University of Tehran Press

Industrial Management Journal

Online ISSN: 3115 - 7386

Homepage: https://imj.ut.ac.ir

Analyzing the Role of Funding Sources in Research and Development in Driving Global Innovation

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Article Info

Article type:
Research Article

Article history:
Received July 16, 2025
Received in revised form August 07, 2025
Accepted December 09, 2025
Available online January 01, 2026

Keywords:
R&D, innovation, global innovation index (GII), global competitiveness index (GCI), R&D investment.

ABSTRACT

Objective: This study examines how different research and development (R&D) funding sources—business enterprise R&D (BERD), higher education R&D (HERD), and government-financed R&D (GOVERD)—influence national innovation and competitiveness, measured by the Global Innovation Index (GII) and Global Competitiveness Index (GCI). This study addresses a critical gap by moving beyond aggregate R&D spending to examine how funding composition shapes innovation capacity.

Methodology: Ordinary least squares (OLS) regression analysis was conducted on a sample of 47 countries using data from OECD R&D Statistics, World Bank Development Indicators, and GII/GCI reports. Missing values (< 3%) were imputed using mean substitution. Diagnostic tests were applied to verify normality, minimal multicollinearity, and compliance with heteroscedasticity assumptions. Two models were subsequently estimated with GII and GCI as dependent variables.

Results: For the GII model ($R^2 = 0.601$, $F = 12.37$, $p < 0.001$), overall GERD intensity was significantly positive ($\beta = 10.54$, $p = 0.040$), while disaggregated components (BERD, HERD, GOVERD) showed no individual significance due to multicollinearity. GDP per capita was robust ($\beta = 8.78e\text{-}05$, $p = 0.019$). For the GCI model ($R^2 = 0.651$, $F = 15.31$, $p < 0.001$), GERD was non-significant; GDP per capita remained the strongest predictor ($\beta = 0.0003$, $p < 0.001$). Regression assumptions were satisfied (Jarque-Bera $p > 0.44$; Durbin-Watson ≈ 2.1).

Conclusion: Overall R&D intensity significantly influences innovation, but relationships with disaggregated sources are complex. The importance of GDP per capita shows that the quality of institutions and the ability to absorb new ideas are both important for turning R&D spending into innovation and competitiveness benefits. Policymakers should prioritize both R&D funding levels and the institutional environment enabling effective R&D utilization.

Cite this article: Ranjbar, A., Tarighi, S., & Nateghipour, N., (2026). Analyzing the role of funding sources in research and development in driving global innovation, ***Industrial Management Journal***, 18(1), 189-213. https://doi.org/10.22059/imj.2026.404515.1008267

Publisher: University of Tehran Press.

DOI: https://doi.org/10.22059/imj.2026.404515.1008267

Introduction

Innovation has become a central driver of long-term economic growth, productivity, and international competitiveness (Vītola, 2015; Cornell University, INSEAD, & WIPO, 2019). Governments and firms increasingly view research and development (R&D) spending as a strategic investment to foster technological progress, upgrade industrial structures, and move up global value chains (Schwab, 2018). Yet, despite the rapid expansion of R&D expenditure over recent decades, countries continue to display persistent differences in innovation performance and competitiveness, as reflected in the Global Innovation Index (GII) and the Global Competitiveness Index (GCI) (Cornell University, INSEAD, & WIPO, 2019; Schwab, 2018). National innovation systems (NIS) are increasingly recognized as critical frameworks for understanding how R&D expenditure, institutional structures, and policy mechanisms interact to drive innovation performance (Shahriari et al., 2017). Innovation systems are characterized by complex networks of formal and informal interactions among diverse actors, requiring coordination mechanisms to address communication gaps and facilitate knowledge transfer across sectors (Mohseni Kiasari et al., 2024). Understanding which types of R&D investments are most strongly associated with superior outcomes is therefore a critical policy question.

Existing empirical studies generally focus on the aggregate intensity of R&D spending, typically measured by gross domestic expenditure on R&D (GERD) as a percentage of GDP, and confirm its positive association with innovation and economic growth (Vītola, 2015; Luna Cardozo et al., 2021). However, far less attention has been paid to how the allocation of R&D funding across sectors and performers shapes the functioning of national innovation systems (Nasir & Zhang, 2024). Empirical research on national innovation systems has identified the disaggregation of GERD into business enterprise R&D (BERD), higher education R&D (HERD), and government-financed R&D (GOVERD) as essential for understanding the structural drivers of innovation capacity (Shahriari et al., 2017). Business enterprise R&D (BERD) is often associated with near-market innovations and commercial outcomes (Hall et al., 2013), higher-education R&D (HERD) with knowledge creation and human capital formation (Blanco et al., 2020), and government-financed R&D (GOVERD) with basic science and mission-oriented projects (Antonoaie, 2024). The effectiveness of national R&D investments depends critically on collaboration mechanisms among universities, industry, and government, which facilitate the transformation of R&D inputs into measurable innovation outputs (Mohseni Kiasari et al., 2024). While aggregate R&D intensity remains important, research suggests that the efficiency with which countries transform R&D inputs into innovation outputs varies substantially across national contexts, highlighting the importance of institutional quality and absorptive capacity

(Shahriari et al., 2017). The relative importance of these funding channels for national innovation performance and competitiveness remains empirically contested, particularly when they are examined jointly in a cross-country setting (Guellec & Lopes-Bento, 2013; Nasir & Zhang, 2024).

This study addresses this gap by analyzing how both the overall intensity and the sectoral structure of R&D funding relate to cross-country differences in innovation and competitiveness. Using data for 47 countries compiled from OECD R&D statistics, World Bank development indicators, GII, and GCI, the paper investigates whether disaggregated funding sources add explanatory power beyond total GERD and how their effects differ between innovation outcomes (GII) and broader competitiveness outcomes (GCI). In doing so, the study contributes to the literature on national innovation systems, innovation policy, and industrial competitiveness by shifting the focus from "how much" countries spend on R&D to "how" this spending is structured across key funding channels.

The analysis is guided by four research questions:

RQ1: To what extent does overall R&D intensity (GERD as a share of GDP) explain cross-country variation in GII?

