

INNOVATION AND ECONOMIC PERFORMANCE IN THE EU: AN INTEGRATED FRAMEWORK FOR ANALYSIS

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Abstract. Innovations are important for the economic growth, but such impact varies significantly across regions and the EU countries. Existing researches often adopt a sectoral perspective, overlooking the long-term effects of innovations and the need for a comprehensive framework to measure its influence on GDP. Addressing this gap, the study proposes an integrated methodology to identify the relationship between business innovations and economic performance across EU countries. Using three-step integrated methodology the research begins with identification and refinement of datasets on business innovation and GDP, applying Forward Feature Selection method to revise 43 indicators. In the second step, econometric techniques, including Principal Component Analysis are employed to explore the relationship between business innovations indicators and GDP growth. Finally, delivered cluster analysis using k-means identifies groups of EU countries following their innovation activity and GDP growth rates, highlighting those that with innovation ecosystems outperform the EU average. Findings show significant disparities in the impact of innovation on GDP growth in the EU countries, showing the existence of regional inequalities. Results underline the necessity for adopted policy frameworks that aim to strengthen innovation ecosystems and promote equitable economic growth. This study provides actionable insights for policymakers supporting faster innovation-driven applications within the EU.

Keywords: business innovation, clusters, innovation indicators, principal component analysis, GDP.

JEL Classification: O11, O33, O47.

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Notations

Abbreviations

BPCS_XFRMTOT – Business process innovative firms, as a percentage of total firms;

CO_INN_ALL_XINN – Firms cooperating on innovation activities (including R&D), as a percentage of innovation active firms;

COMM_XFRMTOT – Business process innovative firms with innovations in information & communication systems, as a percentage of total firms;

COOP_FOR_XINN – Firms co-operating on innovation activities with enterprises engaged in international collaboration, as a percentage of innovation active firms;

DEVE_PCS_ENT_XFRMTOT – Business process innovative enterprises that developed processes only on their own, as a percentage of total firms;

DEVE_PRD_ENT_XFRMTOT – Product innovative enterprises that developed products only on their own, as a percentage of total firms;

ECO_CON_XINN_OSLO – Innovative enterprises that introduced innovations with environmental benefits generated during the use of the enterprise's good and services by consumers or end users – with significant contributions to environmental protection, as a percentage of innovative firms;

ECO_ENT_CON_XINN_OSLO – Innovative enterprises that introduced innovations with environmental benefits within the enterprise (i.e., within the business processes and supply chain) OR generated during the use of the enterprise's good and services by consumers or end users – with significant contributions to environmental protection, as a percentage of innovative firms;

ECO_ENT_XINN_OSLO – Innovative enterprises that introduced innovations with environmental benefits within the enterprise (i.e., within the business processes and supply chain) – with significant contributions to environmental protection, as a percentage of innovative firms;

EMP20_INN_XEMP20 – Share of persons employed in innovation-active firms in total employment in 2020

EMP20_INNOSLO_XEMP20 – Share of persons employed in innovative firms in total employment in 2020 Firms co-operating on innovation activities with enterprises within the enterprise group, as a percentage of innovation-active firms EU – European Union;

FOR_INN_XFOR – Innovation active firms operating in foreign markets, as a percentage of firms operating in foreign markets;

FOR_INN_XINN – Innovation active firms operating in foreign markets, as a percentage of innovation-active firms;

FOR_NOINN_XNOINN – Share of non-innovation active firms operating in international markets;

FOR_XFRMTOT – Enterprises operating in foreign markets, as a percentage of total firms;

FDI – Foreign direct investment;

GOV_RI_XINN – Firms cooperating on innovation activities with public R&D institutes, as a percentage of innovation-active firms;

IDESG_XFRMTOT – Firms that registered a design, as a percentage of total firms;

INN_NOFOR_XINN – Share of innovation active firms not operating in international markets;

INN_OSLO_XFRMTOT – Innovative firms (product/process), as a percentage of total firms;

INN_XFRMTOT – Innovation-active firms (innovative enterprises (INN_OSLO) as well as firms with innovation activities that have not necessarily led to an innovation), as a percentage of total firms;

LOG_XFRMTOT – Business process innovative firms with innovations in distribution and logistics, as a percentage of total firms;

NPO_XINN – Firms co-operating on innovation activities with non-profit organisations, as a percentage of innovation active firms;

PCA – Principal component analysis;

PAT_XFRMTOT – Firms that applied for patents, as a percentage of total firms;

PCS_ADMIN_MGT_XFRMTOT – Business process innovative firms with innovations in administration & management (accounting, external relations, human resource management), as a percentage of total firms

PCS_GD_SERV_XFRMTOT – Business process innovative firms with innovations in the production of goods or services, as a percentage of total firms;

PDPCS_RD_XINNOSLO – R&D active product and/or business process innovative firms, as a percentage of innovative firms;

PRD_GD_XFRMTOT – Product innovative firms (innovation of goods), as a percentage of total firms
 PRD_NEW_MKT_XFRMTOT – Product innovative enterprises with new to market innovations, as a percentage of total firms;

PRD_SERV_XFRMTOT – Product innovative firms (innovation of services), as a percentage of total firms
 PRD_XFRMTOT – Product innovative firms, as a percentage of total firms;

PRV_OUT_XINN – Firms cooperating on innovation activities with private business enterprises outside the enterprise group, as a percentage of innovation active firms;

PUB_CLCU_XINN – Firms co-operating on innovation activities with clients or customers from the public sector, as a percentage of innovation active firms;

PUB_FUND_RNDINN_XINN – Firms receiving government funding for innovation (including R&D and excluding contracts for goods and services), as a percentage of innovation-active firms;

RNDTOT_XEXPINN – R&D expenditures (including in-house & contracted-out), as a percentage of total expenditures on innovation activities in 2020;

SDG – Sustainable development goals;

SLS_SERV_XFRMTOT – Business process innovative firms with innovations in marketing and sales, as a percentage of total firms;

SUP_RNDINN_XFRMTOT – Firms receiving government funding or tax relief for R&D or other innovation activities, as a percentage of total firms;

TAX_CRED_RNDINN_XINN – Firms receiving tax relief for R&D or other innovation activities, as a percentage of innovation-active firms;

TRDM_XFRMTOT – Firms that registered a trademark, as a percentage of total firms;

TUR_INN_XTUR20 – Turnover in innovation active firms, as a percentage of total turnover in 2020;

TUR_PRD_ENT_XTUR20 – Turnover from new or improved products only new to the firm, as a percentage of total turnover in 2020;

TUR_PRD_MKT_XTUR20 – Turnover from new or improved products new to the market, as a percentage of total turnover in 2020;

UNIV_XINN – Firms cooperating on innovation activities with universities or other higher education institutions, as a percentage of innovation-active firms.

1. Introduction

Even, innovation is generally considered an important driver of economic growth and development, the studies lack to provide integrated frameworks, which support the clustering and to provide a clustering analysis of business innovation's impact on EU countries' GDP. In an EU where economies are closely interlinked and dependent on advanced technologies and innovation capacities, understanding the impact of innovation on GDP is particularly important. The EU has consistently stressed the significance of innovation as a cornerstone of its development strategy in many policy areas and initiatives, particularly Horizon 2020 and Horizon Europe, which aim to boost research and innovation in all Member States. However, there remains a lack of consolidated methodologies capable of capturing the multidimensional and regional nature of innovation-driven growth (European Commission, 2021; Arundel & Schoonraad, 2023).

According to economic theory, innovation stimulates productivity, which leads to economic growth. Schumpeter's theory of creative destruction claims that outdated technologies are replaced by innovations that lead to more efficient production processes and the transformation of new products that contribute to economic growth (Schumpeter, 1934). This dynamic process is expected to significantly impact GDP growth, especially in advanced economies such as the EU, where the transition to growth models based on knowledge and innovation is crucial.

Understanding the mechanisms by which business innovation contributes to economic growth is key to defining effective policies that foster growth based on innovation. Several studies examined these mechanisms in various Member States, emphasizing the different ways and factors influencing the link between innovation and economic performance (Grodzicki & Jankiewicz, 2026).

Recent studies confirm these dynamics and further elaborate on the channels through which innovation affects economic performance. For instance, Castellacci and Lie (2017) show that digital innovation significantly influences economic development through productivity and job creation. Similarly, Doran and Ryan (2019) analyze how firm-level innovation impacts macroeconomic performance and find heterogeneous effects across countries, driven by differences in institutional and innovation system quality.

Coe and Helpman (1995) demonstrated that international R&D spillovers significantly benefit open economies – an observation reaffirmed by recent research (Liu et al., 2018), which found that trade openness and international collaboration in R&D enhance innovation efficiency in smaller EU economies. These spillovers are particularly important for Member States with limited domestic R&D capacity but strong integration into global value chains. This mechanism is also very important for smaller EU countries, which do not have significant research and development capacities but have access to global innovation networks to improve their economic performance.

Innovation, however, is not a uniform process across the EU. Recent comparative analyses, such as those by Filippetti and Vezzani (2021), reveal a persistent innovation divide between Northern and Southern Europe, pointing to structural barriers and uneven absorptive capacities. This gap calls for differentiated policies that consider regional dynamics, technological readiness, and socio-economic environments.

Rodríguez-Pose and Crescenzi (2008) stress the importance of regional innovation systems in boosting economic growth. The authors argue that regions with developed innovation infrastructures, such as research institutes, the technology industry, and skilled workers, show higher economic growth. The effectiveness of these territorial systems is enhanced by strong local governance systems and support measures aimed at fostering innovation and turning it into value for money. This view is further supported by modern empirical evidence (Crescenzi et al., 2020), which underlines the importance of local governance, institutional quality, and spatial innovation diffusion in fostering regional competitiveness.

All these studies show the different mechanisms by which innovation influences economic growth in the EU Member States. They highlight the impact of innovation, regional innovation systems, technology diffusion, patents, R&D investment, and sectoral dynamics. Understanding these mechanisms can lead to more effective policies and strategies to

promote innovation- driven growth in the EU's various economic environments. Innovation and its impact on GDP require a multidimensional analytical approach. The methods include macroeconomic modeling, as in the case of Reissl et al. (2021), and spatial econometric models that consider regional emissions, as evidenced by Zhylynska et al. (2020). These different approaches demonstrate the need to consider different aspects of innovation, like technological elaboration, R&D, human capital, and the political environment affecting different countries' economic performance.

Although the role of innovation in economic growth is widely studied and empirically confirmed, significant gaps remain in understanding this relationship within the context of the European Union. Existing research highlights the positive impact of innovation on productivity and GDP, yet innovation outcomes across EU countries remain heterogeneous, shaped by sectoral structures, institutional conditions, and the maturity of national innovation systems. Insufficient attention is paid to how different types of innovation – product, process, or technological – specifically translate into economic performance. Current indicators, such as the European Innovation Scoreboard (European Commission, 2021), provide general assessments but lack the level of detail needed to capture structural differences between countries. Moreover, there is a shortage of long-term and country-level studies capable of identifying innovation impact mechanisms and evaluating the divergence of R&D investments across Member States. Therefore, there is a clear need for more comprehensive, comparative analyses that would determine how innovation influences economic growth in diverse economic and institutional contexts within the EU.

