimation and testing results

Variables	**RE**	**FE**	**FE Robust**
	INN	***INN***	***INN***
RDI	2.788596***	.7088507	3.345072***
	(.7424136)	(.8958149)	(.6699559)
BERD	-.0114445***	-.0025337	-.0162797***
	(.0028311)	(.0033129)	(.0022586)

GOVERD	-.0180095***	-.0054873	-.020946***
	(.0059242)	(.0063865)	(.0054402)
HERD	.0026725	.0002884	.0104707***
	(.0034128)	(.0035558)	(.0032107)
RPI	.0006506**	.0000725	.0014716***
	(.0002936)	(.0003169)	(.0003042)
GBARD	.0000442	.0000186	.0001054***
	(.0001)	(.0001332)	(.0000332)
Intercept	45.33429***	49.12076***	39.636***
	(1.457623)	(1.416774)	(1.071058)
Number of observations	224	224	224
R-squared	0.7115	0.6649	
Model selection Testing			
Lagrange multiplier test	chibar2(01) = 536.23 Prob > chibar2 = 0.0000		
Hausman test	chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B) = 27.73 Prob>chi2 = 0.0001		
Model defect identification			
Testing for Heteroskedasticity	chi2 (23) = 358.95 Prob>chi2 = 0.0000		

Testing for Autocorrelation	F(1, 22) = 29.568 Prob > F = 0.0000

Source: *Authors, 2023*

Standard errors in parentheses ***p<0.01, **p<0.05,*p<0.1

The test to determine the appropriate model among three models: pooled regression models (POLS), fixed effects model (FE) and random effects model (RE) was based on the results of Breusch and Pagan Lagrangian multiplier test for random effects and Hausman test are shown in Table 4. The authors conducted a Lagrange test, and the results p-value = 0.0000 < α = 0.05. So, the POLS model is not suitable. After that, the authors continued to use the Hausman test to choose between RE and FE models, p-value = 0.0001 < α = 0.05, and the FE model was selected. In addition, to detect and overcome the defects of the model, the authors continue to test the heteroskedasticity and test for autocorrelation. Realizing that the model had 2 defects: heteroskedasticity and autocorrelation, the authors have overcome it with a regression model with Robust.

The regression results of the model show that: Among the 6 variables included in the model, at a 1% significance level, the explanatory variables are all statistically significant and can explain the relationship with the dependent variable which is Innovation. The coefficient of RDI, HERD, RPI, and GBARD illustrates the positive relationship with Innovation as expected, while the relationship between Innovation and BERD, GOVERD is inverse which is not supported by the theory and goes against the hypothesis. Although the result is not expected, it can be explained as follows:

For the BERD, the negative relationship between it and Innovation index could be due to several reasons. This could be due to inadequate R&D processes or investments in areas not aligned with core competencies or market needs. Another possible explanation for this is the innovation index may be biased towards incremental improvements rather than breakthrough innovations, causing businesses that invest heavily in R&D to create breakthrough innovations to not be fully reflected, resulting in a negative relationship between R&D spending and the index.

In terms of GOVERD, the relationship between R&D and innovation is complex, with government sector factors influencing results. Government R&D spending may face bureaucratic constraints and political pressures, limiting its effectiveness in promoting innovation. Previous studies have also shown mixed results on the relationship between government R&D expenditure and innovation. Some studies have found a positive effect, while others have found no significant relationship or even a negative effect. For example, a study found that government R&D expenditure had a negative effect on innovation in developing countries (Luintel & Khan, 1999), while another found that government R&D expenditure had a positive effect on innovation in South Korea (Lee & Kim, 2016).

The relationship between independent variables and SDG9.5 can be clarified through a mediation model, where impact of independent variables towards SD9 has been checked through the influence on Innovation index. The Innovation index has a direct impact on SDG9.5, therefore, it means that independent variables will have different impact on Innovation index, which again has impact on the SDG9.5. Specifically, as RDI, HERD, RPI and GBARD variables have positive impact on Innovation index, we can conclude that they also have positive effect on SDG9.5. For BERD and GOVERD variables, as they have negative impact on Innovation index, we can also conclude that they have negative impact on SDG9.5 goal.

5. Conclusions and recommendations

This study has investigated the connection between R&D, innovation, and achieving SDG9.5 of Sustainable Development Goals by evaluating the impact of R&D intensity, number of researchers, and government budget allocation for R&D on innovation in 27 EU countries. To be more precise, this paper also separates R&D intensity into different sectors: private-business enterprise sector, public-government sector, and higher education sector to examine whether the investments of R&D in different sectors have different effects on innovation. The obtained results show that R&D intensity, R&D expenditure in the government sector, and higher education sector along with the number of researchers have a positive relationship with innovation, while R&D expenditure in the business enterprise sector has an adverse effect on innovation. In addition, the result also indicates that there are considerable disparities in R&D activities throughout the years within a nation and among 27 EU members.

A consistent investment in R&D is necessary to generate increasingly complex and sustainable innovations, and as a result, the study offers policy implications for achieving SDG9, notably Target 9.5 (Ganda, 2019). In order to explore the potential benefits of investing in R&D on SDG9 and general sustainable development, there must be significant efforts made by governments, the commercial sector, and the higher education sector.

The government should keep up its efforts to increase R&D investment volume and boost the efficiency of R&D funding. The government may decrease taxes and provide subsidies to encourage businesses to support their R&D activities in order to improve the intensity of R&D investment. In order to diversify the sources of finance for R&D, financial institutions can be set up to collect unused social funds and draw private capital to invest in R&D businesses.

Even though the results indicate a negative relationship between R&D expenditure in the business enterprise sector and innovation, the significant potential that the private sector's R&D to the attainment of sustainable development is undeniable. Policies should encourage entrepreneurs to integrate R&D and innovation so that these become environmentally friendly, economically viable, and socially responsible. Additionally, industry-academic research collaboration should be promoted to facilitate knowledge transfer, technical expertise transfer, and technological advancement, leading to breakthrough innovations and practical solutions for complex problems (Marijan & Sen, 2022).

6. Limitations and future research

This research inevitably contains several shortcomings. The key limitation is the small number of countries consulted and the short time frame. Given that only EU nations are included, the findings should only be applied to countries at a specific stage of development. It would be ideal to conduct more study into new variables and a new group of countries, especially the least developed (LDCs). Future research initiatives may concentrate on this issue as well, given the connection between Innovation and BERD, GOVERD clashes with the hypotheses.

R&D and innovation are requirements for achieving sustainable development goals (Walz et al., 2017) and therefore, further empirical studies can investigate more deeply into the relationship using similar variables of other economic systems to contribute to the development of a practical vision and guidelines of sustainable development.

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