RQ2: To what extent do these relationships extend to GCI, or is national competitiveness more strongly driven by other structural factors once R&D indicators are controlled for?

Based on prior research, the study expects positive associations between GERD and both GII and GCI (Vītola, 2015; Cornell University, INSEAD, & WIPO, 2019), and positive—but potentially heterogeneous—effects of BERD, HERD, and GOVERD on these outcomes (Hall et al., 2013; Nasir & Zhang, 2024). The empirical results, however, reveal a more nuanced picture: total R&D intensity and GDP per capita emerge as the most robust predictors, while the independent effects of disaggregated funding sources are weaker than commonly assumed, especially once issues of multicollinearity are properly accounted for.

Literature Background

One of the main pillars of innovation and a vital force behind long-term economic growth is research and development, or R&D. Gross Domestic Expenditure on R&D (GERD), which includes total R&D investments from government agencies, private businesses, academic institutions, and nonprofit organizations, is the most comprehensive metric among those used to assess national research capacity. Accordingly, GERD serves as a crucial instrument for cross-national benchmarking as well as policy formulation (Vītola, 2015).

The structure of GERD is typically analyzed by breaking it down into the following components:

- **BERD** (Business Enterprise Expenditure on R&D)
- **HERD** (Higher Education Expenditure on R&D)
- **GOVERD** (Government Expenditure on R&D)

The financing mechanisms and functional allocation that underlie R&D investment are made clear by this disaggregation. According to Nasir and Zhang's research (Nasir & Zhang, 2024), there is significant cross-country heterogeneity in the business sector's proportionate share of total GERD financing, which reflects variations in the level of development and sophistication of national innovation systems.

The dynamics and patterns of GERD in EU nations have been the subject of numerous empirical investigations. Significant variations in R&D intensity and funding sources were documented by Nasir and Zhang in an analysis of GERD dynamics in Romania and other European countries (Nasir & Zhang, 2024). The study reveals that newer EU member states exhibit lower overall R&D intensity and a heavier reliance on public funding, whereas older member states combine higher GERD levels with a larger contribution from the business sector. These patterns highlight how differences in the composition of GERD financing mirror broader asymmetries in the maturity and sophistication of national innovation systems in Europe (Nasir & Zhang, 2024). The study by Hasan et al. confirms the existence of ongoing gaps between new and old member states and focusses on the volume and dynamics of GERD in the EU. These disparities affect the nations' potential for long-term growth and innovation (Hasan, 2023).

These studies have also emphasised the connection between economic growth and GERD. A time-series forecasting model was used by Vitola et al. (2015) to show that GERD is a reliable indicator of growth in per capita GDP. R&D spending enhances productivity, facilitates technological advancement, and strengthens economic resilience. Meanwhile, GERD directly contributes to enhancing innovation (Vitola, 2015). According to Leogrande, consistent R&D spending promotes industrial modernization, a rise in patent registrations, and the creation and dissemination of knowledge.

Although much of the literature focuses on Europe, studies from other regions also provide valuable insights (Leogrande, 2022) Luna et al. examined GERD trends in Latin American countries from 2008 to 2017, showing that low R&D intensity and heavy reliance on public funding have weakened innovation in these nations (Luna, 2021)

Antonoaie's research puts forward novel policy tools, like the affordability index, which helps guide governments to fix logical R&D investment goals in line with their economic status. Even though R&D is strategically important, many countries find it tough to keep GERD growth stable because of limited budgets, poor university-industry ties, and not enough private sector motivation. Policy-wise, coordination among BERD, HERD, and GOVERD is key to getting a balanced national innovation system (Antonoaie, 2024).

Expenditures within higher education, called HERD (Higher Education Expenditure on R&D), are a main part of research and development (R&D) investment. This shows the role of higher education institutions in research and is tied to a country's knowledge production, innovation, and competition (A Blanco, 2020).

Studies show that investment in higher education R&D in European Union countries has seen both convergence and divergence. Countries with better research setups have put a larger share of their GDP into HERD (Leogrande, 2022). Globally, the distribution of R&D expenditure has changed since the 1980s. Countries that have invested more in higher education have gotten a bigger piece of global science and tech output. This shows how important HERD is to the competition of knowledge-based economies (Schwab, 2018).

A firm's R&D spending is a cornerstone of innovation, boosting its competitive edge and fueling economic expansion. Many papers have looked at how public policy, like subsidies and tax breaks, affects how much companies put into R&D.

Hall et al. (2013) examine firm-level panel data for European companies and find that higher business R&D expenditure is strongly associated with both product and process innovation, as well as with increased patenting activity. Their results indicate that BERD plays a pivotal role in transforming scientific and technological opportunities into commercially valuable innovations and intellectual property, underscoring why business-sector R&D is often regarded as the main engine of innovation-driven competitiveness in advanced economies (Hall et al., 2013).

Looking at these papers, government support can really help firms invest in R&D and improve their ability to innovate. Yet, these policies must be designed well to improve innovation and allow for public resources to be assigned well.

The World Economic Forum's (WEF) GCI, started in 2004, is a tool for judging how well countries can support economic growth and productivity. The index lets people compare countries using a variety of economic, institutional, and social elements.

The WEF declares that competitiveness depends on the institutions, policies, and factors that affect a country's productivity. Productivity then powers economic growth and overall wealth.

Thus, being competitive is not just about having low costs or lots of resources. It means creating a space that encourages new ideas, productivity, and the ability to bounce back from economic struggles. This definition shows why both small-scale and large-scale economic factors matter for competitiveness.

GCI has 12 main parts, which are grouped into three sub-indexes based on how developed an economy is: basic needs, things that boost productivity, and factors related to innovation and sophistication.

1. **Basic Requirements:** Institutions, infrastructure, macroeconomic environment, health, and primary education
2. **Efficiency Enhancers:** Higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, and market size
3. **Innovation and Sophistication Factors:** Business sophistication and innovation

The updated GCI 4.0 framework was redesigned to better capture the structural transformations associated with the Fourth Industrial Revolution. The revised methodology reduces dependence on subjective survey data, increases transparency in scoring procedures, and improves the comparability of economies at different stages of development. In this edition, greater emphasis is placed on innovation capability, market efficiency, and institutional robustness as the foundations of national competitiveness.