This paper aims to propose an integrated methodology to identify the relationship between business innovations and economic performance across the EU countries. The study's objective shall be to conduct new research by synthesizing the literature findings and using smart econometric approaches through mechanisms by which innovation stimulates the impact of growth-enhancing and growth-enhancing policies based on innovation in the Union. The analysis adopts a multidimensional approach, reflecting the interaction of regional, time dynamics and sectoral factors, and proposes an integrated framework for measuring the impact of innovation on GDP.

The paper consists of 6 sections. The paper starts with introduction. Later on, it provides a literature review highlighting research gaps. After the authors present the theoretical background that is important for the research, data was presented for use in the research and research methodology. The research results are presented under the section dedicated to data analysis and research results. Finally, the paper ends with discussion and conclusion sections.

2. Literature review

Innovation is considered to be one of the main factors determining competitiveness. It is also a key driver of long-term growth, according to Aghion and Howitt (1992), who modelled economic development through a process of creative destruction. Neely and Hii (1998) investigated the links between innovativeness, business performance and firms' innovative capacity and highlighted factors that enhance innovativeness, such as the importance of information

on knowledge flows in assessing innovative performance and networking. Read (2000), by examining organizational innovation at the macro-organizational level, identified factors such as managerial support for an innovative culture. Romer (1990) argues that technological change, based on investment in research and knowledge, can be a driver of domestic economic growth. It is widely recognized that innovation is an important factor in economic growth and competitiveness, with a direct impact on productivity by increasing the efficiency of production processes and enabling the development of new products and services, but it is important to establish the relationship between innovation and business efficiency and the indicators that influence it.

The literature on the impact of business innovation levels on gross domestic product focuses on aggregate indicators of innovation levels across EU countries, without considering the socio-economic and political characteristics of the regions, and most researchers rely on macroeconomic indicators while ignoring micro-level data (Sawng et al., 2021; Sojoodi & Baghbanpour, 2024). Several studies were found that did not provide an integrated approach to the innovation evaluation system, for example Korkmaz et al. (2024) presented a software innovation evaluation model emphasizing information on participants and development activities, but did not evaluate R&D intensity in regions, R&D impact on GDP growth, or sectoral dimensions. Pammolli (2014) proposed a four-dimensional interpretive system of innovation impact, which was based on company size, growth rate distributions, and relationships between company size and growth rate in the mean and volatility and did not extend the model to studies of regional and sectoral indicators. Wang et al. (2016) proposed a service innovation system business process model for start-ups, but did not extend the model to focus on other company sizes. Zhang et al. (2023) and Iqbal et al. (2024) investigated the effects of expansion of production, technological innovation and energy sources (renewable and non-renewable) on CO₂ emissions, using the Sustainable Development Goals (SDG) system as a model for all EU countries, but did not provide an empirical or theoretical study of the impact of innovation on GDP regions or a sectoral extended analysis. The same development trend demonstrate the African countries (Sibanda et al., 2024). Saqib et al. (2023) and Degirmenci et al. (2024) while examining the impact of technological innovation also observed that there are few studies that empirically and theoretically examine the link between technological innovation and ecological footprint and other factors, in their research they describe the technological innovation influence on the ecological footprint, its relationship with human capital and using renewable energy. Rahman and Khan (2024) proposed a five-spiral model linking academia, industry, government and civil society, applying enhanced financial innovation as an integral part of innovation policy, strengthening the finance-growth nexus in developing countries from a macroeconomic perspective, not considering microeconomic processes, time and sectors dimensions. Chen et al. (2022) studied the effects of natural resources, financial integration, eco-innovation and clean energy on the ecological footprint and sought to propose positive and negative variable models but did not explore the integrated impact of innovation on GDP. Szopik-Depczyńska et al. (2020) propose a new approach to measuring innovation in the context of regional development, which is often lacking in macro-economic studies, but their study lacks an in-depth analysis of how it is applied in practice in different types of regions, and how it contributes to innovation policymaking at the decision-making level.

Another group of researches continue the same approach by evaluating the influence of R&D investments and innovations impact on the economic structure (Aliu Mulaj & Dedaj, 2025). The distribution of R&D in a region is an important determinant of innovativeness and economic growth (Liu et al., 2024; Zerihun et al., 2025; Batool et al., 2025). As Rodríguez-Pose and Crescenzi (2008) point out lacks an analysis of how social and institutional factors, such as the culture of cooperation and the interaction between the public and the private sector, modify the impact of R&D on the innovativeness of a region and its long-term growth.

The authors of this paper have noticed that an integrated framework for assessing the impact of innovation on GDP has not been proposed or explored by other authors in the academic literature and have therefore decided to fill this gap by proposing a multidimensional approach that reflects the interaction of regional, time dynamics and sectoral factors.

An integrated framework for measuring the impact of innovation on GDP is reflected in Figure 1.

González-Serrano et al. (2019) examined the impact of innovation activities in 23 EU countries on GDP in the sports sector without taking into account regional specificities, which means that they may not experience direct benefits from the innovations introduced and may not have sufficient capacity to compete in global and intra-EU markets. Kučera and Fiřa (2022) also argue that innovation has a significant impact on each country's economy, but when looking at the impact of R&D expenditure on innovation activity, they do not take into account the specificities of different economic sectors and regions, and the way R&D is absorbed by firms of different sizes. Similarly, Halásková et al. (2024) find that the R&D sector is significantly associated with innovation performance and the impact on the economy, but their study does not assess the impact of R&D performance in the long run and does not

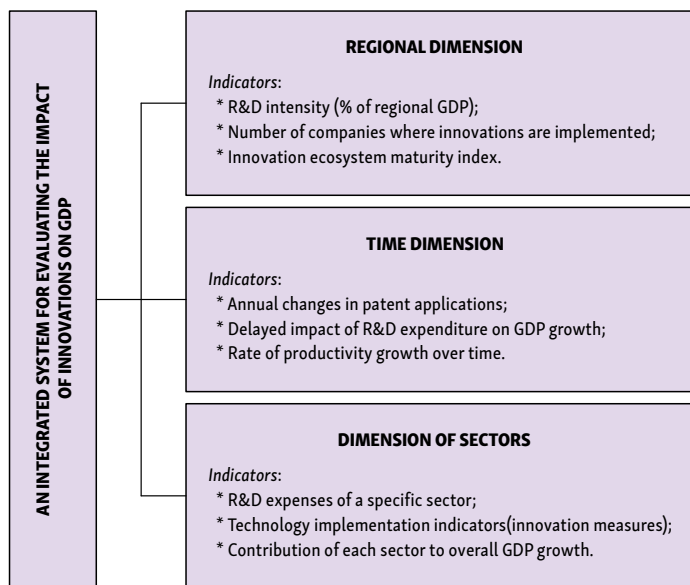


Figure 1. Model of integrated innovation impact GDP assessment system (source: authors' suggestion)

take into account the specificities of regions. Aslan et al. (2024) also demonstrate indicator linkages between EU countries' GDP, investment, R&D expenditure, innovation and labor productivity, basing their study on quantitative innovation indicators, but ignoring aspects of the quality of innovations and their impact on social well-being and sustainability. In the EU, innovation is a key driver of economic growth and regional development. Understanding the link between product and process innovation and sector-specific aspects provides valuable information on their impact on GDP and the emergence of countries clusters.

Combining product and process innovation with EU thematic aspects to analyze the impact on GDP and form clusters

Product innovation refers to the creation of new or significantly improved goods or services that add value to consumers and stimulate competition in the market (Schumpeter, 1934; Aghion & Howitt, 1992; Romer, 1990). These two types of innovation are often linked. For example, the development of production processes can create conditions for the production of new innovative products, and the demand for new products can lead to the need for better processes (Hall et al., 2010; Griliches, 1990; Wang et al., 2016). On the other hand, process innovations involve the introduction of new or significantly improved production or delivery methods that increase efficiency, reduce costs, and improve product quality (Evangelista et al., 2014; Filippetti & Vezzani, 2021; Bresciani et al., 2021).

The impact of product and process innovation varies greatly from sector to sector, reflecting differences in technology intensity, market dynamics and regulatory frameworks (D'Angelo, 2012; Neely & Hii, 1998; Read, 2000). High-tech sectors such as IT, biotechnology, and renewable energy typically rely on product innovation to foster growth and competitiveness (Haefner et al., 2021; Zang et al., 2023; Saqib et al., 2023). Traditional industries, such as manufacturing and logistics, often benefit more directly from process innovations that improve operational efficiency (Crescenzi et al., 2020; Brodny & Tutak, 2022; Bottazzi & Peri, 2002). In sectors with rapid technological development, such as pharmaceuticals and electronics, product innovation is a key driver of GDP growth (Liu et al., 2018; Fagerberg & Verspagen, 2002; Maradana et al., 2017); on the contrary, process innovations that increase resource consumption and improve sustainability can play a greater role in resource-intensive industries such as agriculture or mining (Chen et al., 2022; Miśkiewicz, 2021; Bate et al., 2023).

Innovation contributes to GDP by increasing productivity, increasing market share and stimulating the creation of new industries (Ulku, 2004; Coe & Helpman, 1995; Hall et al., 2010). The extent of its impact depends on the dynamics of the sector. For example, in high-tech sectors product innovations make it possible to create high-quality goods and services that directly increase GDP (Rodríguez-Pose & Crescenzi, 2008; Mewes & Broekel, 2022; Korkmaz et al., 2024). In industries process innovations increase productivity, reduce production costs, and increase production (Fernández-Cerezo & Montero, 2021; Halásková et al., 2024; Paula & da Silva, 2021). In services sector product and process innovation, such as new online platforms or optimized service delivery models, contribute to economic growth (Arundel & Schoonraad, 2023; Hernández de Rojas et al., 2024; Yang & Han, 2021).

Innovation significantly contributes to the development of geographical clusters. Sector specialization is a key factor in cluster dynamics (Rodríguez-Pose & Crescenzi, 2008; Bottazzi

& Peri, 2002; Mewes & Broekel, 2022). For example, process innovation clusters can be set up in regions specialising in high-tech production, while regions focusing on creative industries can prioritise product innovation (Fagerberg & Verspagen, 2002; Bresciani et al., 2021; Perry-Smith & Mannucci, 2017). The ratio of innovation to GDP varies from one Member State to another and depends on the strength of the region and the composition of the industry (Griliches, 1990; Halásková et al., 2024; González-Serrano et al., 2019). In countries with strong high-tech sectors, such as Germany and Sweden, there is a high-level correlation between product innovation and expansion of GDP (Liu et al., 2018; Aghion & Howitt, 1992; Romer, 1990), and countries that focus on traditional industries, such as Poland or Romania, will benefit more from process innovation aimed at increasing efficiency and reducing costs (Crescenzi et al., 2020; Brodny & Tutak, 2022; Evangelista et al., 2014).

The formation of clusters also reflects these differences. Northern and Western European countries have clusters in technology-intensive sectors (Haefner et al., 2021; Hernández de Rojas et al., 2024; Korkmaz et al., 2024), while Southern and Eastern Europe have clusters in other sectors, where process innovation plays a greater role (Szopik-Depczyńska et al., 2020; Maradana et al., 2017; Fernández-Cerezo & Montero, 2021).

Challenges and regional disparities in innovation-led growth

Challenges to unlocking the full potential of innovation include differences in R&D investment, differences in human capital and differences in institutional structures (European Commission, 2021). Bate et al. (2023) have pointed out that access to a skilled workforce and strong education systems, especially in academic disciplines of Science, Technology, Engineering and Mathematics (STEM) fields, are crucial to foster innovation.

Despite the overall positive effects, there are regional disparities in innovation and economic performance across the EU. Regional differences in innovation are often related to the institutional environment, as shown by Crescenzi et al. (2020) in their analysis of innovation growth in EU regions, but their study lacks a more detailed analysis of how specific institutional characteristics (quality of governance, efficiency of public investment, or the stability of local policies) affect the dynamics of innovation across regions. Rodríguez-Pose and Crescenzi (2008) point out that regions in Northern and Western Europe with strong innovation ecosystems grow faster, while regions in Southern and Eastern Europe are less innovative.

Bottazzi and Peri (2002) showed the positive spill-over effects of innovation, whereby R&D in EU countries contributes to global economic growth and countries benefit not only from R&D investment but also from investment in neighboring countries. Mewes and Broekel (2022), investigating the relationship between technological complexity and regional economic growth, found that a 10% increase in technological complexity is associated with regional economic growth of 0.45% GDP per capita growth.

Innovation's impact on GDP growth in various EU countries

The link between business innovations and economic growth has been thoroughly studied (Aghion & Howitt, 1992; Romer, 1990; Griliches, 1990; Hall et al., 2010), but gaps still must be addressed to better understand the dynamics of the European Union (EU). While many studies confirm that innovation fosters productivity and GDP growth (Maradana et al., 2017; Kučera

& Fiła, 2022; Paula & da Silva, 2021), *persistent research gaps remain*, especially regarding *differentiated national outcomes* and the *mechanisms through which innovation translates into economic performance* (Rodríguez-Pose & Crescenzi, 2008; Crescenzi et al., 2020; Bate et al., 2023). Several scholars emphasize the *heterogeneous effects of innovation across sectors and countries*, noting that the *institutional context, innovation system maturity, and regional characteristics* significantly shape outcomes (Filippetti & Vezzani, 2021; Evangelista et al., 2014; Szopik-Depczyńska et al., 2020). However, much of the literature still lacks *granular, country-level analyses* that could reveal *underlying structural patterns and policy-relevant insights* (Brodny & Tutak, 2022; Halásková et al., 2024; Saqib et al., 2023; Liu et al., 2018; Bresciani et al., 2021). Therefore, this debate highlights the need for more *comprehensive and comparative studies* that explore innovation-growth linkages *on a country-by-country basis*, taking into account *sectoral structure, R&D intensity, and governance frameworks*.

Paula and da Silva (2021) examined the increase in a country's economic development and patents through spending at four levels of R&D intensity: government, higher education institutions, firms, and private non-profit organizations. In addition, Mewes and Broekel (2022) examined the impact of technology on regional economic growth, finding that the ability to produce and use sophisticated technologies is an important element of competitive advantage that influences regional economic growth. Brodny and Tutak (2022) investigated the digitalization level and the usage of innovative technologies in firms in the EU-27 to establish the link between innovation and GDP, the level of use of digital technologies and infrastructure for Industry 4.0, and the relationship between the EU-27 digitalization index values and economic parameters that characterize the economy. The authors found that Sweden is the leading country in R&D point of view expenditure as a percentage of GDP (4%), while Romania spends less than 1% of its GDP on R&D activities.

While there is a need for a thorough assessment of innovation and economic growth in the Union (Table 1), more detailed country-by-country studies are needed, considering the specific economic, social, and institutional circumstances in each Member State. For instance, the European Innovation Scoreboard (European Commission, 2021) provides a comprehensive assessment of innovation performance but does not include specific national assessments that take into account the local characteristics of countries with diverse innovation levels, such as Sweden (high innovation rate) and Bulgaria (low innovation rate), so as to understand the different factors affecting their economic performance.

A comprehensive empirical analysis that identifies and quantifies specific ways in which innovation affects constrained GDP is still lacking in current research (Hall et al., 2010; Ulku, 2004; Paula & da Silva, 2021). Future research should focus on distinguishing between the impact of different types of innovation (e. g. product innovations in individual processes) and their concrete impact on economic growth.

Long-term studies are needed to explore the long-term impact of innovation on GDP. This research will help you understand the movement of innovation-driven growth and the sustainability of the profit effects of innovation.

Filling this research gap requires a more modern and comprehensive approach to studying the impact of innovation, mainly product and process, on GDP in EU Member States. By focusing on country analysis, innovation impact mechanisms, regional imbalances, long-term

research, sectoral inequalities and policy frameworks, future research could provide a more comprehensive picture of how this innovation contributes to economic growth in the Union. This will help not only to better understand the theory, but also to formulate more effective policies adapted to the different needs of EU Member States.

Table 1 below is a summary of the articles analyzing the impact of innovation on GDP in various EU countries.

Table 1. Analysis of the impact of innovation on GDP in EU countries (source: authors' calculation and elaborations)

Countries	Authors	Year	Focus
German	Ulku	2004	Discover how innovative inputs and outputs contribute to GDP growth in Germany, with a focus on R&D spending and patent trading.
Poland	Szopik- Depczyńska et al.	2020	The focus is on regional differences in innovation and their relationship to economic performance, particularly on the role of local government policies.
Spain	Fernández-Cerezo & Montero	2021	Analyze the impact of technological innovation on the sector's GDP, especially in manufacturing and services.
Italy	D'Angelo	2012	Discover how national and regional innovation strategies contribute to GDP growth, with a focus on SMEs and high-tech industries.
France	Maradana et al.	2017	The report examines the unique impact of innovation on GDP, highlighting its high GDP per capita.
Ireland	Rios-Morales & Brennan	2009	The impact of innovation on Ireland's GDP is heavily influenced by governmental policies promoting internationalization.
European Union	Evangelista et al.	2014	Comprehensive overview of how innovation contributes to economic growth in the EU and stressed the importance of digital technologies.

Bresciani et al. (2021) highlighted that when assessing innovation processes, it is important to target innovation policies toward regions that need additional strategies to develop potential improvements.

Together, these papers provide a comprehensive picture of how innovation contributes to economic growth in different EU contexts, taking into account national and regional perspectives.

3. Data and research methodology

3.1. Benefits of the application of PCA

Principal Component Analysis (PCA) is a technique for shrinking large datasets by reducing the number of variables in a dataset while saving the most important information about the dataset.

This helps eliminate noise and irrelevant details, improving clustering algorithms' accuracy and speed. By focusing only on the most important information, PCA makes it easier to see

patterns and understand how the data is structured. Visualizing the data in just two or three dimensions after PCA also helps to analyze spot useful groupings and relationships.

PCA can be used with different clustering algorithms (like, k-means), making it a universal tool in various contexts and applications. K-means algorithm calculates the distance between a centroid and everyone data point to accredit it to cluster.

Our research is based on three-steps methodology where each step is designed to enhance the quality and interpretability of the research. These three steps include data cleaning and correlation matrix formation, Principal Component Analysis (PCA), and k-means algorithm clustering are described below.

Step 1: Data preprocessing includes data cleaning and correlation matrix formation

The first step in our methodology aims to find the smallest set of non-redundant columns. It involves constructing a correlation matrix to identify and filter out high-correlation indicators. This step is determinant for removing redundancy and streamlining the dataset, thereby enhancing the efficiency and accuracy of subsequent analyses. The detailed process is as follows:

- 1.1.** Data cleaning process. We filter all non-EU countries and columns where most information is missing, then add missing data about EU countries.
- 1.2.** Correlation calculation. We calculate the correlation coefficient for each pair of columns in the dataset. The correlation coefficient quantifies the linear relationship between two variables, with a possible range from -1 to $+1$. A coefficient points out a strong positive correlation is close to $+1$, and a coefficient close to -1 indicates a strong negative correlation. A coefficient around 0 suggests no linear relationship.
- 1.3.** Threshold determination. In this scientific work, we assume that the strongly correlated indicators show the same statistical information, so we set the threshold value for the correlation coefficient to 0.9 . This threshold was chosen based on previous research, indicating that correlations above this value are considered too high and suggest redundancy. It provides a practical and effective approximation, ensuring that the final dataset is both comprehensive and manageable. This step reduces redundancy by eliminating columns that do not add significantly new information.
- 1.4.** Feature Selection. We used Forward Feature Selection (FFS) to identify the most suitable innovation indicators from the entire input data set, selecting the subset of features that are optimal for constructing a model to assess their impact on the Gross Domestic Product (GDP). Repeat this procedure iteratively until no further columns can be filtered out. This FFS iterative process removes the least important indicators for a cluster's creation and ensures that the dataset is optimally reduced, retaining only the most informative columns that contribute most to the classification task.
- 1.5.** Data Normalization was used to adjust data to a consistent scale to ensure that all values are proportionate and did not distort the values range (for example, the Database consists of patent units, investment in dollars, innovations number, etc.). The Min-Max normalization method was linearly converted into a distribution where the minimum variable value matches the value -1 , and the maximum matches the value $+1$.

Step 2: Principal Component Analysis (PCA)

The next step is Principal Component Analysis (PCA). This is a method for reducing dimensions linearly, which is commonly used in exploratory data analysis, visualization, and data preprocessing. The technique linearly converts the data into a new coordinate system, making it easy to identify the principal components that represent the largest variations in the dataset.

A series of unit vectors serve as the principal components for a set of points in a given coordinate space. In this scenario, the optimal line is defined as the one that minimizes the root mean square perpendicular distance between the points and the line. These directions, known as principal components, constitute an orthonormal basis where the various individual dimensions of the data are not linearly related. Numerous studies use the first two principal components to create two-dimensional plots, allowing for the visual identification of clusters of closely related data points (Greenacre et al., 2022).

Principal component analysis defines how it influences different components on the result indicator.

The first component 0, allows you to form a main factor with the greatest dispersion among other linear combinations (main factors).

Step 3: Clustering

The final 3 step involves clustering data according to main components using the k-means algorithm. Clustering is a method for grouping similar data points together, facilitating the identification of patterns and relationships. The detailed steps are as follows:

3.1. Clusters creation

K-means carries out precise clustering by assigning each data vector to a single cluster. The algorithm concludes when cluster assignments can no longer be altered. To form the clusters authors used the Euclidean distance on the selected attributes.

3.2. The number of clusters optimization

In this step, the centers for a specified number of clusters are determined (there is no dynamic number of clusters). We used an iterative loop to determine the number of clusters. Then chose the best option.