GII jointly developed by WIPO, INSEAD, and Cornell University, has been published annually since 2007 as a comprehensive benchmarking tool for national innovation performance. Unlike traditional R&D-focused indicators, the GII integrates broader dimensions of innovation—such as institutional quality, human capital, infrastructure, market sophistication, and business capabilities—to evaluate both innovation inputs and outputs. This framework enables cross-country comparison of how effectively economies transform their innovation resources into measurable outcomes. In this index, innovation inputs are the things that help innovation happen. These inputs are grouped into five main areas: institutions, human resources and research, infrastructure, market knowledge, and business knowledge. The goal is to see how well each country can innovate (Cornell University, INSEAD, & WIPO, 2019).

Innovation outputs, on the other hand, are the results of innovation, measured by knowledge and technology outputs and creative outputs. These outputs show how well a country turns its innovation inputs into real innovation results (Hamidi, 2018).

Cultural factors are also seen as increasingly important for innovation. Studies comparing the Global Innovation Index with the World Values Survey's Cultural Map indicate that communication, decision-making, and views on authority can greatly change how well a country innovates. A study in 2021 found that cultural traits affect a country's ranking in the Global Innovation Index. It concluded that cultures that value openness, risk-taking, and shared decision-making tend to do better in innovation. The researchers found that cultural context, along with things like infrastructure and human resources, is key to how countries use these resources for innovation (Firlej, 2019).

GDP per capita is seen as a key way to judge a country's economy. Still, researchers have long debated if it really shows the full picture of economic growth.

Dědeček and Dudzich (2022) looked at how GDP per capita falls short as a measure of economic progress across countries. They declare that it gives a basic idea of a country's financial state but doesn't show important things like how income is spread out, quality of life, education, healthcare, and strong institutions. They warn that if leaders only look at GDP per capita, they might not notice issues such as inequality and the human side of progress. So, they suggest using other measures along with GDP per capita, like the Human Development Index (HDI) and ways to measure income distribution (Dědeček & Dudzich, 2022).

Cảnh and Hoài (2022) used Bayesian regression to find some things that really change GDP per capita. Their work looked at things like how well people work, how many educated workers there are, how many people don't have jobs, and how much money is invested per person (Cảnh & Hoài, 2022).

Empirical studies on R&D funding structure and innovation/competitiveness

Empirical evidence directly addressing the structure of R&D funding and its impact on innovation performance is still relatively limited, yet a few studies provide important insights that inform the present research. Guellec and van Pottelsberghe de la Potterie (2003) examine how different types of public R&D expenditure affect business-sector R&D across OECD countries. Their results show that the effect of government R&D is not uniform: direct public funding to firms tends to complement and stimulate private R&D investment, whereas government-performed R&D can partially crowd out business R&D when it overlaps with industrial research activities. The study further reports substantial cross-country variation in these effects, which the authors attribute to differences in national innovation systems and in the design of R&D policies. This evidence underscores that the composition and targeting of public R&D spending are crucial determinants of its effectiveness in leveraging private-sector innovation, rather than the aggregate level of expenditure alone.

In addition, prior conceptual work by Gamba (2025) has explicitly linked R&D activities to both innovation and competitiveness by integrating GII and GCI into a unified framework (Cornell University et al., 2019; Oyeyinka, 2004; Wang, 2014). In this framework, R&D is positioned as the initial driver feeding into the GII structure, which distinguishes between innovation inputs—such as institutions, infrastructure, R&D and human capital, and business and market sophistication—and innovation outputs in the form of knowledge, technological output, and creative output. These outputs are translated into firm- and sector-level innovation outcomes (e.g., new or improved products, processes, marketing and distribution practices), which then shape competitiveness outcomes including access to international markets, lower costs and prices, higher quality, and greater efficiency. The GCI structure captures these competitiveness outcomes through its twelve pillars, thereby making explicit the causal chain from R&D funding and activities to innovation performance (GII) and, ultimately, to national competitiveness (GCI). This integrated perspective provides the conceptual foundation for the present study's focus on how different R&D funding sources (BERD, HERD, and government-financed GERD) are related to both GII and GCI.

The evidence synthesized across the preceding sections reveals several key insights about R&D investment, innovation, and competitiveness. First, R&D expenditure—measured through GERD and its components (BERD, HERD, and GOVERD)—is consistently associated with innovation capacity and economic growth across countries and regions. However, the relationship is not uniform; the composition and structure of R&D funding matter substantially. BERD drives near-market innovation and commercial outcomes, while HERD contributes to knowledge creation and human capital formation, and government-financed R&D (GOVERD) supports basic research and strategic priorities. Second, GII and GCI provide complementary frameworks for assessing national innovation systems. The GII captures both innovation inputs and outputs within a systems perspective, whereas the GCI situates innovation within broader institutional and economic structures that enable competitiveness. Third, despite the recognized importance of R&D funding composition, empirical studies examining how different funding sources jointly influence both innovation and competitiveness remain limited, particularly across diverse economic contexts and in cross-country comparative settings. This gap underscores the need for comprehensive multivariate analyses that disaggregate R&D funding sources and assess their simultaneous effects on both GII and GCI, thereby moving beyond aggregate measures of R&D intensity to understand how specific funding structures drive national innovation performance and economic competitiveness. The present study addresses this gap by analyzing the differential impacts of BERD, HERD, and government-financed GERD on both.

Studies such as Guellec and van Pottelsberghe de la Potterie (2003) show that the form and composition of public R&D expenditure (direct funding to firms versus government-performed R&D) can have complementary or substitution effects on private-sector R&D, but they do not directly investigate how this funding structure translates into country-level innovation and competitiveness indicators. In parallel, the literature using the GII and GCI frameworks treats R&D as one of several inputs into innovation and competitiveness within national innovation systems, yet typically does not distinguish between different funding sources (BERD, HERD, and government-financed GERD) or disentangle their specific effects on innovation and competitiveness outcomes. Consequently, it remains unclear which components of the national R&D funding structure are most strongly associated with innovation performance (GII) and with competitiveness (GCI), and how these relationships play out over time and across countries.