3.3. Dataset denormalization

Further on based on the normalization algorithm from step 1.5, authors used the denormalization algorithm, and the indicators returned to their normal measurements.

The cauterization algorithm outputs the centers of each cluster for a predetermined number of clusters, providing clear and distinct groupings of the data. It performs crisp clustering, meaning each data vector is assigned to exactly one cluster, which aids in the clarity and interpretability of the results.

Our data processing methodology systematically reduces data dimensionality and clusters the processed data, ensuring efficient and meaningful analysis of economic innovativeness indicators. Each step, from correlation matrix formation and filtering to PCA and clustering with k-means, is meticulously designed to enhance the quality and interpretability of the dataset, providing a robust foundation for further analysis and insights.

3.2. Data

The primary data for this study are open-source OECD data based on Organisation for Economic Co-operation and Development [OECD] (2023) Survey of National Innovation Statistics and Eurostat's Community Innovation Survey, combined into final innovation indicators. The indicators included in this file are based on data from innovation surveys carried out in 42 countries in accordance with the OECD and Eurostat (2018) guidelines for the 2020 edition of the Oslo Manual. The database consists of 43 indicators identifying two types of innovation by object, mainly on product and business process innovation (presented in Abbreviations list by the end of the paper) and GDP per capita.

The dataset, released in November 2023, is updated biennially, with the most recent update reflecting this schedule. It highlights business innovation activities from 2018 to 2020 across OECD and EU countries. For the first time, it offers indicators of innovations that deliver environmental benefits and showcases the evident resilience of business innovation

The statistical information used applies to companies of all sizes and all industries.

After the correlation analysis we chosen the important indicators for our research. We used the Firms that registered a design (INN_XFRMTOT), total number of innovative companies (INN_OSLO_XFRMTOT), Number of product innovative firms (PRD_XFRMTOT), Number of companies that developed Business processes only on their own (DEVE_PCS_ENT_XFRMTOT),

Table 2. Variables description (source: authors' calculation and elaborations)

Variable symbol	Calculation method	Description
INN_XFRMTOT	percentage of total firms	companies that registered a design
INN_OSLO_XFRMTOT	percentage of total firms	Innovative companies (product/process)
PRD_XFRMTOT	percentage of total firms	Product innovative companies
DEVE_PCS_ENT_XFRMTOT	percentage of total firms	Business process innovative companies that developed processes only on their own
SUP_RNDINN_XFRMTOT	percentage of total firms	companies receiving government funding or tax relief for R&D or other innovation activities
PDPCS_RD_XINNOSLO	percentage of innovative firms	innovative companies developed R&D active product and/or business process
ECO_ENT_CON_XINN_OSLO	percentage of innovative firms	Companies that introduced innovations with environmental benefits
INN_NOFOR_XINN	Share of innovation active firms	Innovation-active companies not operating in international markets
EMP20_INN_OSLO_XEMP20	Share of persons in total employment in 2020.	Number of employees in innovative companies
EMP20_INN_XEMP20	Share of persons	Number of employees in innovation-active companies in total employment
RNDTOT_XEXPINN	percentage of total expenditures on innovation activities	R&D expenditures (including in-house & contracted-out)

number of companies received R&D government grants (SUP_RNDINN_XFRMTOT), number of active innovative firms (PDPCS_RD_XINNOSLO) number of companies introduced eco-friendly Innovations (ECO_ENT_CON_XINN_OSLO), number of local innovative companies (INN_NOFOR_XINN), the number of Employees in innovative firms (EMP20_INN_OSLO_XEMP20), Number of employees in innovation-active firms in total employment (EMP20_INN_XEMP20), share of R&D expenditures of total expenditures (RNDTOT_XEXPINN) as indicators to describe a level of innovation the country. The method of calculating the selected variables is described in Table 2.

4. Data analysis and research results

Table 3 provides descriptive statistics of the chosen variables. The variable INN_XFRMTOT, represents total innovation activity within EU countries, with values ranging from 7.55 to a maximum of 100.00. The indicator shows a moderately high and fairly concentrated level of innovation efforts across the sample, exhibiting an average value of the indicator of 50.82 with a standard deviation of 15.14.

A closely related indicator, INN_OSLO_XFRMTOT, shows a slightly lower average value of 46.78 and a higher dispersion ($SD = 16.94$), ranging from 1.12 to 99.85, indicating more heterogeneity in how firms meet standardized innovation criteria.

In terms of innovation outputs, PRD_XFRMTOT – capturing product-related innovation – has a mean of 27.68 ($SD = 12.05$), with values spanning from 0.28 to 84.42, reflecting a lower but still notable engagement with product development relative to total innovation.

Internal development processes (DEVE_PCS_ENT_XFRMTOT) yield an even lower mean of 18.62 ($SD = 8.43$), with a range of 0.29–80.25, suggesting that while most firms engage in process development to some extent, few do so intensively.

Indicator of innovation input reveal, SUP_RNDINN_XFRMTOT, representing support for R&D within the innovation context, has a low mean of 11.28 with a standard deviation of 7.55, and a minimum of 0.00, which highlights the absence of R&D activities in a considerable portion of firms, though some still report support levels up to 60.85.

Table 3. Descriptive statistics (source: authors' calculation and elaborations)

Variable symbol	Mean	Standard deviation	Min	Max
INN_XFRMTOT	50.82	15.14	7.55	100.00
INN_OSLO_XFRMTOT	46.78	16.94	1.12	99.85
PRD_XFRMTOT	27.68	12.05	0.28	84.42
DEVE_PCS_ENT_XFRMTOT	18.62	8.43	0.29	80.25
SUP_RNDINN_XFRMTOT	11.28	7.55	0.00	60.85
PDPCS_RD_XINNOSLO	40.87	15.83	0.00	100.00
ECO_ENT_CON_XINN_OSLO	35.48	13.16	8.27	93.58
INN_NOFOR_XINN	45.25	21.29	1.37	99.33
EMP20_INN_OSLO_XEMP20	63.51	17.59	1.18	98.65
EMP20_INN_XEMP20	66.51	17.52	1.18	100.00
RNDTOT_XEXPINN	59.23	21.77	0.00	95.17

Conversely, the variable PDP_CS_RD_XINN_OSLO, indicating the extent of R&D-based product/process innovation (Oslo-aligned), shows a mean of 40.87 (SD = 15.83, range 0.00–100.00), implying that a significant portion of firms engage in R&D-intensive innovation, although there remains a wide disparity in commitment levels.

The economic contribution of innovation, captured by ECO_ENT_CON_XINN_OSLO, reports an average of 35.48 (SD = 13.16, min–max: 8.27–93.58), suggesting that innovation-related economic returns are generally positive, though not uniformly high. INN_NOFOR_XINN, which excludes foreign collaboration from innovation metrics, records a mean of 45.25 and the highest variability among all indicators (SD = 21.29, range 1.37–99.33), pointing to marked differences in how domestically driven innovation plays out across entities.

Employment-based innovation measures reflect broader organizational engagement. Specifically, the percentage of employees in innovative firms (EMP20_INN_OSLO_XEMP20) stands at an average value of 63.51 (SD = 17.59), while the corresponding national figure (EMP20_INN_XEMP20) is slightly higher at 66.51 (SD = 17.52), indicating strong alignment between regional and national innovation workforce distribution.

Finally, RNDTOT_XEXPINN, denoting the share of total R&D in overall innovation expenditures, presents the average value of the indicator of 59.23 with a substantial standard deviation of 21.77 and a wide range (0.00–95.17), underscoring the central but uneven role of R&D spending within innovation budgets.

The first step (Step 1) in data pre-processing is data cleaning, which removes countries that are not part of the EU. The next step was the data pre-processing, where a correlation coefficient was computed for every pair of chosen columns, i. e. a measure of the correlation between two variables. Figure 2 is a linear correlation map (colored table), showing the pairwise correlation between activities of innovation. The indicator ranges from –1 (correlation is strong negative and marked in dark red) to 1 (correlation is strong positive and marked in dark blue). The absence of a linear correlation is indicated by a value of zero (0), which is shown in white. Indicators with resembling information were further discarded (the aggregated indicator “Product innovative firms, as a percentage of total firms” conclude of two indicators: “Product innovative firms (innovation of goods), as a percentage of total firms” and “Product innovative firms (innovation of services), as a percentage of total firms”). The latter two indicators, as well as the aggregate indicator of which they are parts, are similarly related to all other characteristics of activities of innovation.

This reason has led to the exclusion of the latter two indicators from further analysis, and to the identification of indicators with a negligible correlation with all indicators (more than –0.3 and less than 0.3).

The red cells in Figure 2 show a negative correlation between:

- the percentage of innovative firms not operating in international markets has a negative correlation with the innovation performance of all types of firms. It means that middle and small companies have the worst opportunities for innovation compared to international enterprises.
- the number of environmental innovations is not increasing in line with the overall growth in the number of innovative companies in the country.
- the number of firms in applied for patents, registered a design or a trademark does not grow with the percentage of innovative firms.

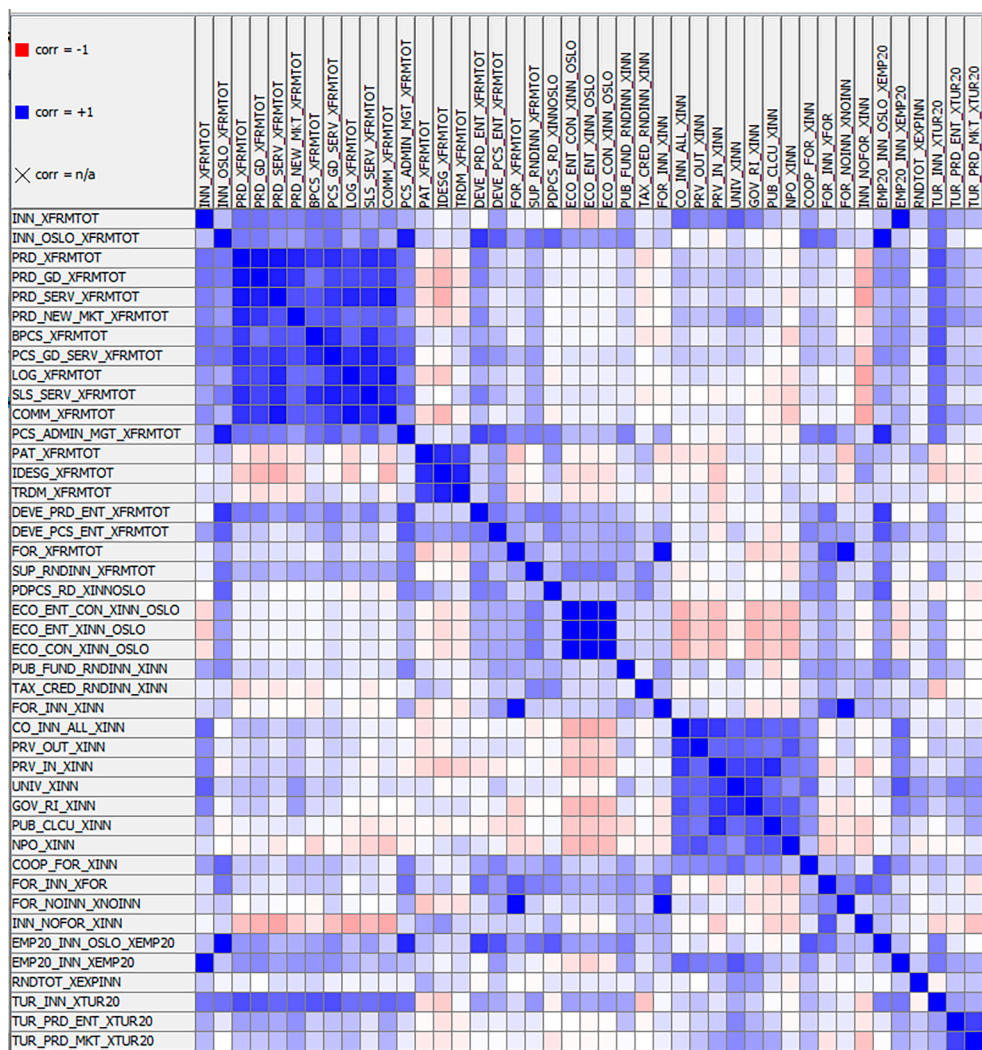


Figure 2. The correlation matrix by all 43 indicators (source: authors' calculation and elaborations)

For the reasons that corresponded and based on Forward Feature Selection, we excluded 20 indicators.

For each of the remaining indicators, PCA was generated (Step 2). These principal components represent linear combinations of the initial economic innovativeness indicators. Each principal component is orthogonal to the preceding ones and captures the largest possible variance in the data. This transformation simplifies the dataset while preserving its most significant features, making it easier to analyze and interpret.

However, after the 11th main component, the impact of each becomes insignificant (Table 4). According to Table 4 the first principal component accounts for 35.29% of the total variation, the second – 21.52%, etc. Thus, the first three principal components retain 73.3% of the information contained in the 20 original variables. This is quite sufficient for practical use and maximum for easy visualization.

Table 4. PCA indicators (source: authors' calculation and elaborations)

	PCA0	PCA1	PCA2	PCA3
variance	0.3529	0.2152	0.1649	0.0836
sum	0.35	0.57	0.73	0.82
	PCA4	PCA5	PCA6	PCA7
variance	0.0621	0.0483	0.0254	0.0194
sum	0.88	0.93	0.95	0.97
	PCA8	PCA9	PCA102	PCA11
variance	0.0129	0.0054	0.0031	4.00E-04
sum	0.99	0.99	0.99	0.99

PCA of a multivariate distribution centered at the point (0.3). In this case a standard deviation is 0.35, approximately in the direction of (0.266, 0.352) from Table 4.

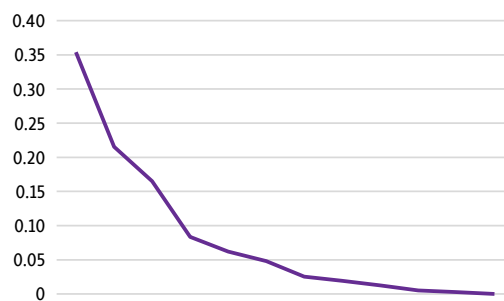
In total, the first 3 Principal components have been chosen, representing a linear combination of the initial indicators of the innovativeness of the economy, and the principal components are a collection of weighting coefficients used to create this combination. These first 3 explain 73.3% of the influence of the selected indicators on GDP (Figure 3).

Five clear clusters are obtained (Step 3) and shown in Figure 4 shows a 3D image of clusters from different sides. Using cluster analysis, intra-group homogeneity of country profiles by the number (volume) of innovations was revealed. To describe clusters, we turn to the matrix of country profiles depending on the innovation level.

The first cluster (cluster_4 according the Figure 4) is characterized by a poor innovation level. The center of the cluster is defined by the following coordinates (Table 5): PCA0 center = 0.20; PCA1 center = 0.69; PCA2 center = 0.44. These coordinates reflect the cluster's overall performance in terms of innovation and related metrics.

This cluster includes countries that are in a catching-up phase of development. Specifically, this cluster comprises Croatia, Greece, Malta, Romania, and Bulgaria.

One of the clusters defining characteristics is the weak development of the institutional framework necessary for the implementation of innovation strategies. This includes the lack of robust systems and structures to support and promote innovation within these countries. Additionally, there is a lack of effective coordination among various stakeholders, which hinders the implementation of innovative strategies.

**Figure 3.** PCA variance (source: authors' calculation and elaborations)

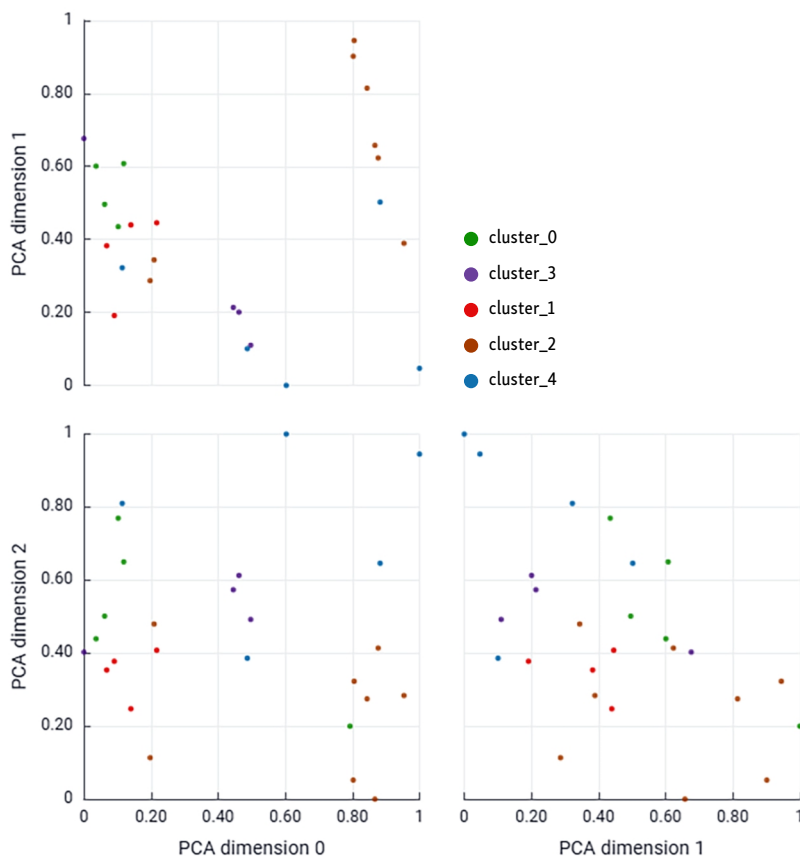


Figure 4. Clusters matrix (source: authors' calculation and elaborations)

Table 5. Clusters centers(source: authors' calculation and elaborations)

	PCA0	PCA1	PCA2
cluster_0	0.85	0.83	0.42
cluster_1	0.07	0.66	0.55
cluster_2	0.73	0.30	0.71
cluster_3	0.39	0.46	0.52
cluster_4	0.20	0.69	0.44

Furthermore, the interest and engagement of stakeholders in the innovation process are relatively low in this cluster.

Overall, the countries in the cluster face significant challenges in fostering an environment conducive to innovation. Addressing these challenges requires strengthening the institutional framework, enhancing coordination among stakeholders, and increasing the overall interest and investment in innovation and sustainable practices initiatives.

Countries in the second cluster (identified as cluster_3 in Figure 4) have a below-average level of innovation and average economic growth rate. The coordinates of the cluster's center is located at: PCA0 center = 0.39; PCA1 center = 0.46; PCA2 center = 0.52.

The cluster includes four countries: Cyprus, Lithuania, Poland, and Italy. These countries currently face challenges in fostering innovation, which is reflected in their below-average innovation levels. However, their economic growth rate is average, indicating that while they are not leading in innovation, they are maintaining a steady economic performance.

Despite these challenges, there is significant potential for these countries to advance and join the ranks of countries with more advanced economic development.

Countries in the third cluster (cluster_1 in Figure 4) have a below-average innovation level and below-average innovation rate growth. According to the PCA, the center of this cluster is located at the following coordinates: PCA0 center = 0.07; PCA1 center = 0.66; PCA2 center = 0.55.

The third cluster (cluster_1 according Figure 4) includes five countries: Spain, Portugal, Hungary, Latvia, Slovenia, and Slovakia. These countries currently face challenges in fostering innovation and achieving significant growth in their innovation rates. Their innovation performance is not so high when compared to cluster leader, indicating that there is substantial room for improvement.

With the further successful development of measures to stimulate economic growth considering innovative transformations, countries can move into the cluster of countries with advanced economic development.

The fourth cluster (cluster_2 according Figure 4) is characterized by a sustainable and upper- average level of innovation. According to the PCA, the center of this cluster is located at the following coordinates: PCA0 center = 0.73; PCA1 center = 0.3; PCA2 center = 0.71.

The cluster includes eight countries: Austria, Belgium, Czech Republic, Estonia, France, Iceland, Luxembourg, Norway, and Ireland. These countries exhibit a solid foundation in innovation, with well-established systems and practices that support innovative activities. Their current level of innovation is sustainable, indicating that they can maintain and potentially enhance their innovative capabilities over time.

In the future, 8 countries of the second cluster may move into the block of leading countries if they strengthen the stimulation of innovation activity by the rising stakeholder interest and integration of scientific developments and their implementation.

The fifth cluster (cluster_0 in Figure 4) includes of countries that are recognized as leaders in the field of innovation. These countries exhibit a high level of innovation, which is reflected in their advanced technological capabilities, robust research and development activities, and strong support for innovative enterprises. Additionally, these countries have economies that are oriented towards environmental protection, ensuring that their economic growth does not come from environmental costs.

The center of the cluster is defined by the following coordinates in the Principal Component Analysis (PCA) space: PCA0 = 0.85; PCA1 = 0.83; PCA2 = 0.42. It includes the following countries: Germany, Denmark, Finland, the Netherlands, and Sweden. These countries are characterized by high efficiency and the link between innovative potential and economic development.

In these countries, there is a well-established institutional framework that supports innovation and further practices oriented to sustainable development. This framework includes

policies and regulations that encourage research and development, as well as mechanisms for coordinating efforts among various stakeholders, such as government agencies, private sector companies, and research institutions.

Thus, clustering countries according to innovation indicators made it possible to empirically confirm the dependency which exists the degree of economic development of countries on indicators of innovation activity.

Next, we will identify the degree of influence of individual indicators of innovation activity on the innovation level in the economy. This means that the original variables are influenced by the principal components (Table 6).