Materials and Methods

This study examines how financial resources help innovation and global competition, using a quantitative approach with a descriptive-correlational design. Because the information is assessed at one point, this study is cross-sectional and relies on secondary data analysis.

Data came from international sources like the World Bank and the OECD. The most recent data available for each country in these databases were used, generally up to 2023, but in some cases, data from prior years was employed.

The statistical sample consists of 47 countries, mostly OECD members

In this research, two key indicators are considered as dependent (outcome) variables:

1. Global Innovation Index (GII)
2. Global Competitiveness Index (GCI)

The effects of several independent variables on the two indices will be examined. These variables include:

- Business Expenditure on R&D (BERD)
- Higher Education Expenditure on R&D (HERD)
- Government-financed Gross Domestic Expenditure on R&D (Government-financed GERD)

- Gross Domestic Product per capita (GDP per capita) as a control variable.

Data analysis was conducted in Python using specialized libraries for data manipulation and statistical computation. The dataset underwent data cleaning and preparation. Subsequently, descriptive statistics were calculated, correlation matrices were generated using Pearson correlation analysis, and multiple linear regression was employed to assess relationships among variables.

Two multiple linear regression models were constructed to assess the effects of independent variables on each dependent variable.

Model 1 – Determinants of GII:

$$GII = \beta_0 + \beta_1(BERD) + \beta_2(HERD) + \beta_3(GovFin_{GERD}) + \beta_4(GDP_{PC}) + \in$$

Model 2 – Determinants of GCI:

$$GCI = \alpha_0 + \alpha_1(BERD) + \alpha_2(HERD) + \alpha_3(GovFin_{GERD}) + \alpha_4(GDP_{PC}) + \in$$

These models aim to assess how different sources of R&D financing contribute to countries' innovation performance and global competitiveness, while controlling for the level of economic development.

Definition of Variables in the Model:

- GII: *Global Innovation Index* (dependent variable)
- BERD: *Business Expenditure on R&D* (share of the business sector in total R&D expenditure)
- HERD: *Higher Education Expenditure on R&D* (share of the higher education sector in total R&D expenditure)
- GovFin_GERD: *Government-financed Gross Domestic Expenditure on R&D* (share of government funding in total R&D expenditure)
- GDPpc: *Gross Domestic Product per capita* (control variable)

By examining the coefficients (β and α) and their statistical significance in the two regression models, it is possible to determine whether the same factors drive both innovation and global competitiveness.

This check will show how much each funding source—business, higher education, and government—helps explain changes in GII, after considering national wealth (GDP per capita).

The dataset was changed into a DataFrame using Pandas library, and then data cleaning was done. This meant dealing with missing values and changing data types to make sure all variables were in a number format ready for stats work.

During the data preparation stage, missing observations in the R&D and macroeconomic variables were addressed using an imputation strategy based on both median and mean replacement. Specifically, Median imputation was initially applied to all variables with missing values, and corresponding descriptive statistics were computed. Subsequently, the same procedure was repeated using mean imputation. This two-step procedure was designed ex ante as a sensitivity analysis to assess whether alternative imputation rules would materially affect the central tendency and dispersion of the key variables, particularly the GII and GDP per capita. The final regression models were estimated on the imputed datasets, and the outcomes under the two imputation schemes were systematically compared. The formal results of this sensitivity analysis are reported separately in the findings section and summarized in Table 1.

After cleaning the data, exploratory data analysis (EDA) was done to understand the relationships between variables. Then, correlation matrices were made and checked to see how strong the links between the key variables were.

Results

Analysis of R&D Expenditure Distribution by Type

An examination of how nations allocate funds for Research and Development (R&D) shows differences in their investment approaches. The boxplot in Figure 1 compares three main categories:

- Gross Domestic Expenditure on R&D (GERD): Represents the total national investment in R&D.
- Business Expenditure on R&D (BERD): Reflects the R&D spending of the business and industrial sectors.
- Higher Education Expenditure on R&D (HERD): Captures the R&D activities financed and performed within higher education institutions.

The data shows that total R&D spending has the highest median value. Looking at each part of the total gives some interesting details.

BERD has a large IQR and many outliers. This means countries differ a lot in how they invest in R&D. Some lean on private companies, while others depend more on public or academic R&D.

Higher education R&D spending (HERD) has the lowest median and least variance. This shows a steadier pattern across countries, but it is still a smaller share of GDP than business spending.

The outliers in total and business R&D spending are from innovation-focused countries like South Korea, and Switzerland. These countries spend a very high portion of their GDP on R&D.