Table 6. Impact of 11 indicators on the final indicator (source: authors' calculation and elaborations)

	PCA0	PCA1	PCA2
INN_XFRMTOT	-1.10	0.73	0.29
INN_OSLO_XFRMTOT	0.18	-1.17	0.20
PRD_XFRMTOT	0.78	0.43	0.58
DEVE_PCS_ENT_XFRMTOT	2.06	0.30	0.26
SUP_RNDINN_XFRMTOT	2.69	0.49	0.34
PDPCS_RD_XINNOSLO	0.65	-0.86	-0.34
ECO_ENT_CON_XINN_OSLO	1.82	0.09	0.51
INN_NOFOR_XINN	0.85	0.12	-1.74
EMP20_INN_OSLO_XEMP20	-0.99	-1.83	-0.14
EMP20_INN_XEMP20	-2.62	0.63	0.07
RNDTOT_XEXPINN	-1.40	1.27	-0.61

The summary influence of each indicator on the main component determines the list of the most important 11 indicators for increasing the innovation volume in the economy.

The Table 6 shows the 11 indicators impact on the ultimate indicator. Among 11 indicators there is one indicator, which shows significant contributions to environmental protection, as a percentage of innovative firms.

The impact of indicators on components PCA0, PCA1, PCA2 and PCA3 are divided into two types:

1. On the one side there are indicators that are directly dependent: a percentage of firms developed Product innovations; a percentage of enterprises that developed Business process innovation; a percentage of firms receiving government funding or tax relief for R&D or other innovation activities; the number of enterprises that introduced innovations with significant contributions to environmental protection;
2. On the other side, there are inversely related indicators – persons employed in innovation active enterprises as a share of total employment, a percentage of local innovation-active firms.

At the same time, PCA0 has the greatest impact on innovation development and, in accordance with the table, to increase innovation in the economy, it is imperative to develop government funding or tax relief for R&D with the rising number of receiving.

The absence of distinct clusters in Figures 5 and 6 is due to their formation in 3D space. However, a clear correlation is evident between the size of innovative activities and the GDP per capita of the country. The figures confirm the hypothesis regarding the innovation's impact on economic growth and validate the proposed research methodology.

To achieve GDP growth from the selected model indicators by 0.64%, it is needful to increase the share of R&D expenditures (including in-house & contracted-out) in total expenditures with the percentage increasing companies with innovation activities (Figure 5). At the same time, the share of employees of innovative firms in the total number of employees

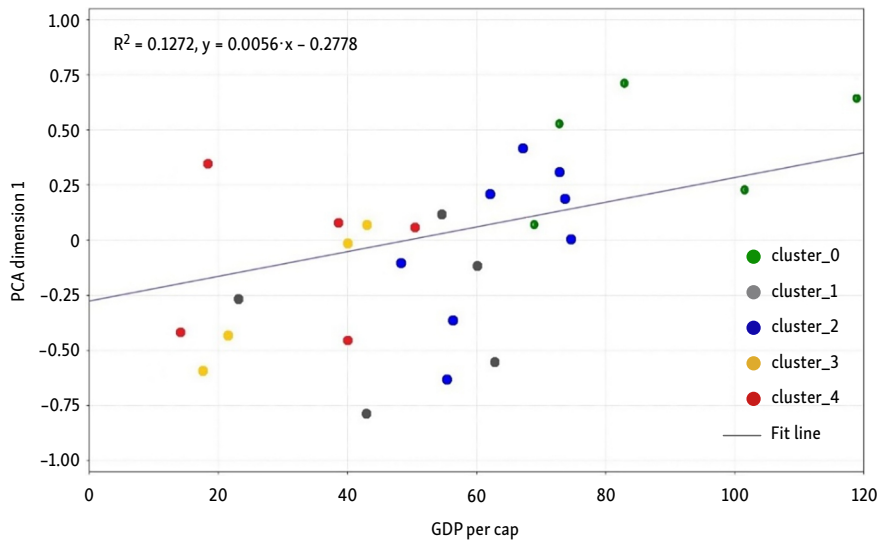


Figure 5. Influence PCA dimation 1 on GDP per capita (source: authors' calculation and elaborations)

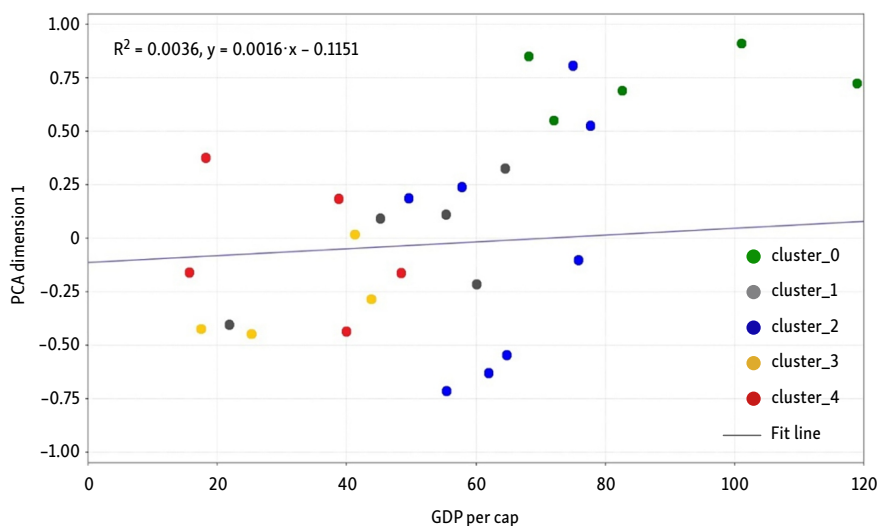


Figure 6. Influence PCA dimation 0 on GDP per capita (source: authors' calculation and elaborations)

should decrease. This indicates the need to hire employees in such companies not part-time, but full-time.

Government measures to stimulate innovation have a beneficial effect to GDP growth (Figure 6). In the created model, these measures are reflected by government financial support for R&D activities and the share of persons employed in innovation-active firms in total employment in 2020. The negative impact of the number of employees on GDP growth with the R&D budget increasing may indicate the need to change the intensity of employee work and attract more highly qualified researchers. Companies that have evolved business processes entirely on their own are also of great importance in this component. With an increase in indicators, while maintaining the proportions of the model, principle component 0 will cause GDP growth for the year by 0.0018%.

Thus, the study made it possible to empirically confirm the need to stimulate and create conditions for innovative economic development, that countries with a high level of digital innovation have a higher level of economic development.

5. Discussions

Innovation is widely recognized as a key driver of economic growth, and numerous studies highlight its significant role in increasing productivity, increasing competitiveness, and promoting sustainable practices. For the European Union (EU), this relationship is particularly important given the different innovation capacities and economic adjustments of the Member States. The aim of the debate is to examine the influence of innovation levels on the Gross Domestic Product (GDP) of EU countries on the basis of various theoretical and empirical concepts.

Aghion and Howitt's (1992) developed model provides a key basis for understanding the relationship between innovation and economic growth through creative destruction. Their model emphasizes innovation in the expansion of new products and processes that stimulate economic growth by replacing outdated technologies. Likewise, Romer (1990) endogenous development theory emphasizes that the greatest obstacle to long-term economic growth is technological change caused by investment in research and development.

These theoretical findings are confirmed by empirical evidence. Bottazzi and Peri (2002) and Coe and Helpman (1995) show that innovations, often measured by patent data and R&D expenditure, are positively correlated with the performance of Europe's regional economy. Innovation is interested in the effect that if progress in one area or sector increases productivity in other areas, this effect will increase further. Rodríguez-Pose and Crescenzi (2008) also emphasize the significance of regional innovation systems in fostering growth of economy, stressing that regions with powerful innovation infrastructure tend to have higher GDP growth.

The European Innovation Scoreboard (European Commission, 2021) provides a comprehensive assessment of the innovation performance of EU Member States, taking into account significant differences. Innovation leaders such as Sweden, Finland, and Denmark are constantly improving various innovation indicators that correlate with higher GDP per capita. Otherwise, countries with low innovation levels, such as Bulgaria and Romania, have lower GDP, indicating a direct link between innovation potential and economic performance.

In addition, Fagerberg and Verspagen (2002) discuss the concept of technological gaps, according to which countries with advanced innovation potential can maintain a competitive advantage while underperforming countries may experience slower economic growth. This dynamic is evident in the European Union, where the more innovative countries are growing faster and where regional disparities are also widening.

Griliches (1990) emphasizes that patent statistics are important economic indicators that are often used as a substitute for innovation. The authors Hall et al. (2010) no longer explain that R&D investment has a significant return, reinforcing the idea that higher R&D expenditure is due to better economic returns. This is confirmed by Maradana et al. (2017), who have shown a strong positive relationship between innovation and economic growth in European countries. Additionally, the direct economic benefits, innovation plays a significant role in addressing today's challenges, such as environmental sustainability and digitalization. Recent research between 2020 and 2024 significantly advances the classical theories of innovation-driven growth by incorporating digitalization, environmental sustainability, and regional divergence into the analysis of innovation's role in economic performance. Coccia (2020) emphasizes that innovation functions as an adaptive mechanism in response to socioeconomic and environmental changes, showing that technological innovation fosters structural change essential for economic renewal. Miśkiewicz (2021) confirms that innovation, particularly in green technologies and ICT, is vital for reducing greenhouse gas emissions while supporting sustainable economic development, while Evangelista et al. (2014) demonstrate the economic impact of digital technologies. Similarly, D'Agostino and Scarlato (2014) demonstrate that innovation in the digital economy contributes to productivity gains and resilience in regional economies. Furthermore, Gamrba et al. (2025) explore the positive effects of R&D investment on innovation efficiency in EU countries, finding that stronger public R&D systems significantly enhance GDP per capita. Guillamón et al. (2025) provide empirical support that institutional quality conditions the effectiveness of innovation policies on economic growth, particularly in less developed EU regions. Adding to this, Fernández et al. (2023) and Ding et al. (2025) argue that technological advancement, especially in Industry 4.0 sectors, accelerates growth disparities between EU countries by concentrating innovation capacity in more advanced regions. Moreover, the analysis by Maradana et al. (2017) validates the long-run cointegration between innovation indicators (such as patents and R&D intensity) and GDP growth across multiple European economies.

In addition, the innovation level significantly impacts Member States' GDP, while higher innovation capacity usually leads to higher economic growth. The synergies between innovation, R&D investment, and regional innovation programs demonstrate the significance of encouraging an innovation-friendly environment so as to increase economic prosperity. Policymakers should therefore prioritize innovation-driven growth strategies that take a multi-dimensional approach, reflecting the interaction of regional, time dynamics and sectoral factors, ensuring sustainable practices and inclusive growth across the Union.

6. Conclusions

It is clear from the literature that innovation is a main driver of economic growth in EU countries. However, fully to exploit the innovation potential of economic growth, the Union needs to apply an integrated methodology of the innovation impact on GDP framework, which contributes to reducing regional disparities, allows different sectors to contribute to GDP growth, respects the time dimension. To boost growth and competitiveness in the Union, preferably through an integrated methodology, further investment in innovation and the carrying out of additional measures is needed. The theoretical contribution of this study lies in the formulation of an integrated innovation-GDP impact framework that synthesizes diverse innovation indicators (product, process, green innovations) with macroeconomic outputs, offering a structured model for understanding causality between innovation and economic performance.