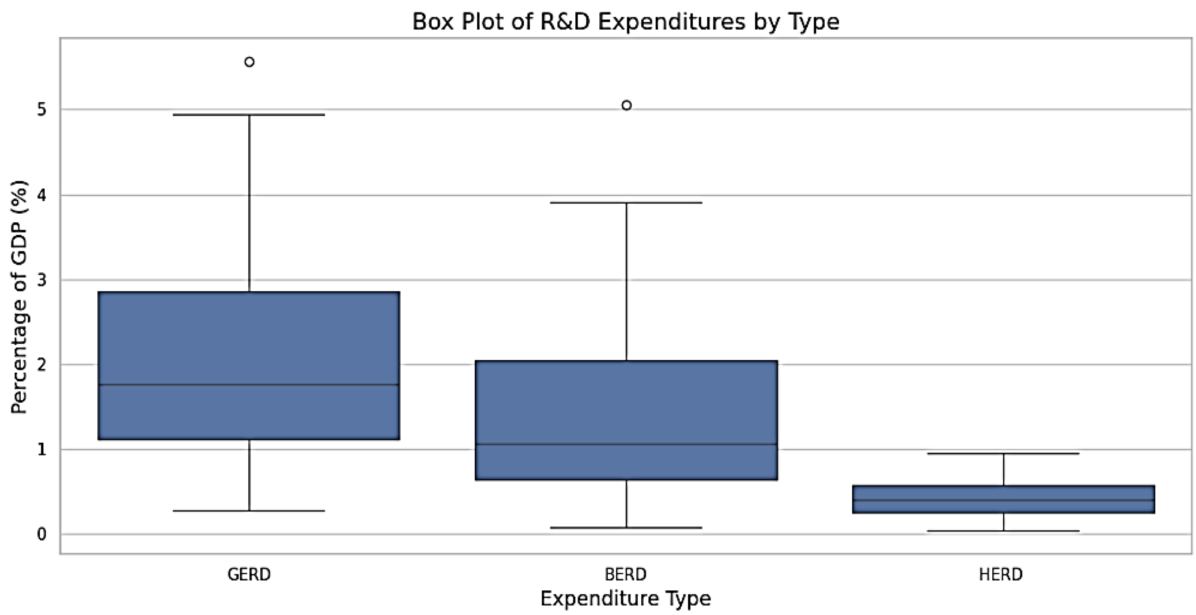

Figure 1. R&D Expenditures by Type

Correlation among R&D, Innovation, Competitiveness, and Economic Indicators

This section examines the correlation matrix (Figure 2) of key indicators related to R&D, innovation, competitiveness, and economic performance. The results point to structural relationships among these items, showing how countries perform in science, tech, and knowledge-based economics.

The data suggest a hierarchy in national innovation systems. A strong relationship exists between total R&D spending (GERD) and BERD, with a correlation coefficient of 0.98. Private sector involvement in innovation, as seen in South Korea and the United States, strengthens this relationship.

A solid relationship exists between HERD and government-financed GERD (as a percentage of GDP), with a correlation coefficient of 0.72. This shows the government's backing of universities and research institutions.

The link between GDP per capita and GCI is 0.73. This suggests that countries with higher incomes usually have better economic, tech, and institutional setups, boosting their competitiveness. The connection between competitiveness (GCI) and innovation (GII) is also high (r = 0.76), meaning that a good market, sound institutions, and open economic policies help innovation. Also, innovation boosts competitiveness.

A link between GERD and GII (r = 0.64) indicates that national investment in R&D helps innovation, but just funding is not enough—implementation matters. A correlation between HERD and GCI (r = 0.57) shows that higher education helps national competitiveness by creating skilled researchers. The same is true for the BERD and GII correlation (r = 0.58), showing that corporate innovation improves a country’s tech skills.

In contrast, the relationships between income and R&D indicators are weaker—GERD and GDP per capita (r = 0.38), and BERD and GDP per capita (r = 0.31). This says that high income doesn't always mean high R&D investment. For instance, some oil-producing countries might have high per capita income but weak innovation policies and little R&D.

In general, the correlation matrix shows that innovation and R&D work best within a structure that includes competitiveness, institutional help, government investment, and private-sector involvement. Looking at these relationships gives useful ideas for making policies about science, tech, and knowledge-based economic growth.

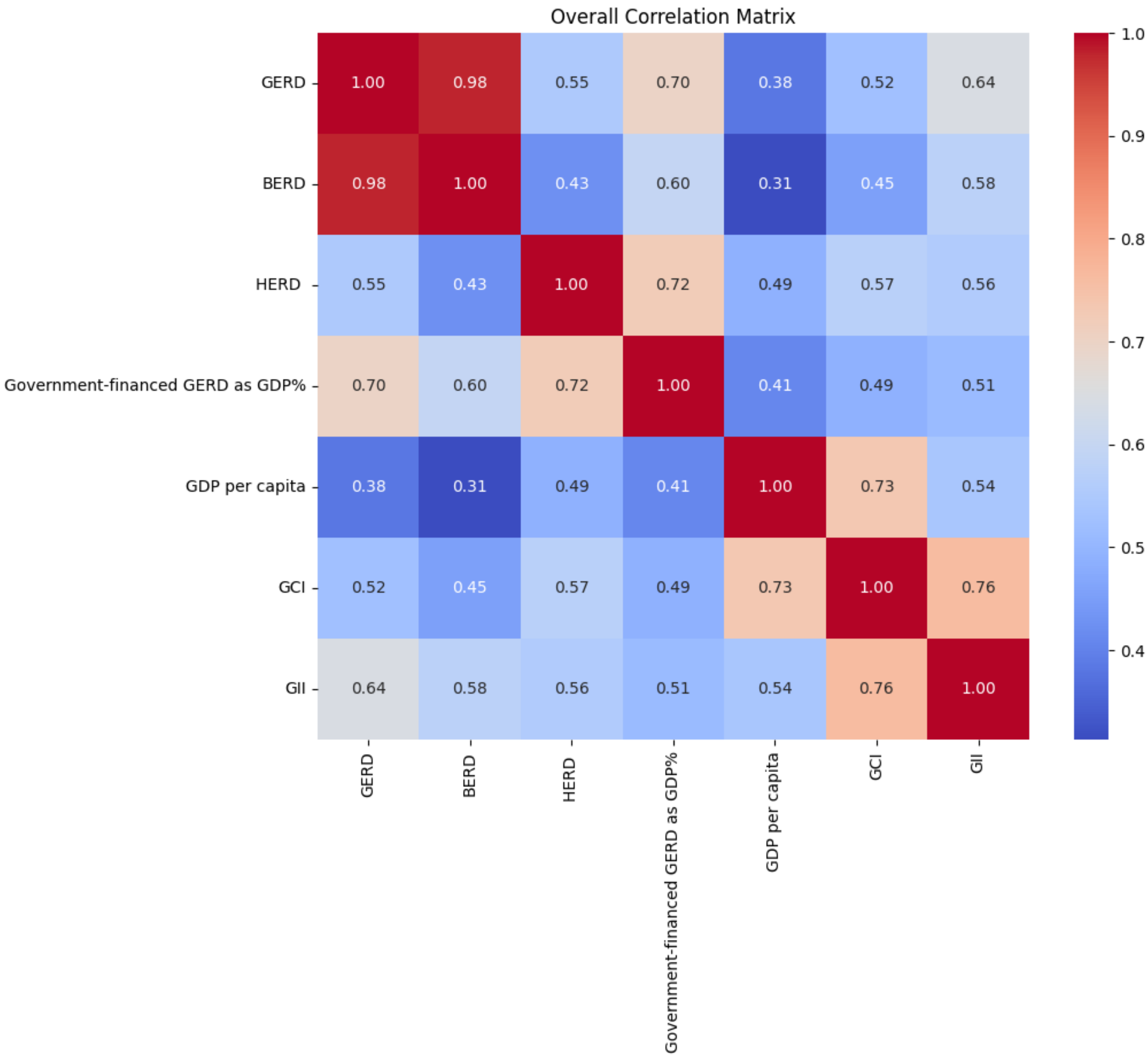

Figure 2. Correlation Matrix Analysis among R&D, Innovation, Competitiveness, and Economic Indicators

Robustness checks: mean vs. median imputation

The sensitivity analysis comparing median and mean imputation shows that the choice of imputation rule has no material impact on the descriptive properties of the data or on the subsequent regression results. The mean and standard deviation of the GII differ by only about 0.5 points between the two approaches, a change that is not statistically or substantively significant. Likewise, the mean and standard deviation of GDP per capita differ by less than 0.5 percent across methods. Coefficient estimates, model fit (R^2 and F-statistics), and diagnostic statistics remain virtually unchanged. These results indicate that the empirical findings are robust to alternative treatments of missing values and justify the use of mean-imputed variables in the main regression models. The detailed comparison is reported in Table 1.

Table 1. Comparing median and mean imputation schemes for R&D variables

R&D Variable	mean_mean_imputed	mean_median_imputed	diff_in_means	std_mean_imputed	std_median_imputed	diff_in_std
GII	47.8086	48.3170	-0.5084	8.8282	8.8718	-0.0435
GCI	73.5064	73.7286	-0.2222	15.9686	15.9819	-0.0133
GERD	1.9885	1.9885	0.0000	1.2156	1.2156	0.0000
BERD	1.3739	1.3673	0.0066	1.0441	1.0451	-0.0010
HERD	0.4257	0.4252	0.0004	0.2221	0.2221	-0.0000
Government-financed GERD as GDP%	0.5533	0.5540	-0.0007	0.2364	0.2365	-0.0000
GDP per capita	40320.5702	40165.5570	155.0132	28405.4444	28425.3168	-19.8725 ≃-0.2%

Regression Results for GII & GCI Model

The regression analysis with GII as the dependent variable was estimated using a multiple linear model that includes overall GERD, BERD, HERD, government-financed GERD as a share of GDP, and GDP per capita as explanatory variables. The model, based on 47 countries, yields an R-squared of 0.601 and an adjusted R-squared of 0.553, indicating that roughly 55–60% of the cross-country variation in GII can be explained by the intensity and structure of R&D expenditure together with the level of economic development. The F-statistic of 12.37 ($p = 2.42e\text{-}07$) confirms that the model is jointly significant at the 1% level, while the Durbin–Watson statistic of about 2.11 suggests no serious autocorrelation in the residuals; omnibus and Jarque–Bera tests, together with low skewness and acceptable kurtosis, further indicate that the normality assumption for the error term is not violated.

Regarding individual coefficients, overall GERD enters the model with a positive and statistically significant coefficient of approximately 10.54 ($t = 2.13$, $p = 0.040$), implying that a one-percentage-point increase in GERD as a share of GDP is associated with about a 10.5-point increase in a country’s GII score, ceteris paribus. In contrast, BERD has a negative but statistically insignificant coefficient (around −7.48, $p \approx 0.15$), indicating that, once overall GERD, HERD, government funding, and income levels are controlled for, the relative share of business R&D does not display a robust independent association with GII; this pattern is consistent with strong overlap between BERD and total GERD and with structural differences in how corporate R&D translates into innovation outputs across countries.

The coefficient on HERD is positive (about 5.89) but not statistically significant ($p \approx 0.36$), suggesting that higher education R&D spending tends to move GII in the expected direction, yet the available sample does not provide enough statistical power to isolate a clear effect once other funding components are included. Similarly, the variable capturing government-financed GERD as a share of GDP has a negative but insignificant coefficient (around −6.23, $p \approx 0.35$), implying that, conditional on total GERD and its business and higher-education components, the direct budgetary contribution of government does not exhibit a distinct marginal impact on national innovation performance.

GDP per capita enters the model with a small but statistically significant positive coefficient (approximately 8.78e-05, $t = 2.44$, $p = 0.019$), meaning that countries with higher income levels achieve higher GII scores even after controlling for the intensity and composition of R&D expenditure. Substantively, this finding underscores the role of broader development factors—such as institutional quality, human capital, and infrastructure—that are proxied by income and enhance the capacity of economies to convert R&D inputs into innovation outcomes.

Overall, the GII regression indicates that the intensity of total R&D investment and the level of economic development are the two most robust predictors of cross-national differences in innovation performance, whereas disaggregating funding into business, higher-education, and government-financed components does not yield consistently significant marginal effects in this specification. This pattern is in line with prior empirical work emphasizing that both sufficient aggregate R&D effort and a supportive economic and institutional environment are necessary conditions for achieving superior innovation outcomes at the country level. The result of regression is shown in Table 2.

Table 2. Statistical Results about GII Model

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI Lower	95% CI Upper
Constant	34.5301	2.2750	15.181	0.000	29.937	39.124
GERD	10.5396	4.9570	2.126	0.040	0.530	20.549
BERD	-7.4807	5.0980	-1.467	0.150	-17.777	2.816
HERD	5.8877	6.3800	0.923	0.362	-6.997	18.773
Government-financed GERD as GDP%	-6.2314	6.6130	-0.942	0.352	-19.588	7.125
GDP per capita	8.78e-05	3.60e-05	2.441	0.019	1.51e-05	0.000

The regression analysis with GCI as the dependent variable was estimated using the same multiple linear specification that includes overall GERD, BERD, HERD, government-financed GERD as a share of GDP, and GDP per capita as explanatory variables. Based on 47 country observations, the model achieves an R-squared of 0.651 and an adjusted R-squared of 0.609, indicating that about 61–65% of the cross-country variation in GCI is explained by the intensity and structure of R&D spending together with income levels. The F-statistic of 15.31 with a p-value of 1.74e-08 shows that the set of predictors is jointly significant at conventional levels, while the Durbin–Watson statistic of 1.73 suggests no serious autocorrelation in the residuals. In addition, the Omnibus and Jarque–Bera tests yield high p-values, and the skewness (0.247) and kurtosis (2.762) statistics are close to those of a normal distribution, supporting the validity of the normality assumption for the error term.