The revised papers underline the significance of innovation as a driver of economic growth across the EU and highlight some important findings and impacts.

First, the analysis confirms that innovation significantly contributes to GDP growth in the EU contributing to productivity increase, job creation, and the competitiveness of sectors. Key indicators, such as R&D expenditure, patent activity, and the percentage of innovative enterprises, consistently correlate with economic performance, underscoring the transformative role of technological advancements. This supports and extends foundational economic theories (Aghion & Howitt, 1992; Romer, 1990) by offering empirical confirmation from recent EU-specific data, showing how innovation acts not only as a growth accelerator but also as a mechanism of regional transformation and structural adjustment.

Secondly, the study shows that the influence of innovation on GDP varies greatly between EU countries and regions shaped by differences in R&D investment, workforce skills, policy environments, and economic development levels. These findings stress the need for tailored policy approaches that address the unique needs of individual regions while fostering balanced economic growth across the Union. From a practical standpoint, this implies the necessity for region-specific innovation policies, supported by decentralized governance structures, innovation hubs, and smart specialization strategies.

Product and process innovations, particularly those with environmental benefits, emerge as major contributors to GDP growth, aligning economic development with sustainability goals. This confirms the dual role of innovation in economic and environmental policy, offering guidance for the EU Green Deal and similar sustainability-oriented initiatives.

During the analysis, we concluded that the following indicators make a significant contribution to GDP per capita:

1. Percentage of enterprises that have created product innovations and innovations of business process characterizes the potential for increasing the efficiency of enterprises and creates the basis for the country's economic development.
2. The number of firms receiving government funding or tax breaks for R&D is directly involved the companies' desire to develop and create a basis for competitiveness and it's a basement for GDP increasing.

These findings have direct policy implications: financial incentives such as R&D tax credits and innovation subsidies should be prioritized to enhance enterprise-level innovation performance.

The proposed integrated methodology for assessing the impact of innovation on GDP support the integrated framework with the empirical research evidence. As the proposed integrated framework emphasizes the importance of addressing regional disparities, leveraging sectoral strengths, and accounting for time dynamics in innovation policy design, the findings reveal significant disparities among the EU countries. This clustering insight contributes theoretically by mapping the spatial heterogeneity of innovation impact, and practically by informing transnational cooperation mechanisms such as macro-regional strategies (e.g., Baltic Sea Strategy).

Leading innovation-oriented countries like Germany, Denmark, Finland, the Netherlands, and Sweden exhibit strong links between innovation and economic development. However, even neighboring countries like Sweden and Norway or Lithuania, Latvia, and Estonia belong to different clusters, underscoring the need for enhanced cross-border cooperation to maximize the EU's innovation potential.

The findings show the importance of prioritizing investment into innovations, supported by strategic policies and infrastructure development. Policymakers should prioritize fostering innovation-friendly environments, addressing disparities, and encouraging collaboration to strengthen innovation ecosystems. Enhanced cross-border cooperation can help leverage diverse regional competencies and capacities, creating a more integrated and innovative EU economic growth. From a policy perspective, this underscores the need for coordination between cohesion policy, innovation policy, and digitalization agendas at both EU and national levels.

While this study aims to enhance the innovation efficiency evaluation framework, there are the limitations of this research. This study covers a limited time period analysis and does not account for dynamics over subsequent years. Future research should expand the temporal scope to capture long-term trends as identified in the integrated framework, constructed after literature review. This opens avenues for longitudinal studies incorporating lagged innovation effects, time-series modelling, and the exploration of post-2024 innovation trends.

Given that innovation development has become an integral part of national strategies globally in recent years, it is also suggested that future research should include more countries for comparison. This would reveal the distinctive R&D features of EU countries and help assess the efficiency of innovation policies. Such an evaluation could serve as a reference for future innovation development strategies in EU countries, contributing to a more comprehensive study. Comparative international research would strengthen the external validity of EU-focused models and allow benchmarking with global innovation leaders such as the USA, South Korea, or Japan.

By addressing regional disparities, supporting innovation ecosystems, and fostering collaboration, the EU can ensure sustainable GDP growth and maintain global competitiveness in an increasingly knowledge-driven economy. Strategic policy actions and a robust evaluation framework are essential to unlock the full potential of innovation as a catalyst for economic development. This study thus offers both a conceptual advancement and a toolkit for evidence-based policymaking in innovation-driven economic planning.

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Author contributions

The researchers jointly worked on the methodology, software, analysis, investigation, writing, and editing of the research paper. One author conceived the study and the data analysis, and was responsible for the idea and for data collection, and contributed to the empirical analysis, and data interpretation and wrote the first draft of the article. Other authors contributed to the theoretical background, empirical analysis and writing draft.

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References

- Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, 60(2), 323–351. <https://doi.org/10.2307/2951599>
- Aliu Mulaj, L., & Dedaj, B. (2025). R&D impact in the changes of economic structure of population. *Business: Theory and Practice*, 26(1), 176–181. <https://doi.org/10.3846/btp.2025.18665>
- Arundel, A., & Schoonraad, P. (2023). Measuring public sector innovation. In F. Gault, A. Arundel, & E. Kraemer-Mbula (Eds.), *Handbook of innovation indicators and measurement* (pp. 158–176). Edward Elgar Publishing. <https://doi.org/10.4337/9781800883024.00019>
- Aslan, A., Altinoz, B., & Polat, M. A. (2024). Investigation of the sensitivity of EU countries to temperature anomalies in terms of economic and technological indicators. *Journal of the Knowledge Economy*, 15(1), 2401–2421. <https://doi.org/10.1007/s13132-023-01291-z>
- Bate, A. F., Wachira, E. W., & Danko, S. (2023). The determinants of innovation performance: An income-based cross-country comparative analysis using the Global Innovation Index (GII). *Journal of Innovation and Entrepreneurship*, 12, Article 20. <https://doi.org/10.1186/s13731-023-00283-2>
- Batool, M., Khan, F. A., & Tufail, S. (2025). Radical innovations and economic development: Comparative role of social and human capital in developing countries. *Zagreb International Review of Economics and Business*, 28(2), 231–254. <https://doi.org/10.2478/zireb-2025-0023>
- Bottazzi, L., & Peri, G. (2002). *Innovation and spillovers in regions: Evidence from European patent data* (Working Paper No. 215). Innocenzo Gasparini Institute for Economic Research. <https://doi.org/10.2139/ssrn.318920>
- Bresciani, S., Puertas, R., Ferraris, A., & Santoro, G. (2021). Innovation, environmental sustainability and economic development: DEA-Bootstrap and multilevel analysis to compare two regions. *Technological Forecasting and Social Change*, 172, Article 121040. <https://doi.org/10.1016/j.techfore.2021.121040>
- Brodny, J., & Tutak, M. (2022). Analyzing the level of digitalization among the enterprises of the European Union member states and their impact on economic growth. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(2), Article 70. <https://doi.org/10.3390/joitmc8020070>
- Castellacci, F., & Lie, C. M. (2017). A taxonomy of green innovators: Empirical evidence from South Korea. *Journal of Cleaner Production*, 143, 1036–1047. <https://doi.org/10.1016/j.jclepro.2016.12.016>

- Chen, H., Rehman, M. A., Luo, J., & Ali, M. (2022). Dynamic influence of natural resources, financial integration and eco-innovation on ecological sustainability in EKC framework: Fresh insights from China. *Resources Policy*, 79, Article 103043. <https://doi.org/10.1016/j.resourpol.2022.103043>
- Coccia, M. (2020). How does institutional change of democratization affect the origin and diffusion of technological innovation across countries?. *Journal of Economic and Social Thought*, 7(2), 60–91.
- Coe, D. T., & Helpman, E. (1995). International R&D spillovers. *European Economic Review*, 39(5), 859–887. [https://doi.org/10.1016/0014-2921\(94\)00100-E](https://doi.org/10.1016/0014-2921(94)00100-E)
- Crescenzi, R., Di Cataldo, M., & Rodríguez-Pose, A. (2020). Innovation and regional growth in the EU: The role of institutions. *Regional Studies*, 54(10), 1338–1350.
- D'Agostino, G., & Scarlato, M. (2014). *Inclusive institutions, innovation and economic growth: Estimates for European countries*. SSRN. <https://doi.org/10.2139/ssrn.2539521>
- D'Angelo, A. (2012). Innovation and export performance: A study of Italian high-tech SMEs. *Journal of Management & Governance*, 16, 393–423. <https://doi.org/10.1007/s10997-010-9157-y>
- Degirmenci, T., Aydin, M., Cakmak, B. Y., & Yigit, B. (2024). A path to cleaner energy: The nexus of technological regulations, green technological innovation, economic globalization, and human capital. *Energy*, 311, Article 133316. <https://doi.org/10.1016/j.energy.2024.133316>
- Ding, Y., Yin, F., Chin, L., Zhou, K., Taghizadeh-Hesary, F., & Li, Y. (2025). Can government R&D expenditure promote innovation? New evidence from 37 OECD countries. *Technological and Economic Development of Economy*, 31(2), 572–596. <https://doi.org/10.3846/tede.2024.22293>
- Doran, J., & Ryan, G. (2019). Does nanotechnology research generate an innovation premium over other types of research? Evidence from Ireland. *Technology in Society*, 59, Article 101183. <https://doi.org/10.1016/j.techsoc.2019.101183>
- European Commission. (2021). *European Innovation Scoreboard 2021*. Publications Office of the European Union. https://es.eurostat.eus/elementos/ele0019100/european-innovation-scoreboard/inf0019112_c.pdf
- Evangelista, R., Guerrieri, P., & Meliciani, V. (2014). The economic impact of digital technologies in Europe. *Economics of Innovation and New Technology*, 23(8), 802–824. <https://doi.org/10.1080/10438599.2014.918438>
- Fernández-Cerezo, A., & Montero, J. M. (2021). *A sectoral analysis of the future challenges facing the Spanish economy* (Documentos Ocasionales No. 2133). Banco de España.
- Fernández-Mireles, V., Martínez-Cruz, M., Cardenas-Juarez, M., Montalvo-Rodríguez, Á., & Alemán-Mendiola, V. (2023, October 18–20). Design and implementation of an augmented reality-based app for assembly lines in industry 4.0. In *2023 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC)* (pp. 1–6). Ixtapa, Mexico: IEEE. <https://doi.org/10.1109/ROPEC58757.2023.10409306>
- Filippetti, A., & Vezzani, A. (2021). The uneven impact of the COVID-19 crisis on European innovation systems. *Science and Public Policy*, 48(6), 904–916.
- Fagerberg, J., & Verspagen, B. (2002). Technology-gaps, innovation-diffusion and transformation: An evolutionary interpretation. *Research Policy*, 31(8–9), 1291–1304. [https://doi.org/10.1016/S0048-7333\(02\)00064-1](https://doi.org/10.1016/S0048-7333(02)00064-1)
- Gamba, F. J. (2025). R&D, innovation and competitiveness: Global evidences on conceptual and practical connectedness. *African Journal of Management Research*, 32(1). <https://doi.org/10.4314/ajmr.v32i1.6>
- González-Serrano, M. H., Prado-Gascó, V., Crespo-Hervás, J., & Calabuig-Moreno, F. (2019). Does sport affect the competitiveness of European Union countries? An analysis of the degree of innovation and GDP per capita using linear and QCA models. *International Entrepreneurship and Management Journal*, 15(4), 1343–1362. <https://doi.org/10.1007/s11365-019-00592-7>