Turning to the individual coefficients, overall GERD enters the GCI model with a positive but statistically insignificant coefficient of about 8.19 ($t = 0.98$, $p = 0.334$), implying that once other R&D components and income are controlled for, the marginal contribution of total R&D intensity to competitiveness cannot be distinguished from zero in this specification. The coefficient on BERD is negative (approximately −5.56) and likewise insignificant ($p \approx 0.52$), suggesting that the relative share of business R&D does not exert a robust independent effect on GCI after accounting for total GERD, HERD, and public funding. In contrast to the GII model, where total GERD was significant, this pattern indicates that increasing R&D spending may translate more directly into innovation outputs than into the broader competitiveness metrics captured by GCI.

HERD shows a relatively large positive coefficient of about 13.30, but it is not statistically significant ($t = 1.23$, $p \approx 0.225$). This result points to a potentially beneficial role of university-based research for competitiveness, yet the available data do not permit a precise estimation of its marginal effect once overlapping funding channels are taken into account. The government-financed GERD as a percentage of GDP carries a small negative and insignificant coefficient (around −5.78, $p \approx 0.608$), which implies that, conditional on total and sectoral R&D expenditures, the direct fiscal contribution of governments does not have a clearly identifiable stand-alone impact on global competitiveness.

As in the GII regression, GDP per capita emerges as the most robust determinant of GCI. Its coefficient is positive and highly significant (0.0003, $t = 5.20$, $p < 0.001$), meaning that countries with higher income levels tend to achieve substantially higher competitiveness scores even after controlling for R&D intensity and funding composition. Substantively, this highlights that the broad set of structural conditions associated with higher income—such as infrastructure, human capital, institutional quality, and market sophistication—are central to sustaining global competitiveness and may mediate how effectively R&D investments improve a country's position in the GCI ranking.

Overall, the GCI regression indicates that the level of economic development is a systematically stronger predictor of competitiveness than any single component of R&D funding, while total and sectoral R&D expenditures, although directionally consistent with theory, do not reach statistical significance in this specification. In combination with the GII results, this suggests that R&D spending contributes more directly to innovation performance, whereas competitiveness additionally depends on a wider set of macroeconomic and institutional factors that are only imperfectly captured by R&D indicators alone.

Table 3. Statistical Results about GCI Model

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI Lower	95% CI Upper
Constant	49.6328	3.848	12.899	0.000	41.862	57.404
GERD	8.1926	8.385	0.977	0.334	-8.741	25.127
BERD	-5.5611	8.625	-0.645	0.522	-22.980	11.858
HERD	13.2968	10.794	1.232	0.225	-8.501	35.095
Government-financed GERD as GDP%	-5.7770	11.188	-0.516	0.608	-28.372	16.818
GDP per capita	0.0003	6.09e-05	5.200	0.000	0.000	0.000

Discussion and Conclusion

The study examined how the intensity and structure of national R&D funding relate to cross-country differences in innovation performance and global competitiveness, as measured by GII and GCI. The main empirical result is that overall R&D intensity (GERD as a share of GDP) and GDP per capita are the most robust predictors of GII and GCI, while the disaggregated funding components (BERD, HERD, government-financed GERD) do not exhibit statistically significant independent effects once included simultaneously in the models. This suggests that aggregate R&D effort and the broader level of economic development and institutional quality matter more consistently for national outcomes than the precise sectoral allocation of R&D funding.

These findings both confirm and qualify previous empirical work. Studies such as Guellec and van Pottelsberghe de la Potterie (2003) show that different forms of public R&D support can either complement or crowd out business R&D, emphasizing the importance of the composition and targeting of public research budgets. The present study is consistent with their evidence in highlighting the relevance of funding structure, but it also indicates that, at the aggregate country level, the net separate effects of business, higher-education, and government-financed R&D are difficult to isolate once total GERD and income are controlled for. Similarly, firm-level analyses such as Hall et al. (2013) find strong positive links between BERD and innovation and patenting, whereas the macro-level regressions here show that BERD's marginal effect becomes statistically insignificant when entered alongside total GERD and other components, likely due to multicollinearity and cross-country heterogeneity in how corporate R&D translates into national innovation indicators.

At the same time, the strong positive associations observed between GERD and GII, and between GII and GCI, are in line with broader literature showing that higher R&D investment supports innovation capacity and that innovation and competitiveness are mutually reinforcing dimensions of national performance. The prominence of GDP per capita in both models echoes prior work arguing that institutional quality, human capital, and absorptive capacity are crucial for converting R&D inputs into effective innovation and competitiveness outcomes. Taken together, these convergences and divergences with earlier studies suggest that policy efforts should simultaneously aim to raise overall R&D intensity and strengthen the economic and institutional environment, while recognizing that fine-tuning the sectoral mix of R&D funding may yield more context-dependent and less easily generalizable effects at the macro level.

An analysis of how science, tech, and innovation relate (using GERD, BERD, HERD, GII, GCI, and GDP per capita) shows clear links between R&D policy and how well economies do. Results suggest that investing in research and development—by governments, universities, or companies— greatly shapes a country's ability to innovate, compete, and grow economically.

However, data also suggest that just increasing budgets or indicator values is not enough. It is more important to target well, use resources efficiently, and build connections between those involved in a country's innovation system. For instance, innovation drives economic growth only when it fits into a solid competitive, institutional, and infrastructural structure. Also, lasting growth in GDP per capita needs to be rooted in knowledge, productivity, and tech advances.

Based on this, here are some policy suggestions to help policymakers, planners, and decision-makers strengthen the innovation environment, improve R&D output, and boost national competitiveness.

A correlation analysis showed a strong between private sector R&D investment (BERD) and total national R&D investment (GERD), with a correlation coefficient of 0.98. This suggests a active private sector corresponds to a stronger innovation system. In developed nations, businesses often drive innovation, sometimes ahead of government in identifying key technologies.

To increase private sector involvement in R&D, governments can use tax policies to encourage company investment in innovation. Tax breaks or deductions for R&D spending, whether internal or outsourced, are important.

Also, joint R&D funds between government and the private sector can lower some money risks tied to long-term or tech projects. These funds are very helpful in high- areas like AI, biotech, and advanced materials.

Regional innovation groups that link small businesses, startups, big companies, and schools can promote a dynamic innovation setting. Plus, easing rules for setting up corporate R&D labs is needed to boost internal innovation skills and knowledge output.

Research and development spending in higher education has a clear tie to innovation and competition (over 0.55). Universities are where basic info is found, researchers are trained, and new tech gets its start. But, higher education gets most of its money from the government, especially in countries where the government plays a big role.

If we want higher education to do more for the country's innovation, the government needs to put a steady amount of the country's money into academic research. Ideally, this would be written into law, so research money is safe from money problems or politics.

Besides keeping the money steady, how we give out resources needs to change. Instead of giving everyone the same amount, the government should push for a system where people compete for grants. The projects that get picked should be both scientifically sound and have real-world uses.

Other good steps would be to create innovation centers at universities, build national research labs, and make better science and tech parks near universities.

Lastly, making academic research more global by creating research networks and getting money from other countries can really boost the quality and global impact of what universities produce.

The strong link between GII and GCI shows that they support each other. Innovation spurs productivity, competitive edge, and better production, while competitiveness offers the needed structure for innovation.

To connect innovation policies with economic growth, it is key that their plans work together. For instance, creating a National Industrial Innovation Program with a National Competitiveness Strategy pushes leaders to use a united approach instead of separate actions.

In this plan, stronger ties between industry needs, science, and innovation work need to be made. Changes to rules are also important, such as making patenting easier and improving how innovation is funded and protected.

Plus, having indicators that measure both innovation and competitiveness helps leaders watch and judge how well their actions are doing over time.

Analyses suggest that while innovation and GDP per capita aren't perfectly linked, richer countries usually have better innovation setups. This includes good schools, digital access, and active consumer bases. So, innovation plans should go hand in hand with larger economic and social fairness plans.

Innovation boosts output and can spread chances more fairly and raise income per person. To do this, leaders need to focus on growing people along with tech. Investments in schools, job training, and digital skills make sure people can join the knowledge economy.

Also, building tech resources in poorer areas -- like labs, fast internet, and business centers -- can lessen gaps between regions. More widely, trade policies for knowledge goods should let firms reach global markets and bring in foreign money.

Helping small businesses link to global supply chains via tech deals with big firms at home and abroad will make them more competitive and create fairer growth driven by innovation.

The empirical results indicate that although higher GERD is positively associated with innovation performance, increases in R&D budgets alone are not sufficient; what matters equally is how effectively resources are targeted, managed, and aligned with national comparative advantages.

Worldwide examples suggest that just spending more on R&D does not guarantee innovation without a clear plan. So, we need to track and judge research projects well, looking at things like patents, new technologies in the market, research papers used, and new tech companies.

Also, money should go to areas where a country has a lead. For example, countries without much water should focus on saving water or creating desalination tech. Making tech roadmaps with important people can aid to clarify the direction of the investment.

In the end, the science and tech budget must be clear, responsible, and based on facts to make sure R&D turns into real social, economic, and tech results.

The Triple Helix model is viewed as a leading global structure for turning knowledge into economic and social worth. Technology transfer, knowledge commercialization, and tech jobs happen faster when government, industry, and schools work together through set up innovation groups instead of working alone.

In this setup, the government makes policy and provides infrastructure, the university produces knowledge and research, and industry commercializes and uses technology. To make this setup work well, cooperation between these three groups must be made stronger.

One good way is to push for graduate research projects that focus on industry and are created with company help. This makes sure that school research deals with actual industry needs. Setting up Technology Transfer Offices (TTOs) run by both universities and industries can also assist knowledge exchange and commercialization.

Also, creating innovation challenges or tech contests funded by both the government and the private sector can focus research on fixing real economic and social problems. Lastly, changing rules to allow researchers to move between schools and industries encourages the flow of expertise and strengthens the innovation environment.

Limitations and Future Directions

This study examines cross-sectional relationships among R&D funding, innovation, and competitiveness using data from 47 countries at a single point in time. The absence of longitudinal or panel data prevents assessment of dynamic relationships, causal mechanisms, and temporal lags between R&D investments and outcomes. Additionally, the high multicollinearity among R&D funding sources (BERD, HERD, and government-financed GERD) limits the ability to isolate the precise independent effects of each funding source on innovation and competitiveness. Data availability constraints—particularly the time lag in R&D reporting and the underrepresentation of developing countries in available statistics—further limit the comprehensiveness and timeliness of the analysis. Finally, analysis at the level of composite GII and GCI indices masks variation in how R&D investments influence specific innovation dimensions or competitiveness pillars.

Future research should employ panel data spanning multiple years to examine temporal dynamics and assess whether R&D effects operate immediately or with significant lags. Longitudinal analysis would clarify whether countries that increase R&D intensity subsequently experience improvements in innovation and competitiveness. Additionally, instrumental variables or natural experiment designs could move beyond correlation toward causal inference, addressing endogeneity concerns and providing more rigorous evidence on R&D policy effectiveness. In-depth case studies examining how institutional structures, governance quality, and university-industry linkages moderate the R&D-innovation relationship would illuminate mechanisms that cannot be fully captured through macro-level quantitative analysis. Finally, disaggregated analysis of specific GII and GCI components—rather than composite indices—could reveal which R&D funding sources most effectively target particular innovation outputs or competitiveness dimensions.

Data Availability Statement

Data available on request from the authors.

Acknowledgements

The authors would like to thank all participants of the present study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Funding

This research received no external funding.

Ethical Considerations

This study utilizes only secondary, publicly available data and does not involve human subjects or sensitive information. The authors confirm adherence to research integrity standards, transparency in methodology, and appropriate attribution of all sources.

Appendix

List of mentioned countries in this article:

Australia, Argentina, Austria, Belgium, Canada, China (People's Republic of), Chile, Chinese Taipei, Colombia, Costa Rica, Czech Republic, Denmark, European Union(27), Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Iran, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, Romania, Russia, Singapore, South Africa

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