- Greenacre, M., Groenen, P. J. F., Hastie, T., Iodice D'Enza, A., Markos, A., Tuzhilina, E. (2022). Principal component analysis. *Nature Reviews Methods Primers*, 2, Article 100. <https://doi.org/10.1038/s43586-022-00184-w>
- Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, 28(4), 1661–1707.
- Grodzicki, T., & Jankiewicz, M. (2026). Innovation spillovers as a driver of economic development: Evidence from regions located in Central and Eastern European Union countries. *Technological and Economic Development of Economy*, 32(4), 1087–1101. <https://doi.org/10.3846/tede.2025.23984>
- Guillamón, A. L. D. G., García-Pérez-de-Lema, D., Gálvez-Albarracín, E. J., & Vera-Jaramillo, F. (2025). Innovation, digitalization, and sustainability as drivers of performance in tourism MSMEs: A multigroup evidence from the Pacific Alliance. *Journal of Entrepreneurship, Management and Innovation*, 21(4), 5–29. <https://doi.org/10.7341/20252141>
- Haefner, N., Wincent, J., Parida, V., & Gassmann, O. (2021). Artificial intelligence and innovation management: A review, framework, and research agenda. *Technological Forecasting and Social Change*, 162, Article 120392. <https://doi.org/10.1016/j.techfore.2020.120392>
- Hall, B. H., Mairesse, J., & Mohnen, P. (2010). Measuring the returns to R&D. In B. H. Hall & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (Vol. 2, pp. 1031–1082). Elsevier. [https://doi.org/10.1016/S0169-7218\(10\)02008-3](https://doi.org/10.1016/S0169-7218(10)02008-3)
- Halásková, M., Halásková, R., & Pomp, M. (2024). The impact of selected R+D indicators on economic activity in EU countries. *Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration*, 32(1), Article 2055. <https://doi.org/10.46585/sp32012055>
- Hernández de Rojas, F., & Pita, P. R., & Pérez Martínez, J. E. (2024). Assessing the European association between digitalization and innovation. *Telecommunications Policy*, 48, Article 102810. <https://doi.org/10.1016/j.telpol.2024.102810>
- Iqbal, K., Hassan, S. T., Geng, Y., & Cai, C. (2024). Impact of green technological innovations, ICT, and renewable energy on CO₂ emissions in emerging economies. *International Journal of Energy Research*, 2024, Article 5594324. <https://doi.org/10.1155/er/5594324>
- Korkmaz, G., Calderón, J. B. S., Kramer, B. L., Guci, L., & Robbins, C. A. (2024). From GitHub to GDP: A framework for measuring open source software innovation. *Research Policy*, 53(3), Article 104954. <https://doi.org/10.1016/j.respol.2024.104954>
- Kučera, J., & Fiľa, M. (2022). R&D expenditure, innovation performance and economic development of the EU countries. *Entrepreneurship and Sustainability Issues*, 9(3), 227–241. [https://doi.org/10.9770/jesi.2022.9.3\(14\)](https://doi.org/10.9770/jesi.2022.9.3(14))
- Liu, J., Lu, K., & Cheng, S. (2018). International R&D spillovers and innovation efficiency. *Sustainability*, 49(1), Article 3974. <https://doi.org/10.3390/su10113974>
- Liu, Z., Tong, Z., & Zhang, Z. (2024). Government expenditure structure, technological progress and economic growth. *International Journal of Emerging Markets*, 19(11), 3729–3767. <https://doi.org/10.1108/IJOEM-09-2022-1384>
- Maradana, R. P., Pradhan, R. P., Dash, S., Gaurav, K., Jayakumar, M., & Chatterjee, D. (2017). Does innovation promote economic growth? Evidence from European countries. *Journal of Innovation and Entrepreneurship*, 6, Article 1. <https://doi.org/10.1186/s13731-016-0061-9>
- Mewes, L., & Broekel, T. (2022). Technological complexity and economic growth of regions. *Research Policy*, 51(8), Article 104156. <https://doi.org/10.1016/j.respol.2020.104156>
- Miśkiewicz, R. (2021). The impact of innovation and information technology on greenhouse gas emissions: A case of the Visegrád countries. *Journal of Risk and Financial Management*, 14(2), Article 59. <https://doi.org/10.3390/jrfm14020059>

- Neely, A., & Hii, J. (1998). *Innovation and business performance: A literature review*. University of Cambridge.
- Organisation for Economic Co-operation and Development & Eurostat. (2018). *Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation* (4th ed.). <https://doi.org/10.1787/9789264304604-en>
- Organisation for Economic Co-operation and Development. (2023). *OECD Business Innovation Indicators 2023 edition*. <https://www.oecd.org/content/dam/oecd/en/data/datasets/business-innovation-statistics-and-indicators/business-innovation-indicators-2023-highlights.pdf>
- Pammolli, F. (2014). On innovation, instability, and growth. A review and an interpretative framework. *Economia Politica*, 31(1), 17–32.
- Paula, F. D. O., & da Silva, J. F. D. (2021). R&D spending and patents: Levers of national development. *Innovation & Management Review*, 18(2), 175–191. <https://doi.org/10.1108/INMR-11-2019-0142>
- Perry-Smith, J. E., & Mannucci, P. V. (2017). From creativity to innovation: The social network drivers of the four phases of the idea journey. *Academy of Management Review*, 42(1), 53–79. <https://doi.org/10.5465/amr.2014.0462>
- Rahman, A., & Khan, M. A. (2024). The relationship between financial development and economic growth: New insights using quadruple and quintuple helix innovation framework and way forward. *Journal of the Knowledge Economy*, 15(2), 5939–5964. <https://doi.org/10.1007/s13132-023-01276-y>
- Read, A. (2000). Determinants of successful organisational innovation: A review of current research. *Journal of Management Practice*, 3(1), 95–119.
- Reissl, S., Caiani, A., Lamperti, F., Guerini, M., Vanni, F., Fagiolo, G., Ferraresi, T., Ghezzi, L., Napoletano, M., & Roventini, A. (2021). *Assessing the economic effects of lockdowns in Italy: A dynamic input-output approach* (Working Paper No. 2021-03). Laboratory of Economics and Management. <https://doi.org/10.2139/ssrn.3778996>
- Rios-Morales, R., & Brennan, L. (2009). Ireland's innovative governmental policies promoting internationalisation. *Research in International Business and Finance*, 23(2), 157–168. <https://doi.org/10.1016/j.ribaf.2008.03.012>
- Rodríguez-Pose, A., & Crescenzi, R. (2008). Research and development, spillovers, innovation systems, and the genesis of regional growth in Europe. *Regional Studies*, 42(1), 51–67. <https://doi.org/10.1080/00343400701654186>
- Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5), S71–S102. <https://doi.org/10.1086/261725>
- Saqib, N., Sharif, A., Razzaq, A., & Usman, M. (2023). Integration of renewable energy and technological innovation in realizing environmental sustainability: The role of human capital in EKC framework. *Environmental Science and Pollution Research*, 30(6), 16372–16385. <https://doi.org/10.1007/s11356-022-23345-6>
- Sawng, Y.-W., Kim, P.-R., & Park, J. Y. (2021). ICT investment and GDP growth: Causality analysis for the case of Korea. *Telecommunications Policy*, 45(7), Article 102157. <https://doi.org/10.1016/j.telpol.2021.102157>
- Schumpeter, J. A. (1934). *The theory of economic development: An inquiry into profits, capital, credit, interest, and the Business cycle*. Harvard University Press.
- Sibanda, K., Takentsi, S., & Gonese, D. (2024). Energy consumption, technological innovation, and environmental degradation in SADC countries. *Cogent Social Sciences*, 10(1), Article 2355553. <https://doi.org/10.1080/23311886.2024.2355553>
- Sojoodi, S., & Baghbanpour, J. (2024). The relationship between high-tech industries exports and GDP growth in the selected developing and developed countries. *Journal of the Knowledge Economy*, 15(1), 2073–2095. <https://doi.org/10.1007/s13132-023-01174-3>

- Szopik-Decpczyńska, K., Cheba, K., Bąk, I., Kędzierska-Szczepaniak, A., Szczepaniak, K., & Ioppolo, G. (2020). Innovation level and local development of EU regions. A new assessment approach. *Land Use Policy*, 99, Article 104837. <https://doi.org/10.1016/j.landusepol.2020.104837>
- Ulku, H. (2004). *R&D, innovation, and economic growth: An empirical analysis* (IMF Working Papers 185). International Monetary Fund. <https://doi.org/10.5089/9781451859447.001>
- Wang, K. J., Widagdo, J., Lin, Y. S., Yang, H. L., & Hsiao, S. L. (2016). A service innovation framework for start-up firms by integrating service experience engineering approach and capability maturity model. *Service Business*, 10, 867–916. <https://doi.org/10.1007/s11628-015-0294-x>
- Yang, M., & Han, C. (2021). Stimulating innovation: Managing peer interaction for idea generation on digital innovation platforms. *Journal of Business Research*, 125, 456–465. <https://doi.org/10.1016/j.jbusres.2019.08.005>
- Zang, X., Adebayo, T. S., Oladipupo, S. D., & Kirikkaleli, D. (2023). Asymmetric impact of renewable energy consumption and technological innovation on environmental degradation: Designing an SDG framework for developed economy. *Environmental Technology*, 44(6), 774–791. <https://doi.org/10.1080/09593330.2021.1983027>
- Zerihun, H. L., Erena, O. T., Tegene, K. B., Mekonnen, D. Z., Woyessa, M. A., Anjulo, D. D., Alaka, H. M., Gellebo, D. G., Ademe, B. T., & Debele, S. A. (2025). Foreign direct investment, institutional quality and innovation: Insight from African countries. *International Journal of Innovation Science*. <https://doi.org/10.1108/IJIS-05-2025-0234>
- Zhang, J., Chen, X., & Zhao, X. (2023). A perspective of government investment and enterprise innovation: Marketization of business environment. *Journal of Business Research*, 164, Article 113925. <https://doi.org/10.1016/j.jbusres.2023.113925>
- Zhylynska, O., Bazhenova, O., Zatonatska, T., Dluhopolskyi, O. V., Bedianashvili, G., & Chornodid, I. (2020). Innovation processes and economic growth in the context of European integration. *Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration*, 28(3), Article 1209. <https://doi.org/10.46585/sp28031209>